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NUMERICAL ANALYSIS OF THE PERFORMANCE CHARACTERISTICS OF CONICAL ENTRANCE ORIFICE METER

Ramya B N*, Prof. Yogesh Kumar K J, Dr. V Seshadri
M.Tech Student, Thermal Power Engineering, Maharaja Institute of Technology, Mysore
Assistant Professor, Department of Mechanical Engineering, Maharaja Institute of Technology, Mysore
Professor (Emeritus), Department of Mechanical Engineering, Maharaja Institute of Technology, Mysore

ABSTRACT

Orifice meters are one of the most widely used flow meters in industrial applications due to their simplicity, accuracy and economy. However, the sharp edge orifice plates cannot be used for low Reynolds number flows, due to a large variation in discharge coefficient with Reynolds number. Conical entrance orifice plates are developed for this purpose. In the present study, a CFD methodology using 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 (as per ISO 5167). K-ω SST model is found to be best suited for this class of problems.. The flow is assumed to be steady and axisymmetric and the fluid is incompressible and Newtonian. The computed values of discharge coefficient and other parameters are in excellent agreement with the values given BS 1042 as long as operating conditions are within the specified range. The parametric study has demonstrated that the acceptable range of Reynolds number can be extended to 50 to 10^6 as compared to 80 to 80000 as specified by BS 1042.Pipe roughness does not have significant effect on the value of discharge coefficient. The minimum acceptable pipe diameter is 10mm for these types of orifice plates. Quantitative data on pressure loss coefficient are also presented in the thesis. The study has 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.

Key Words*: Conical entrance, Coefficient of Discharge, Orifice Meter, Pressure loss Coefficient, Reynolds number.*

INTRODUCTION

Flow measurement is a critical activity in many industrial applications involving the flow of fluids like water, oil, chemical, power, food, and waste treatment industries. It is important to accurately measure the quantity of a fluid flow in order to have an effective control over the process. The parameter to be determined may be flow velocity, volumetric flow rate, mass flow rate, etc. Flow measuring device or a flow meter is a device which measures the above parameters. There are large varieties of flow meters like obstruction type, turbine, ultrasound, electromagnetic, Coriolis etc.. The most common types of flow meters used in the practical applications are Differential Pressure type flow meters. Occasionally they are called as Head-Loss or Obstruction type flow meters. The most common type of Obstruction type flow meters are Orifice meters, Venturi meters, Flow Nozzles, Elbow meters etc.

The standard orifice meters have some limitations. They are not suitable for low Reynolds number applications since the variation in discharge coefficient is substantial. To overcome these disadvantages and also to reduce energy losses, conical entrance orifice meters and quadrant edge orifice meters are developed. Conical entrance orifice meters are most suitable for low Reynolds number applications. The important characteristic of conical orifice meter is that, the discharge coefficient remains constant down to a low Reynolds number and it is equal to 0.734. The uncertainty on the value of C_d is 2%. In industrial applications sometimes it is difficult to change C_d for each trial. In those conditions conical orifice meter is the best suitable orifice meter. Conical orifice meter is further distinguished from other types of orifices in that their discharge coefficient is independent of diameter ratio within the limits specified in the standard. Compared to standard orifice meter and other orifice meter types, the C_d of conical orifice meter is higher and hence the energy losses are less in comparison with standard orifice meter. This is because of the reason that in the conical orifice meter, the flow is guided better as compared to the standard sharp edged orifice meter.

BACKGROUND

The orifice meters are extensively studied and adopted, because of their advantages like low cost, robust design, longer life etc. Numerous studies have been carried out on the subject of finding discharge coefficient of standard orifice meter. Available literature related to present study is reviewed and utilized. But standard orifice meter has some disadvantages. They do not perform well in viscous flows .To overcome these disadvantages and also to reduce energy losses, conical orifice meters and quadrant edge orifice meters are developed. The presence of conical entrance, guides the flow and hence the coefficient of discharge is higher and pressure drop is less. In this study, conical entrance orifice meters are analyzed and results are compared with the literature available wherever it is feasible. Literature survey has been made related to Standard Orifice meter, Quadrant edge Orifice meter and Conical Entrance Orifice meters in this present study.

Karthik et al. [7] have worked on the prediction of performance characteristics of Orifice plate assembly for non standard conditions using CFD. The work was carried out to observe the effect of pipe diameter and also the effect of thickness of orifice plate on discharge coefficient and permanent pressure loss using CFD. Effect of Reynolds number on the discharge coefficient of standard sharp edge & quadrant orifice using CFD along with their characteristics are analyzed. **Y.S. Ho and T.P. Leung [9]** have discussed the performance of conical entrance orifice plates at low Reynolds numbers**”**. They have investigated the performance of conical entrance orifice plates manufactured according to BS 1042. In this experiment, they had taken three plates with diameter ratios of 0.247, 0.360 and 0.448 & were tested in the region $100 < Re_D \leq 1000$ and in both the concentric and the fully eccentric position. **Y.S.Ho and F Abdullah [10]** have discussed the modeling the Conical Entrance Orifice Plate Flow Sensor. In this study, numerical model for the conical entrance orifice plate flow sensor are analyzed, these sensors are used as low Reynolds number flow measuring devices.

