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CFD Analysis on Different Shapes of Concentric Orifice Plate for Turbulent Flow

Likitha J
BE, Student
Department of Mechanical engineering
Cauvery Institute of Technology, Mandya

Savitha T M
BE, Student
Department of Mechanical engineering
Cauvery Institute of Technology, Mandya

Karthik MS
Assistant professor
Department of Mechanical engineering
Cauvery Institute of Technology, Mandya

Kavya P
BE, Student
Department of Mechanical engineering
Cauvery Institute of Technology, Mandya

Usha G
BE, Student
Department of Mechanical engineering
Cauvery Institute of Technology, Mandya

***Abstract*— Obstruction type flow meters are widely used in industry for flow measurement. Orifice meter cover a wide range of applications of fluid and operating conditions. ISO 5167 Prescribes the standard design of the Orifice meter with respect to various parameters, namely, flow rate, differential pressure, pipe diameter, beta ratio, plate thickness and working fluid. The focus of the study was directed towards the behaviour of Concentric Orifice meters for very low to high Reynolds numbers, varying the beta ratio and different shapes of Orifice plate. The Computational Fluid Dynamics (CFD) program STAR CCM + was used to perform the research. In particular, the CFD predictions of discharge coefficients were verified through comparison through results available in the literature. Results are presented in terms of predicted discharge coefficients. The outcomes of the simulations in terms of profiles of velocity, pressure, etc. Results are presented in terms of predicted discharge coefficients. Reynolds numbers, beta ratio and shape of the Orifice plate deserve excessive observation when it comes to analysing the capabilities of Concentric Orifice Meter**.

Keywords - Orifice Meter, Computational Fluid Dynamics (CFD), Discharge Coefficient, Reynolds Number, Beta Value

I. INTRODUCTION

At present, flow measurement is an important and significant task in distributing and regulating the limited but high demandable fluids (water, gases, petroleum etc) in different sectors. Perhaps, most of the fluids with a great utility are transmitted through pipe flow systems because of its suitability, durability and effectiveness. So, an easy, accurate and economical flow measurement technique is expected for better management of fluids flowed through pipes. A standard Orifice plate is one of a variety of obstruction-type flow meters that is used extensively to measure the flow rate of fluid in a pipe; it consists of a thin plate with a hole in the middle. Orifices are also used for various engineering applications such as cooling holes, fuel lines, hydraulic systems, air conditioning and water pipe systems. Normally in practice the discharge coefficient is used to relate flow rate to differential pressure across the Orifice plate.

In the present work computational fluid dynamics techniques were utilized to characterize the behaviour of Orifice meters for very low to high Reynolds numbers, varying the beta ratio and different types of Orifice plate. In particular, the CFD predictions of discharge coefficients were verified through comparison through results available in the literature. Results are presented in terms of predicted discharge coefficients. Reynolds numbers, beta ratio and shape of the Orifice plate deserve excessive observation when it comes to analyzing the capabilities of concentric Orifice Meter. The value of the Reynolds number for a particular pipe flow can be decreased by either decreasing the velocity, or increasing the viscosity.

CONCENTRIC ORIFICE METER

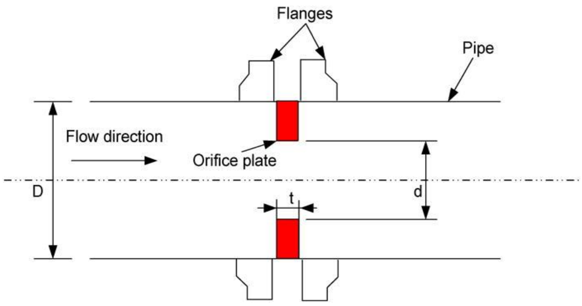

Fig-1: Concentric Orifice meter

As Per ISO 5167 standard, the mass flow rate in a Orifice meter (q_m) is given by:

$$q_m = \frac{C_d}{\sqrt{1-\beta^4}} \frac{\pi d^2}{4} \sqrt{2(p_1 - p_2)\rho_1} \quad ....(1)$$

Where:

C_d Orifice meter discharge coefficient

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β beta ratio, d/D
d Orifice diameter, mm
D Upstream Pipe diameter , mm
p_1 Static pressure at the upstream pressure tap
p_2 Static pressure at the downstream pressure tap
ρ_1 Fluid density at the upstream tap location, Kg/mm^3

