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MEASUREMENT OF FLUID FLOW BY MEANS OF ORIFICE PLATES AND NOZZLES

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BRIEF HISTORY

The ISO Recommendation R 541, *Measurement of Fluid Flow by Means of Orifice Plates and Nozzles*, was drawn up by Technical Committee ISO/TC 30, *Measurement of Fluid Flow in Closed Conduits*, the Secretariat of which is held by the Association Française de Normalisation (AFNOR).

Work on this question by the Technical Committee began in 1948, taking into account the studies which had been made by the former International Federation of the National Standardizing Associations (ISA), and led in 1962 to the adoption of a Draft ISO Recommendation.

In February 1963, this Draft ISO Recommendation (No. 532) was circulated to all the ISO Member Bodies for enquiry. It was approved, subject to a few modifications of an editorial nature, by the following Member Bodies:

Australia	Hungary	Sweden
Austria	India	Switzerland
Belgium	Iran	United Kingdom
Chile	Italy	U.S.A.
Czechoslovakia	Japan	U.S.S.R.
France	Netherlands	
Germany	Portugal	

No Member Body opposed the approval of the Draft.

The Draft ISO Recommendation was then submitted by correspondence to the ISO Council, which decided, in January 1967, to accept it as an ISO RECOMMENDATION.

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MEASUREMENT OF FLUID FLOW BY MEANS OF ORIFICE PLATES AND NOZZLES

1. GENERAL

1.1 Principle of the method of measurement

A device such as an orifice plate or a nozzle is placed in a pipe-line through which a fluid is flowing.

A static pressure difference then exists between the upstream side and the downstream side of the device and whenever the device is geometrically similar to one on which direct calibration has been made, the conditions of use being the same, the rate of flow can be determined from the measured value of this pressure difference and from a knowledge of the circumstances under which the device is being used.

This ISO Recommendation describes the shape and method of use of certain of these devices, on which direct calibration experiments have been made, sufficient in number and quality to enable coherent systems of application to be based on their results.

The devices introduced in the pipe are called " primary elements ", which term includes the pressure taps; all other instruments or devices required for measuring are known as " secondary devices ". This ISO Recommendation covers the primary elements; secondary devices will be mentioned only occasionally.

1.2 Standard primary elements

The standard primary elements are the following:

1.2.1 *Orifice plate*, a sharp square-edged orifice in a thin plate, with which are used various arrangements of pressure tappings, known as

— Corner taps,

— *Vena contracta* taps,

— Flange taps.

1.2.2 *Nozzles*, which differ in shape and/or in position of the pressure taps and are known as either

— ISA 1932 nozzle,

— Long-radius nozzle.

2. GENERAL REQUIREMENTS FOR VALIDITY OF THE MEASUREMENTS

It is necessary to ensure that all the following requirements, some of which are explained in detail in the following sections, are completely fulfilled during the period of measurement.

2.1 Primary element

2.1.1 The primary element should be manufactured, installed and used in accordance with this ISO Recommendation.

2.1.2 The condition of the primary element should be checked after each measurement or each series of measurements.

2.1.3 The primary element should be manufactured from material the coefficient of thermal expansion of which is known.

2.2 Type of fluid

2.2.1 The fluid may be either compressible (gas) or considered as incompressible (liquid).

2.2.2 The fluid should be physically and thermally homogeneous and of single (gas or liquid) phase.

Colloidal solutions with a high degree of dispersion (such as milk), and those only, are considered to behave as a single phase fluid.

2.3 Installation

2.3.1 The measuring process applies only to fluids flowing through a pipe-line.

2.3.2 The primary element is fitted between two sections of straight cylindrical pipe of constant cross-sectional area, in which there is no obstruction or branch connection (whether or not there is flow into or out of such connections during measurement) other than those specified in this ISO Recommendation.

The pipe is considered straight when it appears so by mere visual inspection.

The required minimum straight lengths of pipe, which conform to the description above, vary according to the nature of the fittings and are indicated in Table 1, on page 7.

The pipe bore is truly circular over the entire minimum lengths of straight pipe required. The cross-section is taken to be circular if it appears so by mere visual inspection. The circularity of the outside of the pipe may be taken as a guide, except in the immediate vicinity of the primary element.

Over an upstream length of at least 2 D measured from the upstream face of the primary element, the pipe should be cylindrical. The value of the diameter D of the pipe should be taken as the mean of the measurements of several diameters situated in meridian planes at approximately even angles to each other and in several planes normal to the pipe centre line within the specified length of 2 D. Four diameters at least should be measured.

The pipe is said to be cylindrical when no diameter in any plane differs by more than 0.3 per cent from the value of D obtained as a mean of all measurements.

Attention is called to the fact that it is possible to check circularity of a pipe bore, within the accuracy required, without measuring the mean diameter of the pipe bore itself.

The mean diameter of the downstream straight length, considered along a length of at least 2 D from the upstream face of the primary element, should not differ from the mean diameter of the upstream straight length by more than $\pm$ 2 per cent, this being judged by the check of a single diameter of the downstream straight length.

2.3.3 The inside diameter of the pipe should be equal to or more than 2 in (50 mm) and equal to or less than the maximum diameters specified for each device.

2.3.4 The inside surface of the measuring pipe should be clean, free from pitting and deposit and not encrusted. However, it may be either " smooth " or " rough ".

2.3.5 The pipe should run full at the measuring section.

2.3.6 The rate of flow should be constant or, in practice, vary only slightly and slowly with time. This ISO Recommendation does not provide for the measurement of pulsating flow.

2.3.7 The flow of fluid through the primary element should not cause any change of phase. To determine whether there is a change of phase, the computation of flow should be carried out on the assumption that the expansion is isentropic if the fluid is a gas, or isothermal if the fluid is a liquid.

2.3.8 If the fluid is a gas, the ratio of the downstream to the upstream absolute pressures should be greater than 0.75.

2.4 Straight lengths

2.4.1 The minimum straight lengths to be installed upstream and downstream of any primary element, according to clause 2.3.2, are the same regardless of the actual type of the primary element, as described in clauses 1.2.1 and 1.2.2.

The minimum upstream and downstream straight lengths required for installation between various fittings and the primary element are given in Table 1 below.

TABLE 1. — **Minimum straight lengths required between various fittings located upstream or downstream of the primary element and the primary element itself**

β	On upstream (inlet) side of the primary element						On downstream (outlet) side
	Single 90° bend or tee (flow from one branch only)	Two or more 90° bends in the same plane	Two or more 90° bends in different planes	Reducer (2 *D* to *D* over a length of 3 *D*). Expander (0.5 *D* to *D* over a length of 1.5 *D*)	Globe valve fully open	Gate valve fully open	All fittings included in this Table
⩽0.20	10 (6)	14 (7)	34 (17)	16 (8)	18 (9)	12 (6)	4 (2)
0.25	10 (6)	14 (7)	34 (17)	16 (8)	18 (9)	12 (6)	4 (2)
0.30	10 (6)	16 (8)	34 (17)	16 (8)	18 (9)	12 (6)	5 (2.5)
0.35	12 (6)	16 (8)	36 (18)	16 (8)	18 (9)	12 (6)	5 (2.5)
0.40	14 (7)	18 (9)	36 (18)	16 (8)	20 (10)	12 (6)	6 (3)
0.45	14 (7)	18 (9)	38 (19)	18 (9)	20 (10)	12 (6)	6 (3)
0.50	14 (7)	20 (10)	40 (20)	20 (10)	22 (11)	12 (6)	6 (3)
0.55	16 (8)	22 (11)	44 (22)	20 (10)	24 (12)	14 (7)	6 (3)
0.60	18 (9)	26 (13)	48 (24)	22 (11)	26 (13)	14 (7)	7 (3.5)
0.65	22 (11)	32 (16)	54 (27)	24 (12)	28 (14)	16 (8)	7 (3.5)
0.70	28 (14)	36 (18)	62 (31)	26 (13)	32 (16)	20 (10)	7 (3.5)
0.75	36 (18)	42 (21)	70 (35)	28 (14)	36 (18)	24 (12)	8 (4)
0.80	46 (23)	50 (25)	80 (40)	30 (15)	44 (22)	30 (15)	8 (4)

Fittings	Minimum upstream (inlet) straight length required
Abrupt symmetrical reduction having a diameter ratio ⩾ 0.5	30 (15)
Thermometer pocket of diameter ⩽ 0.03 *D*	5 (3)
Thermometer pocket of diameter between 0.03 *D* and 0.13 *D*	20 (10)

NOTE.—Table 1 is valid for all primary elements defined in this ISO Recommendation.
The unbracketed values are " zero additional tolerance " values (see clause 2.4.3).
The bracketed values are "± 0.5 per cent additional tolerance " values (see clause 2.4.4).
All straight lengths are expressed as multiples of the diameter *D*. They should be measured from the upstream face of the primary element.

2.4.2 The straight lengths given in Table 1 are minimum values, and it is always recommended to have straight lengths longer than those indicated. For research work especially, it is recommended to double at least the upstream values given in Table 1 for " zero additional tolerance ".*

2.4.3 When the straight lengths comply with the requirements of Table 1 and when they are longer than or equal to the values given for " zero additional tolerance ",* there is no need to add any additional deviation to the flow measurement error to take account of the effect of such installation conditions.

2.4.4 When the upstream or downstream straight lengths are shorter than the " zero additional tolerance " values * and equal to or greater than the "$\pm$ 0.5 per cent additional tolerance " values,** as given in Table 1, an additional deviation of $\pm$ 0.5 per cent should be added to the error in flow measurement, in the following manner:

First computation Compute the tolerance for the flow measurement as if there was no additional tolerance for installation conditions. This computation should be made as shown in section 5 dealing with errors. Assume the result to be $\pm 2\sigma_q$ per cent.

Second computation Then add to this value of the tolerance an additional deviation of $\pm$ 0.5 per cent. This should be made *arithmetically*, in such a way that the final result will be $\pm$ ($2\ \sigma_q + 0.5$) per cent.

If the straight lengths are *shorter* than the "$\pm$ 0.5 per cent additional tolerance" values ** given in Table 1, this ISO Recommendation gives *no information* by which to predict the value of any further tolerance to be taken into account; this is also the case when the upstream and downstream straight lengths are *simultaneously* shorter than the " zero additional tolerance " values.*

2.4.5 The valves mentioned in Table 1 should be fully open. It is recommended that control be effected by valves located downstream of the primary element. Isolating valves located upstream should be preferably of the " gate " type and should be fully open.

2.4.6 After a single change of direction (bend or tee), it is recommended that the tappings (if single tappings) be in a plane at right angles to the plane containing the change of direction (plane of the bend or tee).

2.4.7 The values given in Table 1 were obtained experimentally with a very long straight length upstream of the particular fitting in question. Usually, such conditions are not available and the following remarks may be used as a guide in usual installation practice.

(*a*) If the primary element is installed in a pipe leading to an upstream open space or large vessel, either directly or through any fitting given in Table 1, the total length of pipe between the open space and the primary element should never be less than 30 *D*.

* Unbracketed values in Table 1.
** Bracketed values in Table 1.

(*b*) If several fittings other than 90° bends are placed in series upstream from the primary element, the following rule should be applied: between the closest fitting (1) to the primary element and the primary element itself, there should be a minimum straight length such as is indicated for the fitting (1) in question and the actual value β in Table 1. But, in addition, between this fitting (1) and the preceding one (2), there should be a straight length equal to one half of the value given in the Table 1 for fitting (2) applicable to a primary element of diameter ratio $\beta = 0.7$, whatever the actual value of β may be. This requirement does not apply when the fitting (2) is an abrupt symmetrical reduction, which case is covered by paragraph (*a*) above.

