

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 BS EN ISO 5167-1

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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

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- Engineering Equipment and Materials Users' Association
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Foreword

This Section of BS 1042 has been prepared by Technical Committee CPL/30. It supersedes BS 1042 : Section 1.5 : 1987, which is withdrawn.

This revision of BS 1042 Section 1.5 was prepared in order to bring it up-to-date with BS EN ISO 5167-1 : 1992 (formerly BS 1042 : Section 1.1) to which it refers, and to incorporate new data.

This Section of BS 1042 : Part 1 is one of a series dealing with measurement of fluid flow by differential pressure devices, as follows: BS EN ISO 5167-1 *Specification for square-edged orifice plates, nozzles and Venturi tubes in circular cross-section conduits running full*.

BS 1042 : Part 1 : 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*.

BS EN ISO 9300 *Method of measurement of gas flow by means of critical flow Venturi nozzles*.

BS 1042 : Part 1 : Section 1.4 *Guide to the use of devices specified in Sections 1.1 (i.e. BS EN ISO 5167-1) and 1.2*.

Section 1.5 *Guide to the effect of departure from the conditions specified in BS EN ISO 5167-1*.

Section 1.6 *Method of measurement of pulsating fluid flow in a pipe, by means of orifice plates, nozzles or Venturi tubes*.

BS 1042 : Section 1.4 contains an index to Sections 1.2 and 1.4 and to BS EN ISO 5167-1, to facilitate the rapid cross-referencing of subject matter.

As a Guide, this British Standard takes the form of guidance and recommendations. It should not be quoted as if it were a specification and particular care should be taken to ensure that claims of compliance are not misleading.

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

Section 1. General

Introduction

BS EN ISO 5167-1 is a standard for flowrate measurement using a differential pressure device. Adherence to that standard will result in flowrate measurements the uncertainty of which will lie within specified limits. If, however, a flowmetering installation departs, for whatever reason, from the conditions specified in BS EN ISO 5167-1, the specified limits of uncertainty 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 the precise effect of any such deviations. However, a considerable amount of data exists which can be used to give a general indication of the effect of non-conformity to BS EN ISO 5167-1, and it is presented here as a guide to users of flow metering equipment.

1.1 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 EN ISO 5167-1.

It should not be inferred 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 differential devices by describing some of the effects of non-conformity to 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 error in flowrate.

Each variation dealt with is treated as though it were the only one present. Where more than one is known to exist, there may be unpredictable interactions and care has to be taken when combining the assessment of these errors. If there is a significant number of errors, means of eliminating some of them must be considered. The variations included in this standard are by no means complete and relate largely to examples with orifice plates. There are, no doubt, many similar examples of installations not conforming to BS EN ISO 5167-1 for which no comparable data have 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.

1.2 References

1.2.1 Normative references

This standard incorporates, by dated or undated reference, provisions from other publications. These normative references are made at the appropriate places in the text and the cited publications are listed on the inside back cover. For dated references, only the edition cited applies; any subsequent amendments to or revisions of the cited publication apply to this Section of BS 1042 only when incorporated in the reference by amendment or revision. For undated references, the latest edition of the cited publication applies, together with any amendments.

1.2.2 Informative references

This standard refers to other publications that provide information or guidance. Editions of these publications current at the time of issue of this standard are listed on the inside back cover, but reference should be made to the latest editions.

1.3 Symbols and definitions

1.3.1 Symbols

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

1.3.2 Definitions

For the purposes of this Section of BS 1042, the definitions given in BS EN ISO 5167-1 apply, together with the following.

1.3.2.1 square edge

The angular relationship between the orifice bore and the upstream face, when the angle between them is $90^\circ \pm 0.3^\circ$.

1.3.2.2 sharpness

The radius of the edge between the orifice bore and the upstream face.

NOTE. The upstream edge of the orifice bore is considered to be sharp when its radius is not greater than $0.0004 d$, where d is the diameter of the orifice bore.

Table 1. Symbols			
Symbol	Represented quantity	Dimensions M: mass L: length T: time	SI units
c	Percentage change in discharge coefficient $\left(\equiv 100 \frac{\Delta C}{C} \right)$	dimensionless	
C	Discharge coefficient	dimensionless	
C_c	Contraction coefficient	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
E_e	Thickness of orifice	L	m
k	Uniform equivalent roughness	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
u	Local axial velocity	LT^{-1}	m/s
u_{CL}	Centre line axial velocity	LT^{-1}	m/s
U	Mean axial velocity	LT^{-1}	m/s
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_1	Expansibility (expansion) factor at the upstream pressure tapping	dimensionless	
λ	Friction factor	dimensionless	
ρ	Fluid density	ML^{-3}	kg/m ³
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

1.4 Effect of errors on flowrate calculations

1.4.1 General

In this Section of BS 1042 the effects of deviations from the conditions specified in BS EN ISO 5167-1 are described in terms of changes in the discharge coefficient of the meter. The discharge coefficient of a pressure differential device (C) is given by the following equation:

$$C = \frac{4 q_m \sqrt{(1 - \beta^4)}}{\varepsilon_1 \pi d_2 \sqrt{(2\Delta p \rho_1)}}$$

The sharp edge of an orifice plate ensures separation of the flow and consequently contraction of the fluid stream to the vena contracta. Defining the contraction coefficient,

$$C_c, \text{ as } \frac{\text{flow area}}{\text{geometric area}},$$

the orifice produces $C_c \approx 0.6$, which mainly accounts for the discharge coefficient, $C \approx 0.6$.

