Effect of Beta-Ratio in Multiple Restricted Orifice in Flow Through Pipes

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Abstract— Multi-stage orifice assemblies are used in many industrial processes as pressure reduction devices. Performance characteristics of orifice plates for variation in different geometrical parameters are examined with the help of computational fluid dynamics (CFD). In the present study, a CFD methodology using ANSYS, Fluent 19.1 software has been used for analyzing flow through multiple orifice plate assemblies. A parametric study is conducted for flow analysis through threefold orifice plate assemblies with diameter ratio (β = 0.5, 0.65, 0.7) in a pipe of 3, 4 and 5 inch diameter. It is found that a spacing between inlet to orifice and orifice to orifice is kept as 5D. The value of Coefficient of Discharge depends on the type of flow, pressure tapping's, contour of the obstruction. The results and outcomes of the study are obtainable with velocity and pressure contours. The pressure drop and the velocity of flow along the pipe is studied.

Keywords: CFD, Coefficient of discharge (C_d), Threefold orifice plate, Beta ratio, Fluent 19.1

I. Introduction

Flow measurement is important part in many industries today. Flow can be measured with the help of velocity of the fluid over a known area. Flow measuring devices are Venturi meter, Orifice Plate, Pitot tube, Flow Nozzles, Weirs etc. Out of these orifice meters is having least coefficient of discharge. The performance of orifice meter can be improved by changing shape of plate.

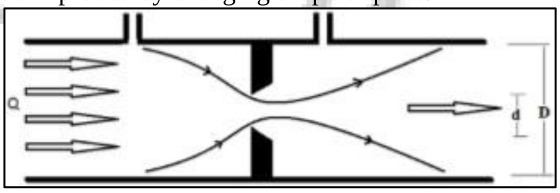

Fig. 1: Orifice Meter

An orifice plate is a plate with a hole in it which is used to measure the flow rate of flowing fluid.

When the fluid passes through the orifice the pressure increases at the upstream of the orifice and the fluid is forced to pass through the hole. Due to obstruction, the velocity increases and the pressure decreases. At downstream, flow reaches at point where velocity is maximum and pressure is minimum and this section is known as vena contract.

G. S. Karthik et al. did the analysis on standard sharp edge orifice meter for different plate thicknesses in a pipe of 50 mm diameter and the effect of pipe diameter on coefficient of discharge has been analyzed. From the work it has been shown that if the pipe diameter is decreased below 50 mm the value of Cd increases.

Yogesh Kumar et al. did the analysis on standard sharp edge orifice meter for different plate thicknesses (3 mm, 5 mm, 10 mm and 15 mm) in a pipe of 50 mm diameter and the effect of pipe diameter on coefficient of discharge has been analyzed. The rate of coefficient of discharge depends on the type of flow, pressure tapping's, contour of the obstruction and it is a function of Reynolds number.

Mohamed A. Siba et al. studied the solution of unsteady and incompressible fluid was sought using a circular orifice as a function of three aspect ratios of 0.2, 0.4, and 0.6 taken at Reynolds number of 10000, 20000, and 30000. The study includes the velocity profile, the differential pressure, and the mechanical properties.

T. Sridevi et al. Flow analysis has been done on different types of flow meter using FLUENT solver and provision of track vena contracta has been explained.

F. Saltara et al. evaluate the coefficient of discharge of orifice plate and long radius nozzles with diameters ratio 0:50 in the Reynolds range 15,000-5,00,000. using finite- volume based commercial code FLUENT. Incompressible steady-state examines are conducted in three-dimensional domains discretized with unstructured meshes.

II. Geometric Modeling:

The geometry of the orifice plates are created by using ANSYS Workbench. The analysis of flow is conducted for threefold orifice plate assemblies with diameter ratio 0.5, 0.65 and 0.7 in a pipe of 3, 4 and 5 inch diameter. The distance between inlet of the pipe and the orifice is known as upstream length and the distance between outlet of the pipe and the orifice is known as downstream length .It is found that the spacing between inlet to the orifice, orifice to orifice, & outlet to orifice is kept as 5D.Where D is the diameter of the pipe.

