

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

Committees responsible for this British Standard

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- British Compressed Air Society
- British Gas plc
- Department of Energy (Gas and Oil Measurement Branch)
- Department of Trade and Industry (National Engineering Laboratory)
- Electricity Industry in United Kingdom
- Energy Industries Council
- GAMBICA (BEAMA Ltd.)
- Institute of Measurement and Control
- Institute of Petroleum
- Institute of Trading Standards Administration
- Institution of Gas Engineers
- Institution of Mechanical Engineers
- Society of British Gas Industries
- Water Services Association of England and Wales

The following bodies were also represented in the drafting of the standard, through subcommittees and panels:

- Engineering Equipment and Materials Users' Association
- Institution of Water and Environmental Management
- United Kingdom Offshore Operators' Association

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Foreword

This Section of BS 1042 has been prepared under the direction of the Industrial-process Measurement and Control Standards Policy Committee. It supersedes BS 1042-1.4:1984, which is withdrawn.

This is Section 1.4 of a series of Sections of BS 1042 on the measurement of fluid flow in closed conduits, as follows:

Section 1.1 Specification for square-edged orifice plates, nozzles and venturi tubes 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

Section 1.3 Method of measurement of gas flow by means of critical flow Venturi nozzles.

Section 1.5 Guide to the effect of departure from the conditions specified in Section 1.1

Section 1.1 specifies the geometry and method of use of orifice plates, nozzles and Venturi tubes inserted in conduit running full, to measure the flowrate of the fluid in the conduit. 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 conditions specified in BS 1042-1.1 can be found in BS 1042-1.5:1987.

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.

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Summary of pages

This document comprises a front cover, an inside front cover, pages i and ii, pages 1 to 33 and a back cover.

This standard has been updated (see copyright date) and may have had amendments incorporated. This will be indicated in the amendment table on the inside front cover.

Section 1. General

1 Scope

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

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

Symbol	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, $E = (1 - \beta^4)^{-1/2} c$	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 flowrate	MT^{-1}	kg/s
q_v	Volume flowrate	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, $X = \frac{\Delta p}{P_1 k}$	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	
k	Isentropic exponent	dimensionless	
μ	Dynamic viscosity of the fluid	$ML^{-1}T^{-1}$	Pa s
ν	Kinematic viscosity of the fluid, $\nu = \frac{\mu}{\rho}$	L^2T^{-1}	m^2/s
ρ	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 1042-1.1.

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.

Section 2. Calculations

3 General

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 11 of BS 1042-1.1:1992.

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 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, e.g. upstream, downstream fittings, straight lengths (influence on β limits);
- e) attitude, i.e. vertical, horizontal or sloping;
- f) internal roughness of pipe.

4.3 Pressure differential device

The following information is required regarding the pressure differential 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, i.e. slip plate, carrier;
- e) tappings, i.e. 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;
NOTE 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, i.e. 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:

- mass flow or volumetric flow;
- compressible or incompressible fluids;
- Reynolds number;
- 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 5.1 of BS 1042-1.1:1992.

$$\begin{aligned} q_m &= \alpha \varepsilon \frac{\pi}{4} d^2 (2\Delta p \rho_1)^{1/2} \\ &= CE \varepsilon \frac{\pi}{4} d^2 (2\Delta p \rho_1)^{1/2} \\ q_v &= \alpha \varepsilon \frac{\pi}{4} d^2 (2\Delta p / \rho_1)^{1/2} \\ &= CE \varepsilon \frac{\pi}{4} d^2 (2\Delta p / \rho_1)^{1/2} \end{aligned}$$

where:

$$\begin{aligned} E &= 1/(1 - \beta^4)^{1/2} \\ \beta &= d/D \end{aligned}$$

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

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

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

$$\begin{aligned} CE\beta^2 &= \frac{4q_m}{\varepsilon \pi D^2 (2\Delta p \rho_1)^{1/2}} \\ &= \frac{4q_v}{\varepsilon \pi D^2 (2\Delta p / \rho_1)^{1/2}} \end{aligned}$$

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 3.3.2 of BS 1042-1.1:1992 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

NOTE See clauses 6 and 7 of BS 1042-1.1:1992, sections 2 and 3 of BS 1042-1.2:1989 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 12.2.)

