



BS 1042 : Section 1.4 : 1984

UDC 532.542:532.575.52

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British Standard

Measurement of fluid flow in closed conduits

Part 1. Pressure differential devices

Section 1.4 Guide to the use of devices specified
in Sections 1.1 and 1.2

Mesure de débit des fluides dans les conduites fermées

Partie 1. Appareils déprimogènes

Section 4.1 Guide pour l'emploi des appareils spécifiés en 1.1 et 1.2

Durchflußmessung von Flüssigkeiten in geschlossenen Leitungen

Teil 1. Differenzdruckmessgeräte

Abschnitt 1.4 Richtlinien für den Gebrauch der Geräte nach Abschnitt 1.1 und 1.2

British Standards Institution

BS 1042 : Section 1.4 : 1984

Contents	Page	Page
Foreword	Inside front cover	
Committees responsible	Back cover	
Guide		
Section one. General		
1. Scope	1	
2. Symbols	1	
Section two. Calculations		
3. Introduction	2	
4. Information required	2	
5. Basic equations	2	
6. Calculation of orifice or throat diameter	3	
7. Calculation of rate of flow	5	
Section three. Physical data		
8. Introduction	10	
9. Density of fluid	10	
10. Viscosity of fluid	11	
11. Isentropic exponent	11	
Section four. Additional information on measurements and on pulsating and swirling flow		
12. Introduction	13	
13. Measurements	13	
14. Pulsating flow	15	
15. Swirling flow	17	
		Appendix
		A. References for physical data
		21
		Tables
		1. Symbols
		1
		2. Approximate values of $CE\beta^2$ for square-edged orifice plates with corner, D , $D/2$ or flange taps
		7
		3. Approximate values of $CE\beta^2$ for ISA 1932 nozzles, and rough cast, machined and rough welded convergent venturi tubes
		8
		4. Approximate values of $CE\beta^2$ for long radius nozzles
		9
		5. Approximate values of $CE\beta^2$ for quarter circle orifice plates
		9
		6. Approximate values of $CE\beta^2$ for eccentric orifice plates
		9
		7. Physical properties of selected liquids
		11
		8. Physical properties of selected gases
		12
		Figures
		1. Location of density meter
		18
		2. Multiplying factors for thermal expansion
		19
		3. Damping pulsations in gas flow
		20
		4. Damping pulsations in liquid flow
		20
		Index
		22

Foreword

This Section of this British Standard has been prepared under the direction of the Industrial-process Measurement and Control Standards Committee and is Section 1.4 of a revision of BS 1042 : Part 1 : 1964 which is being revised in four sections.

Section 1.1 Specification for square-edged orifice plates, nozzles and venturi tubes inserted in circular cross-section conduits running full

Section 1.2 Specification for square-edged orifice plates and nozzles (with drain holes, in pipes below 50 mm diameter, as inlet and outlet devices) and other orifice plates and Borda inlets

*Section 1.3 Method of use of critical flow venturi nozzles inserted in a closed conduit and calculation of critical flowrates and their associated uncertainties

Section 1.4 Guide to the use of devices specified in Sections 1.1 and 1.2

Section 1.1 specifies the geometry and use of orifice plates, nozzles and venturi tubes inserted in a conduit in which the flow remains subsonic throughout the measuring section. It is technically equivalent to ISO 5167 : 1980 published by the International Organization for Standardization (ISO). It should be noted that guidance on the effects of departure from the requirements given in BS 1042 : Section 1.1 can be found in BS 1042 : Part 3 : 1965.

An index to Sections 1.1, 1.2 and 1.4 is provided in this Section to facilitate the rapid cross-referencing of subject matter.

Compliance with a British Standard does not of itself confer immunity from legal obligations.

*In course of preparation.

British Standard

Measurement of fluid flow in closed conduits

Part 1. Pressure differential devices

Section 1.4 Guide to the use of devices specified in Sections 1.1 and 1.2

Section one. General

1. Scope

This Section of this British Standard provides sample calculations, physical data and other additional information for using the pressure differential devices specified in BS 1042 : Section 1.1 and Section 1.2.

NOTE. The titles of the publications referred to in this standard are listed on the inside back cover.

2. Symbols

The symbols used in this standard are given in table 1.

