
British Standard

Measurement of fluid flow in closed conduits

Part 1. Pressure differential devices

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

Mesure de débit des fluides dans les conduites fermées

Partie 1. Appareils déprimogènes

Section 1.5 Guide des effets des divergences par rapport aux conditions spécifiées à la Section 1.1

Durchflußmessung von Flüssigkeiten in geschlossenen Leitungen

Teil 1. Differenzdruckmessgeräte

Abschnitt 1.5 Leitfaden über Abweichungen von den in Abschnitt 1.1 festgelegten Bedingungen

Foreword

This Section of BS 1042 has been prepared under the direction of the Industrial-process Measurement and Control Standards Committee. It supersedes BS 1042 : Part 3 : 1965 which is withdrawn.

This is Section 1.5 of a series of Sections of BS 1042 on pressure differential devices as follows:

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

Appendix A of this Section of BS 1042 provides a bibliography of related publications for further information.

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

*In preparation.

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Section one. General

0 Introduction

BS 1042 : Section 1.1 constitutes a standard for flowrate measurement. Adherence to that standard will result in flowrate measurements whose accuracy will lie within specified limits. If, however, a flowmetering installation departs, for whatever reason, from the conditions specified in the standard, then the specified accuracies may not be achieved. Many metering installations exist where these conditions either have not been or cannot be met. In these circumstances it is usually not possible to evaluate precisely the effect of deviations from the standard. However, a considerable amount of data exists, which can be used to give a general indication of the effect of non-compliance with the standard. It is presented here as a guide to users of flow metering equipment.

1 Scope

This Section of BS 1042 provides guidance to assist in estimating the flowrate when using pressure differential devices constructed or operated outside the scope of BS 1042 : Section 1.1.

It should not be implied that additional tolerances or corrections can necessarily compensate for the effects of deviating from the standard. The information is given, in the first place, to indicate the degree of care necessary in the manufacture, installation and maintenance of pressure difference devices by describing some of the effects of non-compliance with the requirements; and in the second place, to permit those users who may not be able to comply fully with the requirements to assess, however roughly, the magnitude and direction of the resulting errors.

Each variation dealt with is treated as though it were the only one present, but where more than one is known to exist, there will be interactions causing increases or decreases of error, largely unpredictable. This list of variations is by no means complete and relates largely to examples with orifice plates. There are, no doubt, many similar examples of installations not complying with BS 1042 : Section 1.1 for which no comparable data has been published. Such additional information from users, manufacturers and any others may be taken into account in future revisions of this Section of BS 1042.

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

2 Symbols and definitions

2.1 Symbols

For the purposes of this Section of BS 1042, the symbols given in table 1 apply.

2.2 Definitions

For the purposes of this Section of BS 1042, the definitions given in BS 1042 : Section 1.1 apply.

3 Effect of errors on flowrate calculations

3.1 General

In this Section of BS 1042 the effects of deviations from the conditions specified in BS 1042 : Section 1.1 are described in terms of changes in the discharge coefficient of the meter. The discharge coefficient of a pressure difference device (C) is given by the following equation:

$$C = \frac{q_m}{(1 - \beta^4)^{-0.5} \epsilon \frac{(\pi d^2)}{4} \sqrt{2 \Delta p \rho_1}}$$

The effect of change in the discharge coefficient is best shown by recourse to an example.

Consider an orifice plate with an unduly rounded edge. The result of this will be a decreased inward radial momentum in the jet and a consequent increase in the area of the vena contracta leading in turn to reduced velocities at that position. The observed differential pressure will therefore decrease. From the equation above, it can be seen that the discharge coefficient would therefore increase.

3.2 Quantifiable effects

When the user is aware of such effects and they can be quantified, the appropriate discharge coefficient can be used and the correct flowrate calculated. However, the precise quantification of these effects is difficult and so any flowrate calculated in such a manner should be considered to have an increased uncertainty.

Except where otherwise stated, an additional uncertainty, equivalent to 100 % of the discharge coefficient correction, should be added arithmetically to the discharge coefficient uncertainty when estimating the overall uncertainty of the flowrate measurement.