When working with Orifice meters, Reynolds numbers based on inlet pipe diameter (D) and Orifice diameter (d) are frequently used. These are defined as follows:

$$Re_D = \frac{\rho v D}{\mu} \quad \text{(2a)}$$

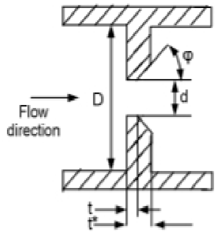
$$Re_d = \frac{\rho v d}{\mu} \quad \text{(2b)}$$

Where μ, ρ and V are the dynamic viscosity, density, and average velocity, respectively, corresponding to either D or d.

Equation (1) is based on the assumptions that include steady, incompressible, and in-viscid flow (no frictional pressure losses).

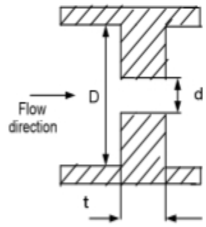
Shape of Orifice Plate

1.Short square edged Orifice with back bevel angle.



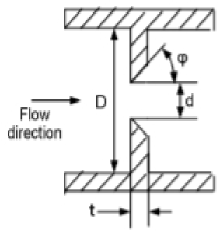
Dia of the pipe (D) = 50mm
Dia of the Orifice (d) = 25mm
Thickness (t*) = 2mm
Thickness (t) = 0.5mm
Angle (φ) = 45°
Beta ratio (β) = 0.5

2.Long square edged Orifice.



Dia of the pipe (D) = 50mm
Dia of the Orifice (d) = 25mm
Thickness (t) = 2mm
Beta ratio (β)= 0.5

3.Knife edged Orifice with back bevel angle.



Dia of the pipe (D) = 50mm
Dia of the Orifice (d) = 25mm
Angle (φ) = 45°
Beta ratio (β) = 0.5

II. GEOMETRICAL MODEL

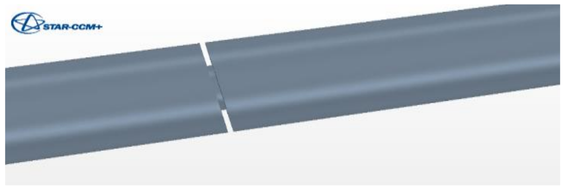


Fig-2.1: 3D Model

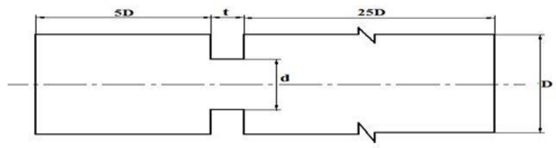


Fig-2.2: 2D Model

The geometries of the Concentric Orifice Meter were constructed as per ISO-5167 standards. Orifice meter for 50 mm diameter pipe at β values 0.5 and 0.3 with 5D upstream and 25D downstream of the Orifice meter have been modelled as shown in fig-2.2.

III. MESH MODEL , BOUNDARY CONDITIONS AND PARAMETERS.

Flow predictions were carried out for concentric orifice meter having pipe diameter of 50mm and beta ratio is 0.5 and 0.3. The models were created and meshed in STAR CCM+.

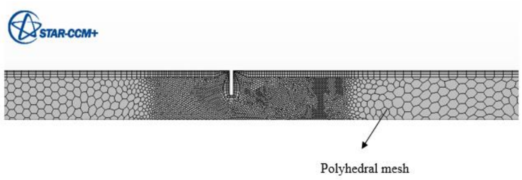


Fig-3.1: Meshed Model, Polyhedral Mesh

Once the geometry was constructed, meshing was applied to determine the points within the model where numerical computations would occur. After the testing of multiple meshing schemes, it was decided that the best fit for the geometries were polyhedral cells. Once the models had been meshed, there were up to 12,000 computational cells in a model.

Boundary Conditions:

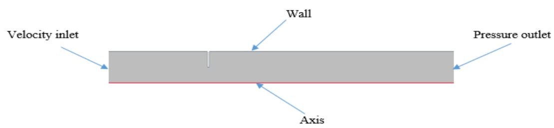


Fig-3.2: Boundary Conditions

Fig-3.2 shows the boundary conditions applied in STAR CCM+. The flow inlet on the 5-diameter upstream pipe was defined as the Velocity Inlet, The flow outlet on the 25-diameter downstream pipe was defined as a Pressure Outlet, all solid surfaces are treated as Wall. For 2D axis-symmetric studies central line has taken as Axis in simulation.