Table 1. Symbols

Symbols	Represented quantity	Dimensions M: mass L: length T: time Θ: temperature	SI unit
A	Cross-sectional area	L^2	m^2
C	Coefficient of discharge, $C = \frac{\alpha}{E}$	dimensionless	
d	Diameter of orifice or throat of primary device at operating conditions	L	m
D	Upstream internal pipe diameter at operating conditions	L	m
E	Velocity of approach factor, $E = (1 - \beta^4)^{-1/2}$	dimensionless	
F_A, F_B	Correction factors	dimensionless	
k	Uniform equivalent roughness	L	m
p	Static pressure of the fluid	$ML^{-1}T^{-2}$	Pa
q_m	Mass rate of flow	MT^{-1}	kg/s
q_v	Volume rate of flow	L^3T^{-1}	m^3/s
Re	Reynolds number	dimensionless	
Re_D Re_d	Reynolds number referred to D or d	dimensionless	
t	Temperature of the fluid	Θ	$^{\circ}C$
X	Acoustic ratio, $X = \frac{\Delta p}{p_1 \kappa}$	dimensionless	
α	Flow coefficient	dimensionless	
β	Diameter ratio, $\beta = \frac{d}{D}$	dimensionless	
Δp	Differential pressure	$ML^{-1}T^{-2}$	Pa
ϵ	Expansibility (expansion) factor	dimensionless	
κ	Isentropic exponent	dimensionless	
μ	Dynamic viscosity of the fluid	$ML^{-1}T^{-1}$	$Pa \cdot s$
ν	Kinematic viscosity of the fluid, $\nu = \frac{\mu}{\rho}$	L^2T^{-1}	m^2/s
ρ	Mass density of the fluid	ML^{-3}	kg/m^3
τ	Pressure ratio, $\tau = \frac{p_2}{p_1}$	dimensionless	

NOTE 1. Other symbols used in this standard are defined at their place of use.

NOTE 2. Some of the symbols used in this standard are different from those used in BS 1042 : Section 1.1.

NOTE 3. Subscript 1 refers to the cross section at the plane of the upstream pressure tapping. Subscript 2 refers to the cross section at the plane of the downstream pressure tapping.

Documents

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Section two. Calculations

3. Introduction

In clauses 4 to 7, typical design calculations for the design of orifice plates, nozzles, venturi tubes and venturi nozzles are given.

The principal design calculations that are commonly required for pressure differential devices are:

- (a) assessment of the differential pressure and calculation of the diameter of an orifice (or nozzle or venturi throat) for a stated flow of a given fluid in a given pipe at specified conditions of pressure and temperature;
- (b) calculation of the differential pressure for a stated flow of a given fluid at known temperature and pressure, for a pressure differential device and pipe of known diameter;
- (c) calculation of the flowrate, given the fluid, pressure differential device diameter and pipe diameter, differential pressure and fluid pressure and temperature;
- (d) calculation of the overall uncertainty of the installation for a given flowrate.

Items (a) and (d) are particularly relevant to the design of a new installation whereas (b) and (c) are applicable to working installations. The method of calculating the overall uncertainty is described in clause 10 of BS 1042 : Section 1.1 : 1981.

The precise sequence of the calculation will depend upon the information required and on the choice of pressure differential device.

The calculations are based on the assumption that the size of the pipe needed to carry the fluid flow is known.

4. Information required

4.1 General. The following information is required regarding the installation:

- (a) maximum, normal and minimum flowrates (i.e. will one flowmeter cover this flow range?);
- NOTE. Where reference volumes are used, the pressure and temperature should be clearly stated; general statements such as 'standard pressure and temperature (S.T.P.)' should not be relied upon.
- (b) accuracy required;
- (c) maximum permissible pressure loss.

4.2 Pipe. The following information is required regarding the pipe:

- (a) material, temperature coefficient of expansion;
- (b) operating temperature;
- (c) internal diameter, how obtained (the mean of six measurements or as specified in the relevant pipe standards), uniformity;
- (d) layout: upstream, downstream fittings, straight lengths (influence on β limits);
- (e) attitude: vertical, horizontal or sloping;
- (f) internal roughness of pipe.

4.3 Pressure differential device. The following information is required regarding the differential pressure device:

- (a) type (e.g. squared-edged orifice plate, nozzle, venturi);

- (b) suitability for the application;
- (c) limits on d , D , β and Re_D ;
- (d) mounting: slip plate, carrier;
- (e) tappings: location, number of, diameter;
- (f) material, temperature coefficient of expansion, operating temperature;
- (g) diameter;
- (h) drain hole diameter;
- (i) strength of orifice plate material to calculate deformation under flow conditions.

4.4 Fluid. The following information is required regarding the fluid:

- (a) state and composition;
- (b) operating temperature and pressure (and local barometric pressure if appropriate);
- (c) density at operating conditions: for gases density at reference conditions is also often required;
- (d) viscosity at operating conditions;
- (e) for compressible fluids only: isentropic exponent (ratio of specific heats for ideal gases);
- (f) nature of flow: viscous or turbulent.