3.3 Non-quantifiable effects

If the user cannot quantify the effect of a deviation or is unaware of its presence, and calculates flowrate using a discharge coefficient which has not been corrected, then an error in the calculated flowrate will occur. In the example of 3.1, the failure to increase the discharge coefficient would produce a calculated flowrate that was too small.

It can therefore be concluded that:

- (a) an effect which causes an increase in discharge coefficient will result in an under-registration of flow if the coefficient is not corrected, and conversely
- (b) an effect which causes a decrease in discharge coefficient will result in an over-registration of flow if the coefficient is not corrected.

Table 1. Symbols			
Symbol	Represented quantity	Dimensions M: mass L: length T: time	SI unit
C	Coefficient of discharge	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
D_1	Carrier ring diameter	L	m
D_2	Orifice plate support diameter	L	m
e	Relative uncertainty	dimensionless	
E	Orifice plate thickness	L	m
L_1	Distance of upstream pressure tapping from upstream face of plate divided by pipe bore (D)	dimensionless	
L'_2	Distance of downstream pressure tapping from downstream face of plate divided by pipe bore (D)	dimensionless	
q_m	Mass rate of flow	MT^{-1}	kg/s
r	Orifice plate edge radius	L	m
Re_D	Reynolds number based on upstream pipe diameter	dimensionless	
Re_d	Reynolds number based on throat bore of device	dimensionless	
$S_{L,1}$	Distance from upstream fitting to straightener	L	m
$S_{L,2}$	Distance from straightener to primary device	L	m
$S_{L,3}$	Distance from primary device to downstream fitting	L	m
Y	Modulus of elasticity of orifice plate material	$ML^{-1}T^{-2}$	Pa
β	Diameter ratio, $\beta = d/D$	dimensionless	
Δp	Differential pressure	$ML^{-1}T^{-2}$	Pa
Δp_y	Differential pressure required to reach orifice plate yield stress	$ML^{-1}T^{-2}$	Pa
ϵ	Expansibility (expansion) factor	dimensionless	
ρ_1	Fluid density at the upstream pressure tapping	ML^{-3}	kg/m ³
σ_y	Yield stress of orifice plate material	$ML^{-1}T^{-2}$	Pa

Section two. Effects of deviations in construction

4 Orifice plate edge sharpness

Orifice plates that do not have the specified sharpness of the inlet edge (edge radius $\leq 0.0004d$ in 7.1.6.2 of BS 1042 : Section 1.1 : 1981), will have progressively increasing discharge coefficients as the edge radius increases. Tests have shown that, for pipes with bores in the range 50 mm to 150 mm, the effect on the discharge coefficient C is to increase it by 0.5 % for r/d of 0.001, and by about 5 % for r/d of 0.01. These values apply particularly to Re_d values above 300 000 and for β values below 0.7, but they can be used as a general guide for other values.

Measurement techniques for edge radius are available, but in general it is better to improve the edge radius to the required sharpness rather than attempt to measure it and make appropriate corrections.

5 Thickness of orifice edge

For orifice plates, the error due to excessive thickness of the orifice edge (i.e. in 7.1.4 of BS 1042 : Section 1.1 : 1981) can be appreciable and is always negative. For example, with orifice plates of $\beta = 0.2$ the increase in discharge coefficient due to doubling the maximum permissible edge thickness of $0.02D$ can be of the order of 1 %.

6 Flatness of upstream face

The upstream face should be flat and smooth. Excessive roughness will lead to an increase in the discharge coefficient. Tests have indicated that a surface roughness of $0.0003d$ will cause an increase in discharge coefficient of the order of 0.1 %. Since the requirement for edge sharpness is $\leq 0.0004d$ problems may also be experienced in defining or confirming that the square edge requirement is met.

