Energy Loss Analysis of 3D Asymmetric Trifurcations Using CFD

Nagappa Pattanashetti[1], Manjunatha S.S[2]

[1]M.Tech Student- Department of Mechanical Engineering, Government Engineering College, Devagiri, Haveri – 581110, Karnataka, India. Mobile: +91 98 80 112696
nageshpattanshetty55@gmail.com
[2]HOD- Department of Mechanical Engineering, Government Engineering College, Devagiri, Haveri – 581110, Karnataka, India.
ssmbdt@gmail.com

Abstract— *Head losses are very common in penstock trifurcations. In this paper, six cases of 3D asymmetric trifurcations have been modeled with main pipe length & diameter of 1.3716m & 0.0254m, respectively and branch pipe lengths & diameters of 0.762m & 0.0196m, respectively. Volumetric flow rates, velocity magnitudes, dynamic and total pressure contours and their values have been computed. Energy loss coefficients have been computed for branch pipes for an input air velocity of 3m/s by pressure data obtained from the CFD analysis. The maximum values of velocity magnitude, dynamic and total pressures are observed in the branch-2 and head losses in branch-2 are relatively less.*

Keywords— Head losses, Energy loss coefficients, 3D asymmetric trifurcations.

I. INTRODUCTION

In penstocks used for hydropower projects, trifurcations along with the other components, help in producing electricity. These trifurcations supplement water supply to multiple turbines at the same time. Despite having the economical advantage over independent systems, even this system is not free from losses. The comparison of velocity magnitudes, dynamic and total pressure contours and determination of head loss coefficients in the branch pipes sums up the interest of this study.

II. DOMAIN

A total of six cases have been modeled using Gambit 2.4.6, with each model displaying an asymmetry about the central branch axis. The dimensions used for the six cases in the current analysis are shown in the table 1.

TABLE 1
DIMENSIONS OF ASYMMETRIC TRIFURCATIONS

Dimensions	In Meter
Length of Main Pipe (L)	1.3716
Diameter of Main Pipe (D)	0.0254
Lengths of branch pipes (l_1, l_2, l_3)	0.762
Diameters of branch pipes (d_1, d_2, d_3)	0.0196

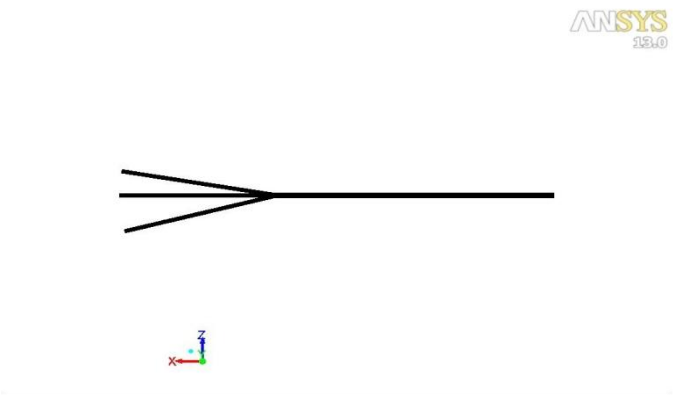
The angle between the branch-2 and branch-1 is termed "α" and the angle between the branch-2 and branch-3 is termed "β". The angles used for the six cases are shown in the table 2.

TABLE 2
ANGLES "α" AND "β" FOR THE SIX CASES

Case No.	1	2	3	4	5	6
Angle "α" in Degrees	5	10	15	10	15	20
Angle "β" in Degrees	10	15	20	5	10	15

A model created using Gambit for the case 2 of this study is shown in figure 1.