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 flowrate 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, 6.2.2.2, 6.2.3.2, 6.3.2.2, 6.3.3.2, 7.2, 8.2 and 9.2 and of BS 1042-1.2:1989 and Table 2 to Table 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;

NOTE The Stolz equation for corner tappings given in 8.3.2.1 of BS 1042-1.1:1992 is used for deriving the discharge coefficients provided the minimum Reynolds numbers are above the following values.

$$Re \geq 40\,000\beta^2 \text{ for } 0.23 \leq \beta \leq 0.5$$

$$Re \geq 10\,000 \text{ for } 0.5 \leq \beta \leq 0.7$$

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 7.5.1 of BS 1042-1.2:1989.)

10) Square-edged orifice plates with corner tappings when measuring flow from a large space, calculate β directly. (See 6.2.2.3 of BS 1042-1.2:1989.)

11) ISA 1932 nozzles and venturi nozzles when measuring flow from a large space, calculate β directly. (See 6.2.3.3 of BS 1042-1.2:1989.)

NOTE β can be calculated directly for procedures 9) to 11) 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 by reducing d 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 8.3.1, 9.1.6.2, 9.2.6.1 and 10.1.2.6 of BS 1042-1.1:1992.)

j) Calculate the expansibility factor ($\epsilon = 1$ 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 $\Delta p/p_1 k$, where k 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 8.3.2.2, 9.1.6.3, and 10.1.6 of BS 1042-1.1:1992 and 6.2.2.4, 6.2.3.4, 7.5.2, 8.5.2 and 9.4.3 of BS 1042-1.2:1989.)

k) Calculate a revised value of $CE\beta^2$ by dividing the value obtained in f) by ϵ . 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 $E = 1(1 - \beta^4)^{1/2}$). 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 8.3.2.1, 9.1.6.2, 9.2.6.2, 10.1.5.2 and 10.1.5.4 of BS 1042-1.1:1992 and 6.2.2.3, 6.2.3.3, 7.5.1, 8.5.1 and 9.4.1 of BS 1042-1.2:1989.)

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 4 of BS 1042-1.2:1989.)

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

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

Table 3 — Approximate values of $CE\beta^2$ for ISA 1932 nozzles, and rough cast, machined and rough welded convergent venturi tubes