Large scale lack of flatness e.g. 'dishing', will lead to flow measurement errors. A 'dishing' of 1 % in the direction of flow will cause under-registration of about 0.2 % for $\beta = 0.2$ and about 0.1 % for $\beta = 0.7$. Distortion against the direction of flow will also cause errors which could be either positive or negative depending on the amount of distortion.

BS 1042 : Section 1.1 requires the flatness to be less than 1 % slope under flowing conditions. The flatness during laboratory inspection is not defined, however any plate with a 'dishing' approaching 1 % during inspection is liable to exceed the 1 % limit when in use (see clause 20).

7 Position of pressure tapings

7.1 General

Values of the orifice plate discharge coefficient for the three standard tapping positions (corner, flange, D and $D/2$) can be calculated using the Stolz equation (see 7.3.2.1 of BS 1042 : Section 1.1 : 1981). Where the tapping positions fall outside the tolerances permitted in BS 1042 : Section 1.1 for the three positions, the discharge coefficient may be estimated as described in 7.2. It should be emphasized that an additional uncertainty needs to be associated with the use of non-standard tapping positions.

7.2 Calculation of discharge coefficient

7.2.1 Calculate the actual values of L_1 and L_2' . The discharge coefficient can be estimated only if $L_1 \leq 1$ and $L_2' \leq 0.47$.

7.2.2 Using the actual values of L_1 and L_2' , estimate the discharge coefficient using the Stolz equation.

7.3 Estimation of additional uncertainty

7.3.1 If tapings lie between the flange and corner taps the additional uncertainty (e), expressed as a percentage, can be estimated from:

$$e = 25 \left(\frac{C_{FL}}{C_{CT}} - 1 \right)$$

where

C_{FL} is the discharge coefficient for flange taps;

C_{CT} is the discharge coefficient for corner taps.

7.3.2 If tapings lie between D , $D/2$ and flange taps, the additional uncertainty (e), expressed as a percentage, can be estimated from:

$$e = 25 \left(\frac{C_{D,D/2}}{C_{FL}} - 1 \right)$$

where $C_{D,D/2}$ is the discharge coefficient for D , $D/2$ taps.

7.4 Example

Consider an orifice meter with $\beta = 0.6$, $Re_D = 10^6$, $D = 254$ mm and tapings at $0.15D$ upstream and downstream of the plate.

To estimate the discharge coefficient, use the Stolz equation with $L_1 = L_2' = 0.15$.

The tapings in this example lie between the flange and D , $D/2$ tapping positions. From tables 24 and 12 respectively of BS 1042 : Section 1.1 : 1981:

$$C_{FL} = 0.6049$$

$$C_{D,D/2} = 0.6067$$

$$\begin{aligned} \text{therefore additional uncertainty} &= 25 \left(\frac{0.6067}{0.6049} - 1 \right) \% \\ &= 0.074 \% \end{aligned}$$

The uncertainty of the discharge coefficient is 0.6 (see 7.3.3.1 of BS 1042 : Section 1.1 : 1981).

$$\text{therefore overall uncertainty} = 0.6 + 0.074 \approx 0.7 \%$$

8 Condition of pressure tapings

Experience has shown that large errors can be created by pressure tapings which have burrs or deposits on, or close to, the edge where the tapping penetrates the pipe wall. This is particularly the case where the tapping is in the main flow stream such as throat taps in nozzles or venturi tubes, where quite small burrs can give rise to significant percentage errors. Upstream corner tapings and downstream tapings in relatively dead zones are much less susceptible to this problem.

The installation should be inspected before use and at regular intervals to ensure that the anomalies are not present.

Section three. Effects of pipeline near the device

9 Pipe diameter

The pipe internal diameter upstream and downstream from the device should always be measured to ensure that it is in accordance with 6.5 and 6.6 of BS 1042 : Section 1.1 : 1981. Errors in the upstream internal diameter measurement, especially, will cause errors in the calculated rate of flow, e.g. a positive 5 % error in D for an orifice plate having $\beta = 0.74$ will cause an error of more than 4 % in the calculated rate of flow.