Mesh of T-Grid type using Tet/Hybrid elements was generated for all the six cases in Gambit. A typical mesh generated for the case 3 of this study is shown in figure 2



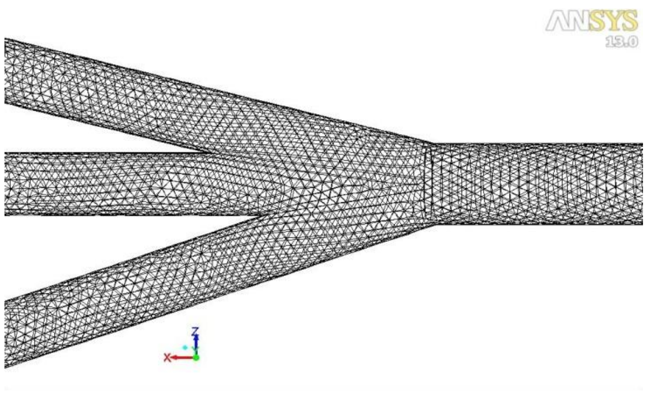


FIG. 1: GAMBIT MODEL OF TRIFURCATION **FIG. 2: MESHED TRIFURCATION**

The mesh sizes for all the cases are enlisted in table 3.

TABLE 3
MESH SIZES FOR THE SIX CASES

Case No.	Mesh Size		
	Cells	Faces	Nodes
1	469301	978796	99471
2	320336	674755	71535
3	320336	674755	71535
4	316436	666226	70469
5	321042	676181	71632
6	314140	662439	70526

The boundary conditions for all the six cases were applied as shown in the figure 3 and table 4.

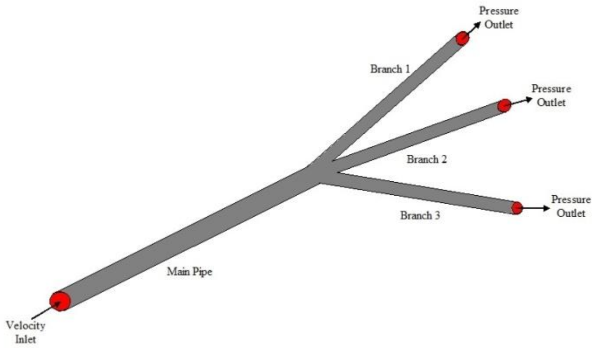


FIG. 3: APPLICATION OF THE BOUNDARY CONDITIONS AT INLETS AND OUTLETS

TABLE 4
BOUNDARY CONDITIONS FOR THE DOMAIN

Pipe	Entity	Boundary Condition Type	Magnitude
Main Pipe	Face	Velocity Inlet	3m/s
Branch Pipe-1	Face	Pressure Outlet	0Pa
Branch Pipe-2	Face	Pressure Outlet	0Pa
Branch Pipe-3	Face	Pressure Outlet	0Pa

Ansys fluent 13.0 was the solver used for the analysis. The details of the fluid properties and solver parameters are given in the tables 5 and 6 respectively.

TABLE 5
FLUID PROPERTIES

Fluid	Fluid Properties	
	Density	Viscosity
Air	1.225kg/m^3	1.7874 × 10^{-5} kg/m-s

TABLE 6
SOLVER PARAMETERS, INITIALISATION AND CALCULATION DETAILS

Pressure-Velocity Coupling	Simple	
Spatial Discretization	Gradient	Least Square Cells Based
	Pressure	Second Order
	Momentum	Second Order Upwind
Solution Initialization	Initialisation Methods	Standard Initialisation
	Reference Frames	Relative to Cell Zone
No. of Iterations	1000	

The analysis has been carried out for the six cases under the following assumptions:

- No slip condition; which means that the relative velocity of the fluid at the solid boundaries is zero.
- The fluid flow is incompressible.
- Air is a Newtonian fluid.
- Steady flow occurs.

III. VOLUMETRIC FLOW RATES, VELOCITIES AND DYNAMIC & TOTAL PRESSURE VALUES

The values of velocity magnitudes, dynamic and total pressures have been obtained for the branched flow as well as inlet for the surface areas of all the six cases from fluent. These values are tabulated in the tables 7-12.