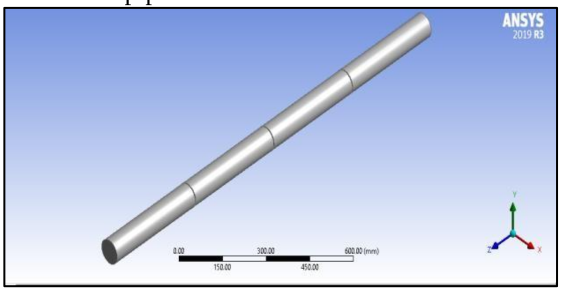

Fig. 2: Geometrical modeling of orifice pipe

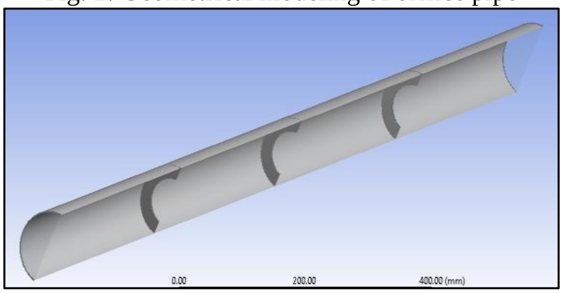

Fig. 3: Threefold orifice plate assemblies.

III. MESHING

The meshing of the pipe is done to know the how much pressure of the material is acting on each element of the pipe. The type of mesh, size of mesh & its quality affects the accuracy of results. The tetrahedral elements used for meshing. All the orifice plates surfaces and the surface of the pipe are meshed by using tetrahedral mesh. The total number of elements were 3,60,000 and total nodes were 68,152.

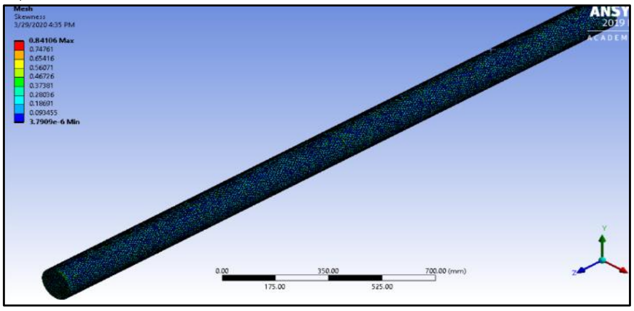

Fig. 4: Meshing of pipe

IV. BOUNDARY CONDITION:

The boundary conditions are the important values for the mathematical model. The boundary condition is applied to different zones. There are different types of boundary conditions for the fluid flow to enter and exit the domain. The boundary condition is depending upon the type of fluid use for the analysis. The fluid used for this analysis is incompressible hence velocity inlet condition applies. Inlet velocity profile was assumed, slip condition is allotted to all surfaces. The boundary conditions used for the analysis are listed in table 1.

SL,NO	Quantities	Condition
1	Working fluid	Water
2	Gauge pressure	Zero Pascal
3	Inlet velocity profile	2 m/s
4	Slip	No slip

Table 1: Boundary conditions.

V. ANALYSIS OF FLOW THROUGH THREEFOLD ORIFICE PLATE ASSEMBLY:

The major objective of the study is to analyze the flow through multi-stage orifice plate assembly using CFD. The analysis of flow is done for the 3, 4, & 5 inch pipe having diameter ratio 0.5, 0.65 and 0.7 for this velocity profile and pressure drop along the pipe is studied.

Beta Ratio	Diameter of pipe (1 inch=25.4mm)	Diameter of orifice	Spacing 5D	Total length of pipe
0.5	3 inch	38.1mm	381mm	1524mm
0.5	4 inch	50.8mm	508mm	2032mm
0.5	5 inch	63.5mm	635mm	2540mm
0.65	3 inch	49.53mm	381mm	1524mm
0.65	4 inch	66.04mm	508mm	2032mm
0.65	5 inch	82.55mm	635mm	2540mm
0.7	3 inch	53.34mm	381mm	1524mm
0.7	4 inch	71.12mm	508mm	2032mm
0.7	5 inch	88.9mm	635mm	2540mm

Table 2: These are the following dimension used for the analysis of flow

The meshing gave a total of 3, 60,000 that consisted of Tetrahedral. The working fluid is water. Static pressure is allotted to the outlet pipe in order to obtain relative pressure drop between inlet and outlet. The inlet velocity profile is assumed to be uniform and set to subsonic flow of 2 m/s. The pipe is modeled as solid wall with no slip condition. The numerical correctness was set to first order. All the discretized equations were solved in a separate manner with the SIMPLE (Semi Implicit Pressure Linked Equation) algorithm.