4.5 Differential pressure measuring device. The following information is required regarding the differential pressure measuring device:

- (a) type (microdisplacement, displacement), wet or dry (i.e. manometric or mechanical), calibration correction factors;
- (b) span (fixed or adjustable), maximum permitted pressure loss for the installation in question;
- (c) maximum operating pressure and temperature of the pressure difference measuring device;
- (d) corrosion resistance (to metered fluid).

4.6 Basic equations. The basic equations for the following are required:

- (a) mass flow or volumetric flow;
- (b) compressible or incompressible fluids;
- (c) Reynolds number;
- (d) uncertainties.

5. Basic equations

In the calculation sequences that follow, SI units are used. If it is the user's practice to use other units, these should be converted into the appropriate SI units.

The following equations for mass flowrate, q_m , and volume flowrate, q_v , are given in 3.1 of BS 1042 : Section 1.1 : 1981.

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

$$= CE \epsilon \frac{\pi}{4} d^2 \sqrt{(2\Delta p \rho_1)}$$

$$q_v = \alpha \epsilon \frac{\pi}{4} d^2 \sqrt{(2\Delta p / \rho_1)}$$

$$= CE \epsilon \frac{\pi}{4} d^2 \sqrt{(2\Delta p / \rho_1)}$$

where

$$E = 1/\sqrt{1 - \beta^4}$$

$$\beta = d/D$$

If the flowmeter is to be calibrated in units of volume flowrate referred to standard (or other specified) conditions of pressure and temperature, q_0 , then the following equation should be used, the suffix '0' denoting standard conditions of pressure and temperature.

$$q_0 = q_v \frac{\rho_1}{\rho_0}$$

The above equations enable calculations described in clause 3(a) to (c) to be made, since α , C , E , d and p are unknown, the equations can be transposed to:

$$\begin{aligned} CE\beta^2 &= \frac{4q_m}{\epsilon\pi D^2 \sqrt{(2\Delta p\rho_1)}} \\ &= \frac{4q_v}{\epsilon\pi D^2 \sqrt{(2\Delta p/\rho_1)}} \end{aligned}$$

The values of d and D in the above equations are to be corrected for the effect of fluid temperature. At temperatures within 10 °C of the temperature at which D and d are determined, the measured diameter values are sufficiently accurate, but at temperatures outside this range, corrections for expansion or contraction are necessary.

It is also convenient to transpose the equations for Reynolds number (Re_D and Re_d) given in 2.4.2 of BS 1042 : Section 1.1 : 1981 into the following.

$$Re_D = \frac{4q_m}{\pi D \mu_1} = \frac{4q_v}{\pi D \nu_1}$$

and

$$Re_d = \frac{4q_m}{\pi d \mu_1} = \frac{4q_v}{\pi d \nu_1}$$

NOTE. In the equations for mass flowrate the dynamic viscosity, μ , is used and for volume flowrate the kinematic viscosity, ν , is used. However, as the dynamic viscosity is equal to the kinematic viscosity multiplied by the density, the appropriate viscosity can be obtained.

6. Calculation of orifice or throat diameter

6.1 General. The procedure for assessment of the differential pressure and calculation of the orifice or throat diameter to measure a stated flowrate of a given fluid in a given pipeline at specified conditions of pressure and temperature is described. The relevant clause references are given at the beginning of each step.

6.2 Procedure. (See clauses 4, 5 and 6 of BS 1042 : Section 1.1 : 1981, sections two and three of BS 1042 : Section 1.2 : 1984 and 4.2 and 4.3 of this standard.)

Before proceeding with the details of the calculation, check the suitability of the device for the application in question and the general acceptability of the pipeline configuration.

NOTE. The example for each item is given in the corresponding item of 6.3.

(a) Calculate the pipe internal diameter, D , at the operating temperature, t °C, preferably using the

measured diameter or if this is not possible the diameter obtained from the relevant pipe standards. (See 13.2.)

(b) Obtain/calculate the fluid density at reference conditions (required only for gas flows measured in volume units at reference conditions of pressure and temperature). Obtain the compressibility factor of the gas at operating conditions.

(c) Obtain/calculate the density and the kinematic or dynamic viscosity of the fluid at operating conditions.

(d) Select appropriate equations from clause 5 for $CE\beta^2$ and Re_D according to whether the rate of flow is given for mass or volume.

(e) Choose a value of Δp taking account of the required pressure loss. Check that $(p_1 - \Delta p)/p_1$ is not less than 0.75. If it is, choose a smaller value of Δp . (It is desirable to keep $(p_1 - \Delta p)/p_1$ as close to unity as possible.)