10 Steps and taper sections

Sudden enlargements of the pipe in the vicinity of the device should always be avoided as large errors in flow measurement result from their use. Similarly, tapering sections of pipe exert a significant influence on the accuracy as will be seen from table 2 which gives the order of errors to be expected when an orifice plate with corner tapplings is immediately preceded or followed by a taper piece.

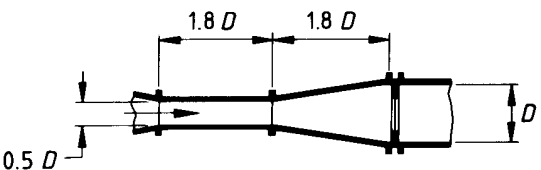
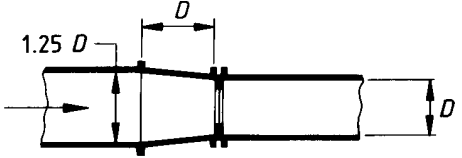
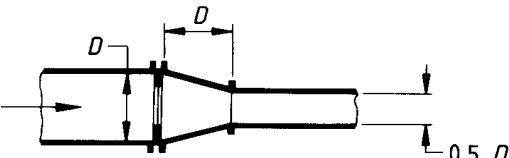
From this it will be seen that a taper piece divergent in the direction of flow, and placed immediately upstream, is not recommended, since discharge coefficient increases of up to 50 % are caused. On the other hand, a convergent

taper piece, whether installed before or after the orifice plate, and provided it is not of steeper angle than those shown, results in coefficient changes generally less than 2 %.

11 Diameter of carrier ring

The requirements concerning the sizing and concentric mounting of carrier rings for orifice plates and nozzles are specified in 6.5.1.3, 6.5.3.3, 6.5.3.4 and 7.2.4 of BS 1042 : Section 1.1 : 1981. If the requirement of 6.5.3.4 (i.e. that the centred carrier ring should not protrude into the pipe) is not met, relatively large flow measurement errors will be introduced. Figure 1 shows such an installation and figure 2, using the same notation, shows the approximate errors introduced for the given conditions. It is emphasized that, in arriving at these errors, the internal diameter of the carrier ring, D_1 , and not the diameter of the main line is to be used for D in determining the correction factor when making use of the values shown.

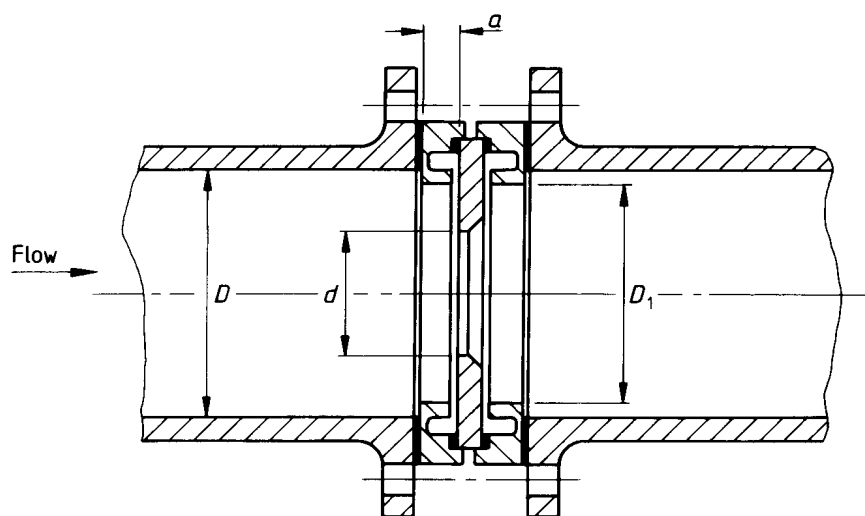
Where the carrier is oversize, experimental results indicate that for $\beta = 0.74$, a carrier 11 % oversize and extending $0.05D$ upstream from the plate might increase the discharge coefficient by approximately 0.5 %. However, for a similar geometry but with $\beta = 0.63$, no effect was found.

