Performance of conical entrance orifice plates at low Reynolds numbers

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Results are presented of an experimental investigation into the performance of conical entrance orifice plates manufactured according to BS 1042. Three plates, with diameter ratios of 0.247, 0.360 and 0.448, were tested in the region $100 < Re_D \lesssim 1000$ and in both the concentric and the fully eccentric position. The discharge coefficient, C_Z, of the orifice was found to agree with that specified in BS 1042 for a diameter ratio of 0.247. For other diameter ratios, the discharge coefficient increased with the diameter ratio, as observed by other workers for the Kent plates. The eccentricity has no appreciable effect on the discharge coefficient, probably due to the effect of viscous action on the flow being more or less the same for the concentric and eccentric position of the orifice at low Reynolds numbers

Keywords: *flow measurement, orifice plates, eccentricity*

Although the characteristics of orifice meters are well known and have been explored thoroughly by a number of investigators over a considerable range of Reynolds numbers, the low Reynolds number range has received comparatively little attention. There is a considerable interest among differential pressure flowmeter users in any device which has a constant discharge coefficient in the low Reynolds number region. The conical entrance orifice plate, first developed in 1930 by George Kent Ltd, has been used for low Reynolds number conditions.

Conical entrance orifice plates have been extensively studied since the publication of BS 1042, Part 1 (1964). Kastner and McVeigh[1] conducted tests on eight plates using a 50 mm (2 in) internal diameter brass pipe, with β value ranges from 0.063 to 0.3. Stoll and Zientara[2] reported work by three fluid metering companies using a 50 mm (2 in) diameter pipe and 5 plates having β values of 0.1 to 0.5. The effect of installation conditions on the discharge coefficient of the conical entrance orifice plate was investigated by McVeigh[3] using a 38.1 mm (1.5 in) diameter copper pipe and plates having diameter ratios of 0.267, 0.4 and 0.5. Further tests were carried out by Turton[4] on plates having diameter ratios of 0.1 to 0.5 and using a 50 mm internal diameter copper pipe.

The work reported by Stoll and Zientara[2] and McVeigh[3] was on plates similar to the Kent plates. Only the work by Kastner and McVeigh[1] and Turton[4] was based on plates as specified in BS 1042. The British Standard[5] for conical entrance orifice plates specifies a constant conic entrance angle of 45° and a constant value of 0.084 for the ratio J/d. It is limited to $0.1 \leqslant \beta \leqslant 0.316$ and gives a combined discharge coefficient of 0.734 for Re_D between 80 and 60 000 with a tolerance of $\pm 2\%$. For the Kent plates, the geometry and discharge coefficient varies with β. At low values of β, the Kent plate is similar to that specified by BS 1042. The difference between the two plates increases with β. At $\beta = 0.3$, the difference in conical entrance angle is about 6%; the difference in J/d is about 12% and that in the discharge coefficient about 2%.

Kastner and McVeigh[1] conducted tests for pipe Reynolds numbers below 1200 for six of the plates and below 4000 for the remaining two plates. Turton[4] performed tests over a range of pipe Reynolds numbers of 800 to 23 000. All the experimental work was on concentric orifices with pipe diameters greater than 38.1 mm (1.5 in). No experimental data have been reported for an eccentric conical entrance orifice and for pipe diameters smaller than 38.1 mm, although BS 1042 mentions that the conical entrance orifice plate may be used in pipes of internal diameter not less than 25 mm (1 in).

This paper presents experimental data obtained on three conical entrance orifice plates as specified in BS 1042 in both the concentric and eccentric positions with an internal pipe diameter of 25 mm (1 in).

Experimental investigation

The test rig (Fig 1) has a 25.4 mm (1 in) diameter smooth bore copper pipe. Water was pumped from the sump to a constant head tank from which it flowed to the straight length of pipe before the orifice under test. An upstream straight length of 35 diameters and downstream straight length of 28 diameters was provided. The small pressure differentials across the test orifice were measured by a diaphragm type inductive pressure transducer, corner tappings being used as recommended in BS 1042. The

Notation

C_Z	Discharge coefficient as in BS 1042, Section 1.1, 1981
D	Diameter of pipe
d	Diameter of orifice
m	Area ratio (β^2)
Re_D	Reynolds number based on pipe diameter
β	Ratio of orifice diameter to pipe diameter