2D axis-symmetric model has been used for different Orifice meter the process of grid generation is very crucial for accuracy, stability and economy of the prediction. A fine

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grid leads to better accuracy and hence it is necessary to generate a reasonably fine grid in the region of steep velocity gradients. For efficient discretization, the geometry was divided in to three parts, upstream and downstream region were meshed with reasonably coarse grid whereas the central region containing the obstruction (Orifice plate) and pressure taps was meshed with very fine grids in order to effect of obstruction geometry. The size of grid were kept very fine in the central region to account for the expected steep velocity gradients there. The grid independence test were carried out by grid adaptation and comparing the value of C_d obtained with different grid size. Through the completion of many test runs it was determined that the best viscous turbulence model for this study was the realizable k-epsilon model with the standard wall function enabled. This particular model was used for any of the model that had a Reynolds number greater than 4000.

The study includes water as fluid to be examined in order to obtain data for the different range of Reynolds numbers (10,000 to 10,00000). Water was used for the turbulent flow. The velocity inlet condition only required the calculated velocity based on Reynolds numbers. The pressure outlet was usually set anywhere from 1-30 bar normal downstream pressures. The simulations performed the same whether 1-30 bar was used for the downstream pressure outlet. It is important to observe when studying the results that potential cavitations is not taken into account using STAR CCM+ therefore high negative pressures are not a cause for concern.

Residual monitors were used to determine when a solution had converged to a point where the results had very little difference between successive iterations. When the k-epsilon model was applied, there were six different residuals being monitored which included: continuity, x, y, and z velocities, k, and epsilon. The study aimed to ensure the utmost iterative accuracy by requiring all of the residuals to converge to 1e-04, before the model runs were complete.

Geometrical Details of The Orifice meter used for Simulations:

Summary Table of Orifice Meter Tested		
Orifice plate	Diameter (mm)	Beta(β) Value
1. Short square edged Orifice with back bevel angle.	50	0.3
2. Short or thin square edged Orifice		
3. Knife edged Orifice		0.5

IV. VALIDATION

Numerical solution of a physical problem must be validated with available published data, ISO Standard, and Data hand book to ensure that it gives a reasonably accurate description of the physical reality. The validation for the present work is as shown in Table.4.1. and Fig 4.1 where D = 50mm, β = 0.5 models are compared with the available published data, ISO Standard and Data hand book. The data presented by ISO Standard, published data and data hand book for concentric Orifice flow meters were compared to the results of this study of which both were comparable.

Re	C_d			
	Present study	ISO	Hand book	Journal paper
1000000	0.71	0.732	0.73	0.7405
100000	0.71	0.732	0.73	0.7405
10000	0.44			

Table.4.1 Comparison of Present Study Vs published data, ISO Standard, and Data hand book

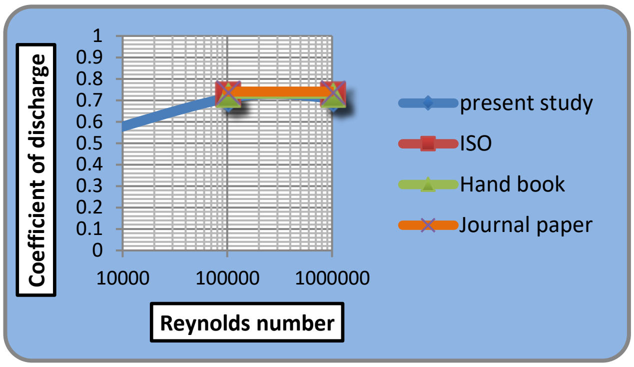

Fig 4.1 Comparison of Present Study V/S published data, ISO Standard, and Data hand book.

V. RESULTS AND DISCUSSION

Flow measuring devices having a high level of accuracy and relatively low cost are a couple of the most important parameters when deciding on the purchase of a flow meter. Most differential pressure flow meters meet both of these requirements. Many of the most common flow meters have a specified range where the discharge coefficient may be considered constant and where the lower end is usually the minimum recommended Re number that should be used with the specified meter. With the additional knowledge of this study it will enable the user to better estimate the flow through a pipeline over a wider range of Reynolds numbers for different shapes of Orifice plate . The research completed in this study on discharge coefficients focused on concentric orifice meter with varying beta ratios for different shapes of Concentric Orifice plate.