Table 2. Effect of taper pieces		
Position of device	β ratio	Order of the discharge coefficient change to be expected
(a) Immediately downstream from a divergent taper piece 	0.4 0.7	% + 10 + 50
(b) Immediately downstream from a convergent taper piece 	0.4 0.7	± 0.5 - 2
(c) Immediately upstream from a convergent taper piece 	0.4 0.7	0 to - 1 + 1

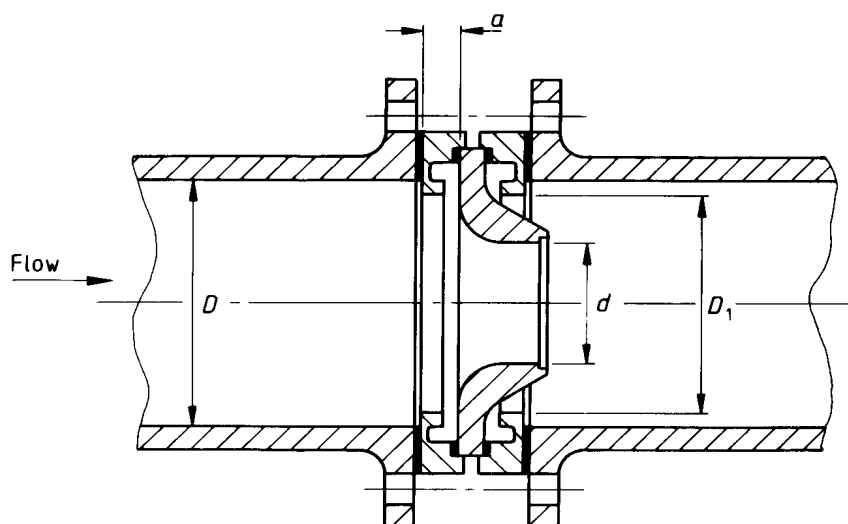
12 Undersize joint rings

When the inside diameter of a joint ring or gasket is smaller than the pipe diameter, especially on the upstream side of an orifice plate or nozzle, very large flow measurement errors may occur. This anomaly can be eliminated by ensuring that the correct size joint ring or gasket is fitted. The magnitude and sign of the effect in relation to the measurement of flowrate is dependent on the combination

of a number of variables, e.g. the thickness of the joint ring, the extent of its protrusion into the flow, its position relative to the orifice plate and pressure tapings, as well as on the degree of roughness of the upstream pipe. The sign of the effect will, in general, be the same as that for a carrier ring which is undersize in diameter and thus clause 11 and figures 1 and 2 will provide an indication of the sign of the error.