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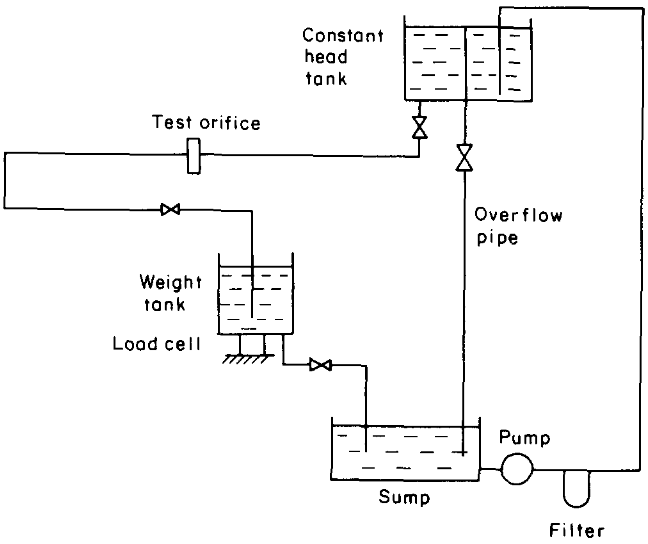

Fig 1 Pipe system

pressure transducer was calibrated against a known differential pressure before and after each series of tests with each orifice plate, and the accuracy was estimated to be 1.5%. The average flow rate was determined by weighing the water collected in a tank during a given time interval using a strain gauge type load cell. The weighing system was calibrated using dead weights before and after each test and the accuracy of the weighing system was estimated to be 1%.

Three orifice plates, with diameter ratios of 0.247, 0.36 and 0.448 were tested. They were manufactured from brass to the dimensions given in Fig 2 (see Table 1). The figures given are the average of four different diameters taken on a Ferranti co-ordinate measuring machine. Surface finish was also measured, using a Talysurf surface texture measuring system. Since the pipe diameter is only 25.4 mm, it is difficult to determine if the dimensional tolerance specified in BS 1042 ($\pm 0.003d$) for the thickness of the conical entrance and the parallel bore is observed with the orifice plate still mounted on the machine tool. The plate had to be taken down and the optical image of the plate projected onto the screen of the Ferranti co-ordinate measuring machine for inspection. If the plate does not meet the specification, it cannot be used as it is very difficult to re-mount correctly in the machine tool for further machining due to the narrow limits of tolerance involved; another new plate must be made. The three test plates were chosen from a total of 25 plates manufactured.

Each orifice plate was tested in the concentric as well as eccentric position. The flow rates were varied in a random manner and the experimental results were obtained over a period of four months.

Discussion of experimental results

Water was used as the test fluid and the experimental results are shown in Figs 3–8. The three orifices were tested in the region $100 < Re_D \lesssim 1000$, and the experimental data were obtained with the orifice in the concentric position as well as in the fully eccentric position (eccentricity $= (D-d)/2$). For the eccentric position, the pressure tappings were displaced by 180° from the centreline of the orifice, ie diametrically opposite.

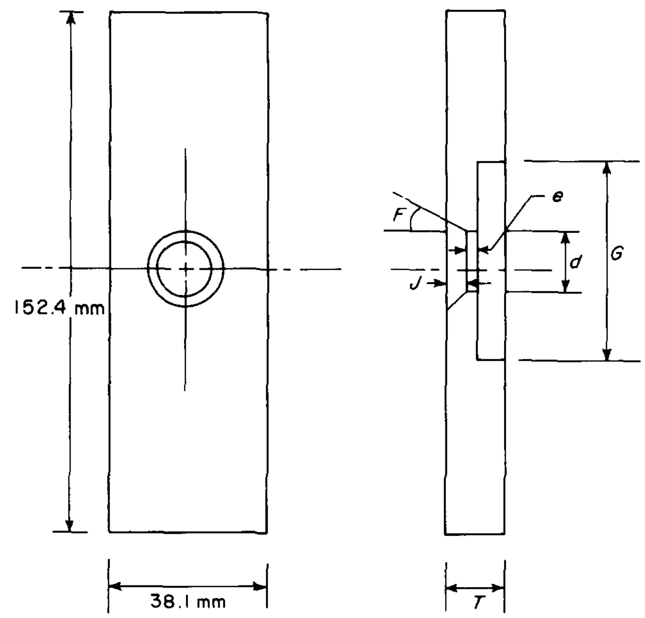

Fig 2 Dimensions of the test plates (see Table 1)