It was determined that the best way to present the data for it to be easily interpreted for the Orifice meters investigated was to provide the discharge coefficient vs. Reynolds number plots on semi-log graphs. The velocities that were needed to obtain different Re values were the primary variable put into the numerical model when computing Orifice meters discharge coefficients.

Concentric Orifice flow meter models were created to determine their discharge coefficient data for different shapes of Orifice plate. The different beta (β) values used for the models were 0.5 and 0.3 to observe if there was any significant difference in results based on the above parametric study.

1. Long square edged Orifice:

Table.5.1. For Long Square edged Orifice

[Re]	C_d	
	beta=0.3	beta=0.5
1,000000	0.73	0.71
100000	0.73	0.71
10000	0.73	0.71

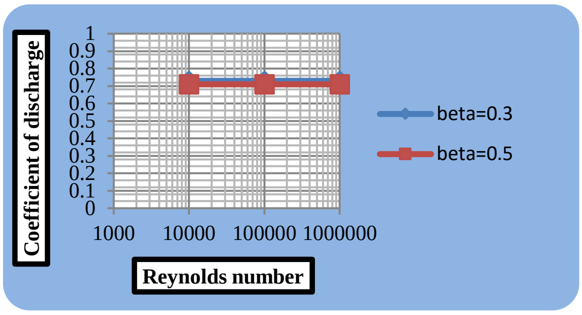

Fig 5.1 Discharge Coefficients for Long square edged Orifice meter

From Fig 5.1, It is shown that for 0.3 and 0.5 beta ratio for Long square edged Orifice meter, a linear relationship exists between Cd and Re. For beta ratio 0.3, Coefficient of discharge is 0.73 with decreasing Reynolds number from 1,00000 to 10000. For beta ratio 0.5, Coefficient of discharge is 0.71 with decreasing Reynolds number from 1,000000 to 10000.

Pressure and Velocity Contours.

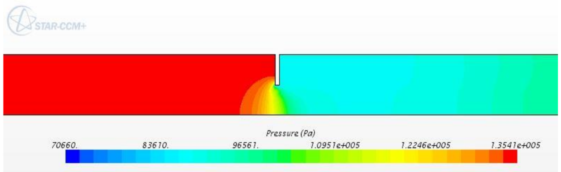

Fig 5.2 Pressure Contours for (Re = 1,00000) (β = 0.5)

The pressure contour is as shown in Fig 5.2. The pressure is decreases as we move from upstream tap to downstream tap. The pressure difference for the upstream tap and the downstream tap is 46153.57 Pa.

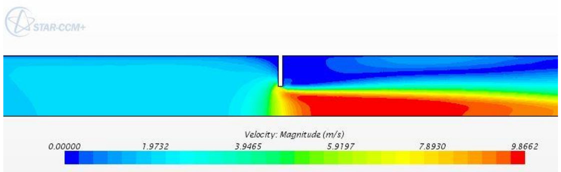

Fig 5.3 Velocity Contours for (Re = 1,00000) (β = 0.5)

The velocity contour is as shown in Fig 5.3. The velocity magnitude is increase as we move from upstream tap to downstream tap. The velocity at the upstream tap is 1.7779181 m/s. The velocity at the downstream tap is 2.56499 m/s.

2. Short square edged back bevel angle Orifice :

Table.5.2. For Short Square edged back bevel angle Orifice

[Re]	C_d	
	beta=0.3	beta=0.5
1000000	0.67	0.65
100000	0.67	0.65
10000	0.67	0.55

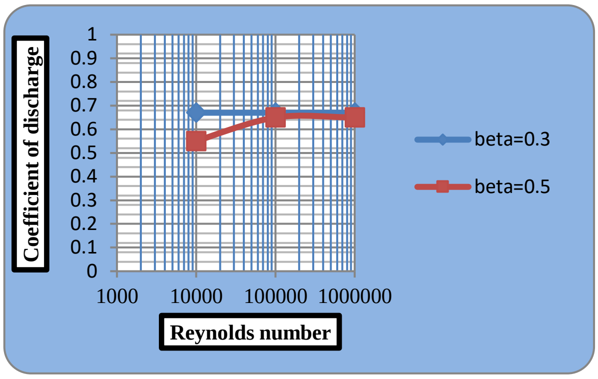

Fig 5.4 Discharge Coefficients Short square edged back bevel angle Orifice.

