Numerical and Experimental Investigation of Orifice Meter for Different ß-Ratio

MithunAadimane AN[1] , Ponnappa M P[2], Karthik S[3], Sagar H N[4], Madhu B P[5]
[1,2, 3,4]Dept of Mechanical Engineering
[5]REVA University,Bengaluru

Abstract- *In the present study, a CFD code ANSYS, FLUENT software has been adopted for analyzing flow through conical orifice plate assemblies. The methodology has been validated by analyzing flow through standard orifice plate assembly. Quantitative data on pressure loss coefficient are also presented in this study. The flow is assumed to be steady and axi-symmetric and the fluid is incompressible and Newtonian. The study has been demonstrated that a validated CFD methodology can be used to accurately predict the performance characteristics of conical entrance orifice plate even under non standard conditions. In this work the commercial finite-volume based code FLUENT is used to evaluate the value of* C_d*of orifice plates with diameter ratioß=0.518 – 0.66 in the Reynolds range 68,000 – 1,31,000. Incompressible steady-state analysis are conducted in two-dimensional domains discretized with unstructured meshes.*

Keywords- Orifice meter, ß-ratio, Reynolds number, FLUENT

I. INTRODUCTION

An Orifice plate is a thin plate with hole in it, which is usually placed in a pipe. When a fluid (whether liquid or gaseous) passes through the orifice, its pressure builds up slightly upstream of the orifice but as the fluid is forced to converge to pass through the hole, the velocity increases and the fluid pressure decreases. A little downstream of the orifice flow reaches its point of maximum convergence, the vena contracta where the velocity reaches its maximum and the pressure reaches its minimum. Beyond that, the flow expands, the velocity falls and the pressure increases. By measuring the difference in fluid pressure across tappings upstream and downstream of the plate, the flow rate can be obtained from Bernoulli’s equation using coefficients established from extensive research. Orifice plates are most commonly used to measure flow rates in pipes, when the fluid is single-phase (rather than being a mixture of gases and liquids, or of liquids and solids) and well-mixed, the flow is continuous rather than pulsating, the fluid occupies the entire pipe (precluding silt or trapped gas), the flow profile is even and well-developed and the fluid and flow rate meet certain other conditions. Under these circumstances and when the orifice plate is constructed and installed according to appropriate standards, the flow rate can easily be determined using published formulae based on substantial research and published in industry, national and international standards. An orifice plate is called a calibrated orifice if it has been calibrated with an appropriate fluid flow and a traceable flow measurement device.

II. DETAILED PROCEDURE

Extensive study of existing literature on experimental and numerical analysis of expansion through orifice meter has been done. Orifice meter geometry, expansion ratios, flow and boundary conditions have been drawn on the basis of the literature survey. Creation of two-dimensional geometry of the orifice plate and meshing is done on Workbench of ANSYS 15®. Simulation of expansion is carried on ANSYS FLUENT 15®software using different levels grid refinement and turbulent models. Grid independence test is carried for each of the cases studied to select appropriate number of elements for the computational domain. Validation of simulated results with that of experimental is done and the numerical approach, which resulted in acceptably proximate predictions, is adopted for further study of the cases taken in this work. Post processing features of ANSYS FLUENT are used to generate static pressure, total pressure and velocity contours for plots for all cases. Parameters that are essential for detailed analysis of expansion like flow exit velocity, pressure at exit are obtained from post processor generated contours and plots.