The effect of change in the discharge coefficient is illustrated by the following example.

Consider an orifice plate with an unduly rounded edge. The result of this will be to reduce the separation and increase C_c , leading in turn to reduced velocities at the vena contracta. The observed differential pressure will therefore decrease. From the equation above, it can be seen that the discharge coefficient would therefore increase. Alternatively, as C_c increases so does C . If no correction is made for this change in C , the meter will under-read (register).

It can therefore be concluded that:

- a) an effect which causes an increase in discharge coefficient will result in an under-reading 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-reading of flow if the coefficient is not corrected.

1.4.2 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 factor, equivalent to 100 % of the discharge coefficient correction, should be added arithmetically to that of the discharge coefficient when estimating the overall uncertainty of the flowrate measurement.

Section 2. Effects of deviations in construction

2.1 Orifice plate edge sharpness

Orifice plates that do not have the specified sharpness of the inlet edge (edge radius $r \leq 0.0004 d$ in accordance with 8.1.6.2 of BS EN ISO 5167-1 : 1992), will have progressively increasing discharge coefficients as the edge radius increases. Tests have shown that 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. This is an approximately linear relationship (see figure 1 and Hobbs and Humphreys[1]). 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 sharpness to the required value rather than attempt to measure it and make appropriate corrections.

2.2 Thickness of orifice edge

For orifice plates, the increase in discharge coefficient due to the excessive thickness of the orifice edge (see 8.1.4 of BS EN ISO 5167-1 : 1992) can be appreciable. With a straight bore orifice plate in a 150 mm pipe, the changes in discharge coefficient shown in figure 2 were obtained (see Husain and Teyssandier [2]).

2.3 Condition of upstream and downstream faces of orifice plate

The upstream face should be flat and smooth. Excessive roughness leads to an increase in the discharge coefficient. Tests have indicated that a surface roughness of $0.0003 d$ will cause an increase in discharge coefficient of the order of 0.1 %. Since the requirement for edge sharpness is $r \leq 0.0004 d$, an increase in plate roughness will make it difficult to define or confirm that the sharp edge requirement has been met.

Local damage to the upstream face or edge of an orifice plate does not adversely affect the discharge coefficient provided that the damage is kept as far away from the pressure tapping as possible (see Hobbs and Humphreys [1]). The discharge coefficient is much less sensitive to the surface condition of the downstream face of the plate (Hobbs and Humphreys[1]).

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

2.4 Position of pressure tapings for an orifice meter

2.4.1 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 8.3.2.1 of BS EN ISO 5167-1 : 1992). Where the tapping positions fall outside the tolerances permitted in BS EN ISO 5167-1 for the three positions, the discharge coefficient may be estimated as described in 2.4.2. It should be emphasized that an additional uncertainty factor needs to be associated with the use of non-standard tapping positions.

2.4.2 Calculation of discharge coefficient

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

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

2.4.3 Estimation of additional uncertainty

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

$$e = 25 \left| \frac{C_{FL}}{C_{CT}} - 1 \right| \quad (2)$$

where

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

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

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

$$e = 25 \left| \frac{C_{D \text{ AND } D/2}}{C_{FL}} - 1 \right| \quad (3)$$

where

$C_{D \text{ AND } D/2}$ is the discharge coefficient for D and $D/2$ taps.