Pressure and Velocity Contours.

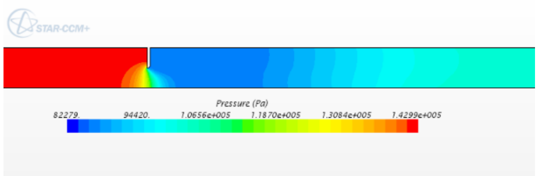

Fig 5.5 Pressure Contours for (Re = 1,00000) (β = 0.5)

The pressure contour is as shown in Fig 5.2. The pressure is decreases as we move from upstream tap to downstream tap. The pressure difference for the upstream tap and the downstream tap is 55718.43 Pa.

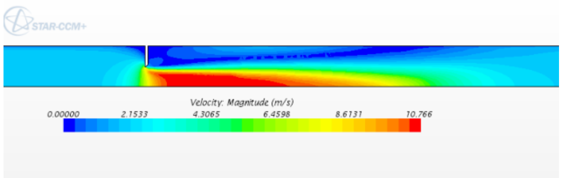

Fig 5.6 Velocity Contours for (Re = 1,00000) (β = 0.5)

The velocity contour is as shown in Fig 5.3. The velocity magnitude is increase as we move from upstream tap to downstream tap. The velocity at the upstream tap is 1.84337 m/s. The velocity at the downstream tap is 2.445188 m/s.

3. Knife edged Orifice with back bevel angle .

Table.5.3. For Knife edged Orifice with back bevel angle

[Re]	C_d	
	beta=0.3	beta=0.5
1000000	0.69	0.65
100000	0.69	0.65
10000	0.66	0.68

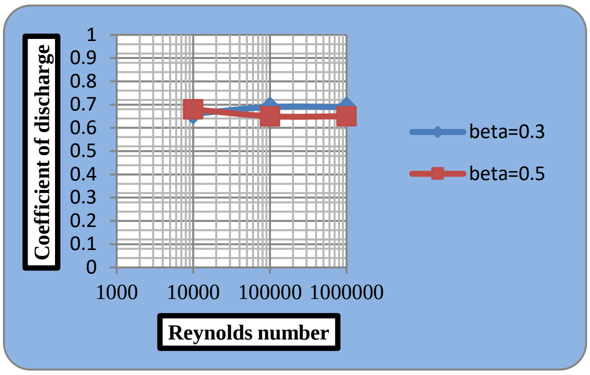

Fig.5.7 Discharge Coefficients for Knife Edge Orifice With Back Bevel Angle

From fig 5.7 It is shown that for 0.3 and 0.5 beta ratio for knife edge orifice with back bevel angle, a curvilinear relationship exists between C_d and Re. For beta ratio 0.3, Coefficient of discharge decreases from 0.69 to 0.66 with decreasing Reynolds number from 10,00000 to 10000. For beta ratio 0.5, Coefficient of discharge increases from 0.65 to 0.68 with decreasing Reynolds number from 10,00000 to 10000.

Pressure and Velocity Contours.

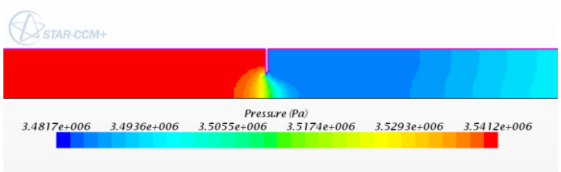

Fig 5.8 Pressure Contours for (Re = 1,00000) (β = 0.5)

The pressure contour is as shown in Fig 5.8. The pressure is decreases as we move from upstream tap to downstream tap. The pressure difference for the upstream tap and the downstream tap is 54651Pa.