2.4.8 The primary element should be calibrated under actual installation conditions in cases which are not covered by the above statements.

3. SYMBOLS AND DEFINITIONS

The symbols used in this ISO Recommendation are given in Table 2, under clause 3.1. The definitions, in the following clauses, are given only for terms used in some special sense or for terms the meaning of which it seems useful to emphasize.

3.1 Symbols

TABLE 2. — Symbols

Symbol	Represented quantity	Dimensions *
α	Flow coefficient	Pure number
β	Diameter ratio, $\beta = \frac{d}{D}$	Pure number
C	Coefficient of discharge, $C = \frac{\alpha}{E}$	Pure number
E	Velocity of approach factor, $E = (1 - \beta^4)^{-\frac{1}{2}}$	Pure number
ε	Expansibility (expansion) factor	Pure number
κ	Isentropic exponent **	Pure number
m	Area ratio, $m = \beta^2$	Pure number
Re_D	Reynolds number of upstream pipe referred to D	Pure number
x	Differential pressure ratio, $x = \frac{\Delta p}{p_1}$	Pure number
X	Acoustic ratio, $X = \frac{x}{\kappa}$	Pure number
d	Diameter of orifice or throat of primary element at operating conditions	L
D	Upstream pipe diameter at operating conditions	L
k	Absolute roughness (see clause 6.4.1.2)	L
Δp	Differential pressure	$ML^{-1}T^{-2}$
η	Dynamic viscosity of the fluid	$ML^{-1}T^{-1}$
ν	Kinematic viscosity of the fluid	L^2T^{-1}
p	Absolute static pressure of the fluid	$ML^{-1}T^{-2}$
q_m	Mass rate of flow	MT^{-1}
q_v	Volume rate of flow	L^3T^{-1}
ρ	Mass density of the fluid	ML^{-3}
t	Temperature of the fluid	Θ
$\bar{v}$	Mean axial velocity of the fluid in the pipe	LT^{-1}

* M = mass. L = length. T = time.
** For ideal gases, the ratio of the specific heat capacities and the isentropic exponent have the same values.

Subscript 1 applies to conditions (of the fluid, etc.) in the plane of the upstream pressure tap.
Subscript 2 applies to conditions (of the fluid, etc.) in the plane of the downstream pressure tap.

3.2 Pressure measurement: definitions

3.2.1 *Pipe-wall pressure tap.* Hole drilled in the wall of a pipe, the inside edge of which is flush with the inside surface of the pipe.

The hole is usually circular but in certain cases may be an annular slit.

3.2.2 *Static pressure* of a fluid flowing through a straight pipe-line. Pressure which can be measured by connecting a pressure gauge to a pipe-wall pressure tap. Only the value of the absolute static pressure is used in this ISO Recommendation.

3.2.3 *Differential pressure.* Difference between the static pressure measured by pipe-wall taps, one of which is on the upstream side and the other on the downstream side of a primary element inserted in a straight pipe through which flow occurs, when there is no variation in gravitational energy between the upstream and downstream taps.

The term " differential pressure " is used only if the pressure taps are in the positions specified by the ISO Recommendation for each standard primary element.

3.2.4 *Differential pressure ratio.* The differential pressure divided by the absolute static pressure existing at the level of the centre of the cross-section of the pipe in the plane containing the centre-line of the upstream pressure tapping.

3.2.5 *Pressure loss.* Difference in static pressure between the pressure measured on the upstream side of the primary element, at a point free from the influence of approach impact pressure, and that measured on the downstream side of the element, at a point where static pressure recovery by expansion of the jet is completed.

3.3 Primary elements: Definitions

3.3.1 *Orifice or throat.* Opening of minimum cross-sectional area in a primary element.

Standard primary element orifices are always circular and coaxial with the pipe-line.

3.3.2 *Orifice plate.* Thin plate in which a circular aperture has been machined.

Standard orifice plates are described as " thin plate " and " with sharp square edge ", because the thickness of the plate is small compared with the diameter of the measuring section and because the upstream edge of the orifice is sharp and square.

3.3.3 *Nozzle.* Device which consists of a convergent inlet to a cylindrical portion generally called the " throat ".

3.3.4 *Diameter ratio* of a primary element in a given pipe. The diameter of the orifice of the primary element divided by the diameter of the measuring pipe upstream of the primary element.

3.4 Flow

3.4.1 *Rate of flow* of fluid passing through a primary element. Quantity of fluid passing through this orifice in unit time.

This quantity can be characterized by its mass or its volume and the rate of flow can be expressed in units of mass or volume per unit time.

In all cases, it is necessary to state explicitly whether the type of flow rate referred to is expressed by mass or by volume per unit time.

3.4.2 *Pipe Reynolds number.* The pipe Reynolds number used in this ISO Recommendation is referred to the upstream condition of the fluid and to the upstream diameter of the pipe, i.e.

$$Re_D = \frac{\bar{v}_1 D}{\nu_1}$$

3.4.3 *Isentropic exponent.* The isentropic exponent κ appears in the different formulae for expansibility (expansion) factor ε either directly or in the ratio X. There are many gases and vapours for which no values for κ have been published so far. For gases, however, the behaviour of which fairly equals that of ideal gases, the isentropic exponent may be replaced by the ratio of the specific heat capacities. The isentropic exponent, as well as the ratio of the specific heat capacities, vary in general whenever the gas temperature and/or pressure vary.

3.4.4 *Acoustic ratio.* The differential pressure ratio divided by the isentropic exponent (compressible fluid).

3.4.5 *Velocity of approach factor.* It is equal to:

$$E = (1 - \beta^4)^{-\frac{1}{2}} = D^2 / \sqrt{D^4 - d^4} = (1 - m^2)^{-\frac{1}{2}}$$

3.4.6 *Flow coefficient.* Calibration of standard primary elements by means of incompressible fluids (liquids) shows that the quantity α defined by the following relation is dependent only on the Reynolds number for a given primary element in a given installation.

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

The quantity α, a pure number, is called the " flow coefficient ".

The numerical value of α is the same for different installations, whenever such installations are geometrically similar and the flows are characterized by the identical Reynolds number.

The ratio $C = \frac{\alpha}{E}$ is called the " coefficient of discharge ".

The numerical values of α and of C given in this ISO Recommendation were determined experimentally.

3.4.7 *Expansibility (expansion) factor.* Calibration of a given primary element by means of a compressible fluid (gas), shows that the ratio

$$\frac{q_m}{\frac{\pi}{4} d^2 \sqrt{2 \Delta p \, \rho_1}}$$

is dependent both on the value of the Reynolds number and on those of the relative differential pressure and the isentropic exponent of the gas.

The method adopted for representing these variations consists in multiplying the flow coefficient α of the considered primary element, as determined by direct calibration effected by means of liquids for the same value of Reynolds number, by the " expansibility ", a so-called (expansion) factor defined by the relation

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

ε differs from and is less than unity, when the fluid is compressible.

This method is possible because experiments show that practically ε is independent of Reynolds number, and, for a given diameter ratio of a given primary element, depends on the differential pressure ratio and the isentropic exponent.

The numerical values of ε given in this ISO Recommendation have been determined experimentally.

4. COMPUTATION — FORMULAE

4.1 Basic formula

4.1.1 For calculating the mass rate of flow, q_m, the flow coefficient α and expansibility (expansion) factor ε, as specified in this ISO Recommendation, should be used in the following formula:

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

ε is equal to unity when the fluid is incompressible.

4.1.2 Similarly, the value of the volume rate of flow, at the upstream conditions of the fluid, may be calculated by the following relation:

$$q_{v_1} = q_m / \rho_1$$

4.1.3 The formulae of clauses 4.1.1 and 4.1.2 apply for any consistent system of units.

4.2 Method of determination of a standard primary element

The principle of the method consists essentially in selecting *a priori*

— the type of standard primary element to be used,

— a rate of flow and the corresponding value of the differential pressure.

The related values of q_m and Δp should be inserted in the basic formula rewritten in the form below:

$$\alpha\, \beta^2 = \frac{4 q_m}{\varepsilon\, \pi\, D^2 \sqrt{2\, \Delta p\, \rho_1}}$$

and the diameter ratio of the selected primary element is determined by successive approximations.

4.3 Computation of rate of flow

Computation of the rate of flow is effected by replacing the different terms on the right-hand side of the basic formula

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

by their numerical values, obtained in the course of the measurement, and by calculating their product. The computation itself involves no difficulty other than of an arithmetical nature and merely calls for the following comments:

(1) α may be dependent on Re_D, which is itself dependent on q_m. Therefore, the final value of q_m may be obtained by successive approximations, after first calculating q_m from a value of Re_D (or of α) chosen *a priori*. For instance, $\alpha = \alpha_0$ can be taken as a first value.

(2) Δp represents the differential pressure, as defined under clause 3.2.3.

5. ERRORS

5.1 Definition of the tolerance

5.1.1 For the purpose of this ISO Recommendation, tolerance is defined as a value equal to *twice* the standard deviation; this deviation should be calculated and given under this name whenever a measurement is claimed to be in conformity with this ISO Recommendation.

5.1.2 When the partial deviations, the combination of which gives the standard deviation, are independent of one another, are small and numerous, and have a distribution conforming to the so-called Laplace-Gauss normal law, there is a 95 per cent probability that the absolute value of the true error does not exceed *twice* the standard deviation.

5.1.3 When the standard deviation σ_q of the flow measurement q has been calculated, the absolute tolerance e_a is therefore defined as

$$e_a = 2\,\sigma_q$$

The relative tolerance e_r is

$$e_r = \frac{e_a}{q} = 2\,\frac{\sigma_q}{q}$$

The result of the flow measurement q should be then given in any one of the following forms:

rate of flow $= q \pm e_a$
or rate of flow $= q\,(1 \pm e_r)$
or rate of flow $= q$, within $(100\,e_r)$ per cent

5.2 Definition of the standard deviation

5.2.1 If the different *independent* quantities which are used to compute the flow rate are called $X_1, X_2, \ldots, X_i$, then the flow rate can be expressed as a certain function of these quantities:

$$q = \text{function}\,(X_1, X_2, \ldots\ldots, X_i)$$

and if the standard deviations of the quantities $X_1, X_2, \ldots, X_i$ are designated σ_{X_1}, $\sigma_{X_2}, \ldots, \sigma_{X_i}$, the standard deviation of the rate of flow q is defined as

$$\sigma_q = \left[\left(\frac{\partial q}{\partial X_1}\,\sigma_{X_1}\right)^2 + \left(\frac{\partial q}{\partial X_2}\,\sigma_{X_2}\right)^2 + \ldots + \left(\frac{\partial q}{\partial X_i}\,\sigma_{X_i}\right)^2\right]^{\frac{1}{2}}$$

where the partial derivatives $\frac{\partial q}{\partial X_i}$ depend on the manner in which q is a function of the quantities X_i.

5.2.2 If a certain quantity X_i has been measured several times, each measurement being independent of the others,

the standard deviation of an *individual* measurement of X_i is

$$\sigma_{X_i} = \left[\frac{\sum_{j=1}^{j=n} (X_i - X_j)^2}{n - 1}\right]^{\frac{1}{2}}$$

where X_i is the most probable value of the quantity;
X_j are the values obtained of each individual measurement;
n is the total number of measurements.