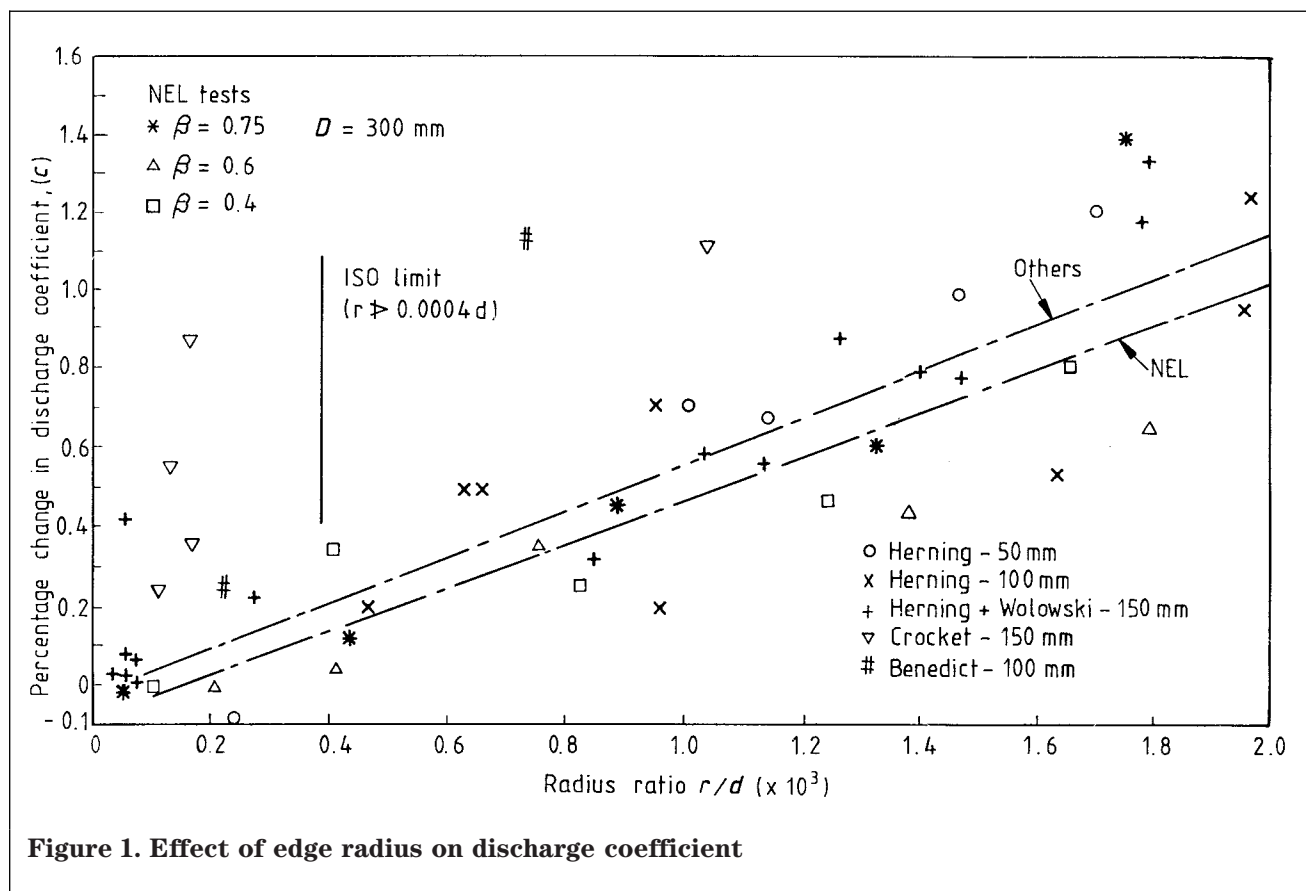


Figure 1. Effect of edge radius on discharge coefficient

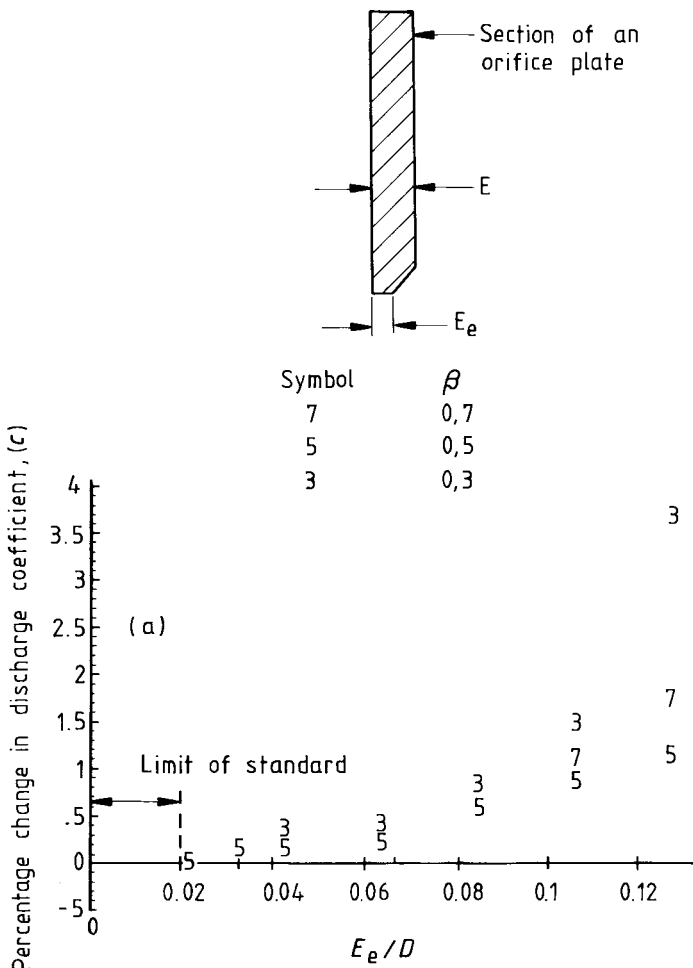


Figure 2. Change in discharge coefficient as a function of orifice thickness