TABLE 7
VOLUMETRIC FLOW RATES, VELOCITY MAGNITUDES, DYNAMIC AND TOTAL PRESSURES FOR CASE 1

Surface Area	Volumetric Flow Rate (m^3/s)	Velocity Magnitude (m/s)	Dynamic Pressure (Pa)	Total Pressure (Pa)
Inlet	1.5 × 10^{-3}	3	5.3621	15.7877
Branch Pipe-1	4.32 × 10^{-4}	1.44	1.4374	1.4466
Branch Pipe-2	6.94 × 10^{-4}	2.32	3.6253	3.6428
Branch Pipe-3	3.82 × 10^{-4}	1.28	1.1392	1.1464

TABLE 8
VOLUMETRIC FLOW RATES, VELOCITY MAGNITUDES, DYNAMIC AND TOTAL PRESSURES FOR CASE 2

Surface Area	Volumetric Flow Rate (m^3/s)	Velocity Magnitude (m/s)	Dynamic Pressure (Pa)	Total Pressure (Pa)
Inlet	1.5 × 10^{-3}	3	5.3892	16.0206
Branch Pipe-1	4.4 × 10^{-4}	1.47	1.4711	1.4851
Branch Pipe-2	7.05 × 10^{-4}	2.36	3.6804	3.7145
Branch Pipe-3	3.61 × 10^{-4}	1.21	1.0035	1.0092

TABLE 9
VOLUMETRIC FLOW RATES, VELOCITY MAGNITUDES, DYNAMIC AND TOTAL PRESSURES FOR CASE 3

Surface Area	Volumetric Flow Rate (m^3/s)	Velocity Magnitude (m/s)	Dynamic Pressure (Pa)	Total Pressure (Pa)
Inlet	1.5 × 10^{-3}	3	5.3957	16.2117
Branch Pipe-1	4.2 × 10^{-4}	1.41	1.3503	1.3603
Branch Pipe-2	7.02 × 10^{-4}	2.35	3.6775	3.7062
Branch Pipe-3	3.84 × 10^{-4}	1.29	1.1277	1.1363

TABLE 10
VOLUMETRIC FLOW RATES, VELOCITY MAGNITUDES, DYNAMIC AND TOTAL PRESSURES FOR CASE 4

Surface Area	Volumetric Flow Rate (m^3/s)	Velocity Magnitude (m/s)	Dynamic Pressure (Pa)	Total Pressure (Pa)
Inlet	1.5×10^{-3}	3	5.3956	15.7296
Branch Pipe-1	3.6×10^{-4}	1.21	1.0018	1.0100
Branch Pipe-2	6.66×10^{-4}	2.23	3.3027	3.3298
Branch Pipe-3	4.8×10^{-4}	1.61	1.7367	1.7520

TABLE 11
VOLUMETRIC FLOW RATES, VELOCITY MAGNITUDES, DYNAMIC AND TOTAL PRESSURES FOR CASE 5

Surface Area	Volumetric Flow Rate (m^3/s)	Velocity Magnitude (m/s)	Dynamic Pressure (Pa)	Total Pressure (Pa)
Inlet	1.5×10^{-3}	3	5.3892	16.0252
Branch Pipe-1	3.84×10^{-4}	1.29	1.1389	1.1488
Branch Pipe-2	6.89×10^{-4}	2.31	3.5319	3.5633
Branch Pipe-3	4.32×10^{-4}	1.45	1.4160	1.4296

TABLE 12
VOLUMETRIC FLOW RATES, VELOCITY MAGNITUDES, DYNAMIC AND TOTAL PRESSURES FOR CASE 6

Surface Area	Volumetric Flow Rate (m^3/s)	Velocity Magnitude (m/s)	Dynamic Pressure (Pa)	Total Pressure (Pa)
Inlet	1.5×10^{-3}	3	5.3890	16.2039
Branch Pipe-1	3.95×10^{-4}	1.33	1.1957	1.2054
Branch Pipe-2	6.86×10^{-4}	2.3	3.4997	3.5283
Branch Pipe-3	4.25×10^{-4}	1.42	1.3707	1.3799