VI. RESULTS & DISCUSSION

At the initial length of the pipe there is developing of flow take place, means the boundary layer is getting developed. The initial velocity of flow is equal to the velocity which we have provided in boundary condition i.e. 2 m/s. As we move along the pipe there will be formation of fully developed flow and the shaded part indicates the variation of velocity as shown in the fig (5, 7, and 9). The red color indicates the maximum velocity of flow which is at the center of the pipe. Blue color indicates the minimum velocity of flow i.e 0m/s which is near the wall of pipe.

A. *Analysis of flow in 3 inch pipe for different beta ratio:*

– FOR BETA RATIO 0.5:

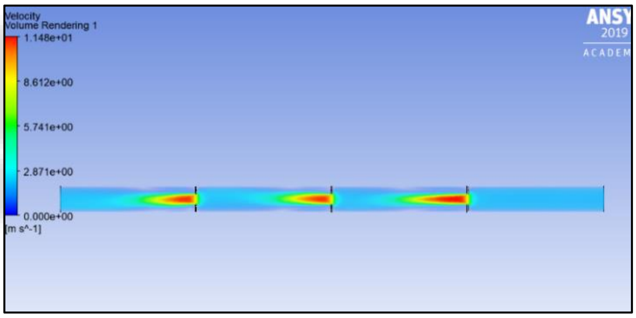

Fig. 5: Velocity contour; Max value: 11.48m/s; Min value: 0m/s

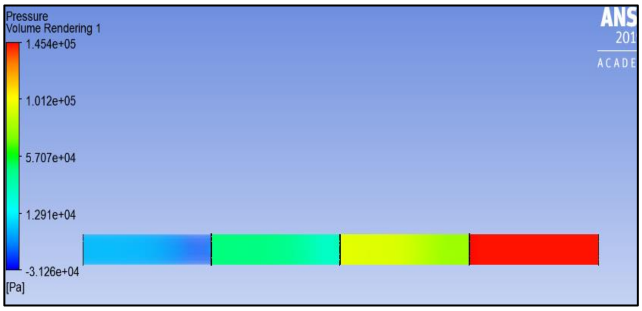

Fig. 6: Pressure contour; Max value: 1.454e+05pa; Min value: -3.126e+04pa

– FOR BETA RATIO 0.65:

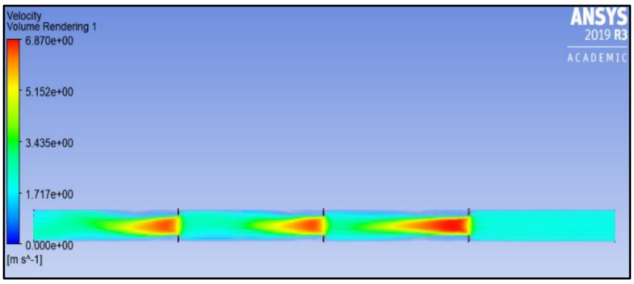

Fig. 7: Velocity contour; Max value: 6.870 m/s; Min value: 0m/s

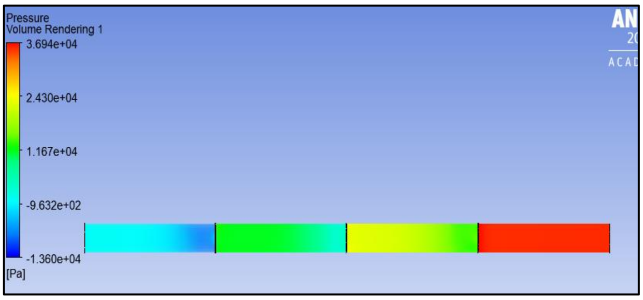

Fig. 8: Pressure contour; Max value: 3.694e+04pa; Min value: -1.360e+04pa

– FOR BETA RATIO 0.7:

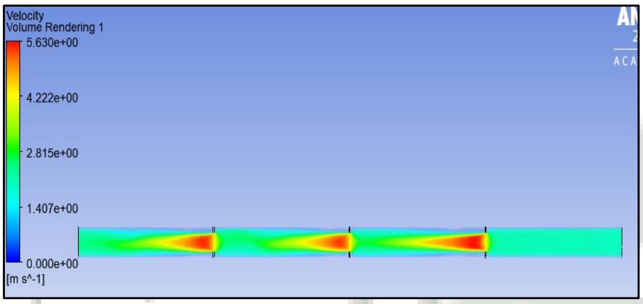

Fig. 9: Velocity contour; Max value: 5.63m/s; Min value: 0m/s

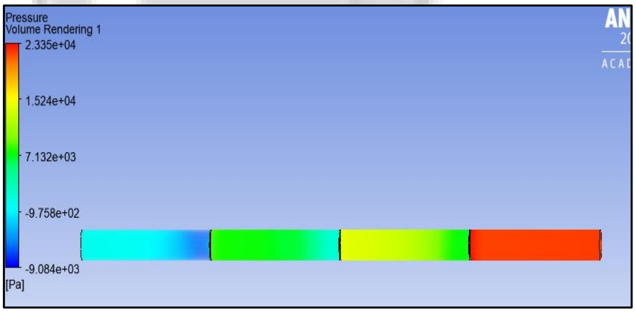

Fig. 10: Pressure contour; Max value: 2.335e+04pa; Min value: 9.084e+03pa

B. Analysis of Flow In 4 Inch Pipe for Different Beta Ratio:

– FOR BETA RATIO 0.5:

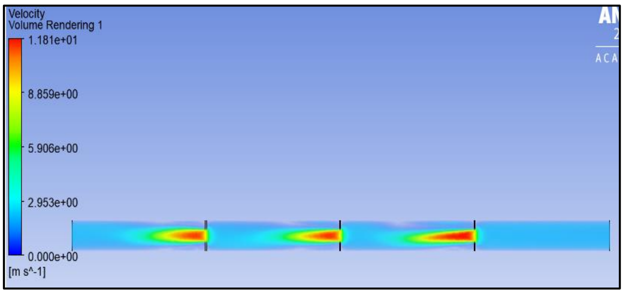

Fig. 11: Velocity Contour; Max Value: 11.8m/s; Min value: 0m/s

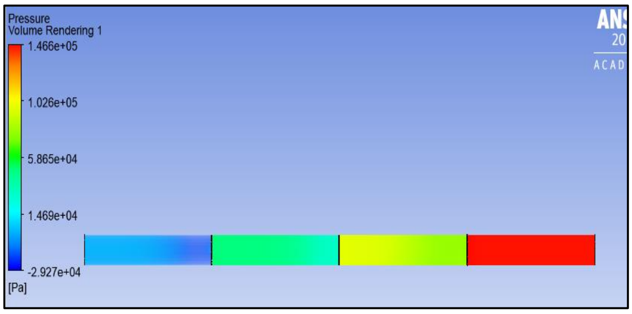

Fig. 12: Pressure contour; Max value: 1.466e+04pa; Min value: -2.927e+04pa

– FOR BETA RATIO 0.65:

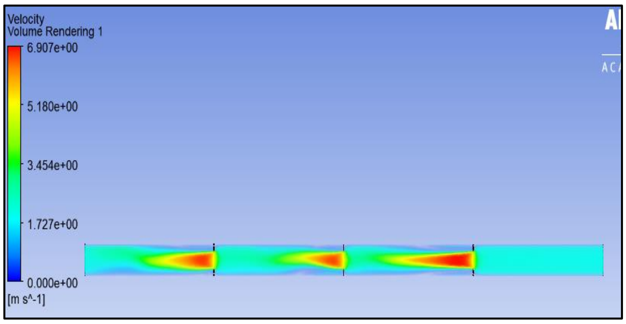

Fig.13 Velocity contour; Max value: 6.907m/s; Min value: 0m/s

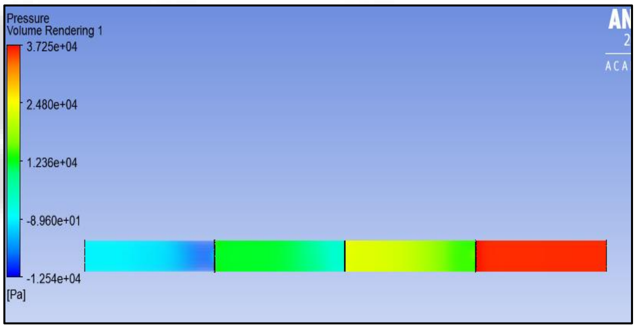

Fig.14 Pressure contour; Max value: 3.725e+04pa; Min value: -1.254e+01pa.