(f) Calculate $CE\beta^2$ appropriate to the device to be used (orifice plate, nozzle, venturi). If the value obtained is outside the range specified for the particular device, the lower (or upper) limits on β and d for the device will not be met. Choose another value of Δp and repeat (e) and (f). When continuous flow measurements are required over a range of flows, the Re_D value used in these calculations should be calculated using 70 % of the maximum flow to be encountered. (See clause 4, 5.1.2.1, 5.1.3.1, 5.2.2.1, 5.2.3.1, 6.1, 7.1 and 8.1 of BS 1042 : Section 1.2 : 1984 and tables 2, 3, 4, 5 and 6 of this standard.)

(g) When an acceptable value of $CE\beta^2$ has been obtained, calculate the approximate values of β and d . The calculation procedure is dependent on the device to be used, as follows:

- (1) Square-edged orifice plates, $D \geq 50$ mm, use table 2.
- (2) ISA 1932 nozzles and rough cast, machined and rough welded convergent venturi tubes, use table 3.
- (3) Long radius nozzles use table 4.
- (4) Square-edged orifice plates in the size range $25 \leq D < 50$ mm, use table 2 and correction factor F_A or F_B from figure 1 or 2 of BS 1042 : Section 1.2 : 1984.
- (5) Square-edged orifice plates with corner tappings when measuring flow into a large space, use procedures (1) and (4).
- (6) ISA 1932 nozzles and venturi nozzles when measuring flow into a large space, use procedure (2).
- (7) Quarter circle orifice plates, use table 5.
- (8) Eccentric orifice plates, use table 6.
- (9) Conical entrance orifice plates; calculate β directly. (See 6.11.1 of BS 1042 : Section 1.2 : 1984.)
- (10) Square-edged orifice plates with corner tappings when measuring flow from a large space; calculate β directly. (See 5.1.2.2.1 of BS 1042 : Section 1.2 : 1984.)
- (11) ISA 1932 nozzles and venturi nozzles when measuring flow from a large space; calculate β directly. (See 5.1.3.2.1 of BS 1042 : Section 1.2 : 1984.)
- (12) Borda inlet; calculate β directly (see 9.7 of BS 1042 : Section 1.2 : 1984). (See 7.3.1, 7.4, 8.1.6.1,

BS 1042 : Section 1.4 : 1984

8.1.8, 8.2.5.1, 8.2.7, 9.1.5.1, 9.1.9.1, 9.1.9.2 and annex B of BS 1042 : Section 1.1 : 1981 and 5.1.2, 5.1.3, 5.2.2, 5.2.3, 6.1, 6.11.1, 6.11.2, tables 4, 5 and 6 and figure 4 of BS 1042 : Section 1.2 : 1984.)

NOTE. β can be calculated directly for procedures (9) to (12) because C has a single predetermined value.

(h) Check that the Reynolds number, Re_D or Re_d , is within the permitted limits for the device. If the Reynolds number is greater than the upper limit, then D or d is too small. If the Reynolds number is less than the lower limit, try increasing Δp and go back to (e).

(i) Calculate the relative roughness criterion appropriate to the pipeline material and diameter and check that it is within the permitted limits for the device used. This is vital for high accuracy measurements, especially if D is small. (See 7.3.1, 8.1.6.2, 8.2.5.1 and 9.1.2.6 of BS 1042 : Section 1.1 : 1981.)

(j) Calculate the expansibility factor ($e = 1$ for liquids). There is one equation for square-edged orifices, and another for nozzles and venturis. Use β obtained in (g). Note that the acoustic ratio X in the orifice plate equation is equal to $\Delta p/p_1 \kappa$, where κ is the isentropic exponent.

For nozzles and venturis, the pressure ratio, τ , which is equal to $1 - \Delta p/p_1$ is also required. When continuous flow measurements over a range of flows is required and Re_D is based on 70 % of the maximum flow (see step (f)) then 50 % of the Δp value chosen in step (e) should be used. (See 7.3.2.2, 8.1.6.3 and 9.1.6 of BS 1042 : Section 1.1 : 1981 and 5.1.2.2.2, 5.1.3.2.2, 6.11.2, 7.10.2 and 8.10.3 of BS 1042 : Section 1.2 : 1984.)

(k) Calculate a revised value of $CE\beta^2$ by dividing the value obtained in (f) by e . Update the value of β as in step (g).