IV. VELOCITY MAGNITUDE CONTOURS

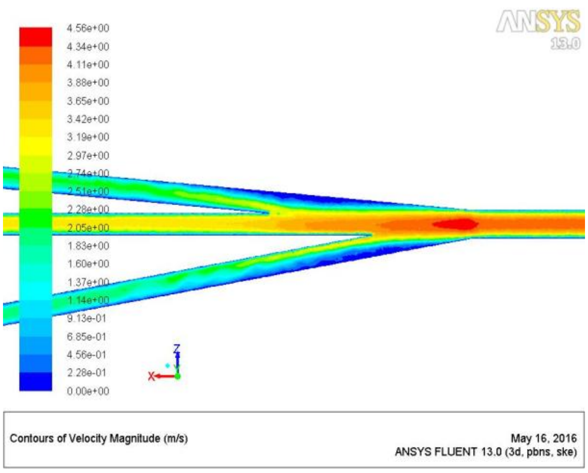


FIG. 4 VELOCITY MAGNITUDE CONTOUR-CASE 1 (m/s)

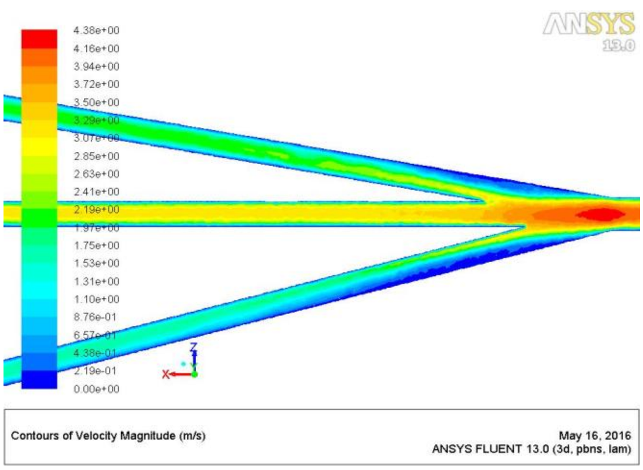


FIG. 5: VELOCITY MAGNITUDE CONTOUR-CASE 2 (m/s)

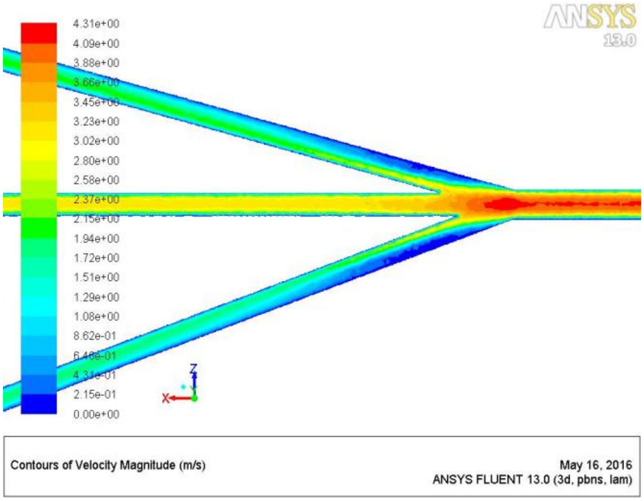


FIG. 6: VELOCITY MAGNITUDE CONTOUR-CASE 3 (m/s)

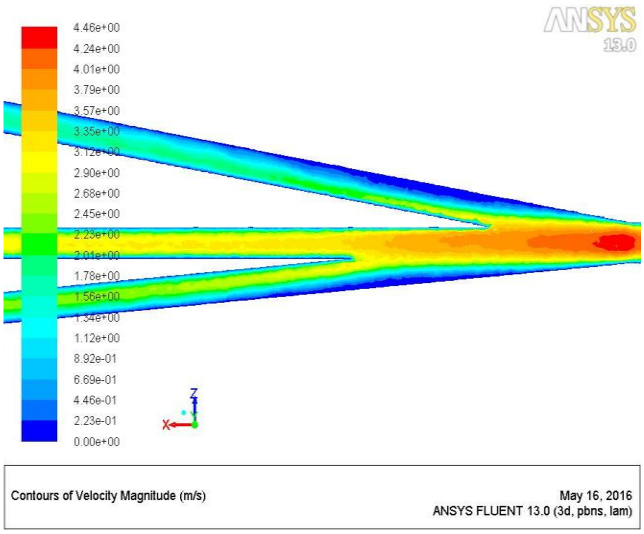


FIG. 7: VELOCITY MAGNITUDE CONTOUR-CASE 4 (m/s)