In the present study, ANSYS FLUENTsoftware version 15 is used for analyzing the flow. Theflow is assumed to be steady and axis-symmetric. Thefluid is incompressible and follows Newton’s law ofviscosity. Thus, the governing equations consist ofconservation of mass and Navier-Stokes equations.The flow domain is discretized into a large number of small volumes which are called as elements. The meshhas to be fine enough and the number has to besufficiently large in order to ensure accuracy andconvergence. The basic laws are applied to each subdomain by using finite volume technique. Thesedifferential equations are converted into algebraicequations which are solved iteratively until therequired convergence is achieved. Further, when theflow is turbulent RANS (Reynolds Averaged Navier-Stokes) equations need to be solving which introducenew unknowns like Reynolds stresses. Henceadditional equations need to be written and solved sothat the set of equations becomes complete. Thisprocess is called as turbulence modeling. Fluentsoftware has options to use any one of the severalturbulence models that are available. It is well known that no single turbulence model gives accurate solution for all types of flows. Hence it is very essential that in any CFD analysis the most appropriate model has to be identified and the discretization has to be sufficiently finer. This is known as the validation and convergence study.For the validation problem, the standard sharp edge orifice meter is chosen. The geometry of the orifice plate is selected based on ISO 5167 and BS 1042. In a pipe line orifice plate with a hole is inserted. By using orifice meter the rate of flow and coefficient of discharge can be calculated. The equation, which is governing for orifice meter assembly is given by

$$q_m = \frac{Cd}{\sqrt{1-\beta^4}}\,\epsilon\,\frac{\pi}{4}d^2\sqrt{2\rho_1\Delta p}$$

The flow is considered as incompressible and steady. The orifice plate considered here is sharpedged and concentric.

III. GEOMETRY DETAILS

The geometry was done in the ANSYS FLUENT with measurements, pipe diameter is 27mm, and thickness of the plate is 4mm and length of the pipe 475 mm. Defining required boundaries like inlet, outlet and wall of the geometry and mesh under tetrahedron. Defining the boundary conditions for the media as the water. The figure shows the axis-symmetrygeometry of the orifice meter. Figure 1 shows orifice geometry.

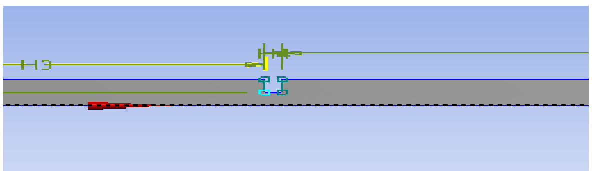

Fig 1 Geometry of orifice

IV. SOLUTION STRATEGY AND CONVERGENCE

The simulation is done in the FLUENT based upon the governing equations. The steps followed in the fluent are define Model, define Material, define cell zone, boundary condition, solve, iterate, and analyze results.

Equation used to get Analytical solution for C_d

$$Q = \frac{C_d A_2}{\sqrt{1-\beta^4}}\sqrt{\frac{2\times(p_1-p_2)}{\rho}}$$

Equation used to get theoretical solution for C_d

$$Cd = 0.5959 + 0.312\beta^{2.1} - 0.184\beta^{8} + 91.71\left[\frac{\beta^{2.5}}{Re^{0.75}}\right]$$

Continuity equation:

Q=AV

Where Q= Rate of flow in m^3/s
A= Area of pipe in m^2
V= Velocity in m/s

V. RESULTS AND DISCUSSION

CASE 1: Velocity 5.27 m/s, plate thickness 4 mm, diameter of orifice 14mm

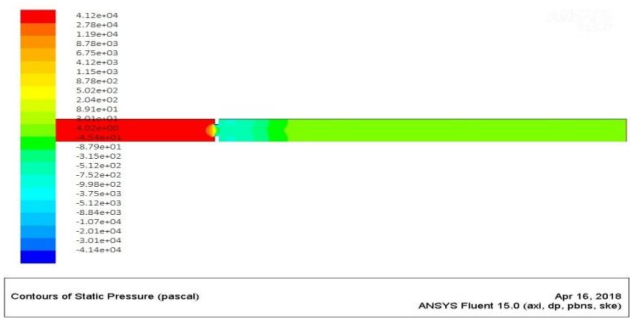

Fig 2 Pressure contour

Figure 2 shows that the pressure is constant till it reaches throat of an orifice plate, there is change in pressure due to decrease in area at the exit pressure is equal to atmospheric pressure. The Pressure at the throat is 1.25e+02 Pa .The pressure is maximum at the inlet of the orifice of 4.25e+04 Pa. The minimum pressure is -4.78e+04 Pa