5.2.3 If repeated measurements of a quantity X_i are not available or are so few that direct computation of the standard deviation σ_{X_i} is likely to be unreliable, it is assumed that one is able to, at least, estimate the maximum deviation of the measurements, above *and* below the adopted value of X_i.

It is then permissible to take the standard deviation as ¼ of this estimated total deviation (that is to say as one half of the mean maximum deviation above *or* below the adopted value of X_i).

5.2.4 The ruling in clause 5.2.2 is valid only if the deviations such as are given by clause 5.2.2 or 5.2.3 are independent, or is only applicable to those deviations which can be considered as such.

5.3 Practical computation of the standard deviation

5.3.1 *The basic formula of computation* of the mass rate of flow q_m is

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

As a matter of fact, the various quantities which appear on the right-hand side of this formula are not independent, so that it is not correct to compute the standard deviation of q_m directly from the standard deviations of these quantities.

For example α is a function of d, D, k, $\bar{v}_1$, ν_1
ε is a function of d, D, Δp, p_1, κ

5.3.1.1 However, it is sufficient, for most practical purposes, to assume that the standard deviations of ε, Δp and ρ_1 are independent of each other and are also independent of the standard deviations of α and d.

5.3.1.2 A practical working formula for σ_{q_m} may then be derived, which takes account of the interdependence of α on d and on D, that enters into the calculations as a consequence of the dependence of α on β. It should be noted that α may also be dependent on the pipe diameter D or on $\frac{D}{k}$, as well as on the Reynolds number Re_D. However, the deviations of α due to these influences are negligible in most actual cases and will be neglected.

Similarly, the deviations of ε which are due to uncertainties in the value of β, the pressure ratio and the isentropic exponent will also be neglected.

5.3.1.3 The standard deviations which should be included in a practical working formula for σ_{q_m} are therefore those of the quantities α, ε, d, D, Δp and ρ_1.

5.3.2 *The practical working formula* for the standard deviation of the mass rate of flow σ_{q_m} is as follows:

$$\frac{\sigma_{q_m}}{q_m} = \left[\left(\frac{\sigma_\alpha}{\alpha}\right)^2 + \left(\frac{\sigma_\varepsilon}{\varepsilon}\right)^2 + 4\left(\frac{\beta^4}{\alpha}\right)^2\left(\frac{\sigma_D}{D}\right)^2 + 4\left(1+\frac{\beta^4}{\alpha}\right)^2\left(\frac{\sigma_d}{d}\right)^2 + \frac{1}{4}\left(\frac{\sigma_{\Delta p}}{\Delta p}\right)^2 + \frac{1}{4}\left(\frac{\sigma_{\rho_1}}{\rho_1}\right)^2\right]^{\frac{1}{2}}$$

5.3.2.1 In the formula above, the values of $\frac{\sigma_\alpha}{\alpha}$ and of $\frac{\sigma_\varepsilon}{\varepsilon}$ should be taken from clauses 6.4.2, 6.5.2, 6.6.2, 7.1.8 and 7.2.7 of this ISO Recommendation.

For long-radius nozzles (see clause 7.2.7), where C is used instead of α, the term $\frac{\sigma_c}{C}$ will replace $\frac{\sigma_\alpha}{\alpha}$ and no additional deviation will be included to take account of uncertainties of the velocity of approach factor $E\left(E = \frac{\alpha}{C}\right)$

On the other hand, the values of $\frac{\sigma_D}{D}$, $\frac{\sigma_d}{d}$, $\frac{\sigma_{\Delta p}}{\Delta p}$ and $\frac{\sigma_{\rho_1}}{\rho_1}$ should be estimated by the user, because this ISO Recommendation does not specify the method of measurement of the quantities D, d, Δp and ρ_1.

5.3.2.2 The above formula of clause 5.3.2 is derived as follows:

The total standard deviation of α is made up of the standard deviations σ_d and σ_D in a manner which depends on the functional relation between α, d and D.

It should be noted that α is approximately a linear function of β^4, for both orifice plates and nozzles, according to the relationships below:

$\alpha = b + 0.4\,\beta^4$ for orifice plates,

$\alpha = b' + 0.6\,\beta^4$ for nozzles,

where b and b' are constants.

If a mean slope of 0.5 is taken, the basic equation for determining the mass flow is then approximately (see clause 5.3.1)

for orifice plates:

$$q_m \approx \left(b + 0.5\frac{d^4}{D^4}\right)\varepsilon\,\frac{\pi}{4}\,d^2\sqrt{2\,\Delta p\,\rho_1}$$

for nozzles:

a corresponding equation,

where b' is substituted for b.

The procedure given in clause 5.2.1 leads to an equation identical to that given above in clause 5.3.2, except that the first term of the right-hand side would be $\left(\frac{\sigma_b}{\alpha}\right)^2$ for orifice plates $\left(\text{or would be } \left(\frac{\sigma_b'}{\alpha}\right)^2 \text{ for nozzles}\right)$ instead of $\left(\frac{\sigma_\alpha}{\alpha}\right)^2$

Finally, it may be assumed that the standard deviation σ_b (or σ_b') is equal to the standard deviation σ_χ, as it is given in this ISO Recommendation. Substitution of σ_χ for σ_b (or σ_b') gives the above working formula of clause 5.3.2.

5.4 General method

5.4.1 If the user wishes to obtain as accurate a value as possible of the tolerance, or if he thinks that the process described in clause 5.3.1 cannot legitimately be applied to a particular case of measurement, the general method to be adopted should then be as follows:

(1) Examine thoroughly and in detail all processes of determination and measurement which enable a value of the rate of flow to be obtained.

(2) Split up the basic formula of computation of q into an expression of other quantities said to be independent of each other and called " elementary quantities ".

(3) Compute the multipliers which correspond to each elementary quantity of q or determine them by the method of finite differences.

(4) Break down the determination of each elementary quantity into its various operations by analysing in detail the techniques of measurement so as to discover the sources of independent deviations which the use of the techniques involves. Furthermore, if this is considered useful, isolate the systematic from the random type of deviations.

(5) Compute or estimate the standard deviation of the elementary quantities corresponding to each source of deviation.

(6) Compute the total standard deviation which arises from each elementary quantity.

(7) Compute, by use of the formula of clause 5.2.1, and the values found in the above paragraphs (3) and (6), the standard deviation of flow measurement.

5.4.2 As it proposes no particular technique for measuring the elementary quantities, nor even any precise technique of flow measurement which really determines the elementary quantities to be taken into account, this ISO Recommendation is limited to the above statement of a general method.

5.5 Errors due to installation conditions

When the straight lengths are such that an additional deviation of 0.5 per cent is to be considered, this additional deviation should be added according to clause 2.4.4 and not quadratically to the other deviations of the flow measurement.

6. ORIFICE PLATES

The various types of standard orifice plates are similar and therefore need only one description.

Each type of standard orifice plate is characterized by the arrangement of pressure taps.

No orifice plate can be used according to this ISO Recommendation unless it conforms with the following description.

6.1 Description

The meridian plane cross section of the plate is shown in Figure 1 overleaf.

The letters are for reference purposes.

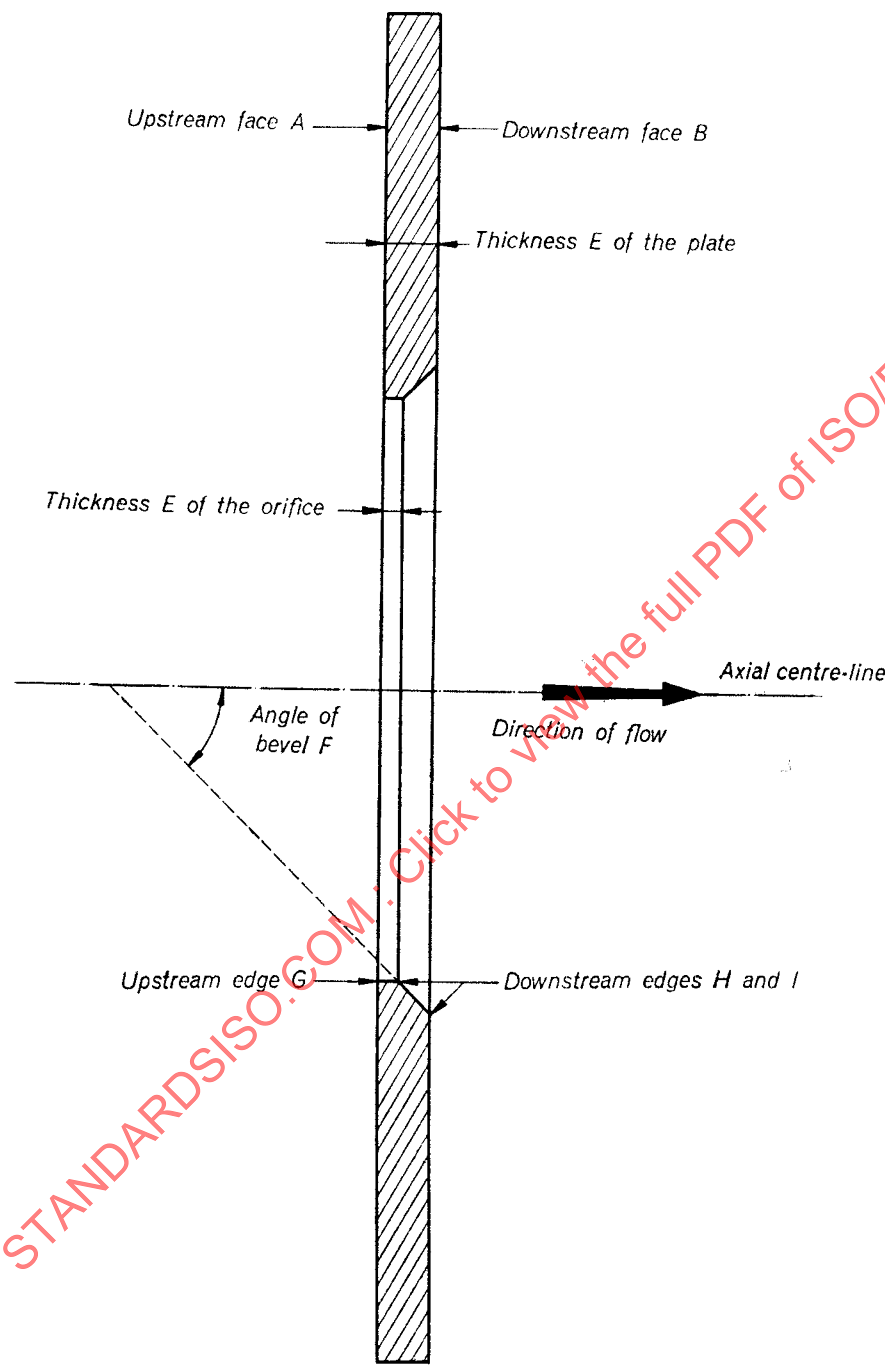

FIG. 1. — **Standard orifice plate**

6.1.1 *General shape*

The part of the plate inside the pipe should be circular and concentric with the pipe centre-line. The faces of this plate should always be flat and parallel.

Unless otherwise stated, the following descriptions apply only to that part of the plate intended to be located within the pipe for measuring purposes.

6.1.2 *Upstream face A*

6.1.2.1 The upstream face of the plate *A* should be flat. It is considered as such when the slope of a straight line connecting any two points of its surface in relation to a plane perpendicular to the centre-line is less than 1 per cent, ignoring the inevitable local defects of the surface which are invisible to the naked eye.