(l) Use the revised value of β to calculate C (or α) from the appropriate equation. Use C , and the revised value of β to calculate $CE\beta^2$ (note that $E = 1/\sqrt{1 - \beta^4}$). Compare this result with that of step (k). Adjust the value of β , and repeat this step until there is agreement to within 0.05 %. (See 7.3.2.1, 8.1.6.2, 8.2.5.2, 9.1.5.2, 9.1.5.3 and 9.1.5.4 of BS 1042 : Section 1.1 : 1981 and 5.1.2.2.1, 5.1.3.2.1, 6.11.1, 7.10.1 and 8.10.1 of BS 1042 : Section 1.2 : 1984.)

(m) Calculate d from β and D corrected for operating temperature.

(n) Correct the value of d obtained in (m) to ambient temperature. This is the diameter to which the orifice or throat will be machined unless drain holes are required.

(o) Correct d to allow for a drain hole, if appropriate. (See clause 3 of BS 1042 : Section 1.2 : 1984.)

6.3 Example. Calculate the size of orifice plate needed, using D and $D/2$ tapings, to measure flowrates of between $0.084 \text{ m}^3/\text{s}$ and $0.264 \text{ m}^3/\text{s}$ of dry air, expressed at $1.01325 \times 10^5 \text{ Pa}$ and 15°C , flowing at 100°C and $5.5 \times 10^5 \text{ Pa}$ gauge in a 0.1018 m diameter pipe of seamless rolled carbon steel in good condition. The pipe diameter is the mean of six measurements taken at a room temperature of 20°C and is accurately known.

(a) In this example the coefficient of expansion of carbon steel is taken as $1.1 \times 10^{-5}/\text{K}$, at operating temperature

$$D = 0.1018 \{1 + (1.1 \times 10^{-5}) (100 - 20)\} \\ = 0.10189 \text{ m}$$

(b) The density of dry air, ρ_0 , at $1.01325 \times 10^5 \text{ Pa}$ and 15°C is 1.2255 kg/m^3 . The compressibility factor of air at 100°C and $6.513 \times 10^5 \text{ Pa}$ is 1.0008.

(c) Density of the air in the pipeline:

$$\rho_1 = 1.2255 \times \frac{(1.01325 + 5.5)}{1.01325} \times \frac{288.15}{373.15} \times \frac{0.9996}{1.0008} \\ = 6.07587 \text{ kg/m}^3$$

The kinematic viscosity of air at pipeline conditions ν_1 is taken as $3.5822 \times 10^{-6} \text{ m}^2/\text{s}$.

(d) Volume flowrate is given, therefore the equations required are:

$$q_v = q_0 \rho_0 / \rho_1 \\ CE\beta^2 = \frac{4q_v}{\epsilon \pi D^2 \sqrt{(2\Delta p / \rho_1)}} \\ Re_D = \frac{4q_v}{\pi D \nu_1}$$

(e) Let $\Delta p = 25000 \text{ Pa}$ at maximum flowrate

$$(p_1 - \Delta p) / p_1 = \frac{\{(5.5 + 1.01325) \times 10^5\} - 25000}{(5.5 + 1.01325) \times 10^5} \\ = 0.9616$$

which is greater than 0.75

(f) Assume $\epsilon = 1$, then the volume flowrate, q_v , at 100°C and $6.513 \times 10^5 \text{ Pa}$ is:

$$q_v = \frac{0.264 \times 1.2255}{6.0736} = 0.053268 \text{ m}^3/\text{s} \\ CE\beta^2 = \frac{4 \times 0.053268}{\pi \times 0.10189^2 \times \sqrt{(2 \times 2500 / 6.07364)}} \\ = 0.07201 \\ Re_D = \frac{4 \times 0.053268 \times 0.7}{\pi \times 0.10189 \times 3.5822 \times 10^{-6}} \\ = 1.3154 \times 10^5$$

(g) Using table 2 and interpolating from the $Re_D = 10^5$ column,

$$\beta = \left\{ \frac{0.07197 - 0.0698}{0.0785 - 0.0698} \times (0.36 - 0.34) \right\} + 0.34 \\ = 0.3450$$

and

$$d = 0.3450 \times 0.10189 \\ = 0.035152 \text{ m}$$

$CE\beta^2$, β , and d are within the permitted limits for D and $D/2$ taps.

The pressure loss (see 7.4 of BS 1042 : Section 1.1 : 1981) is given by:

$$\Delta \bar{\omega} = \frac{1 - CE\beta^2}{1 + CE\beta^2} \times \Delta p \\ = \frac{1 - 0.072}{1 + 0.072} \times 25000$$

$$= 21600 \text{ Pa}$$

or 87 % of Δp at maximum flow

(h) Re_D is within the permitted limits (see 7.3.1 of BS 1042 : Section 1.1 : 1981):

$$1260\beta^2 D \leq Re_D \leq 10^8$$

where D is expressed in millimetres.