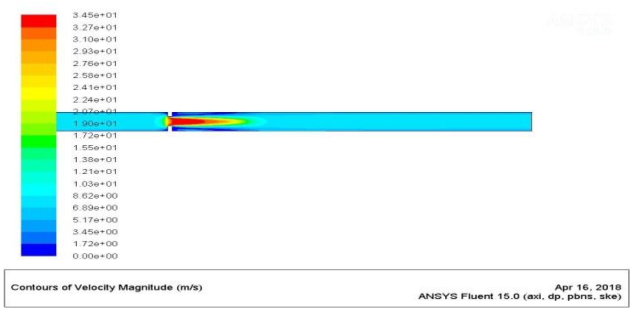

Fig 3 Velocity contour

Figure 3shows that the flow velocity at inlet 6.76 m/s is remaining constant till it reaches throat of an the orifice plate, there is change in the velocity due to decrease in area at the throat. The velocity at the throat is 2.58e+01 m/s .The velocity is maximum after the throat of the orifice of 3.45e+01 m/s. The minimum velocity is 1.72e+00 m/s.

Calculations:

Analytical Calculation:

Diameter of the pipe is 27mm.
Diameter of the orifice meter is 14mm.
Area of the pipe is (A_1) = 5.72e-4m^2.
Area of the orifice meter is (A_2) = 1.53e-4m^2.
Velocity at the inlet = 6.76m/s
Q = A_2V_2 = (1.53e-4)*6.76 = 1.03e-3 m^3/sec.
Pressure inlet p_1 = 2.51e4 pascals.
Pressure outlet p_2 = -1.21e4 pascals

Beta ratio (β) = $\frac{14}{27} = 0.518$

$$Q = \frac{C_d A_2}{\sqrt{1-\beta^4}}\sqrt{\frac{2\times(p_1-p_2)}{\rho}}$$

$$1.03e\text{-}3 = \frac{Cd \times 1.53e-4}{\sqrt{1-(0.518^4)}}\sqrt{\frac{2\times(2.51e4-(-1.21e4))}{1000}}$$

1.03e-3 = Cd$\times$1.53e-3

Cd = 0.670

Theoretical Calculation:

$$\mathbf{C_d = 0.5959 + 0.312\beta^{2.1} - 0.184\beta^{8} + 91.71\left[\frac{\beta^{2.5}}{Re^{0.75}}\right]}$$

$$Cd = 0.5959 + 0.312(0.518)^{2.1} - 0.184(0.518)^{8} + 91.71\left(\frac{0.518^{2.5}}{87.88e3^{0.75}}\right)$$

Cd = 0.6767

$$\mathbf{Re} = \frac{V\times D}{\vartheta}$$

$$= \frac{6.76\times 14e-3}{0.01e-4}$$

Re = 87.88e3

Case 2: Velocity 5.27 m/s, plate thickness 4 mm, diameter 16 mm

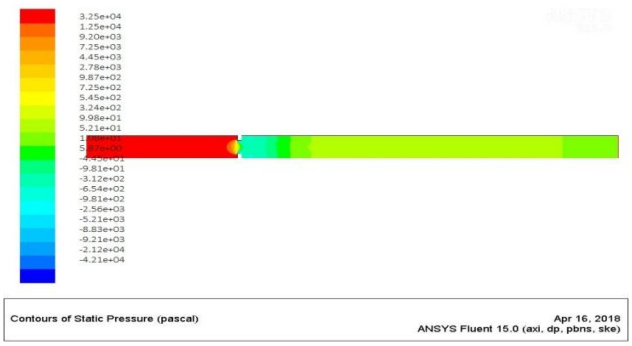

Fig 4 Pressure contour

Figure 4 shows that the pressure is constant till it reaches throat of an orifice plate, there is change in pressure due to decrease in area at the exit pressure is equal to atmospheric pressure. The Pressure at the throat is 5.21e+01 Pa . The pressure is maximum at the inlet of the orifice of 3.25e+04 Pa. The minimum pressure is -4.21e+04 Pa.