SCOPE OF THE PRESENT STUDY

It is observed from the literature survey that the characteristics of conical entrance orifice plate assembly have not been studied over wide range of operating conditions. Thus, it is proposed to use a validated CFD methodology to analyze the performance of conical entrance orifice plates even under operating conditions which are outside the limits given in BS 1042.

Specific Objectives

The main objectives of the present work are as follows;

- Understanding the geometry and concepts of orifice meter for standard conditions described in ISO 5167 and BS 1042 [12, 13, 14] .
- Development of CFD Methodology, Validation, Choice of turbulence model and convergence study for flow through Standard Orifice plate assembly.
- Analysis of effect of various parameters on the characteristics of conical entrance orifice plate assembly. In particular, it is proposed to study the effect of diameter ratio, Reynolds No, plate thickness, pipe diameter and its roughness on coefficients of discharge and pressure loss.

CFD Methodology and Validation

The solution of any fluid flow problem would involve solving for the various flow parameters at each location in the flow domain. In order to do this, a set of governing equations of motions need to be solved subject to the appropriate boundary conditions [15, 16]. These governing equations are obtained by invoking basic laws that govern the fluid flow (like conservation of mass, momentum principle, first law of thermo dynamics etc). These will yield a set of coupled non linear partial differential equations which are not amenable to analytical solutions. Hence, they are solved numerically using Computational Fluid Dynamics (CFD) software [17].

CFD METHODOLOGY

In the present study, ANSYS FLUENT software version 14 is used for analysing the flow. The flow is assumed to be steady and axisymmetric. The fluid is incompressible and follows Newton’s law of viscosity. Thus, the governing equations consist of conservation of mass and Navier-Stokes equations. The flow domain is discritized into a large number of small volumes which are called as elements. The mesh has to be fine enough and the number has to be sufficiently large in order to ensure accuracy and convergence. The basic laws are applied to each sub domain by using finite volume technique. These differential equations are converted into algebraic equations which are solved iteratively until the required convergence is achieved. Further, when the flow is turbulent RANS (Reynolds Averaged Navier-Stokes) equations need to be solved which introduce new unknowns like Reynolds stresses. Hence additional equations need to be written and solved so that the set of equations becomes complete. This process is called as turbulence modelling. Fluent software has options to use any one of the several turbulence 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 [13, 14]. 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

$$q_m = \frac{C_d}{\sqrt{1-\beta^4}} \pi d^2/_4 \sqrt{2\Delta P \rho} \quad \ldots\ldots\ldots\ldots(i)$$

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

Flow domain

The Flow domain chosen for the analysis is shown in Fig.3.1.It consists of a Pipe of 100mm diameter in which an orifice plate is fitted at a distance of 1500mm (15D) from the inlet. The downstream straight length available is 3500mm (35D).The larger downstream length is chosen in order to ensure that the downstream Boundary Condition does not affect the flow computations through the orifice. The upstream Pipe length ensures the development of fully developed velocity profile at the orifice plate. For the comparison with the standard results the various dimensions of the orifice plate are chosen as per BS1042.

The parameters chosen for the analysis are as follows,

L = 5005mm, D = 100mm, β = 0.6, Thickness of orifice plate = 5mm, the angle of bevel is $45^\circ \pm 15^\circ$.

The Flow Domain selected for the analysis is shown in Fig.3.1

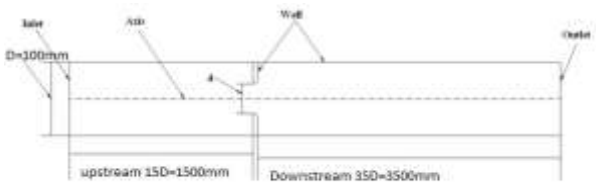

Fig. 3.1: Flow Domain of Standard Orifice plate assembly Chosen for Validation (D =100 mm)

The discritization of the flow domain is as shown in Fig.3.2 structured mesh is chosen in order to ensure faster convergence and accuracy during computations. Thus, the region close to the wall as well as region around the orifice plate (±2.5D) are meshed with very fine elements. The total number of elements used is in the range of 2×10^5.The convergence studies reported in the earlier section have shown that this number is sufficient for getting accurate results. The walls of the pipe and orifice plate are specified as smooth.

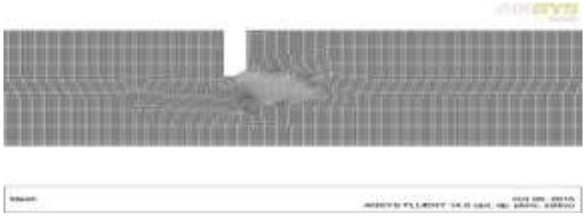

Fig. 3.2 Discritization of the Domain around the Orifice Plate

Boundary Conditions

The various boundary conditions specified for the flow domain are as follows.