6.1.2.2 The upstream face of the orifice plate should be smooth to within 0.0003 d (peak-to-hollow height) within a circle whose diameter is not less than 1.5 d and which is concentric with the orifice.

6.1.2.3 It is useful or convenient to provide a distinctive mark which, whenever possible, is visible even when the orifice plate is installed to show that the upstream face of the orifice plate is correctly installed relative to the direction of flow.

6.1.3 *Downstream face B*

6.1.3.1 The downstream face *B* should be flat and parallel with the upstream face.

6.1.3.2 It is unnecessary to provide the same quality of surface finish for the downstream face as for the upstream face.

6.1.3.3 The flatness and surface condition of the downstream face are judged by mere visual inspection (cf. clauses 6.1.2.1 and 6.1.4.4).

6.1.4 *Thicknesses E and e*

6.1.4.1 The thickness e of the orifice should be between 0.005 D and 0.02 D; however, when the value of β is less than 0.2, the thickness e should be between 0.005 D and 0.1 d (this latter condition does not apply when corner taps are used, because the lower limit for β is then 0.22).

6.1.4.2 The values of e measured at any point on the orifice should not differ among themselves by more than 0.001 D.

6.1.4.3 The thickness E of the plate should be between e and 0.05 D.

6.1.4.4 The values of E measured at any point of the plate should not differ among themselves by more than 0.005 D.

6.1.4.5 For orifice plates with corner taps and when $\beta > 0.7$, e should be approximately equal to $^1/_3$ of E, if the plate is bevelled.

6.1.5 *Angle of bevel F*

6.1.5.1 If the thickness E of the plate exceeds the thickness e of the orifice, the plate should be bevelled on the downstream side. The bevelled surface should be well finished.

6.1.5.2 The angle of bevel F should be between 30° and 45°.

6.1.5.3 The plate may be not bevelled if its thickness E is less than or equal to 0.02 D (cf. clause 6.1.4.1).

6.1.6 *Edges G, H and I*

6.1.6.1 The upstream edge G and the downstream edges H and I should have neither wire-edges, nor burrs, nor, in general, any peculiarities visible to the naked eye.

6.1.6.2 The upstream edge G should be sharp. It is considered so if, when viewed with the naked eye, it does not seem to reflect a beam of light.

6.1.7 *Diameter of orifice d*

6.1.7.1 The value d of the diameter of the orifice should be taken as the mean of the measurements of a number of diameters distributed in meridian planes and at approximately even angles to each other. At least four diameters should be measured.

6.1.7.2 The orifice should be cylindrical. No diameter should differ by more than 0.05 per cent 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 in respect of the mean of the measured diameters.

Attention is called to the fact that it is possible to check circularity of an orifice bore within the accuracy required without measuring the mean diameter of the orifice bore itself.

6.1.7.3 The diameter d should always be between 0.1 D and 0.8 D, although this range does not cover certain standard orifice plates.

The choice of the ratio d/D, within these limits, is left to the user; it is one of the parameters which defines an orifice plate of a given type.

6.1.8 *Symmetrical plates*

6.1.8.1 If the orifice plate is intended to be used for measuring reverse flows,

the plate should not be bevelled,
the two faces should both be as described for the upstream face,
the thickness E of the plate should be equal to the thickness e of the orifice,
the two edges of the orifice should be as described for the upstream edge.

6.1.8.2 Furthermore (see clause 6.2), for orifice plates with *vena contracta* taps, two sets of upstream and downstream pressure taps may be arranged and used alternately.

6.1.9 *Material and manufacture*

6.1.9.1 The plate can be manufactured of any material and in any way, provided it is and remains in accordance with the foregoing description during the proposed flow measurements.

In particular, the plate should be clean when the measurements are made.

6.1.9.2 The orifice plate is usually made of metal, and preferably should be erosion and corrosion proof.

6.1.9.3 The machining required to obtain a plate conforming to the standard description usually calls for the use of machine tools of good quality and in good condition.

6.1.9.4 If the plate is turned, the best result is obtained if, after the orifice has been bored, the upstream face is finished by a very fine radial cut from the centre outwards.

6.2 Pressure taps

For all types of standard orifice plates, pressure taps should be as defined under clause 3.2.1.

At least one upstream pressure tap and one downstream pressure tap should be provided for each primary element, installed in one or other of the recommended standard positions.

A single plate can be used with several sets of pressure taps suitable for different types of standard orifice plates.

6.2.1 *Shape and diameters of pressure taps*, other than corner taps

6.2.1.1 Corner taps are dealt with in clause 6.2.4.

6.2.1.2 The centre-line of the tapping should meet the pipe centre-line and be at right angles to it.

6.2.1.3 At the point of break-through the hole should be circular. The edges should be flush with the pipe-wall, free from burrs and generally have no peculiarities and be rounded to a radius not exceeding one tenth of the diameter of the pressure tap.

6.2.1.4 Conformity of the pressure taps with the two foregoing descriptions is judged by mere visual inspection.

6.2.1.5 The diameters of pressure taps should be less than 0.08 D and preferably between ¼ and ½ in (6 and 12 mm). The upstream and downstream pressure taps should have the same diameter.

6.2.1.6 The pressure pipes to the secondary devices should be cylindrical for a length, from the inside wall of the measured pipe, at least equal to twice the diameter of the pressure taps.

6.2.2 *Angular position of pressure taps*

6.2.2.1 Centre-lines of the pressure taps may be located in any meridian sector of the pipeline.

6.2.2.2 The axis of the upstream tap and that of the downstream tap may be located in different meridian sectors.

6.2.2.3 However, attention is drawn to the fact that, in any case, the readings of differential pressure obtained by these pressure taps should be in accordance with the definition of clause 3.2.3, particularly with respect to gravitational energy variations.

6.2.3 *Spacing of pressure taps*

6.2.3.1 The spacing of a pressure tap is the distance, measured on a straight line parallel to the centre-line of the pipeline, between the centre-line of the pressure tap and the plane of one specific face of the orifice plate.

6.2.3.2 Pressure taps spacing characterizes the type of standard orifice plate.

6.2.3.3 Orifice plate with corner taps. Corner taps are described under clause 6.2.4.

6.2.3.4 Orifice plate with *vena contracta* taps:

Upstream tap — spaced between 0.9 D and 1.1 D from the upstream face of the plate.

Downstream tap — spaced from the upstream face of the plate as defined in Table 7, page 27.

6.2.3.5 Orifice plate with flange taps:

Upstream tap — spaced $1 \pm {}^1/_{32}$ in (25 ± 1 mm) from the upstream face of the plate.

Downstream tap — spaced $1 \pm {}^1/_{32}$ in (25 ± 1 mm) from the downstream face of the plate.

6.2.4 *Corner taps*

6.2.4.1 The spacing between the taps and the respective faces of the plate is equal to half the diameter or to half the width of the taps themselves, so that the tap holes break through the pipe-wall flush with the faces of the plate (see also clause 6.2.4.5).

6.2.4.2 The pressure taps should always be either single tappings, or annular slits, opening into the annular chambers of piezometer rings, as shown in Figures 2 and 3, opposite, to which the following letters refer.

6.2.4.3 The diameter a of single taps or the width a of annular slits are given below (refer also to clause 6.3.3.1) :

Clean fluids and steam

for $\beta \leqslant 0.65$	$a \leqslant 0.03\ D$
for $\beta > 0.65$	$0.01\ D \leqslant a \leqslant 0.02\ D$

Moreover for any values of β

for clean fluids	$^1/_{32}$ in (1 mm) $\leqslant a \leqslant$ $^{25}/_{64}$ in (10 mm)
for steam with annular chambers	$^1/_{32}$ in (1 mm) $\leqslant a \leqslant$ $^{25}/_{64}$ in (10 mm)
for steam and for liquefied gases with single tappings	$^5/_{32}$ in (4 mm) $\leqslant a \leqslant$ $^{25}/_{64}$ in (10 mm)

6.2.4.4 The annular slits usually break through the pipe over the entire perimeter, with no break in continuity. If not, each annular chamber connects with the inside of the pipe by at least 4 openings, the axes of which are at equal angles to one another and the individual opening area of which is at least $^1/_{50}$ in^2 (12 mm^2).

6.2.4.5 If individual pressure taps, as shown in Figure 3, are used, the centre-line of the taps should cross the centre-line of the pipe at as near a right angle (90°) as possible.

If there are several individual pressure taps for one and the same upstream or downstream position, their centre-lines should form equal angles with each other. The diameters of individual pressure taps are given in clause 6.2.4.3.

The pressure lines establishing connection with the secondary devices are cylindrical from the inside wall of the measured pipe, for a length at least equal to twice the diameter of the pressure taps.

6.2.4.6 The inner diameter b of the rings should not be smaller than D. The diameter of the rings should be between D and 1.02 D; the length c of the upstream ring should be less than 0.2 D and the length c of the downstream ring less than 0.5 D. The diameter ratio should be calculated in relation to the pipe diameter D and not to the diameter of the ring.

The thickness f should be more than or equal to twice the width a of the annular slit. The area of the cross-section of the annular chamber ($g \times h$) should be more than or equal to half the total area of the tapping holes connecting the chamber to the pipe.

6.2.4.7 All surfaces of the ring which will be in contact with the measured fluid should be clean and have a good machine finish.

6.2.4.8 The pressure tappings j connecting the annular chambers to the secondary devices are pipe-wall tappings, circular at the point of breakthrough and with diameters between $^5/_{32}$ and $^{25}/_{64}$ in (4 and 10 mm).