(i) Using table 6 of BS 1042 : Section 1.1 : 1981:

$$\begin{aligned} k/D &= \frac{0.1}{1000 \times 0.10189} \\ &= 0.981 \times 10^{-3} \end{aligned}$$

at worst for the type of pipe used which is within the limits set in table 5 of BS 1042 : Section 1.1 : 1981.

(j) The expansibility factor, ϵ , is given by:

$$\epsilon = 1 - \left\{ (0.41 + 0.35 \times \beta^4) \times \frac{\Delta p}{\rho_1 k} \right\}$$

At maximum flow the isentropic exponent for air at the pipeline conditions is:

$$\kappa = 1.404$$

Therefore:

$$\begin{aligned} \epsilon &= 1 - \left\{ (0.41 + 0.35 \times 0.3450^4) \times \frac{25000}{(5.5 + 1.01325) \times 10^5 \times 1.404} \right\} \\ &= 0.98865 \end{aligned}$$

NOTE. ϵ has been calculated in terms of the maximum flow rate.

$$\begin{aligned} \text{(k) } CE\beta^2 \text{ (revised)} &= 0.07197/0.98865 \\ &= 0.07280 \end{aligned}$$

$$\begin{aligned} \beta \text{ (updated)} &= \left\{ \frac{0.07280 - 0.0698}{0.0785 - 0.0698} \times \right. \\ &\quad \left. \times (0.36 - 0.34) \right\} + 0.34 \\ &= 0.3469 \end{aligned}$$

(l) Using the equation in 7.3.2.1 of BS 1042 : Section 1.1 : 1981 for $\beta = 0.3469$, the discharge coefficient is found to be:

$$C = 0.5999$$

Calculating $CE\beta^2$ from the value of β and C just obtained:

$$= 0.07272$$

which is less than 0.07280.

By trial and error, increasing β , it is found that $\beta = 0.3471$ gives:

$$C = 0.5999$$

and a calculated value of $CE\beta^2$ that is well within 0.01 % of 0.07280.

To check the validity of the result:

$$\begin{aligned} q_{\max} &= \frac{6.07364}{1.22505} \times 0.5999 \times \frac{(0.3471)^2}{\sqrt{(1 - 0.3471^4)}} \times \\ &\quad \times \frac{\pi}{4} \times 0.10189^2 \times 0.98865 \times \\ &\quad \times \sqrt{(2 \times 25000/6.07364)} \\ &= 0.264 \text{ m}^3/\text{s} \end{aligned}$$

at $1.01325 \times 10^5 \text{ Pa}$ and 15°C which is the desired result. (Note that the expansibility factor used in this final equation was calculated using $\beta = 0.3471$.)

(m) There is no drain hole, and at pipeline temperature

$$d = 0.10189 \times 0.3471$$

$$= 0.03537 \text{ m}$$

(n) d corrected for room temperature

$$= 0.03537/[1 + (1.8 \times 10^{-5})(100 - 20)]$$

$$= 35.32 \text{ mm}$$

NOTE. For this correction, the coefficient of expansion of stainless steel, from which the plate will be made, is taken as $1.8 \times 10^{-5}/\text{K}$.

7. Calculation of rate of flow

7.1 General. The procedure for calculation of the flowrate, given the pipe and orifice diameters, the physical properties of the flowing fluid, the type of primary device used and the measured pressure difference is described.

NOTE. The example for each item is given in the corresponding item of 7.3.

7.2 Procedure. (See 4.2 and 4.3.) Before proceeding with the details of the calculation, check that the pipeline configuration is acceptable.

(a) Calculate the pipe internal diameter, D , and the orifice (or throat) diameter, d , at the operating temperature $t^\circ \text{C}$. (See 13.2.)

(b) Calculate the diameter ratio, β .

(c) Check that D , d and β are within the limits specified in this standard for the device in question.

(d) Obtain the density, ρ_1 and dynamic viscosity μ_1 of the flowing fluid at pipeline conditions. If they are not quoted explicitly in the calculation information summary:

(1) use relevant tables of physical data,

(2) (see section three) calculate ρ_1 and μ_1 from values found in tables at reference conditions, and

(3) if the flowrate is required in units of volume (per unit time) at reference conditions of pressure and temperature, the density ρ_0 at these conditions is also required.

(e) Select appropriate equations from clause 5 for the flowrate and Reynolds number, Re_D , according to whether mass or volume flowrate is required.