- At the inlet velocity inlet boundary conditions are specified and the constant velocity is specified across the pipe inlet.
- On the pipe wall as well as orifice surface No Slip Wall boundary condition is used.
- Along the axis of the pipe axis boundary conditions are specified.
- Pressure outlet boundary conditions are specified at the pipe outlet. The gauge pressure is assumed to be zero.
- It is to be noted that the fluid is assumed to be Incompressible and Newtonian. The flow is assumed to be axisymmetric and steady. Thus, only one half of the pipe is chosen for flow domain.
- The velocity at the inlet is chosen according to the Reynolds Number (Re) at which computations are being made. Re. is defined

Since the fluid considered is an incompressible liquid for all the analysis, the density is taken as 1000Kg/m^3.The velocity of the fluid is kept in the range of 2m/sec so that the pressure drops are in the reasonable range. The computations for validation study are made for a Reynolds number of 50000.The convergence criteria were specified as 10^{-6} for the residuals. The approximate time taken for one run on processor was in the range 7 hours and the number iterations for convergence were in the range of 15000.

CONVERGENCE AND VALIDATION RESULTS

In the first stage, calculations are made with different turbulence models to identify the model, which is most suitable. Table 4.1 shows the results of model test. K- ε standard, K- ε RNG, K- ε Realize, K- ω Standard and K- ω SST models are analyzed using a mesh having 2.1×10^5 elements.

Table 3.1: Choice of Turbulence model ($Re=10^5$, $\beta=0.6$)

Turbulence model	Δp in Pa	C_d	C_d (Std)	ζ_{pm}	ζ_{pm} (Std)
K- ε standard	34918.6	0.617	0.6096	0.6174	0.6155
K- ε RNG	36232.6	0.6056	0.6096	0.6213	0.6212
K- ε Realize	36184.5	0.6063	0.6096	0.6229	0.6209
K- ω Standard	33938.6	0.625	0.6096	0.6129	0.6114
K- ω SST	36159.5	0.6095	0.6096	0.6165	0.6191

It is noted from the Table 3.1, K- ω SST gives the closest result among all the turbulent models. Hence, K- ω SST model is chosen for further analysis.

In order to check the discritization adequacy, the element numbers are varied in the range 1.1×10^5 to 2.5×10^5. The results are summarized in Table 3.2.

Table.3.2: Convergence study with k-ω SST model ($Re=10^5$, $\beta=0.5$)

No. of Elements	ΔP(Pa)	C_d	C_d (Std)	ζ_{pm}	ζ_{pm} (Std)
112331	35873	0.6119	0.6096	0.6155	0.6179
136099	35869.7	0.6119	0.6096	0.6157	0.6181
196597	36159.5	0.6096	0.6096	0.6165	0.6191
247087	361521	0.6099	0.6096	0.6168	0.6189

From the Table 3.2 it is clearly observed that for all the meshes analyzed here, the computed and standard values of C_d and ζ_{pm} are in reasonably good agreement. On the basis of this study, a mesh size of 1.9×10^5 with finer mesh around the orifice plate is adequate for ensuring accurate computation. From the convergence and validation analysis it is concluded that, elements number 196597 and k-ω SST turbulence model gives the accurate results. Hence we are making use of k-ω SST turbulence model (elements number 196597) in our flow problems.

RESULTS AND DISCUSSION

Detailed parametric study of flow through conical entrance orifice meter by varying parameters like Diameter ratio, Reynolds number, Plate thickness, Pipe diameter and Roughness of the pipe has been made. The Flow domain chosen for the analysis consists of a Pipe of 100mm diameter in which a conical entrance orifice plate is fitted at a distance of 1500mm (15D) from the inlet. The downstream straight length available is 3500mm (35D).The larger downstream length is chosen in order to ensure that the downstream Boundary Condition does not affect the flow computations through the orifice. The upstream pipe length ensures the development of fully developed velocity profile at the orifice plate. For the comparison with the standard results the various dimensions of the orifice plate are chosen as per BS1042**[14]**. The Flow Domain is discretized using axisymmetric quadrilateral elements. Structured mesh is chosen in order to ensure faster convergence and accuracy during computations. Thus, the region close to the wall as well as region around the orifice plate (±2.5D) is meshed with very fine elements. The total number of elements used is in the range of 2×10^5.The convergence studies reported in the earlier section have shown that this number is sufficient for getting accurate results. The walls of the pipe and orifice plate are specified as smooth. It is to be noted that the fluid is assumed to be Incompressible and Newtonian. The flow is assumed to be axisymmetric and steady. Thus, only one half of the pipe is chosen for flow domain. The velocity at the inlet is chosen according to the Reynolds Number (Re) at which computations are being made. The values of ρ,U and μ are chosen appropriately in order to achieve desired Reynolds Number. Since the fluid considered is a liquid for all the analysis the density is taken as 1000Kg/m^3.The velocity of the fluid is kept in the range of 1m/sec so that the pressure drops are in the reasonable range.