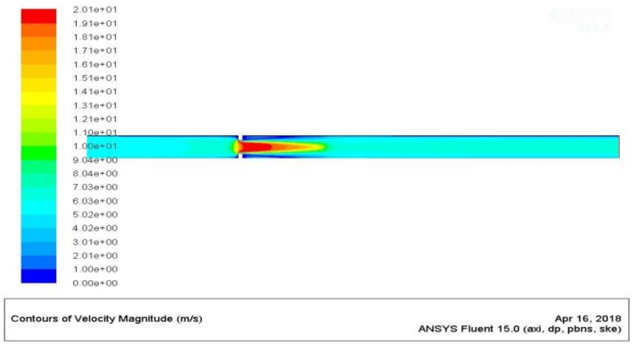

Fig 5 Velocity contour

Figure 5 shows that the flow velocity at inlet 5.27 m/s is remaining constant till it reaches throat of an the orifice plate, there is change in the velocity due to decrease in area at the throat. The velocity at the throat is 1.71e+01 m/s .The velocity is maximum after the throat of the orifice plate of 2.01e+01 m/s. The minimum velocity is 1.00e+00 m/s.

Case 3: Velocity 5.27 m/s, plate thickness 4 mm, diameter 18 mm

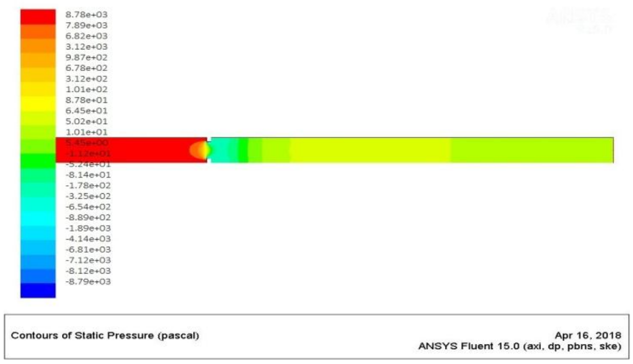

Fig 6 Pressure contour

Figure 6 shows that the pressure is constant till it reaches throat of an orifice plate, there is change in pressure due to decrease in area at the exit pressure is equal to atmospheric pressure. The Pressure at the throat is 5.02e+01 Pa. The pressure is maximum at the inlet of the orifice of 8.78e+03 Pa. The minimum pressure is -8.79e+03 Pa.

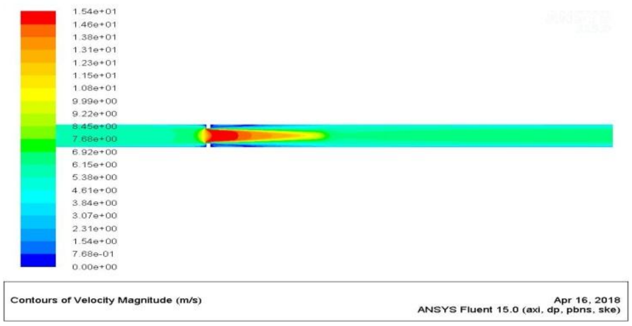

Fig 7 Velocity contour

Figure 7 shows that the flow velocity at inlet 5.27 m/s is remaining constant till it reaches throat of an the orifice plate, there is change in the velocity due to decrease in area at the throat. The velocity at the throat is 1.23e+01 m/s .The velocity is maximum at the throat of the orifice plate of 1.54e+01 m/s. The minimum velocity is 7.68e+01 m/s.