(f) Assume a value of 10^6 for the Reynolds number.

(g) Calculate an interim value for the discharge coefficient, C (or the flow coefficient if appropriate). (See 6.2(k) and 6.2(l).)

(h) Check that $(\rho_1 - \Delta p_{\max})/\rho_1$ is not less than 0.75.

(i) Check that the roughness of the pipe is within limits. (See 6.2(i).)

(j) Calculate the expansibility factor ($\epsilon = 1$ for liquids). Note that the isentropic exponent or the ratio of specific heats is required. (See 6.2(j).)

(k) Use the above data and the interim value of C to calculate an approximate value of the flowrate.

(l) Calculate the Reynolds number, Re_D .

(m) Calculate a precise value of C using the above value of Re_D .

(n) Calculate a revised value of the flowrate.

BS 1042 : Section 1.4 : 1984

7.3 Example. Steam at 20×10^5 Pa absolute and 250°C is flowing in a well-lagged pipeline. A square-edged orifice plate with corner taps is installed at a distance equal to 50 times the pipe diameter downstream of a single right-angle bend. Another bend is situated at a distance equal to at least 20 times the pipe diameter downstream of the orifice plate. The measured diameters of the pipe (carbon steel) and orifice (stainless steel) are 0.152 m and 0.0835 m respectively. The measured pressure difference is 2.5×10^4 Pa.

Calculate the mass flowrate in kg/s.

Referring to 6.2 and table 3 of BS 1042 : Section 1.1 : 1981 shows that the pipeline configuration is acceptable, even without calculating the diameter ratio.

(a) At pipeline temperature:

$$D = 0.152 \{1 + (1.1 \times 10^{-5}) (250 - 20)\} \\ = 0.15238 \text{ m}$$

$$d = 0.0835 \{1 + (1.8 \times 10^{-5}) (250 - 20)\} \\ = 0.083846 \text{ m}$$

$$(b) \beta = d/D \\ = 0.550243$$

(c) Referring to 7.3.1 of BS 1042 : Section 1.1 : 1981:

β is within limits: $0.23 \leq \beta \leq 0.8$

d is within limit: $d \geq 12.5 \text{ mm}$

D is within limits: $50 \text{ mm} \leq D \leq 1000 \text{ mm}$

(d) The density of steam at 20×10^5 Pa and 250°C = 8.9686 kg/m^3 .

The dynamic viscosity at 20×10^5 Pa and 250°C = $1.82 \times 10^{-5} \text{ Pa}\cdot\text{s}$.

(e) The mass flowrate is required, therefore the equations to be used are:

$$q_m = CE\epsilon \frac{\pi}{4} d^2 \sqrt{(2\Delta p \rho_1)}$$

$$Re_D = \frac{4q_m}{\pi D \mu_1}$$

(f) $Re_D = 10^6$ (assumed).

(g) From 7.3.2.1 of BS 1042 : Section 1.1 : 1981:

$$C = 0.5959 + 0.0312\beta^{2.1} - 0.184\beta^8 + \\ + 0.0029\beta^{2.5} \left(\frac{10^6}{Re_D} \right)^{0.75} \\ = 0.603904$$

$$(h) (p_1 - \Delta p)/p_1 = (2000000 - 25000)/2000000 \\ = 0.9875$$

which is greater than 0.75.

(i) It is assumed for the purposes of this example that the relative roughness of the pipe walls, k/D is less than 3.8×10^{-4} (see 7.3.1 of BS 1042 : Section 1.1 : 1981).

(j) For steam, the ratio of specific heats, κ , is 1.31.

$$\epsilon = 1 - (0.41 + 0.35\beta^4)X \\ = 1 - (0.41 + 0.35 \times 0.550243^4)X$$

where

$$X = \frac{\Delta p}{p_1 \kappa} \\ = \frac{25000}{2000000 \times 1.31} \\ \epsilon = 0.99578$$

(k) The approximate flowrate is given by:

$$q_m = CE\epsilon \frac{\pi}{4} d^2 \sqrt{(2\Delta p \rho_1)} \\ = 0.603904 \times \left(\frac{1}{1 - 0.550243^4} \right)^{1/2} \times 0.99578 \times \\ \times \frac{\pi}{4} \times (0.083846)^2 \times \sqrt{(2 \times 25000 \times 8.9686)} \\ = 2.333 \text{ kg/s}$$

(l) The Reynolds number

$$Re_D = \frac{4 \times 2.333}{\pi \times 0.15238 \times 1.82 \times 10^{-5}} \\ = 1071089$$