Based on the validation studies K- ω SST model is chosen for the computation whenever the flow is in turbulent regime. The model constants are chosen as default values. The convergence criteria are specified as 10^{-6} for the residuals. The approximate time taken for one run on processor was in the range 7 hours and the number iterations for convergence were in the range of 15000. The software calculates the velocity and pressure at each point in the flow. These results are processed to calculate various performance parameters. In particular the following results are analyzed for each case.

- ➢ Pressure and Velocity contours in the flow domain, Velocity vector plots to identify the regions of separation and recirculation.

- The Discharge Coefficient of the orifice plate (as per equation in ISO 5167). For the purpose of calculating the pressure differential across the orifice plate, corner taps are used (±3mm from the faces of the orifice plate).
- Reynolds number is calculated from the input data.
- The pressure loss coefficient for a standard orifice plate is calculated using the formula **[13]**.
  - $\Delta\omega = \frac{\sqrt{1-\beta^4} - C\beta^2}{\sqrt{1-\beta^4} + C\beta^2}\Delta p$ ----------- 5.2

Where

$\Delta\omega$ is the pressure drop between the inlet and outlet of the pipe.

Δp is the pressure differential across the orifice plate.

This parameter is a measure of the extent to which pressure recovery takes place after the passage through the orifice plate.

- The pressure loss coefficient by CFD (ζ) is calculated using the formula
  $\zeta = \frac{\Delta p_1}{\Delta p} = \frac{\Delta\omega}{\Delta p}$----------- 5.3
- Permanent Pressure loss Coefficient (ζ_{pm}) is defined as follows
  $\zeta_{pm} = \frac{\Delta p_1 - \Delta p_2}{\Delta p}$ -----------5.4

Where

Δp_1 = Pressure drop between the inlet and outlet of the pipe in the presence of the orifice plate.

Δp_2 = Pressure drop between the inlet and outlet of the pipe in the absence of the orifice plate under the identical flow conditions.

Δp = Pressure differential across the orifice plate.

ζ_{pm} is the measure of permanent loss of Mechanical Energy in the pipe due to the introduction of orifice plate.

A large number of runs have been made in order to analyze the performance characteristics of the conical entrance orifice meter under different flow conditions as well as geometrical configurations.

The Diameter ratio has been varied in order to assess its effects on the characteristics .In particular, computations have been made at six Diameter ratios namely 0.1, 0.3, 0.316, 0.36, 0.448, and 0.5. All these runs are made at a Re = 500.This Re is chosen so that the comparison of the computed results can be made with the experimental data reported in the literature [9]. It is to be noted for each Diameter ratio a separate flow domain is to be created and discretization has to be made.

For a pipe diameter of 100 mm and diameter ratio of 0.3, Re has been varied in the range 1 to 10^6.In particular, computations have been made at ten Re namely 1, 10, 50, 80, 100, 500, $10^{3,}10^4$, 5×10^4 , 10^5, 10^6.

The effect of plate thickness is studied by analyzing for three orifice plate thicknesses of 5, 7 and 15mm.For these studies D = 100mm and d = 30mm.For each plate thickness computations are made at two Re, one is laminar regime (500) and another in turbulent regime (50000).

The effect of pipe diameter is studied by varying it in the range 10 mm 300mm.It is to be noted that as per BS1042 the minimum allowable orifice diameter is 6mm.For this analysis diameter ratio is chosen as 0.3 and for each pipe diameter computations have been made at two Re namely 500 and 5×10^4.

The effect of pipe roughness is studied by varying the roughness height. Computations have been made 7 roughness heights namely 0.01, 0.1,1, 1.5, 2, 3 and 4mm.For these analysis D = 100mm, β = 0.3, plate thickness is 7mm, Re = 5×10^4.

The results obtained from the above runs are discussed in detail below.

EFFECT OF VARIATION IN DIAMETER RATIO

In this case study, we have executed CFD analysis for β ratios 0.1, 0.3, 0.316, 0.36, 0.448 and 0.5. These computations are made for D = 100mm, orifice plate thickness t = 7mm and Re = 500.

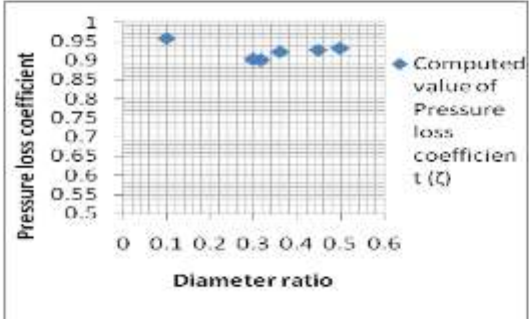

Fig 4.1: Effect of Variation in Diameter ratio on pressure loss coefficient for the conical entrance orifice plate (Re=500, D=100mm, t=7mm, smooth walls)

Fig (4.1) shows the effect of variation in Diameter ratio on C_d. The computed values of discharge coefficients and pressure loss coefficient at Re = 500 are tabulated in Table 4.1.It is observed that in the range of diameter ratios 0.1 to 0.316 the value of discharge coefficient is within the range of 0.734± 2% as specified by BS 1042.However value of C_d increases monotonically with increasing diameter ratios. At higher diameter ratios beyond 0.316 the value of discharge coefficient increases significantly. Thus, at β=0.5 the value of C_d is 0.8146, which is outside the range specified by BS 1042.