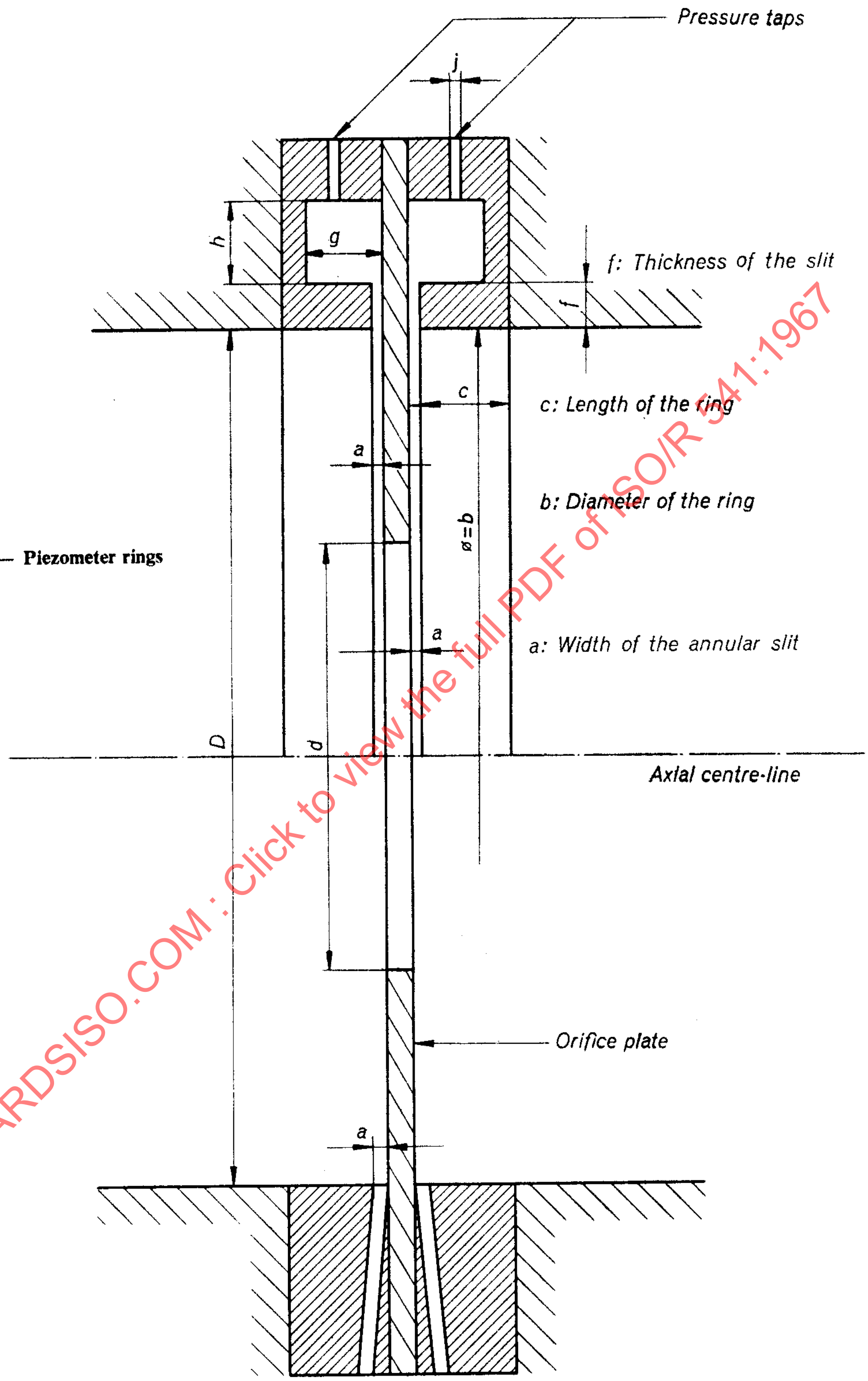

FIG. 2. — **Piezometer rings**

FIG. 3. — **Corner taps (individual taps)**

6.2.4.9 The upstream and downstream piezometer rings are not necessarily symmetrical in relation to each other, but they should both conform with the foregoing specifications.

6.3 Installation of orifice plate

6.3.1 *Measuring section*

6.3.1.1 The pipe may be provided with the necessary drain holes for the removal of solid deposits and fluids other than the measured fluid. There should be no flow through these drain holes while flow measurement is in progress. The drain hole should not be located near to the orifice plate, unless it is unavoidable to do so.

In such a case, the diameter of these drain holes should be smaller than 0.08 D and their location such that the distance, measured on a straight line, from one of these holes to a pressure tap of the primary element placed on the same side of the plate, is always greater than 0.5 D. Furthermore, the centre-line of the drain hole should be situated in a meridian sector of the pipe which does not include any pressure hole.

6.3.1.2 The measuring section should comply with the conditions stated in clauses 2.3.2 to 2.3.4 and 2.4.

6.3.2 *Location of plate and rings*

6.3.2.1 The plate should be placed in the pipe in such a way that the fluid flows from the upstream face towards the downstream face (see clause 6.1.2.3).

6.3.2.2 The plate should be perpendicular to the centre-line of the pipe within $\pm 1°$.

6.3.2.3 The plate should be centred in the pipe or, if applicable, in the piezometer rings. In all cases, the shortest distance between the centre-line of the orifice and the centre-lines of the pipe on the upstream and downstream sides should be less than $0.015\,D\left(\frac{1}{\beta} - 1\right)$.

6.3.2.4 When used, the piezometer rings (whose diameter is between D and 1.02 D) should be so centred that at no point do they protrude into the pipe.

6.3.3 *Fixing and gaskets*

6.3.3.1 The method of fixing and tightening should be such that once the plate has been finally fixed in the proper position, it remains so.

It is necessary, when holding the orifice plate between flanges, to allow for its free thermal expansion and to avoid buckling and distortion.

6.3.3.2 Gaskets, if used, should be made and inserted in such a way that they do not protrude at any point inside the pipe. They should be as thin as possible.

6.3.3.3 The gaskets if used between the plate and the annular chamber rings should not protrude inside said chambers.

6.3.4 *Static pressure measurement and temperature measurement*

6.3.4.1 The static pressure of the fluid should be measured in the plane of the upstream pressure tap, by means of a pipe-wall pressure tap, as described in clause 6.2.1.

This tap should be separate from the tap provided for measuring the upstream component of the differential pressure, unless the intention is to measure upstream and downstream pressures separately.

If there is an upstream annular chamber, the static pressure should be measured at the wall of the said annular chamber.

The static pressure value to be used in subsequent computations is that existing at the level of the centre of the upstream measured cross-section, which may differ from the pressure measured at the wall.

6.3.4.2 The temperature of the fluid should preferably be measured downstream of the primary element, and the thermometer pocket should take up as little space as possible. The distance between it and the orifice plate should be at least equal to 5 D if the pocket is located downstream, and in accordance with the last two lines of Table 1 if the pocket is located upstream.

6.3.4.3 Any method of determining the static pressure and the temperature of the fluid is acceptable if it enables a reliable value of the temperature, the viscosity and the mass density of the fluid upstream of the orifice plate to be obtained without disturbing the flow measurement in any way. The temperature of the orifice plate and that of the fluid upstream of the orifice plate are assumed to be the same.

6.3.5 *Thermal insulation*

6.3.5.1 The measuring section and the pipe flanges should be lagged over at least the whole length of the required straight runs.

6.3.5.2 It is, however, unnecessary to lag the pipe when the temperature of the fluid, between the inlet of the minimum straight length of the upstream pipe and the outlet of the straight length of the downstream pipe, does not exceed any limiting value selected by the user, as being sufficient for the accuracy of flow measurement which he requires.

6.4 Coefficients and standard deviations of orifice plates with corner taps

6.4.1 *Coefficients*

The coefficients are set out in the form of tables and the method of use is given in the accompanying clause.

Interpolation by proportion can be made, when necessary. Extrapolation should *never* be made.

6.4.1.1 FLOW COEFFICIENT α

The flow coefficient α is given as follows:

$$\alpha = \alpha_o \times r_{Re}$$

The values of α_o are given as a function of β^4 and Re_D in Table 3, page 24.

6.4.1.2 ROUGHNESS CORRECTION FACTOR r_{Re}. The correction factor r_{Re} for pipe roughness depends on the relative roughness k/D and on the pipe Reynolds number Re_D. It is computed by the following formula:

$$r_{Re} = (r_o - 1)\left(\frac{\log_{10} Re_D}{6}\right)^2 + 1$$

with the exception that, if $Re_D \geqslant 10^6$

then one will set $r_{Re} = r_o$

The values of r_o are given as a function of β^2 and D/k in Table 4, page 25.

TABLE 3. — **Flow coefficient α_0 for orifice plates with corner taps**

β^4 \ Re_D (α_0)	5.10^3	10^4	2.10^4	3.10^4	5.10^4	10^5	10^6	10^7	β^4
0.0025	0.603	0.600	0.599	0.599	0.598	0.598	0.598	0.597	**0.0025**
0.003	0.604	0.600	0.600	0.600	0.599	0.599	0.599	0.598	**0.003**
0.004	0.605	0.601	0.601	0.601	0.600	0.600	0.600	0.599	**0.004**
0.005	0.606	0.602	0.602	0.602	0.601	0.601	0.600	0.599	**0.005**
0.01	0.611	0.606	0.605	0.604	0.603	0.603	0.602	0.602	**0.01**
0.02	0.619	0.613	0.611	0.608	0.607	0.607	0.606	0.606	**0.02**
0.03	0.627	0.620	0.616	0.613	0.612	0.612	0.611	0.610	**0.03**
0.04	0.634	0.626	0.621	0.618	0.617	0.616	0.615	0.614	**0.04**
0.05		0.632	0.626	0.623	0.622	0.620	0.619	0.618	**0.05**
0.06		0.637	0.631	0.627	0.626	0.624	0.622	0.621	**0.06**
0.07		0.643	0.636	0.632	0.630	0.628	0.626	0.625	**0.07**
0.08		0.648	0.641	0.636	0.634	0.632	0.630	0.629	**0.08**
0.09		0.653	0.646	0.641	0.638	0.636	0.634	0.633	**0.09**
0.10		0.658	0.650	0.645	0.642	0.640	0.637	0.636	**0.10**
0.11		0.663	0.655	0.650	0.647	0.644	0.641	0.640	**0.11**
0.12		0.668	0.659	0.654	0.651	0.647	0.645	0.644	**0.12**
0.13		0.674	0.664	0.659	0.655	0.651	0.649	0.648	**0.13**
0.14		0.679	0.668	0.663	0.659	0.655	0.652	0.651	**0.14**
0.15		0.684	0.673	0.668	0.663	0.659	0.656	0.655	**0.15**
0.16		0.689	0.677	0.672	0.667	0.663	0.660	0.659	**0.16**
0.17		0.695	0.682	0.677	0.671	0.667	0.664	0.663	**0.17**
0.18		0.700	0.687	0.681	0.675	0.671	0.667	0.666	**0.18**
0.19		0.705	0.692	0.685	0.679	0.675	0.671	0.670	**0.19**
0.20		0.710	0.696	0.689	0.683	0.679	0.675	0.674	**0.20**
0.21		0.716	0.701	0.694	0.688	0.683	0.679	0.678	**0.21**
0.22		0.721	0.705	0.698	0.692	0.687	0.683	0.682	**0.22**
0.23		0.726	0.710	0.703	0.696	0.691	0.687	0.685	**0.23**
0.24		0.731	0.714	0.707	0.700	0.695	0.691	0.689	**0.24**
0.25		0.737	0.719	0.712	0.705	0.699	0.695	0.693	**0.25**
0.26		0.742	0.723	0.716	0.709	0.703	0.699	0.697	**0.26**
0.27		0.748	0.728	0.721	0.714	0.708	0.703	0.701	**0.27**
0.28		0.753	0.733	0.726	0.718	0.712	0.707	0.705	**0.28**
0.29		0.758	0.738	0.731	0.723	0.716	0.711	0.709	**0.29**
0.30		0.763	0.743	0.735	0.727	0.720	0.715	0.713	**0.30**
0.31		0.769	0.748	0.740	0.732	0.725	0.719	0.717	**0.31**
0.32		0.775	0.753	0.745	0.736	0.729	0.723	0.721	**0.32**
0.33		0.781	0.759	0.750	0.741	0.734	0.728	0.725	**0.33**
0.34		0.786	0.764	0.755	0.745	0.738	0.732	0.729	**0.34**
0.35		0.792	0.770	0.760	0.750	0.743	0.736	0.733	**0.35**
0.36		0.798	0.775	0.765	0.755	0.748	0.740	0.738	**0.36**
0.37			0.781	0.770	0.761	0.753	0.744	0.742	**0.37**
0.38			0.786	0.775	0.766	0.757	0.748	0.747	**0.38**
0.39			0.792	0.780	0.772	0.762	0.753	0.751	**0.39**
0.40			0.797	0.786	0.777	0.767	0.757	0.756	**0.40**
0.41			0.804	0.793	0.783	0.773	0.763	0.761	**0.41**

Table 3 gives the values of α_0 as a function of β^4 and of Re_D; α_0 is independent of D.

NOTE.—This type of orifice plate should not be used when
$\beta^4 < 0.0025$ or $\beta^4 > 0.41$ ($\beta < 0.22$ or $\beta > 0.8$)
$D < 2$ in (50 mm) or $D > 40$ in (1000 mm)
Re_D is outside of tabulated values.