(m) The precise value of C

$$= 0.5959 + 0.0312\beta^{2.1} - 0.184\beta^8 + \\ + 0.0029\beta^{2.5} \left(\frac{10^6}{1071089} \right)^{0.75} \\ = 0.603871$$

(n) The revised (and final) value of the flowrate

$$= 2.333 \text{ kg/s}$$

Table 2. Approximate values of $CE\beta^2$ for square-edged orifice plates with corner, D , $D/2$ or flange taps

β	$CE\beta^2$ for a Reynolds number, Re_D , of:									
	5×10^3	10^4	2×10^4	3×10^4	5×10^4	7×10^4	10^5	10^6	10^7	10^8
0.23	0.0318	0.0317	0.0317	0.0316	0.0316	0.0316	0.0316	0.0316	0.0316	0.0316
0.24	0.0347	0.0346	0.0345	0.0345	0.0344	0.0344	0.0344	0.0344	0.0344	0.0344
0.26	0.0409	0.0407	0.0406	0.0405	0.0405	0.0405	0.0405	0.0404	0.0404	0.0404
0.28	0.0475	0.0473	0.0472	0.0471	0.0471	0.0470	0.0470	0.0470	0.0469	0.0469
0.30	0.0548	0.0544	0.0543	0.0542	0.0541	0.0541	0.0541	0.0540	0.0540	0.0540
0.32	0.0626	0.0621	0.0619	0.0618	0.0617	0.0617	0.0617	0.0616	0.0616	0.0616
0.34	0.0709	0.0704	0.0701	0.0700	0.0699	0.0698	0.0698	0.0697	0.0697	0.0697
0.36	0.0799	0.0792	0.0789	0.0787	0.0786	0.0785	0.0785	0.0783	0.0783	0.0783
0.38	0.0895	0.0887	0.0882	0.0880	0.0879	0.0878	0.0877	0.0875	0.0875	0.0875
0.40	0.0998	0.0987	0.0982	0.0979	0.0977	0.0976	0.0975	0.0973	0.0973	0.0973
0.42	0.1108	0.1095	0.1087	0.1085	0.1082	0.1081	0.1080	0.1077	0.1076	0.1076
0.44	0.1225	0.1209	0.1200	0.1196	0.1193	0.1192	0.1191	0.1187	0.1186	0.1186
0.46	0.1350	0.1330	0.1319	0.1315	0.1311	0.1310	0.1308	0.1304	0.1303	0.1303
0.48	—	0.1459	0.1446	0.1441	0.1437	0.1435	0.1432	0.1427	0.1426	0.1426
0.50	—	0.1595	0.1580	0.1574	0.1569	0.1566	0.1564	0.1558	0.1556	0.1556
0.52	—	0.1741	0.1723	0.1716	0.1709	0.1706	0.1704	0.1696	0.1694	0.1694
0.54	—	0.1896	0.1874	0.1867	0.1858	0.1855	0.1852	0.1842	0.1840	0.1840
0.56	—	0.2061	0.2035	0.2026	0.2017	0.2012	0.2009	0.1997	0.1995	0.1995
0.58	—	0.2238	0.2207	0.2197	0.2185	0.2180	0.2177	0.2162	0.2159	0.2159
0.60	—	0.2427	0.2389	0.2376	0.2364	0.2358	0.2353	0.2336	0.2333	0.2333
0.62	—	0.2628	0.2584	0.2568	0.2555	0.2547	0.2541	0.2522	0.2518	0.2517
0.64	—	0.2842	0.2793	0.2774	0.2758	0.2749	0.2743	0.2719	0.2714	0.2714
0.66	—	0.3072	0.3016	0.2994	0.2975	0.2965	0.2957	0.2929	0.2923	0.2923
0.68	—	0.3319	0.3256	0.3229	0.3208	0.3195	0.3187	0.3153	0.3146	0.3145
0.70	—	0.3584	0.3499	0.3482	0.3458	0.3443	0.3433	0.3393	0.3385	0.3383
0.72	—	0.3871	0.3772	0.3757	0.3729	0.3711	0.3699	0.3646	0.3635	0.3634
0.74	—	0.4183	0.4068	0.4056	0.4025	0.4003	0.3988	0.3925	0.3912	0.3910
0.76	—	0.4522	0.4390	0.4378	0.4345	0.4325	0.4305	0.4231	0.4216	0.4213
0.78	—	—	0.4756	0.4734	0.4702	0.4682	0.4658	0.4567	0.4549	0.4547
0.80	—	—	0.5129	0.5117	0.5081	0.5061	0.5052	0.4941	0.4919	0.4916