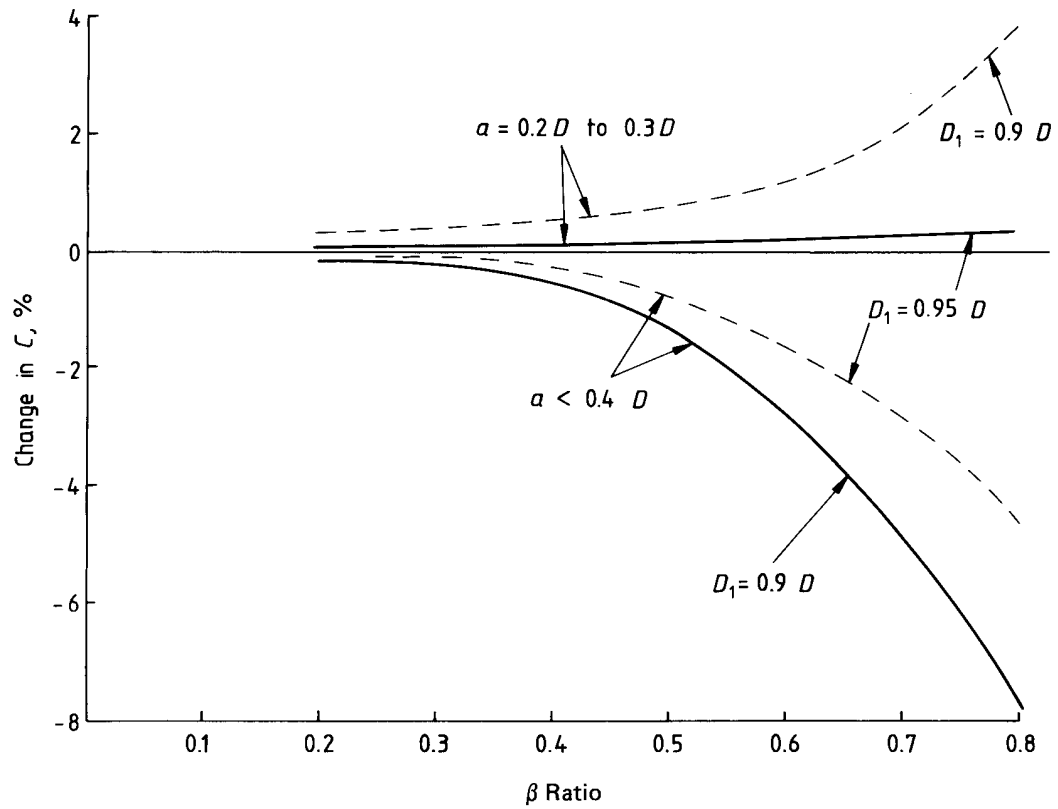


(a) Orifice plate

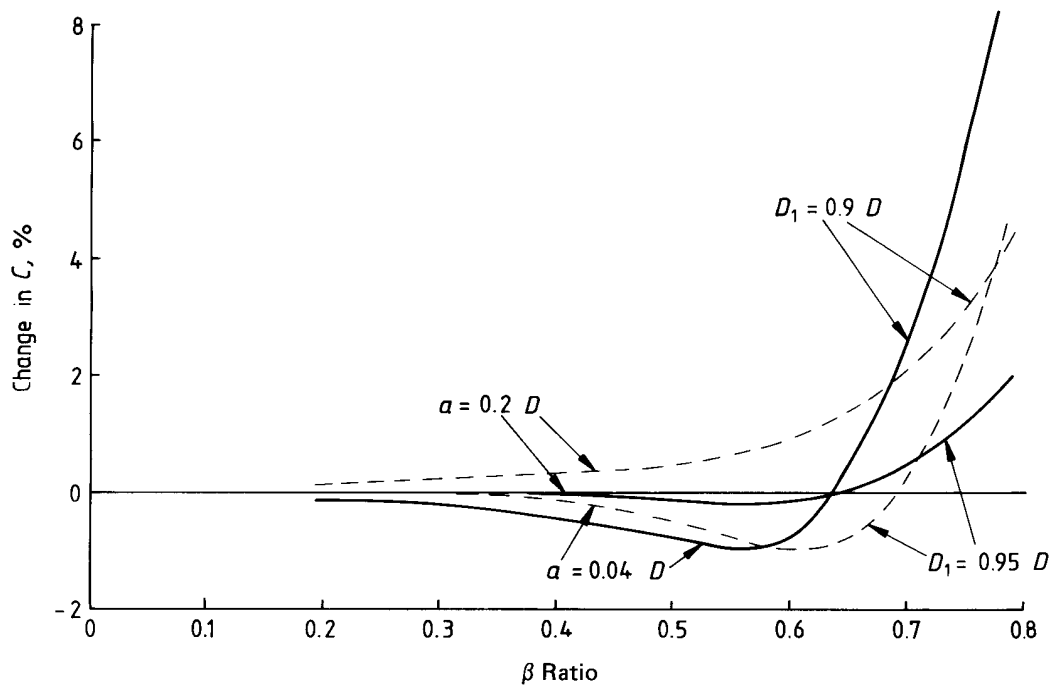


(b) Nozzle

Figure 1. Carrier having internal diameter D_1 less than pipe diameter D



(a) Orifice plate



(b) Nozzle

Figure 2. Effect of incorrect carrier diameter