TABLE 4. — **Values of r_0 for orifice plates with corner taps**

β^2 \ D/k (r_0)	400	800	1200	1600	2000	2400	2800	3200	≥ 3400	β^2
0.1	1.002	1.000	1.000	—	—	—	—	—	1.000	**0.1**
0.2	1.003	1.002	1.001	1.000	—	—	—	—	1.000	**0.2**
0.3	1.006	1.004	1.002	1.001	1.000	—	—	—	1.000	**0.3**
0.4	1.009	1.006	1.004	1.002	1.001	1.000	—	—	1.000	**0.4**
0.5	1.014	1.009	1.006	1.004	1.002	1.001	1.000	—	1.000	**0.5**
0.6	1.020	1.013	1.009	1.006	1.003	1.002	1.000	1.000	1.000	**0.6**
0.64	1.024	1.016	1.011	1.007	1.004	1.002	1.002	1.000	1.000	**0.64**

NOTES

1. The value k is a measure of inside pipe wall roughness and is expressed in units of length.
2. Approximate values of k for different materials can be obtained from the various tables given in reference literature. Table 5 gives values of k for a variety of materials, as derived from the Colebrook formula.
3. When the pipe friction coefficient λ has been experimentally determined after measuring the pressure loss with liquid flow, it is possible to derive D/k from the Colebrook formula using appropriate values of λ and Re_D.

TABLE 5. — **Examples of values of the pipe wall roughness k**

Material	Condition	k in mm
brass, copper, aluminium, plastics, glass	smooth, without sediments	< 0.03
steel	new, seamless cold drawn	< 0.03
	new, seamless hot drawn new, seamless rolled new, welded longitudinally	0.05 to 0.10
	new, welded spirally	0.10
	slightly rusted	0.10 to 0.20
	rusty	0.20 to 0.30
	encrusted	0.50 to 2
	with heavy incrustations	> 2
	bituminized, new	0.03 to 0.05
	bituminized, normal	0.10 to 0.20
	galvanized	0.13
cast iron	new	0.25
	rusty	1.0 to 1.5
	incrusted	> 1.5
	bituminized, new	0.1 to 0.15
asbestos cement	insulated and not insulated, new	< 0.03
	not insulated, normal	0.05

6.4.1.3 EXPANSIBILITY (EXPANSION) FACTOR ε

The expansibility (expansion) factor ε is given in Table 6 below, as derived from the empirical formula

$$\varepsilon = 1 - (0.3707 + 0.3184\,\beta^4)\left[1 - \left(\frac{p_2}{p_1}\right)^{\frac{1}{\kappa}}\right]^{0.935}$$

This formula is applicable only for the values of β, D and Re_D, as stated in the note under Table 3, page 24. Test results for determination of ε are known for air, steam and natural gas only. However, there is no known objection to using the same formula for other gases and vapours, the isentropic exponent of which is known.

Moreover, it is applicable only if $\frac{p_2}{p_1} \geqslant 0.75$.

TABLE 6. — **Expansibility (expansion) factor for orifice plates with corner taps**

$\left(\frac{p_2}{p_1}\right)^{\frac{1}{\kappa}}$ \ β^4	0	0.05	0.1	0.15	0.20	0.25	0.30	0.35	0.40
1	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
0.995	0.9974	0.9973	0.9972	0.9970	0.9969	0.9968	0.9967	0.9966	0.9965
0.99	0.9950	0.9948	0.9946	0.9943	0.9941	0.9939	0.9937	0.9935	0.9933
0.95	0.9775	0.9765	0.9755	0.9746	0.9736	0.9726	0.9717	0.9707	0.9697
0.90	0.9569	0.9551	0.9532	0.9514	0.9495	0.9477	0.9458	0.9440	0.9421
0.80	0.9177	0.9141	0.9106	0.9071	0.9035	0.9000	0.8965	0.8929	0.8894
0.70	0.8797	0.8746	0.8694	0.8642	0.8591	0.8539	0.8487	0.8436	0.8384

NOTE.—Attention is called to the fact that for

$$0.75 < \beta \leqslant 0.8$$

the standard deviation on ε should be doubled (see clause 6.4.2.2 below).

6.4.2 *Standard deviations*

6.4.2.1 STANDARD DEVIATION OF FLOW COEFFICIENT α

When β, D, Re_D and D/k are assumed to be known without error, the standard deviation of the value of α is given, in per cent, by the following formula:

$$\pm\,0.25\left[1 + 2\,\beta^4 + 100\,(r_{Re} - 1) + \beta^2\,(\log_{10} Re_D - 6)^2 + \frac{50}{D}\right]$$

NOTES

1. D should be expressed in millimetres in the above formula.
   If D is expressed in inches, the last term of the formula should be $\frac{2}{D}$ instead of $\frac{50}{D}$.
2. The same formulae should be used even when
   $$10^6 < Re_D \leqslant 10^7$$

6.4.2.2 STANDARD DEVIATION OF EXPANSIBILITY (EXPANSION) FACTOR ε

The standard deviation on ε is expressed, in per cent, by

β	**Standard deviation on ε in per cent**
$0.22 \leqslant \beta \leqslant 0.75$	$\pm\,2\,x$
$0.75 < \beta \leqslant 0.8$	$\pm\,4\,x$

6.5 Coefficients and standard deviations of orifice plates with "vena contracta" taps

6.5.1 *Coefficients*

The coefficients are set out in the form of formulae or tables, the method of use of which is set forth in the accompanying clause. Interpolation by proportion can be made, when necessary. Extrapolation should *never* be made.

6.5.1.1 Spacing

The spacing of the upstream pressure tap is to be in the range 0.9 and 1.1 D.
The spacing of the downstream pressure tap is given by Table 7 below.
Both locations are measured from the upstream face of the orifice plate.

Table 7. — **Spacing of "vena contracta" pressure taps**

β	Spacing of "vena contracta" pressure taps
0.10	0.84 $D \pm 30\%$
0.15	0.82 $D \pm 30\%$
0.20	0.80 $D \pm 30\%$
0.25	0.78 $D \pm 30\%$
0.30	0.76 $D \pm 30\%$
0.35	0.73 $D \pm 25\%$
0.40	0.70 $D \pm 25\%$
0.45	0.67 $D \pm 25\%$
0.50	0.63 $D \pm 20\%$
0.55	0.59 $D \pm 20\%$
0.60	0.55 $D \pm 15\%$
0.65	0.50 $D \pm 15\%$
0.70	0.45 $D \pm 10\%$
0.75	0.40 $D \pm 10\%$
0.80	0.34 $D \pm 10\%$

This Table gives the spacing of the centre-line of the downstream pressure tap as a function of β, together with the tolerance limits of this spacing.

(The spacing of the upstream pressure tap is nominally of D and may, without modification in the flow coefficient, be between 0.9 and 1.1 D).

The centre-line of any new pressure tap should always be at the standard spacing, but an existing pressure tap may be used, provided its spacing is between the specified lower and upper limits.

6.5.1.2 Flow coefficient α

The flow coefficient α is given by the following empirical formulae:

(*a*) When D is expressed in inches

$$\alpha = A + B \sqrt{\frac{10^6}{Re_D}}$$

where $A = 0.5922 + 0.4252 \left| \frac{0.0006}{D^2 \beta^2 + 0.01 D} + \beta^4 + 1.25 \beta^{16} \right|$

and $B = 0.00025 + 0.002325 \left| \beta + 1.75 \beta^4 + 10 \beta^{12} + 2 D \beta^{16} \right|$

(*b*) When D is expressed in millimetres

$$\alpha = A + B \sqrt{\frac{10^6}{Re_D}}$$

where $A = 0.5922 + 0.4252 \left[\frac{0.3871}{D^2 \beta^2 + 0.254\ D} + \beta^4 + 1.25\ \beta^{16} \right]$

and $B = 0.00025 + 0.002325 \left[\beta + 1.75\ \beta^4 + 10\ \beta^{12} + 0.07874\ D\ \beta^{16} \right]$

NOTES

1. Most of the experiments from which the above values were obtained were made in steel pipes in good condition for which an average value was taken of $k = 0.002$ in (0.05 mm).

   The above formulae should be used only when $\frac{D}{k} \geqslant 1000$

   (k has herein the same meaning as in clause 6.4.1.2, Notes 1 and 2).

2. *If D is less than 2 in (50 mm) or more than 30 in (760 mm) this type of orifice plate should not be used. Note also that* β *should be between 0.1 and 0.8.*

3. α *can be computed by the above formula only if* Re_D *is within the limiting values given in Table 8.*

6.5.1.3 LIMITING VALUES OF REYNOLDS NUMBER Re_D

Table 8 opposite shows as a function of β and D the lower and upper limits of Re_D between which α has been determined experimentally.

6.5.1.4 EXPANSIBILITY (EXPANSION) FACTOR ε

The empirical formula for computing the expansibility (expansion) factor ε is as follows:

$$\varepsilon = 1 - (0.41 + 0.35\ \beta^4)\ X$$

This formula is applicable only for values of β, D, $\frac{D}{k}$ and Re_D as stated in the Notes of clause 6.5.1.2. Test results for determination of ε are known for air, steam and natural gas only. However, there is no known objection to using the same formula for other gases and vapours the isentropic exponent of which is known.

Moreover it is applicable only if $\frac{p_2}{p_1} \geqslant 0.75$.

6.5.2 *Standard deviations*

6.5.2.1 SPACING OF PRESSURE TAPS

No additional error to α is introduced if the spacing of the pressure taps is within the limits given in clause 6.5.1.1.

When the spacings are outside the limits given in clause 6.5.1.1, the measurement is not valid and is not in accordance with this ISO Recommendation.

6.5.2.2 STANDARD DEVIATION OF FLOW COEFFICIENT α

When β, D and Re_D are assumed to be known without error, the standard deviation of the value of α is given, in per cent, as follows:

β	Standard deviation of α in per cent
$0.2 \leqslant \beta \leqslant 0.7$	± 0.25
$0.2 > \beta \geqslant 0.1$	$\pm (0.75 - 2.5\ \beta)$
$0.7 < \beta \leqslant 0.8$	$\pm (2.5\ \beta - 1.50)$

TABLE 8. — **Limiting values of Reynolds numbers for orifice plates with "vena contracta" taps**