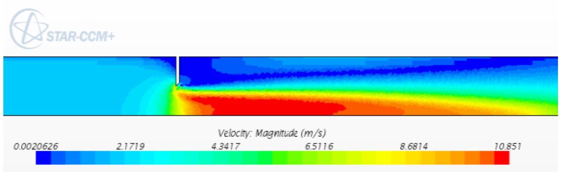

Fig 5.9 Velocity Contours for (Re = 1,00000) (β = 0.5)

The velocity contour is as shown in Fig 5.9. The velocity magnitude is increase as we move from upstream tap to downstream tap. The velocity at the upstream tap is 1.779090m/s. The velocity at the downstream tap is 2.381051m/s.

VI. CONCLUSION

The CFD software STAR CCM+ was used to create multiple models in an effort to understand trends in the discharge coefficients for Concentric Orifice Meter with varying Reynolds numbers. Various models were generated for each of the Concentric Orifice Meter being analyzed to determine effects of different shapes of the Orifice plate and beta values on the discharge coefficient.

The results agree well with the published data, ISO Standard, and Data hand book in terms of Coefficient of discharge, velocity profiles and pressure profile. The use of Computational Fluid Dynamics aids in the ability to replicate this study while minimizing human errors. It is also concluded that the CFD technique can be used as an alternative and cost effective tool towards replacement of experiments required for estimating discharge coefficient, empirically.

Different graphs were developed to present the results of the research. These graphs can be used by readers to determine how Concentric Orifice Meter performance may be characterized for different shapes of orifice plate with varying beta ratio and Reynolds number for in-compressible fluids.

REFERENCES

[1] ISO 5167-4, “Measurement of Fluid Flow by Means of Pressure Differential Devices Inserted in Circular Cross-Section Conduits Running Full -,” 2003.

[2] C. B. Prajapati, V. Seshadri et al, in their work discussed the use of CFD to compute the permanent pressure loss and relative pressure loss for incompressible fluid

[3] C. L. Hollingshead et al, have done experimental studies on the study been directed towards low Reynolds numbers discharge coefficients and validated using numerical analysis.

[4] V Seshadri et al, in this work they have discussed Peristaltic the study of radial flow of viscous non-Newtonian fluids between circular and parallel plates for the laminar flow of non-Newtonian fluid is studied by Tsung Yen Na Arthur.

[5] M M Tukiman1, M N M Ghazali1, A Sadikin1,et al, In this present paper, the commercial Computational Fluid Dynamics (CFD) is used to predict the flow features in the Orifice flow meter.

[6] M. M. RAHMAN, R. BISWAS &W. I.MAHFUZ , in this present paper Orifice meter is a very common flow measuring device installed in a pipe line with minimum troubles and expenses.

[7] BUTTEUR MULUMBA NTAMBA NTAMBA, In this present paper ,Despite the extensive research work carried out on flow through short square-edged Orifice plates over the last century (e.g. Johansen, 1930; Benedict, 1977; Alvi et al., 1978; Swamee, 2005; ESDU, 2007),

[8] MOHAMMAD AZIM AIJAZ, in this paper, Obstruction type flow meters are widely used in industry for flow measurement. Orifice Plates cover a wide range of applications of fluid and operating conditions.

[9] Buckingham, E. 1914. On physically similar systems: illustrations of the use of dimensional equations. *Physical Review*, 4:345-376.

[10] Brinkworth, BJ. 1968. An *introduction to experimentation*. London: English Universities Press.

[11] Chadwick, A.J., Morfett, J.C. & Borthwick, M. 2004. *Hydraulics in civil and environmental engineering*. 4th ed. London: Spon Press.

[12] Chhabra, R.P. & Richardson, J.F. 1999. *Non-Newtonian fluids in the process industries: fundamentals and engineering applications*. Oxford: Butterworth-Heinemann.

[13] Della Valle, D., Tanguy P. A. & Carreau. P.J. 2000. Characterization of the extensional properties of complex fluids using an Orifice flow meter. *Journal of Non-Newtonian Fluid Mechanics*, 94(1):1-13, November.

[14] ESDU TN 07007. 2007. Incompressible flow through Orifice plates – a review of the data in the literature.

[15] ESDU 81039. 1981. Pressure losses across Orifices plates, perforated plates and thick Orifice plates in ducts-flow of liquids.

[16] Miller, R. W., Flow Measurement Engineering Handbook, McGraw-Hill, New York, 1996.

[17] Fox, R. W., and McDonald, A. T., Introduction to Fluid Mechanics, Wiley and Sons, New York, 1992.