Table.4.1 Effect of variation in Diameter ratio for the Conical Entrance orifice plate (Re=500, D=100mm, t=7mm, smooth walls)

Diameter ratio	Computed value of C_d	Computed value of Pressure loss coefficient (ζ)	Pressure loss coefficient for standard orifice meter (ISO 5167)	Permanent Pressure loss coefficient (ζpm)
0.1	0.7243	0.9582	0.9856	0.956
0.3	0.7288	0.9029	0.86442	0.8728
0.316	0.7462	0.9011	0.867	0.8555
0.36	0.7648	0.9234	0.828	0.8541
0.448	0.8057	0.9281	0.7166	0.7288
0.5	0.8146	0.9321	0.6524	0.625

However value of Cd increases monotonically with increasing diameter ratios. At higher diameter ratios beyond 0.316 the value of discharge coefficient increases significantly. Thus, at β=0.5 the value of Cd is 0.8146, which is outside the range specified by BS 1042.In Table 4.1 the computed values of pressure loss coefficient(ζ) at various diameter ratios are also tabulated. These are compared with the values obtained using the formula given ISO 5167.It is to be noted that, this formula is applicable to standard orifice plate assembly only and also not applicable in the range of Reynolds number studied. It is observed from the tabulated values that, the two sets of values are not in agreement for all the diameter ratios. Hence it can be concluded that the formula given in ISO 5167 for standard plate assembly cannot be used for conical plate assembly for the purpose of calculating pressure loss coefficient. The computed values of permanent pressure loss coefficients are also tabulated in Table 4.1 for different diameter ratios. It is observed that the values of ζpm are always lower than those of ζ. This is due to the pressure recovery that occurs after the passage through the orifice. It is also observed from the Table 4.1 there is no significant pressure recovery as the diameter ratio increases. However, the computed values of ζpm are in reasonable agreement with the values of ζ from equation given in ISO 5167. Fig (4.2) shows the velocity contours for diameter ratio 0.1.The changes in the velocity are observed in these contours clearly. In the plots, it is clearly observed that, in the downstream of the orifice plate, for sufficiently long distance the jet coming out from the orifice plate travels without too much expansion. Hence a long pipe line length would be required for the velocity profile to become fully developed.

Fig (4.3) shows the velocity vector plot for diameter ratio 0.1. The separated regions and the zones of recirculation are clearly visible in the plot. The recirculation zones extend to fairly a large distances downstream of the orifice plate.

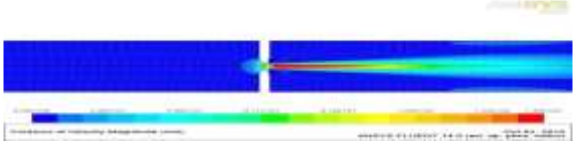

Fig 4.2: Velocity Contour Plot for the conical entrance orifice plate (Re = 500, D = 100mm, t = 7mm, β=0.1)

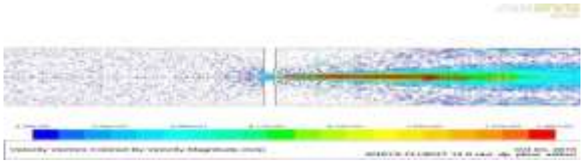

Fig 4.3: Velocity Vectors for the conical entrance orifice plate (Re = 500, D = 100mm, t = 7mm, β=0.1)

EFFECT OF VARIATION IN REYNOLDS NUMBER

The Reynolds numbers chosen for the CFD analysis in this case study are 1, 10, 50, 80, 5×10^2, 10^3, 10^4, 5×10^4, 10^5 and 10^6 .The range of Reynolds number chosen is much wider than that specified in BS 1042.This has been intentionally done in order analyze the performance characteristics of the conical orifice plate outside the range specified by BS 1042.For this analysis, the parameters chosen are D =100mm, β = 0.3 and thickness T = 7mm.