β \ D	2 in (50 mm) Re_D		3 in (75 mm) Re_D		4 in (100 mm) Re_D		6 in (150 mm) Re_D		8 in (200 mm) Re_D		10 in (250 mm) Re_D		15 in (375 mm) Re_D		30 in (750 mm) Re_D	
	min.	max.	min.	max.	min.	max.	min.	max.	min.	max.	min.	max.	min.	max.	min.	max.
0.100	6 000	10^6	9 000	10^6	12 000	10^6	18 000	10^7	24 000	10^7	30 000	10^7	45 000	10^7	90 000	10^7
0.150	6 000	10^6	9 000	10^6	12 000	10^6	18 000	10^7	24 000	10^7	30 000	10^7	45 000	10^7	90 000	10^7
0.200	6 000	10^6	9 000	10^6	12 000	10^6	18 000	10^7	24 000	10^7	30 000	10^7	45 000	10^7	90 000	10^7
0.250	6 000	10^6	9 000	10^6	12 000	10^6	18 000	10^7	24 000	10^7	30 000	10^7	45 000	10^7	90 000	10^7
0.300	6 000	10^6	9 000	10^6	12 000	10^6	18 000	10^7	24 000	10^7	30 000	10^7	45 000	10^7	90 000	10^7
0.325	6 000	10^6	9 000	10^6	12 000	10^6	18 000	10^7	24 000	10^7	30 000	10^7	45 000	10^7	90 000	10^7
0.350	6 000	10^6	9 000	10^6	12 000	10^6	20 000	10^7	25 000	10^7	30 000	10^7	50 000	10^7	100 000	10^7
0.375	6 000	10^6	10 000	10^6	15 000	10^6	25 000	10^7	25 000	10^7	30 000	10^7	50 000	10^7	100 000	10^7
0.400	8 000	10^6	10 000	10^6	15 000	10^6	25 000	10^7	30 000	10^7	50 000	10^7	50 000	10^7	100 000	10^7
0.425	8 000	10^6	15 000	10^6	20 000	10^6	30 000	10^7	30 000	10^7	50 000	10^7	50 000	10^7	150 000	10^7
0.450	10 000	10^6	15 000	10^6	20 000	10^6	30 000	10^7	50 000	10^7	50 000	10^7	50 000	10^7	150 000	10^7
0.475	10 000	10^6	15 000	10^6	20 000	10^6	30 000	10^7	50 000	10^7	50 000	10^7	100 000	10^7	200 000	10^7
0.500	10 000	10^6	20 000	10^6	20 000	10^6	50 000	10^7	50 000	10^7	50 000	10^7	100 000	10^7	200 000	10^7
0.520	15 000	10^6	20 000	10^6	30 000	10^6	50 000	10^7	50 000	10^7	50 000	10^7	100 000	10^7	200 000	10^7
0.540	15 000	10^6	20 000	10^6	30 000	10^6	50 000	10^7	50 000	10^7	100 000	10^7	100 000	10^7	200 000	10^7
0.560	15 000	10^6	25 000	10^6	30 000	10^6	50 000	10^7	50 000	10^7	100 000	10^7	100 000	10^7	200 000	10^7
0.580	15 000	10^6	25 000	10^6	30 000	10^6	50 000	10^7	100 000	10^7	100 000	10^7	100 000	10^7	200 000	10^7
0.600	20 000	10^6	25 000	10^6	30 000	10^6	50 000	10^7	100 000	10^7	100 000	10^7	100 000	10^7	300 000	10^7
0.620	20 000	10^6	25 000	10^6	50 000	10^6	50 000	10^7	100 000	10^7	100 000	10^7	200 000	10^7	300 000	10^7
0.640	20 000	10^6	25 000	10^6	50 000	10^6	50 000	10^7	100 000	10^7	100 000	10^7	200 000	10^7	300 000	10^7
0.660	20 000	10^6	25 000	10^6	50 000	10^6	100 000	10^7	100 000	10^7	100 000	10^7	200 000	10^7	300 000	10^7
0.680	20 000	10^6	25 000	10^6	50 000	10^6	100 000	10^7	100 000	10^7	100 000	10^7	200 000	10^7	300 000	10^7
0.700	25 000	10^6	50 000	10^6	50 000	10^6	100 000	10^7	100 000	10^7	100 000	10^7	200 000	10^7	400 000	10^7
0.720	25 000	10^6	50 000	10^6	50 000	10^6	100 000	10^7	100 000	10^7	200 000	10^7	200 000	10^7	400 000	10^7
0.740	25 000	10^6	50 000	10^6	50 000	10^6	100 000	10^7	100 000	10^7	200 000	10^7	200 000	10^7	400 000	10^7
0.750	25 000	10^6	50 000	10^6	50 000	10^6	100 000	10^7	100 000	10^7	200 000	10^7	200 000	10^7	400 000	10^7
0.760	25 000	10^6	50 000	10^6	50 000	10^6	100 000	10^7	100 000	10^7	200 000	10^7	200 000	10^7	400 000	10^7
0.770	25 000	10^6	50 000	10^6	50 000	10^6	100 000	10^7	100 000	10^7	200 000	10^7	200 000	10^7	400 000	10^7
0.780	25 000	10^6	50 000	10^6	50 000	10^6	100 000	10^7	100 000	10^7	200 000	10^7	200 000	10^7	400 000	10^7
0.790	25 000	10^6	50 000	10^6	50 000	10^6	100 000	10^7	200 000	10^7	200 000	10^7	200 000	10^7	400 000	10^7
0.800	50 000	10^6	50 000	10^6	100 000	10^6	100 000	10^7	200 000	10^7	200 000	10^7	200 000	10^7	500 000	10^7

6.5.2.3 STANDARD DEVIATION OF EXPANSIBILITY (EXPANSION) FACTOR ε

When β, x and κ are assumed to be known without error, the standard deviation of the value of ε is given in per cent as follows:

β	Standard deviation on ε in per cent
$0.2 \leqslant \beta \leqslant 0.75$	$\pm 2\,x$
$0.2 > \beta \geqslant 0.1$ $0.8 \geqslant \beta > 0.75$	$\pm 4\,x$

6.6. Coefficients and standard deviations of orifice plates with flange taps

6.6.1 *Coefficients*

The coefficients are set out in the form of formulae or tables the method of use of which is set forth in the accompanying clause.
Interpolation by proportion can be made when necessary. Extrapolation should *never* be made.

6.6.1.1 FLOW COEFFICIENT α

The flow coefficient α is given by the following empirical formulae:

(*a*) When d and D are expressed in inches

The flow coefficient α is

$$\alpha = \alpha'\left(1 + \frac{\beta A}{Re_D}\right)$$

where $$\alpha' = \alpha_e\left(\frac{10^6\,d}{10^6\,d + 15\,A}\right)$$

$$\alpha_e = 0.5993 + \frac{0.007}{D} + \left(0.364 + \frac{0.076}{\sqrt{D}}\right)\beta^4$$
$$+ 0.4\left(1.6 - \frac{1}{D}\right)^5 \left|\left(0.07 + \frac{0.5}{D}\right) - \beta\right|^{5/2}$$
$$- \left(0.009 + \frac{0.034}{D}\right)\left(0.5 - \beta\right)^{3/2}$$
$$+ \left(\frac{65}{D^2} + 3\right)\left(\beta - 0.7\right)^{5/2}$$

and $$A = d\left(830 - 5000\,\beta + 9000\,\beta^2 - 4200\,\beta^3 + \frac{530}{\sqrt{D}}\right)$$

(*b*) When d and D are expressed in millimetres

The flow coefficient α is

$$\alpha = \alpha'\left(1 + \frac{\beta A}{Re_D}\right)$$

where $$\alpha' = \alpha_e\left(\frac{10^6\,d}{10^6\,d + 381\,A}\right)$$

$$\alpha_e = 0.5993 + \frac{0.1778}{D} + \left(0.364 + \frac{0.3830}{\sqrt{D}}\right)\beta^4$$
$$+ 0.4\left(1.6 - \frac{25.40}{D}\right)^5 \left|\left(0.07 + \frac{12.70}{D}\right) - \beta\right|^{5/2}$$

$$- \left(0.009 + \frac{0.8636}{D}\right) \left(0.5 - \beta\right)^{3/2}$$

$$+ \left(\frac{41935}{D^2} + 3\right) \left(\beta - 0.7\right)^{5/2}$$

and $$A = 0.03937\, d \left(830 - 5000\,\beta + 9000\,\beta^2 - 4200\,\beta^3 + \frac{2671}{\sqrt{D}}\right)$$

NOTES

1. In the above equations, when β has a value such that some of the terms of the equation are imaginary numbers, these terms should be taken to equal zero.
2. Most of the experiments leading to the above values were carried out in steel pipes in good condition for which the average value of k was taken as $k = 0.002$ in (0.05 mm).

   The above formulae should be used only when $\frac{D}{k} \geqslant 1000$ (k here has the same meaning as in clause 6.4.1.2, Notes 1 and 2).
3. *If D is less than 2 in (50 mm) or more than 30 in (760 mm), this type of orifice plate should not be used. Also, the value of* β *should be between 0.1 and 0.75.*
4. α *can be computed by the above formula only if* Re_D *remains between the limiting values given in Table 9.*

6.6.1.2 LIMITING VALUES OF REYNOLDS NUMBERS Re_D

Table 9 below gives, as a function of β and D, the lower and upper limiting values of Re_D between which α has been determined experimentally.

TABLE 9. — **Limiting values of Reynolds numbers for orifice plates with flange taps**

β \ D	2 in (50 mm)		3 in (75 mm)		4 in (100 mm)		6 in (150 mm)		8 in (200 mm)		10 in (250 mm)		15 in (375 mm)		30 in (750 mm)	
Re_D	Re_D		Re_D		Re_D		Re_D		Re_D		Re_D		Re_D		Re_D	
	min.	max.	min.	max.	min.	max.	min.	max.	min.	max.	min.	max.	min.	max.	min.	max.
0.100	8 000	10^6	12 000	10^6	16 000	10^6	24 000	10^7	32 000	10^7	40 000	10^7	60 000	10^7	120 000	10^7
0.150	8 000	10^6	12 000	10^6	16 000	10^6	24 000	10^7	32 000	10^7	40 000	10^7	60 000	10^7	120 000	10^7
0.200	8 000	10^6	12 000	10^6	16 000	10^6	24 000	10^7	32 000	10^7	40 000	10^7	60 000	10^7	120 000	10^7
0.250	8 000	10^6	12 000	10^6	16 000	10^6	24 000	10^7	32 000	10^7	40 000	10^7	60 000	10^7	120 000	10^7
0.300	8 000	10^6	12 000	10^6	16 000	10^6	24 000	10^7	32 000	10^7	40 000	10^7	60 000	10^7	120 000	10^7
0.350	8 000	10^6	12 000	10^6	16 000	10^6	24 000	10^7	32 000	10^7	40 000	10^7	60 000	10^7	120 000	10^7
0.400	8 000	10^6	12 000	10^6	16 000	10^6	30 000	10^7	40 000	10^7	40 000	10^7	60 000	10^7	120 000	10^7
0.450	8 000	10^6	15 000	10^6	20 000	10^6	30 000	10^7	50 000	10^7	40 000	10^7	75 000	10^7	150 000	10^7
0.500	8 000	10^6	20 000	10^6	30 000	10^6	50 000	10^7	75 000	10^7	75 000	10^7	100 000	10^7	200 000	10^7
0.550	10 000	10^6	20 000	10^6	30 000	10^6	50 000	10^7	75 000	10^7	75 000	10^7	100 000	10^7	200 000	10^7
0.600	20 000	10^6	30 000	10^6	40 000	10^6	50 000	10^7	75 000	10^7	100 000	10^7	200 000	10^7	300 000	10^7
0.625	20 000	10^6	30 000	10^6	40 000	10^6	100 000	10^7	100 000	10^7	100 000	10^7	200 000	10^7	300 000	10^7
0.650	30 000	10^6	30 000	10^6	50 000	10^6	100 000	10^7	100 000	10^7	100 000	10^7	200 000	10^7	300 000	10^7
0.675	30 000	10^6	40 000	10^6	50 000	10^6	100 000	10^7	100 000	10^7	100 000	10^7	200 000	10^7	300 000	10^7
0.700	50 000	10^6	40 000	10^6	50 000	10^6	100 000	10^7	100 000	10^7	200 000	10^7	200 000	10^7	400 000	10^7
0.725				10^6	50 000	10^6	100 000	10^7	100 000	10^7	200 000	10^7	500 000	10^7	400 000	10^7
0.750				10^6	50 000	10^6	100 000	10^7	500 000	10^7	200 000	10^7	500 000	10^7	400 000	10^7

6.6.1.3 EXPANSIBILITY (EXPANSION) FACTOR ε

The empirical formula for computing the expansibility (expansion) factor ε is as follows:

$$\varepsilon = 1 - (0.41 + 0.35\,\beta^4)\,X$$

This formula is applicable only for values of β, D, $\frac{D}{k}$ and Re_D, as stated in the Notes of clause 6.6.1.1. Test results for determination of ε are known for air, steam and natural gas only. However, there is no known objection to using the same formula for other gases and vapours, the isentropic exponent of which is known.