All the three orifices have an area ratio of less than 0.205. With an upstream straight length of 35 diameters, the effects of upstream bends and valves on the discharge coefficients of these small area ratio orifices can be regarded as negligible[6,7]. For the lowest of the three area

Table 1 Orifice plate dimensions

		Plate 1	Plate 2	Plate 3
d		6.280	9.144	11.40
T	A	2.324	2.486	2.485
	B	<2.54	<2.54	<2.54
F	A	44.06°	45.25°	45.42°
	B	45°±1	45°±1	45°±1
J	A	0.279	0.787	1.072
	B	$0.546 > J > 0.509$	$0.796 > J > 0.741$	$0.992 > J > 0.923$
e	A	0.152	0.176	0.190
	B	$0.151 > e > 0.113$	$0.219 > e > 0.165$	$0.274 > e > 0.205$

A: measured value
B: values specified by BS 1042
All dimensions in mm
* *Surface finish of the plates are smaller than 0.5 μm CLA*

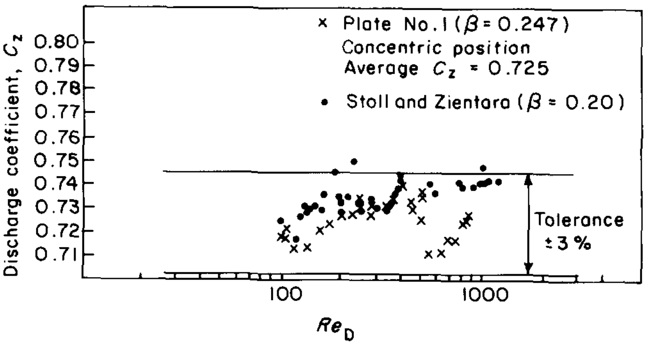

Fig 3 Variation of C_z with Re_D

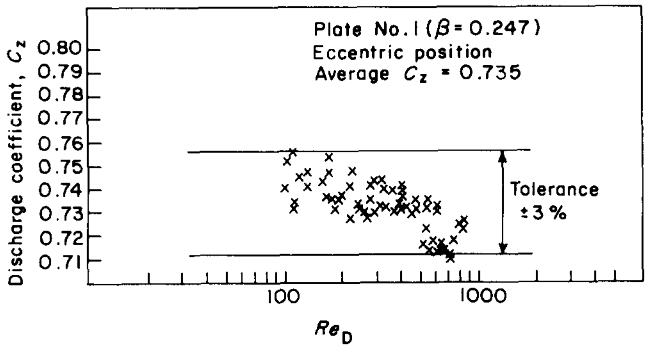

Fig 4 Variation of C_z *with* Re_D

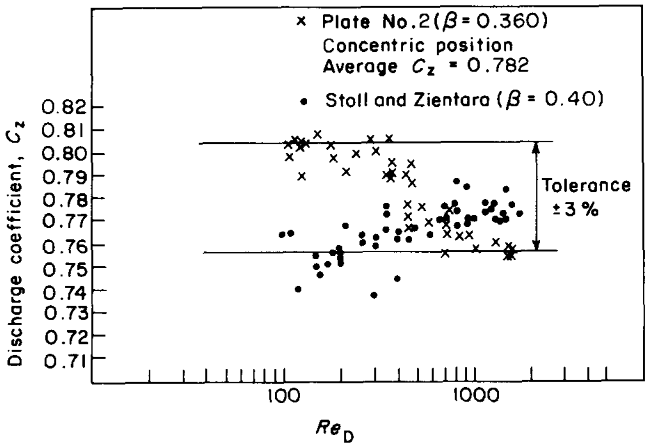

Fig 5 Variation of C_z *with* Re_D

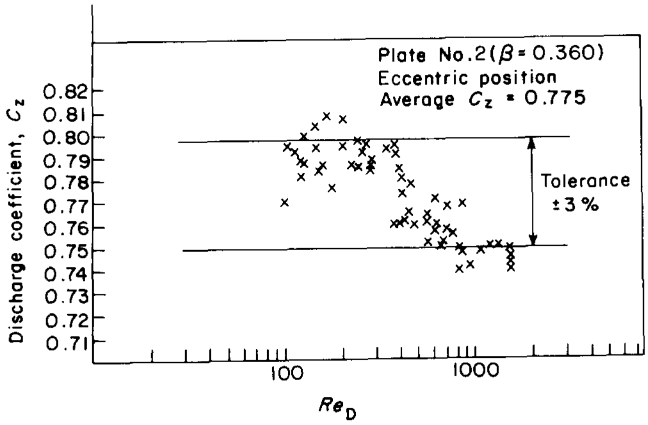

Fig 6 Variation of C_z *with* Re_D

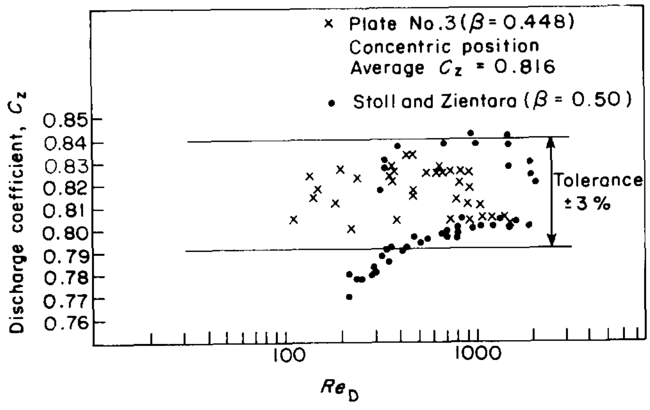

Fig 7 Variation of C_z *with* Re_D

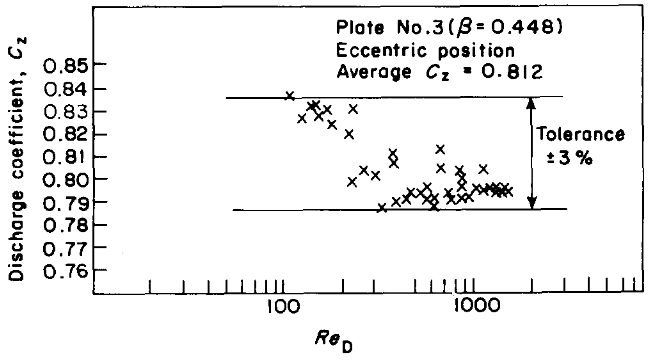

Fig 8 Variation of C_z *with* Re_D

ratios ($m = 0.061$), the average C_Z is 0.725 for the concentric position and 0.735 for the eccentric position. This conforms to the value of 0.734 given in BS 1042. It also verifies the performance of the test rig. For the other two orifices, the area ratios (0.1296 and 0.200) exceeded the limit of 0.1 ($\beta = 0.316$) specified in BS 1042. The average C_Z obtained were greater than the BS value of 0.734. For the concentric position, average C_Z is 0.782 for $\beta = 0.36$ and 0.816 for $\beta = 0.448$. This increase in the average C_Z value with the β ratio is similar to that reported by Stoll and Zientara^2 and McVeigh^3 on conical entrance orifice plates which have a geometry that is a function of β. Figs 3, 5 and 7 show the comparison of some of the results presented by Stoll and Zientara (obtained by three fluid meter manufacturers) with the authors' result for the concentric position.