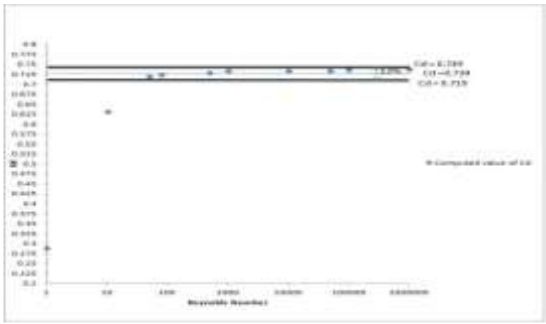

Fig 4.4: Effect of Variation in Reynolds Number on C_d for Conical Entrance orifice plate (D = 100mm, $\beta = 0.3$, t =7mm, Smooth walls)

Table.4.2 Effect of Variation in Reynolds Number on performance characteristic of a conical entrance orifice plate (D = 100mm, β=0.3 , t = 7mm, Smooth walls)

R_e	C_d (Computed)	Pressure loss coefficient (Computed)	Pressure loss coefficient for standard orifice meter (ISO 5167)	Permanent Pressure loss coefficient
1	0.289	0.9985	0.9501	0.9731
10	0.6325	0.9652	0.891	0.8816
50	0.7208	0.9321	0.8711	0.8751
80	0.7242	0.9003	0.8772	0.8731
500	0.7288	0.9029	0.8701	0.8728
1000	0.7346	0.8916	0.8759	0.8754
10000	0.7349	0.8788	0.8754	0.8734
50000	0.7351	0.8783	0.8754	0.8735
100000	0.7367	0.8782	0.8751	0.8738
1000000	0.7377	0.8765	0.8758	0.8733

Fig (4.4) shows the Effect of Variation in Reynolds number on Cd. The computed values of discharge coefficient and pressure loss coefficient at β =0.3 are tabulated in the Table 4.2.It is observed that for Reynolds number 1 and 10, the values of discharge coefficient are 0.289 and 0.6325 respectively and which are not in the range of 0.734 2% as specified by BS 1042.For Reynolds number 50 to 106 ,the values of discharge coefficients are within the range of 0.734 2% as specified by BS 1042.In laminar regime, the coefficient of discharge is increasing monotonically and in turbulent regime the Cd values are increasing marginally with increasing Reynolds number, but the variation is within the specified uncertainty. In Table 4.2, the computed values of pressure loss coefficient (ζ) at various Reynolds numbers are also tabulated. These are compared with the values obtained using the formula given ISO 5167.It is to be noted that, this formula is applicable to standard orifice plate assembly only. It is observed from the tabulated values that, the two sets of values are not in agreement in laminar region. But in the turbulent region, the two sets of values are in reasonably good agreement. Hence, it can be concluded that the formula given in ISO 5167 for standard plate assembly can be used for conical orifice plate assembly for the purpose of calculating pressure loss coefficient at higher Reynolds number. The computed values of permanent pressure loss coefficients are also tabulated in Table 4.2 for different Reynolds number. It is observed that the values of ζpm are always lower than those of ζ. This is due to the pressure recovery that occurs after the passage through the orifice. However, the computed values of ζpm are in reasonable agreement with the values of ζ from equation given in ISO 5167.

Fig (4.5) shows the velocity contour for Re1.the changes in the velocity are observed in these contours clearly. In the plot it is clearly observed that, in the downstream of the orifice plate, for sufficiently long distance the jet coming out from the orifice plate travels without too much expansion. Hence a long pipe line length would be required for the velocity profile to become fully developed.

Fig (4.6) shows the velocity vector plot for Re 1. The separated regions and the zones of recirculation are clearly visible in the plot. The recirculation zones extend to fairly a large distances downstream of the orifice plate.

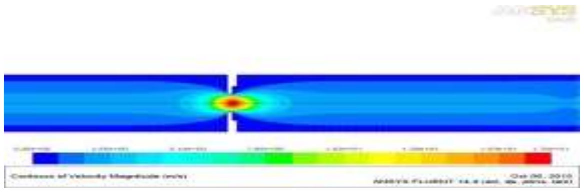

Fig 4.5: Velocity contour for the Conical Entrance orifice plate (D = 100mm, β = 0.3, t = 7mm, Re=1)

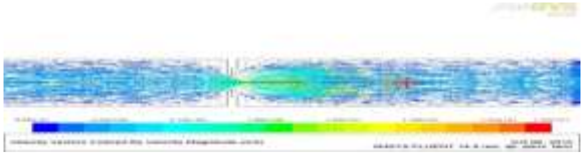

Fig 4.6: Velocity vector for the Conical Entrance orifice plate (D = 100mm, β = 0.3, t = 7mm, Re=1)

EFFECT OF VARIATION IN PIPE DIAMETER

Pipe diameter is an important factor in the fluid flow analysis. According to BS-1042 code, pipe diameter for conical entrance orifice meter should be less than 600mm (D < 600). Conical orifice plate diameter should be greater than 6mm (d > 6mm). In this case study, we are interested to find out, how the pipe diameter variations affect the Coefficient of Discharge. Pipe Diameters taken for the analysis are 10mm, 15mm, 20mm, 25mm, 50mm, 100mm and 300mm.Upto 100 mm pipe diameter the thickness of the plate is taken as 5mm.For 300mm the thickness of the plate is taken as 15mm. For 10mm and 15mm pipe diameters, the orifice diameters are properly chosen. However, the other dimensions of the orifice plate are calculated for the minimum allowable orifice diameter of 6mm.This is done to ensure structural rigidity of the orifice plate. Diameter ratio is taken as 0.3 and the flow is analyzed for the Reynolds numbers 500 and 50000