Moreover, it is applicable only if $\frac{p_2}{p_1} \geqslant 0.75$.

6.6.2 *Standard deviations*

6.6.2.1 SPACING OF PRESSURE TAPS

When the pressure taps satisfy the general conditions set forth in clause 6.2 and the condition in clause 6.2.3.5, the coefficients are assumed to be known with the standard deviation given below.

When the spacings are outside the limits given in clause 6.2.3.5, the measurement is not valid and is not in accordance with this ISO Recommendation.

6.6.2.2 STANDARD DEVIATION OF FLOW COEFFICIENT α

When β, D and Re_D are assumed to be known without error, the standard deviation of the value of α is given, in per cent as follows:

β	**Standard deviation of α in per cent**
$0.2 \leqslant \beta \leqslant 0.7$	$\pm\,0.30$
$0.2 > \beta \geqslant 0.1$	$\pm\,(0.8 - 2.5\,\beta)$
$0.7 < \beta \leqslant 0.75$	$\pm\,(2.5\,\beta - 1.45)$

6.6.2.3 STANDARD DEVIATION OF EXPANSIBILITY (EXPANSION) FACTOR ε

When β, x and κ are assumed to be known without error, the standard deviation of the value of ε is given, in per cent, as follows:

β	**Standard deviation on ε in per cent**
$0.2 \leqslant \beta \leqslant 0.75$	$\pm\,2\,x$
$0.2 > \beta \geqslant 0.1$	$\pm\,4\,x$

6.7 Pressure loss $\Delta\tilde{\omega}$

For the three standard orifice plates, the pressure loss $\Delta\tilde{\omega}$ is related to the differential pressure Δp by the following approximate formula:

$$\Delta\tilde{\omega} \approx \left(\frac{1 - \alpha\beta^2}{1 + \alpha\beta^2}\right)\Delta p$$

7. NOZZLES

There are two types of standard nozzles:

ISA 1932 nozzle and

long radius nozzle,

which are different and are described separately.

7.1 ISA 1932 nozzle

Figure 4, on page 34, shows the section of an ISA 1932 nozzle by a plane passing through the centre-line of the throat.

The letters in the text are those of the reference marks on the drawing.

7.1.1 *General shape*

The part of the nozzle inside the pipe is circular. The nozzle consists of a convergent portion, of rounded profile, and a cylindrical throat.

7.1.2 *Upstream face*

7.1.2.1 This face may be characterized by describing

— a flat inlet part A, perpendicular to the centre-line

— a convergent section defined by two arcs of circumference, B and C

— a cylindrical throat E

— a recess F.

7.1.2.2 The flat inlet part A is limited by a circumference centered on the axis of revolution, with a diameter of 1.5 d, and by the inside perimeter of the pipe, of a diameter D.

When $d = {}^2/_3\ D$, the radial width of this flat part is zero.

When d is more than ${}^2/_3\ D$, the upstream face of the nozzle does not include a flat inlet part within the pipe. In this case, the nozzle is manufactured as if D is greater than ${}^3/_2\ d$ and the inlet flat part is then faced off so that its largest diameter is just equal to D (see Fig. 4 (b), page 34 and clause 7.1.2.7).

7.1.2.3 The arc of circumference B is tangential to the flat inlet part A, when $d < {}^2/_3\ D$, while its radius r_1 is equal to 0.2 $d \pm$ 10 per cent for $\beta < 0.5$; to 0.2 $d \pm$ 3 per cent for $\beta \geqslant 0.5$ and its centre is at 0.2 d from the inlet plane and at 0.75 d from the axial centre-line.

7.1.2.4 The arc of circumference C is tangential to arc of circumference B and to throat E. Its radius r_2 is equal to $d/3 \pm$ 10 per cent for $\beta < 0.5$ and to $d/3 \pm$ 3 per cent for $\beta \geqslant 0.5$. Its centre is at $d/2 + d/3 = 5/6\ d$ from the axial centre-line and at

$$a = \frac{12 + \sqrt{39}}{60} d \; (= 0.3041\ d)$$ from the flat inlet part A.

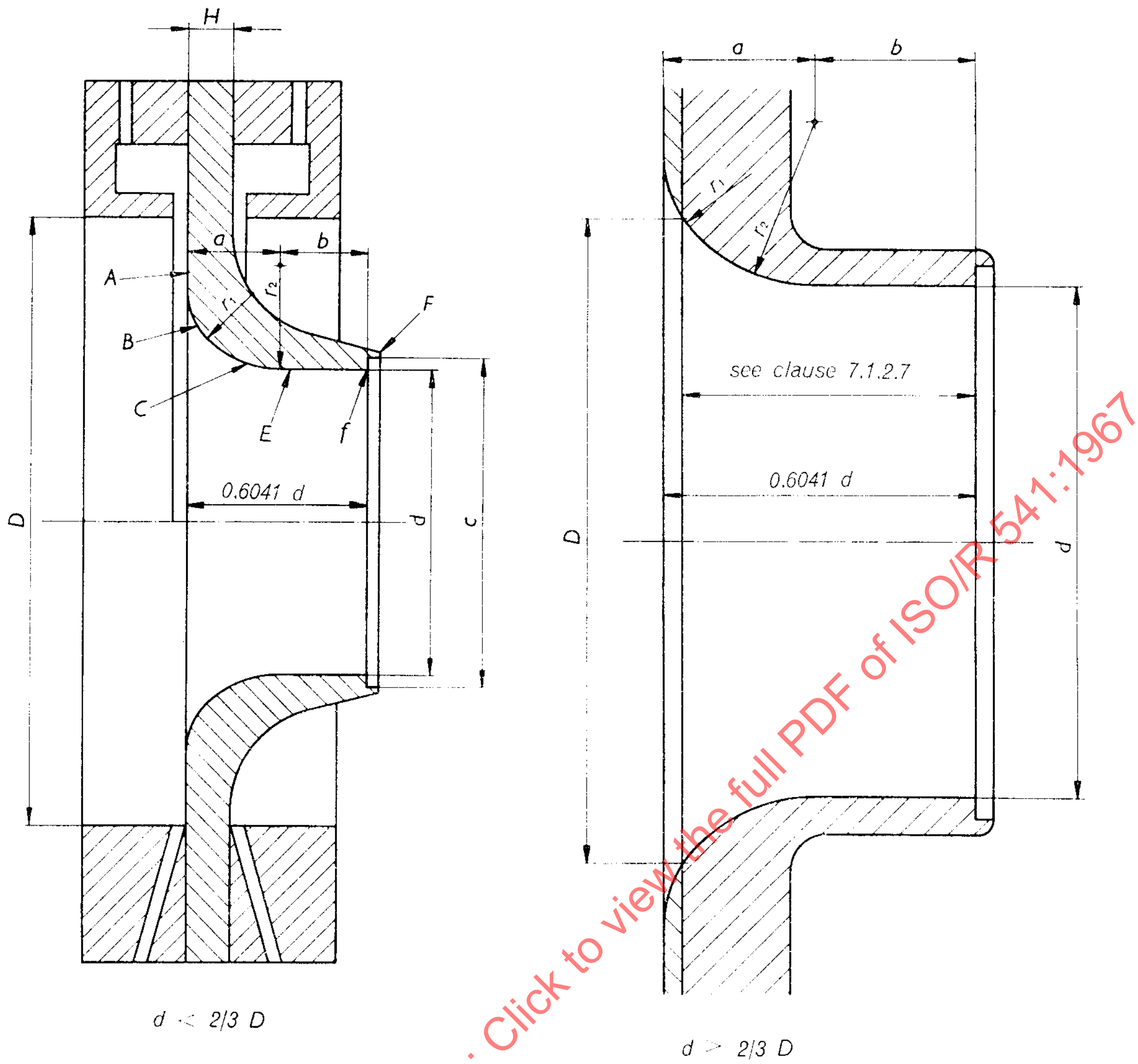

Fig. 4 (*a*)

Fig. 4. — **ISA 1932 nozzle**

Fig. 4 (*b*)

7.1.2.5 The throat *E* has a diameter *d* and a length $b = 0.3\ d$.

The value *d* of the diameter of the throat should be taken as the mean of the measurements of at least four diameters situated in meridian planes distributed at approximately 45° angles to each other.

The throat should be cylindrical. Any diameter of any cross-section should not differ by more than 0.05 per cent from the value of the mean diameter. This requirement is considered as satisfied when the deviations in the length of any of the measured diameters comply with the said requirement in respect of deviation from the mean. Attention is called to the fact that it is possible to check circularity of an orifice bore within the accuracy required without measuring the mean diameter of the orifice bore itself.

7.1.2.6 The recess *F* has a diameter *c* equal to at least 1.06 *d* and a length equal to or less than 0.03 *d*.

The outlet edge *f* should be sharp.

7.1.2.7 The total length of the nozzle, excluding the recess, is 0.6041 d, when d is less than $^2/_3$ D and is shorter, due to the inlet profile, if d is more than $^2/_3$ D.

The values below summarize the total length of the nozzle, excluding the recess, as a function of β.

Values of β	Total length of the nozzle, excluding the recess
$0.32 \leqslant \beta \leqslant \frac{2}{3}$	$0.6041\ d$
$\frac{2}{3} < \beta \leqslant 0.8$	$\left[0.4041 + \left(\frac{0.75}{\beta} - \frac{0.25}{\beta^2} - 0.5225\right)^{\frac{1}{2}}\right] d$

7.1.2.8 The profile of the convergent inlet should be checked *by means of a template*.

Two diameters of the convergent inlet in the same plane perpendicular to the axial centre-line should not differ one from the other by more than 0.1 per cent of their mean value.

7.1.2.9 The surface of the upstream face should be polished so as to keep the maximum roughness (peak-to-hollow height) under 0.0003 d.

7.1.3 *Downstream face*

7.1.3.1 Thickness H should not exceed 0.1 D.

7.1.3.2 Apart from the above condition, the profile and the surface finish of the downstream face are not specified (taking into account clause 7.1.1).

7.1.4 *Material and manufacture*

7.1.4.1 The details given in clauses 6.1.9.1, 6.1.9.2, 6.1.9.3 apply, *mutatis mutandis*, to the manufacture of the ISA 1932 nozzle.

7.1.5 *Pressure taps*

7.1.5.1 Corner pressure taps only should be used with the ISA 1932 nozzle.

7.1.5.2 They should comply with the requirements given in clause 6.2.4.

7.1.6 *Installation of nozzle*

7.1.6.1 The details given in clause 6.3 apply, *mutatis mutandis*, to the installation of ISA 1932 nozzle.

7.1.6.2 The measuring section of the pipe should comply with conditions of clauses 2.3 and 2.4.

7.1.7 *Coefficients of ISA 1932 nozzles*

The coefficients are given in the form of tables, the method of use of which is set down in an accompanying clause. Interpolation by proportion can be made, when necessary. Extrapolation should *never* be made.

7.1.7.1 FLOW COEFFICIENT α

The flow coefficient α is given by

$$\alpha = \alpha'' \times r_{Re}$$