The $\pm 3\%$ tolerance limits on C_Z are also shown in Figs 3–8. This is greater than the $\pm 2\%$ specified in BS 1042. McVeigh^3 also reported sudden and jerky variations in the flow coefficient and attributed these to boundary layer effects and flow changes across the orifice (laminar to turbulent and vice versa).

Figs 3–8 also show the effect of the eccentricity of the orifice plates on the discharge coefficient. Displacement of the conical entrance orifice plates from concentric appears to have no appreciable effect on the discharge coefficient. Lakshmana Rao and Sridharan^7 have shown that for sharp edge orifices, the loss coefficient for eccentric orifices is only marginally higher than that of the concentric orifice for $\beta \leqslant 0.4$ and $R_D > 500$. Therefore, it is probable that at the range of Reynolds numbers under investigation, the effect of viscous action on the coefficient of contraction and coefficient of velocity remains more or less the same for the concentric and eccentric positions of conical entrance orifices.

Conclusions

This investigation provides additional information on the performance characteristics of conical entrance orifice plates at low Reynolds number for a pipe diameter of 25.4 mm. The test plates manufactured according to BS 1042 behaved in a similar manner to Kent plates under the test conditions. It was also shown that eccentricity of the plates has no appreciable effect on the discharge coefficient. From a manufacturing point of view, observing dimensional tolerances associated with the conical entrance orifice plate can be a time-consuming exercise, especially for small pipe diameters, because the tolerance is a function of orifice diameter.