Experimental Calculation:

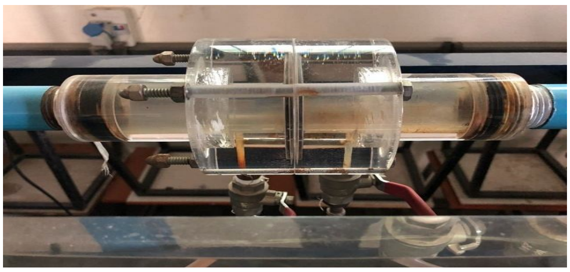

Fig 8:Experimental Setup

Diameter of orifice = 16 mm
Diameter of pipe = 27 mm
Area of pipe = 5.72e-4 m^2
Area of orifice = 2.01e-4 m^2

Table 1: Experimental data

Sl No	Type	Manometer Reading mm of Hg			Time sec	Hm*12.6 m of H_2O	Q_{the}	Q_{act}	C_d	Velocity m/s
		H_1	H_2	(H_1-H_2)						
1	Orifice meter	629	423	206	13	2.595	1.53e-3	9.61e-4	0.628	7.62
2		605	442	163	14	2.053	1.36e-3	8.91e-4	0.654	6.76
3		571	472	99	20	1.247	1.06e-3	6.25e-4	0.589	5.27

Calculations:

H = $(h_1-h_2)*\left[\frac{\rho_m}{\rho_w}-1\right]$ m of water
H = h_m*12.6
= 206*12.6e-3
H = 2.595 m of H_2O
Theoretical Discharge, Q_{the}

$$Q_{the} = A_1 \times A_2 \times \sqrt{\frac{2gh}{A_1^2 - A_2^2}}$$

$$= (5.72e\text{-}4) \times (2.01e\text{-}4) \times \sqrt{\frac{2\times9.81\times2.59}{(5.72e-4)^2-(2.0106e-4)^2}}$$

Q_{the} = 1.532e-3 m^3/s
Actual Discharge, Q_{act}

$$Q_{act} = \frac{A\times R}{t}$$

$$= \frac{0.125\times0.1}{13}$$

Q_{act} = 9.615e-4 m^3/s
Coefficient of Discharge, C_d

$$C_d = \frac{Q_{act}}{Q_{the}}$$

$$= \frac{0.961e-3}{1.53e-3}$$

C_d = 0.628
Velocity:
$Q_{the} = A_2 \times V$
1.5326e-3 = 2.010e-4 $\times$ V
V = 7.62 m/s

Table 2: Final Results

ß-Ratio	Diameter Of Orifice (mm)	Velocity m/s	Coefficient of Discharge	
			Theoretical	Analytical
0.518	14	5.27	0.677	0.677
		6.76	0.676	0.670
		7.62	0.676	0.668
0.592	16	5.27	0.701	0.706
		6.76	0.696	0.707
		7.62	0.699	0.708
0.66	18	5.27	0.725	0.747
		6.76	0.723	0.725
		7.62	0.721	0.714

VI. CONCLUSIONS

1. By Comparing all the results for different diameters ratio ($\beta = 0.66$) gives better C_d and pressure drop.
2. In β ratio 0.51-0.66 which is correct ratio for selecting different diameter to get proper co-efficient of discharge.

3. Numerical result shows even by restricting the computational domain at inlet and exit acceptable results can be obtained.
4. It is concluded that conical orifice meter is better than other shapes.
5. If analysis is carried out less β ratios and more β ratios it leads unacceptable results.

REFERENCES

[1] CFD analysis of permanent pressure loss for different types of flow meters in industrial applications Proceedings of the 37th National & 4th International Conference on Fluid Mechanics and Fluid Power December 16-18, 2010, IIT Madras, Chennai, India.
[2] Comparision of flow analysis through a different geometry of flow meters using fluent software T.Sridevi1, Dhana Sekhar2, V.Subrahmanyam3
[3] Singh, R.K. Singh, S.N. and Seshadri. V 2010."Performance evaluation of orifice plate assemblies under non-standard conditions using cfd". Indian Journal of Engineering and Materials Sciences, Vol.17, pp.397-406.
[4] Seshadri, V., Singh, S.N., Pramod K.B., 2002. Performance Charateristics of Wedge Flow Meter using CFD, Journal of Computational Fluid Dynamics, vol.11,3,279-284.