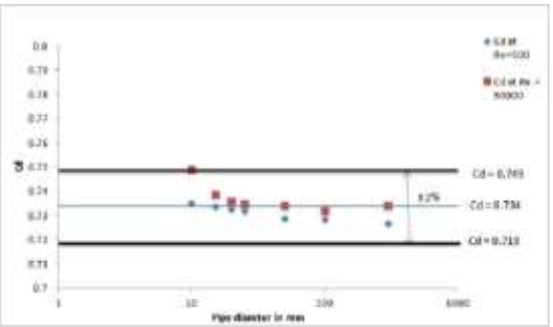

Fig.4.7 Effect of variation in Pipe Diameter on C_d for conical entrance orifice meter (β=0.3, t = 5.15mm, Smooth wall)

Table.4.4 Effect of Variation in Pipe Diameter (β=0.3, t = 5.15mm, Smooth wall)

Pipe Dia	Re	C_d (Computed)	Computed value of Pressure loss coefficient (ζ)	Pressure loss coefficient for standard orifice meter (ISO 5167)	Permanent Pressure loss coefficient (ζpm)
10	500	0.7352	0.9821	0.8755	0.8759
	50000	0.7491	0.9728	0.8595	0.8595
15	500	0.7339	0.9723	0.8756	0.869
	50000	0.7388	0.9252	0.8748	0.8741
20	500	0.7331	0.964	0.8757	0.8385
	50000	0.7361	0.9098	0.8753	0.8758
25	500	0.7323	0.9571	0.8758	0.8442
	50000	0.7351	0.8201	0.8754	0.8736
50	500	0.7291	0.9392	0.8747	0.8747
	50000	0.7342	0.8121	0.8743	0.8743
100	500	0.7288	0.9029	0.871	0.8728
	50000	0.7321	0.8178	0.8754	0.8735
300	500	0.7269	0.8803	0.8767	0.8753
	50000	0.7343	0.8574	0.8751	0.8771

Fig (4.7) shows the Effect of Variation in Reynolds number on Cd The computed values of discharge coefficients and pressure loss coefficient at Re = 500, 50000 are also tabulated in Table 4.4.It is observed that at both Reynolds numbers, in the range of the pipe diameters 10 to 300mm, the values of discharge coefficient are within the range of 0.734 2% as specified by BS 1042.However value of Cd marginally decreases with increasing pipe diameters. The computed values of pressure loss coefficient (ζ) at various pipe diameters are also tabulated. These are compared with the values obtained using the formula given ISO 5167) It is to be noted that, this formula is applicable to standard orifice plate assembly only. It is observed from the tabulated values that, the two sets of values are not in agreement for all pipe diameters. Hence it can be concluded that the formula given in ISO 5167 for standard plate assembly cannot be used for conical plate assembly for the purpose of calculating pressure loss coefficient for different pipe diameters. The computed values of permanent pressure loss coefficients are also tabulated in Table 4.4 for different pipe diameters. It is observed that the values of ζpm are always lower than those of ζ. This is due to the pressure recovery that occurs after the passage through the orifice. It is also observed from the Table 4.4 there is no significant pressure recovery as the pipe diameter increases. However, the computed values of ζpmare in reasonable agreement with the values of ζ from equation given in ISO 5167.

Fig (4.7) shows the velocity contour for pipe diameter 20.the changes in the velocity are observed in these contours clearly. In the plot it is clearly observed that, in the downstream of the orifice plate, for sufficiently long distance the jet coming out from the orifice plate travels without too much expansion. Hence a long pipe line length would be required for the velocity profile to become fully developed.

Fig (4.9) shows the velocity vector plot for pipe diameter 20. The separated regions and the zones of recirculation are clearly visible in the plot. The velocity magnitudes are large in the jet region but in the re circulatory zone it is very small.

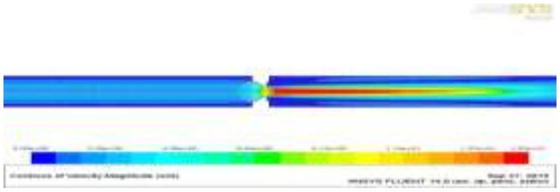

Fig 4.8: Velocity Contours for the Conical Entrance orifice plate (Re=500,β=0.3,t=5mm,Pipe diameter =20 mm)