– FOR BETA RATIO 0.7:

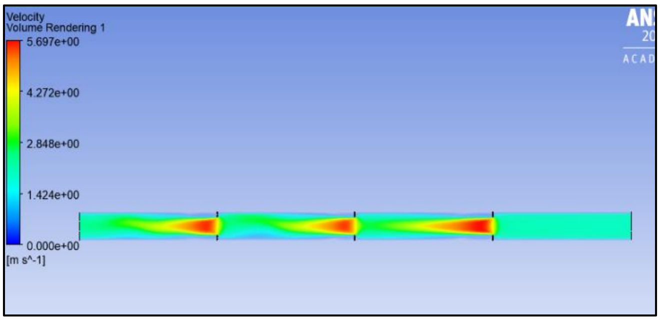

Fig. 15: Velocity contour; Max value: 5.697m/s; Min value: 0m/s

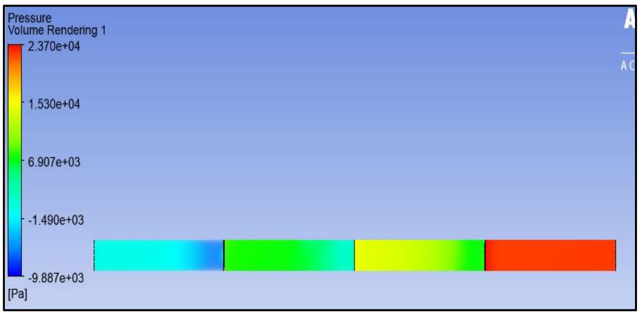

Fig. 16: Pressure contour; Max value: 2.37e+04pa; Min value: -9.887e+03pa

C. Analysis of Flow in 5 Inch Pipe for Different Beta Ratio:

– FOR BETA RATIO 0.5:

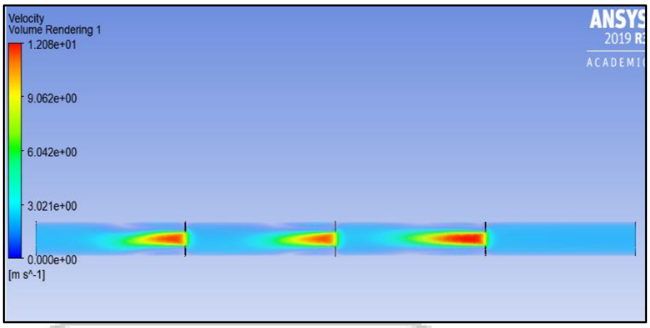

Fig. 17: Velocity contour; Max value:12.08m/s; Min value:0m/s

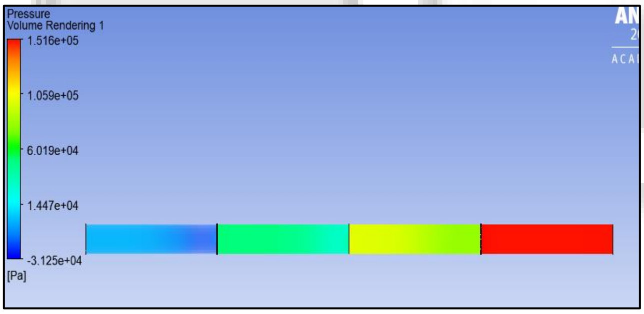

Fig. 18: Pressure contour; Max value: 1.516e+05pa; Min value:-3.125e+04pa

– FOR BETA RATIO 0.65:

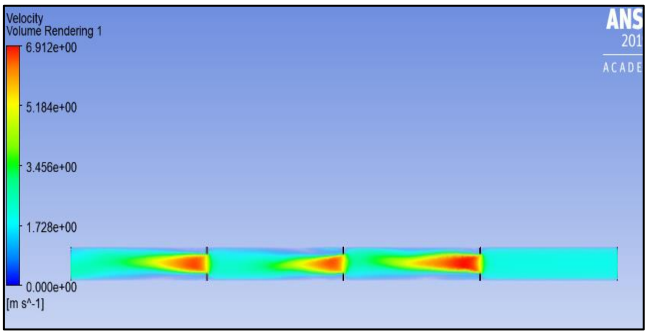

Fig. 19: Velocity contour; Max value: 6.912m/s; Min value: 0m/s

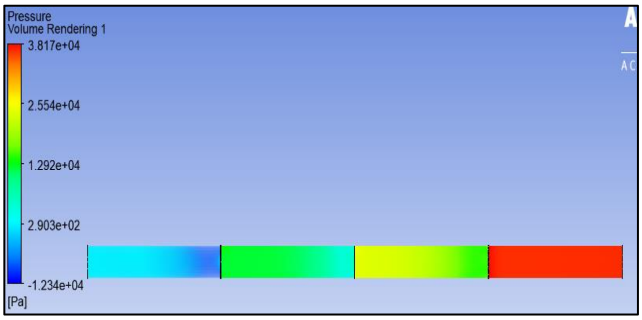

Fig. 20: Pressure contour; Max value: 3.817e+04pa; Min value: -1.234e+04pa

– FOR BETA RATIO 0.7:

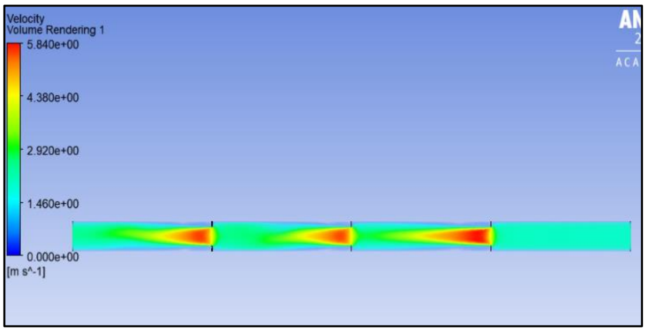

Fig. 21: Velocity contour; Max value: 5.840m/s; Min value: 0m/s

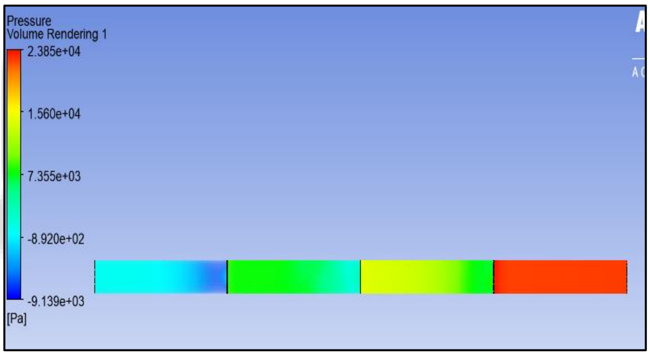

Fig. 22: Pressure contour; Max value: 2.385e+04pa; Min value: -9.139e+03pa

The strong velocity gradient close to the wall because of the no-slip condition is observed. This region is frequently very thin, and it is then called a boundary layer. Fig 6,8,10 shows the cross section of pressure contour plots for 3, 4, & 5 inch pipe for different beta ratio along the length. From pressure contour, pressure distribution in various regions can be seen. Pressure is maximum at inlet of pipe. Due to contraction and expansion of area in the orifice plate region, the pressure decreases and then gradually increases. So, it can be seen that there is difference in pressure between inlet & outlet of pipe because some pressure losses in sections.

VII. PRESSURE DROP:

A. For 3 Inch Pipe:

– FOR BETA RATIO 0.5:

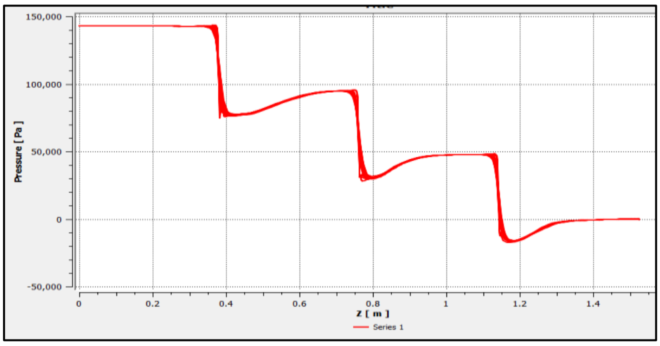

Fig. 23: Centerline pressure profile for beta ratio 0.5

– FOR BETA RATIO 0.65:

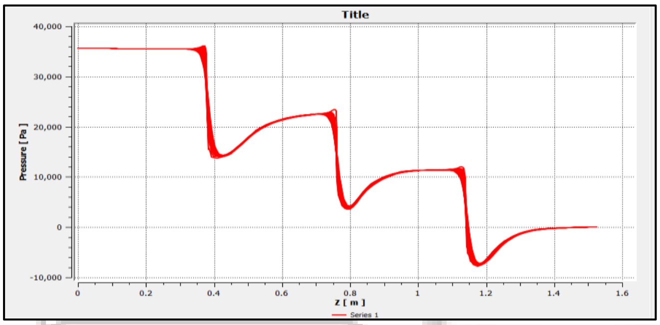

Fig. 24: Centerline pressure profile for beta ratio 0.65

– FOR BETA RATIO 0.7:

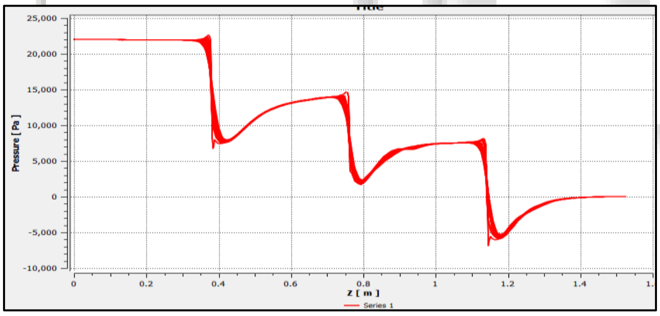

Fig. 25: Centerline pressure profile for beta ratio 0.7

B. For 4 Inch Pipe:

– FOR BETA RATIO 0.5:

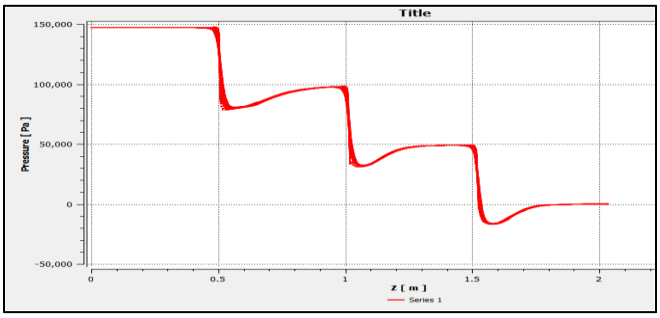

Fig. 26: Centerline pressure profile for beta ratio 0.5

– FOR BETA RATIO 0.65:

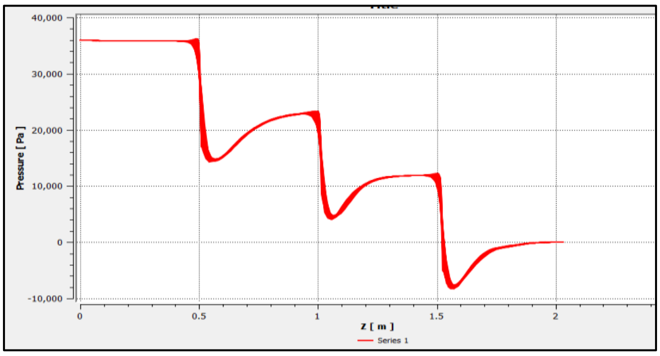

Fig. 27: Centerline pressure profile for beta ratio 0.65

– FOR BETA RATIO 0.7:

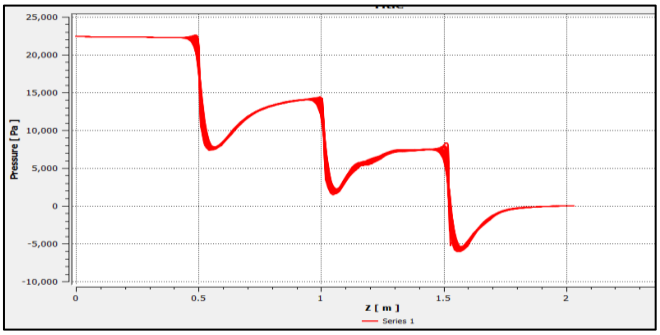

Fig. 28: Centerline pressure profile for beta ratio 0.7

C. For 5 Inch Pipe:

– FOR BETA RATIO 0.5:

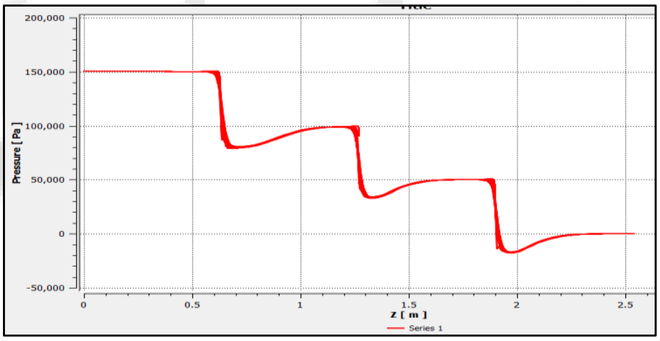

Fig. 29: Centerline pressure profile for beta ratio 0.5

– FOR BETA RATIO 0.65:

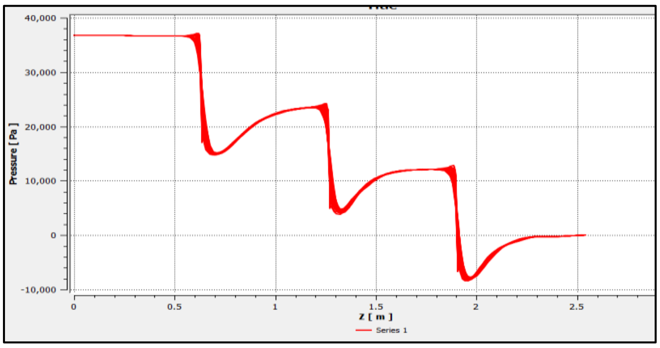

Fig. 30: Centerline pressure profile for beta ratio 0.65

– FOR BETA RATIO 0.7:

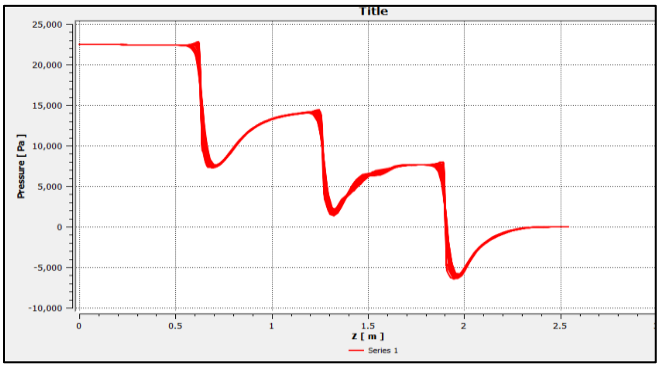

Fig. 31: Centerline pressure profile for beta ratio 0.7

Fig 23, 24, 25, 26, 27, 28, 29, 30 and 31 shows the pressure drop along the length of the pipe for beta ratio 0.5, 0.65 and 0.7. Initially at the inlet the pressure is maximum as the flow move along the pipe and approaches orifice the pressure decreases and reaches to the minimum at vena-contracta and starts recovering as the flow moves further downstream.

VIII. Conclusion

- The flow field characteristics in three-stage orifice system have been numerically investigated by considering the effects of flow inlet velocity, orifice geometry, orifice spacing on velocity and pressure distribution.
- The inlet flow velocity considered are 2m/s, orifice diameter ratio of (0.5, 0.65 ,0.7)
- The flow characteristics downstream of the threefold orifice arrangement is qualitatively similar to that downstream a single orifice of the same size in terms of the existence recirculation zone, reattachment zone and shear layer region.
- Some important differences in the flow structure are identified upstream of the third orifice in the threefold-orifice configurations which has a jet-like flow in the core region surrounded by donut-shaped vertical flow in the wall region influencing the downstream velocity field and pressure recovery region.
- The 5 inch triple orifice of 0.5 beta ratio arrangement pipe produce a peak velocity that is slightly higher than 3 and 4 inch pipe.
- The pressure distribution profiles across the three configurations are similar but the highest pressure drop was recorded in the 5 inch triple orifice pipe of 0.65 beta ratio and least pressure drop was recorded in the 4 inch pipe of beta ratio 0.7.

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