β	$CE\beta^2$ for venturi tubes			$CE\beta^2$ for ISA 1932 nozzles for a Reynolds number, Re_D , of:						
	Machined	Rough cast	Rough welded	2×10^4	3×10^4	5×10^4	7×10^4	10^5	10^6	10^7
0.30	—	—	—	—	0.0887	0.0890	0.0891	0.0892	0.0893	0.0893
0.316	—	0.0889	—	—						
0.32	—	0.1013	—	—	0.1009	0.1013	0.1014	0.1015	0.1017	0.1017
0.34	—	0.1145	—	—	0.1139	0.1143	0.1145	0.1147	0.1149	0.1149
0.36	—	0.1286	—	—	0.1277	0.1283	0.1285	0.1286	0.1289	0.1289
0.38	—	0.1436	—	—	0.1423	0.1430	0.1433	0.1435	0.1438	0.1438
0.40	0.1613	0.1595	0.1597	—	0.1578	0.1587	0.1589	0.1591	0.1596	0.1596
0.42	0.1783	0.1763	0.1765	—	0.1741	0.1751	0.1754	0.1757	0.1762	0.1763
0.44	0.1963	0.1942	0.1944	0.1898	0.1913	0.1924	0.1929	0.1932	0.1938	0.1938
0.46	0.2154	0.2130	0.2133	0.2007	0.2094	0.2107	0.2112	0.2116	0.2123	0.2123
0.48	0.2356	0.2330	0.2332	0.2265	0.2285	0.2299	0.2305	0.2309	0.2317	0.2318
0.50	0.2569	0.2541	0.2543	0.2464	0.2485	0.2502	0.2508	0.2513	0.2521	0.2522
0.52	0.2795	0.2764	0.2766	0.2673	0.2697	0.2715	0.2722	0.2727	0.2736	0.2737
0.54	0.3033	0.3000	0.3003	0.2893	0.2919	0.2939	0.2946	0.2952	0.2962	0.2963
0.56	0.3286	0.3250	0.3253	0.3125	0.3153	0.3174	0.3183	0.3188	0.3199	0.3200
0.58	0.3554	0.3515	0.3519	0.3372	0.3401	0.3422	0.3431	0.3438	0.3449	0.3450
0.60	0.3839	0.3797	0.3801	0.3631	0.3662	0.3684	0.3693	0.3700	0.3712	0.3713
0.62	0.4143	0.4097	0.4101	0.3908	0.3938	0.3961	0.3970	0.3977	0.3989	0.3990
0.64	0.4467	0.4418	0.4423	0.4202	0.4232	0.4254	0.4263	0.4269	0.4281	0.4282
0.66	0.4815	0.4762	0.4767	0.4617	0.4544	0.4565	0.4574	0.4580	0.4591	0.4592
0.68	0.5189	0.5132	0.5137	0.4853	0.4878	0.4897	0.4904	0.4910	0.4919	0.4920
0.70	0.5598	0.5531	0.5537	0.5216	0.5236	0.5251	0.5257	0.5262	0.5270	0.5270
0.72	0.6032	0.5965	—	0.5610	0.5623	0.5633	0.5637	0.5640	0.5645	0.5645
0.74	0.6512	0.6440	—	0.6041	0.6044	0.6046	0.6046	0.6047	0.6048	0.6048
0.76	—	—	—	0.6514	0.6504	0.6495	0.6492	0.6490	0.6486	0.6485
0.78	—	—	—	0.7040	0.7012	0.6990	0.6982	0.6975	0.6964	0.6963
0.80	—	—	—	0.7632	0.7579	0.7540	0.7525	0.7513	0.7493	0.7491