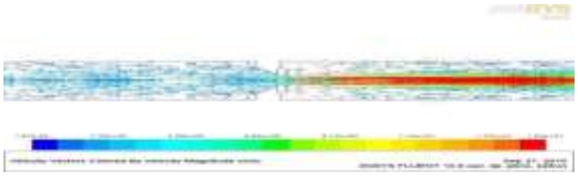

Fig 4.9: Velocity Vectors for the Conical Entrance orifice plate (Re=500,β=0.3,t=5mm,Pipe diameter =20 mm)

CONCLUSIONS

1. The CFD methodology developed gives accurate analysis of flow through orifice plate assemblies as long as certain precautions on the fineness of the mesh are followed. K-ω SST model is the most appropriate model for this class of flows.
2. The diameter ratios cannot be taken beyond the limits mentioned in BS 1042 ($0.1<\beta<0.316$), because the values of discharge coefficient obtained beyond this limit are in variance with the standard values. As diameter ratio increases the values of discharge coefficients also increase.
3. The present study has shown that if Reynolds number below 50 then the discharge coefficient reduces substantially. As per BS 1042 this limit is Re =80.As per BS 1042 the Reynolds number has to be below 80000.However, the present study has shown that up to $Re=10^6$, the discharge coefficient is still within the specified limit.
4. A plate thickness of larger than 0.1D cannot be used in turbulent regimes, since it is giving discharge coefficient value, which is higher than the value specified in BS 1042.
5. For conical entrance orifice meter, minimum pipe diameter can be taken as 10mm with certain assumptions and considerations.
6. Roughness of pipe has no significant effect on the Discharge coefficients of conical entrance orifice meter.
7. The present study can be extended to include eccentric orifices, compressibility effects, non Newtonian flows etc.

REFERENCES

1. M. M. Rahman, R. Biswas &W. I.Mahfuz, "Effects of Beta Ratio and Reynolds's Number on Coefficient of Discharge of Orifice Meter"**,** ISSN 1810-1860, J Agric. Rural Dev.vol **7**(1&2), pp 151-156, June 2009.
2. R.K.Singh, S.N.Singh and V.Seshadri, "Performance evaluation of orifice plate assembly under non-standard conditions using CFD". IJEMS (International Journal of Engineering and Material Science), vol 17, pp 397-406, December2010.
3. H.J.Imada F. Saltara J. L. Balino "Numerical determination of discharge coefficients of Orifice plates and nozzles", ISSN 2176-5480, 2013.
4. Tural Tunay, Besir Sahini and Ali Kahraman," Effects of the Boundary Conditions on the Numerical Solution of the Orifice Flow" Cukurova University Journal of the Faculty of Engineering and Architectecture, 26(2), pp 105-117, December 2011.
5. Arun Naveenji, Sankara Subramanian Malavarayan , M Kaushik, "CFD analysis on discharge coefficient during non-Newtonian flows through orifice meter", International Journal of Engineering science and Technology 01/2010.
6. Stephen T. (Steve) Stark, Stark and Associates, Inc.11101, South Harvard Ave.Tulsa, Oklahoma City, USA, "Measuring high viscosity liquids with quadrant edged orifice meters".
7. Karthik G.S, Yogesh kumar K.J, V.Seshadri, **"**Prediction of performance characteristics of Orifice plate assembly for non standard conditions using CFD". International Journal of Engineering and Technical Research (IJETR) ISSN: 2321-0869, Volume-3, Issue-5, May 2015.
8. Karthik G S, " Analysis of Flow through Standard and Quadrant Edged Orifice meters using CFD", M Tech Thesis, MIT Mysore, Vishveshwaiah Technical University,2015
9. Y.S. Ho and T.P. Leung, **"**Performance of conical entrance orifice plates at low Reynolds numbers**"** International Journal of Heat and Fluid flow , 06/1985; 6(2) 122-125.1985.
10. Y.S.Ho and F Abdullah, "Modeling the Conical Entrance Orifice Plate Flow Sensor". 08/1995; 17(3); 155-160.1995.
11. Mara Nilza StanislausReis. "Experimental study and numerical drain with low Reynolds on board the hole of cone entry". Proceedings of the 11th Brazilian Congress of Thermal Sciences and Engineering -- ENCIT 2006.Braz. Soc. of Mechanical Sciences and Engineering -- ABCM, Curitiba, Brazil, Dec. 5-8, 2006
12. Orifices by W H Howe (1969), J B Arant (1982), B G Liptak (1993) reviewed by S Rudback (1993).
13. Indian Standard IS-14615 (Part 1):1999 ISO 5167-1:1991 "Measurement of Fluid Flow by Means of Pressure Differential Devices".
14. British Standards BS 1042(Part 1: Pressure Differential Devices) "Measurement of Fluid Flow in Closed Conduits".
15. Fluid Mechanics by R.K.Bansal, Laxmi publications 2015,9th edition.
16. Engineering Fluid Mechanics by K.N. Seetharamu and P.A. Aswath Narayan, Narosa Publication 2005, Reprint 2012.
17. ANSYS Fluent User's Guide. Release 15.0.ANSYS Inc. November 2013.South pointe.275 Technology Drive.