References

1. **Kastner L. J. and McVeigh J. C.** A reassessment of metering orifices for low Reynolds number, *Proc. Instn. Mech. Engr., 1965–66*, **180** (*Pt. 1*) (*13*), *331*
2. **Stoll H. W. and Zientara D.** The conic entrance orifice plate, an investigation of its performance characteristics, *Flow, its measurement and control in science and industry, Instrument Society of America, 1974, Vol. 1, Part 2, 517–522*
3. **McVeigh J. C.** The effect of installation conditions on the discharge coefficient of the conical entrance orifice plate at low Reynolds numbers, *Flow, its measurement and control in science and industry, Instrument Society of America, 1974, Vol. 1, Part 2, 533–537*
4. **Turton R. K.** A note on flow through conical entrance orifice plates, *Conference on fluid flow measurement in the mid 1970s, Glasgow, 1975, Paper A-3*
5. BS 1042, Section 1.2, 1984
6. **Martin C. N. B.** Effects of upstream bends and valves on orifice plate pressure distributions and discharge coefficients, *Int. J. Heat & Fluid Flow, 1982*, **3**, (*3*), *135–141*
7. **Lakshmana Rao N. S. and Sridharan K.** Orifice losses for laminar approach flow, *J. Hydraulics Division, Proc. ASCE, 1972, 2015–2034*

BOOK REVIEW

Advances in Drying, volume 3

Ed A. S. Mujumdar

During the past decade drying has become a fashionable subject for academic chemical engineering research. This has been stimulated mainly by the enormous rise in fuel costs and the realisation that drying accounts for a large fraction of the energy used by many industries. It is also a fascinating subject in its own right, being perhaps a unique blend of heat transfer, mass transfer, aerodynamics and particle technology. Professor Mujumdar has been instrumental in creating an international community of drying researchers and this third volume in his series is a welcome addition to the rapidly growing literature in the field.

The format is the same as in the first two volumes. A number of leading drying researchers have been invited to contribute individual chapters, typically of the order of 40 pages each, reviewing critically the present state of knowledge in their own corner and placing their own research in context. The result is a series of authoritative reviews which will be standard references for many years to come and which will be invaluable introductions for newcomers to the field.

One of the highlights is the chapter by King, Kieckbusch and Greenwald on 'Food quality factors in spray drying'. This chapter serves to remind us that dryers do more than remove moisture; they also create products, and in many instances the quality of the product depends critically on the drying conditions and the dryer design. In recent years a scientific basis has been developed for understanding the influence of these design variables on the flavour, aroma and stickiness of spray-dried foods and beverages and this has resulted in considerably enhanced product quality. The authors present a most readable account of this development as well as a very good introduction to the scientific basis of spray drying in general.

The theme of the influence of drying conditions on product quality recurs in the chapter by Sokhansanj on 'Grain drying simulation with respect to energy conservation and grain quality'. Until recently, for drying processes'. Probably as many as half the fluid bed dryers installed in the last few years employ vibration of the distributor to guard against materials handling problems and to enhance drying rates, but fundamental research on this topic has been largely restricted to Eastern Europe. Over two-thirds of the references are from the East European literature, and while this may be frustrating for Western readers who wish to consult the original papers the authors have nevertheless performed a most valuable service in bringing all this work together and evaluating it.

The same fault detracts from an otherwise good review by Kirk of progress in 'Computer simulation of paper drying'. This chapter is unusual in that there are no section headings to act as signposts for the reader. Instead, the author presents a chronological narrative which reads like a gripping detective yarn, ranging from the earliest simulations performed on hand calculators to present day simulations requiring large computers. On the way much progress has been made in sorting out the relative contributions of various mechanisms of heat and mass transfer in these exceedingly large and expensive drying machines. The chapter would have been strengthened by the inclusion of some examples of the practical utility of these simulations.

Pakowski, Mujumdar and Strunillo contribute a chapter entitled 'Theory and application of vibrated beds for drying processes'. Probably as many as half the fluid bed dryers installed in the last few years employ vibration of the distributor to guard against materials handling problems and to enhance drying rates, but fundamental research on this topic has been largely restricted to Eastern Europe. Over two-thirds of the references are from the East European literature, and while this may be frustrating for Western readers who wish to consult the original papers the authors have nevertheless performed a most valuable service in bringing all this work together and evaluating it.

There is an excellent chapter by Basmadjian on