Table 4 — Approximate value of $CE\beta^2$ for long radius nozzles

β	$CE\beta^2$ for a Reynolds number, Re_D of:								
	10^4	2×10^4	5×10^4	10^5	2×10^5	5×10^5	10^6	5×10^6	10^7
0.20	0.0387	0.0391	0.0394	0.0395	0.0396	0.0397	0.0398	0.0398	0.0399
0.22	0.0468	0.0472	0.0476	0.0478	0.0480	0.0481	0.0481	0.0482	0.0482
0.24	0.0556	0.0562	0.0567	0.0569	0.0571	0.0572	0.0573	0.0574	0.0574
0.26	0.0653	0.0659	0.0665	0.0668	0.0670	0.0672	0.0673	0.0674	0.0674
0.28	0.0756	0.0764	0.0772	0.0775	0.0778	0.0780	0.0781	0.0782	0.0783
0.30	0.0868	0.0878	0.0886	0.0890	0.0893	0.0896	0.0897	0.0899	0.0899
0.32	0.9880	0.0999	0.1009	0.1014	0.1017	0.1020	0.1022	0.1024	0.1025
0.34	0.1115	0.1128	0.1140	0.1146	0.1150	0.1153	0.1155	0.1158	0.1158
0.36	0.1251	0.1266	0.1280	0.1286	0.1291	0.1295	0.1297	0.1300	0.1301
0.38	0.1395	0.1413	0.1428	0.1436	0.1441	0.1446	0.1448	0.1452	0.1452
0.40	0.1548	0.1568	0.1585	0.1594	0.1600	0.1606	0.1609	0.1612	0.1613
0.42	0.1710	0.1732	0.1752	0.1762	0.1769	0.1775	0.1778	0.1782	0.1783
0.44	0.1881	0.1906	0.1928	0.1939	0.1947	0.1954	0.1958	0.1963	0.1964
0.46	0.2062	0.2090	0.2115	0.2127	0.2136	0.2144	0.2148	0.2152	0.2154
0.48	0.2252	0.2284	0.2312	0.2326	0.2335	0.2344	0.2349	0.2355	0.2356
0.50	0.2454	0.2489	0.2520	0.2535	0.2546	0.2556	0.2561	0.2568	0.2569
0.52	0.2667	0.2705	0.2740	0.2757	0.2769	0.2780	0.2786	0.2793	0.2795
0.54	0.2892	0.2934	0.2972	0.2992	0.3005	0.3010	0.3023	0.3031	0.3033
0.56	0.3130	0.3177	0.3219	0.3240	0.3255	0.3268	0.3275	0.3284	0.3286
0.58	0.3382	0.3434	0.3480	0.3504	0.3520	0.3535	0.3542	0.3552	0.3554
0.60	0.3650	0.3707	0.3758	0.3783	0.3802	0.3818	0.3826	0.3836	0.3839
0.62	0.3935	0.3998	0.4054	0.4082	0.4101	0.4119	0.4128	0.4140	0.4143
0.64	0.4240	0.4308	0.4369	0.4400	0.4422	0.4441	0.4451	0.4464	0.4467
0.66	0.4566	0.4641	0.4707	0.4741	0.4765	0.4768	0.4797	0.4811	0.4814
0.68	0.4916	0.4998	0.5071	0.5108	0.5134	0.5157	0.5169	0.5184	0.5188
0.70	0.5294	0.5384	0.5464	0.5504	0.5533	0.5558	0.5571	0.5588	0.5592
0.72	0.5705	0.5803	0.5891	0.5935	0.5966	0.5993	0.6007	0.6026	0.6030
0.74	0.6154	0.6262	0.6357	0.6405	0.6439	0.6470	0.6485	0.6505	0.6510
0.76	0.6648	0.6766	0.6871	0.6924	0.6961	0.6994	0.7011	0.7033	0.7038
0.78	0.7197	0.7327	0.7441	0.7499	0.7540	0.7577	0.7595	0.7619	0.7625
0.80	0.7814	0.7956	0.8083	0.8146	0.8191	0.8231	0.8251	0.8278	0.8285

Table 5 — Approximate values of $CE\beta^2$ for quarter circle orifice plates

β	$CE\beta^2$
(0.24) ^a	(0.0445)
0.26	0.0523
0.28	0.0608
0.30	0.0699
0.32	0.0798
0.34	0.0903
0.36	0.1017
0.38	0.1138
0.40	0.1268
0.42	0.1405
0.44	0.1555
0.46	0.1715
0.48	0.1887
0.50	0.2071
0.52	0.2272
0.54	0.2487
0.56	0.2724
0.58	0.2979
0.60	0.3257

^a Value outside recommended limit of use.**Table 6 — Approximate values of $CE\beta^2$ for eccentric orifice plates**

β	$CE\beta$
0.46	0.1358
0.48	0.1484
0.50	0.1619
0.52	0.1761
0.54	0.1911
0.56	0.2074
0.58	0.2243
0.60	0.2427
0.62	0.2619
0.64	0.2824
0.66	0.3044
0.68	0.3275
0.70	0.3524
0.72	0.3789
0.74	0.4077
0.76	0.4387
0.78	0.4722
0.80	0.5089
0.82	0.5496
0.84	0.5945

6.3 Example

NOTE For convenience in the following example, the calculations are performed to 6 significant figures.

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:

$$\rho_1 = 1.2255 \times \frac{(1.01325 + 5.5)}{1.01325} \times$$

$$\times \frac{288.15}{373.15} \times \frac{0.9996}{1.0008}$$

$$= 6.07587 \text{ kg/m}^3$$

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:

$$q_v = q_o \rho_o / \rho_1$$

$$CE\beta^2 = \frac{4q_v}{\varepsilon \pi D^2 (2\Delta p / \rho_1)^{1/2}}$$

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

e) Let $\Delta p = 25\,000 \text{ Pa}$ 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.