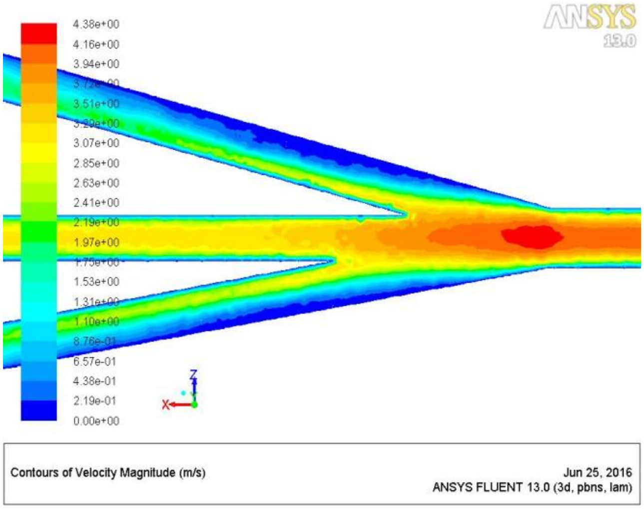


FIG. 8: VELOCITY MAGNITUDE CONTOUR-CASE 5 (m/s)

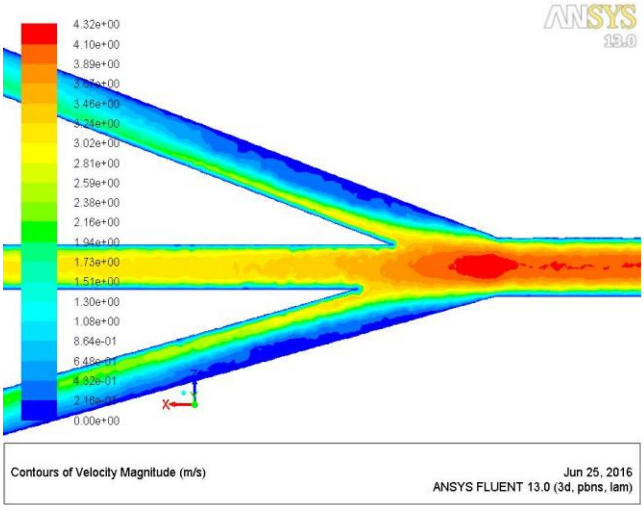


FIG. 9: VELOCITY MAGNITUDE CONTOUR-CASE 6 (m/s)

V. DYNAMIC PRESSURE CONTOURS

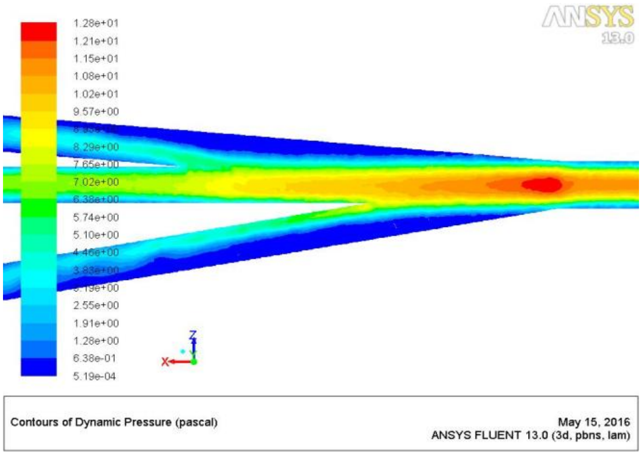


FIG. 10: DYNAMIC PRESSURE CONTOUR-CASE 1 (Pa)

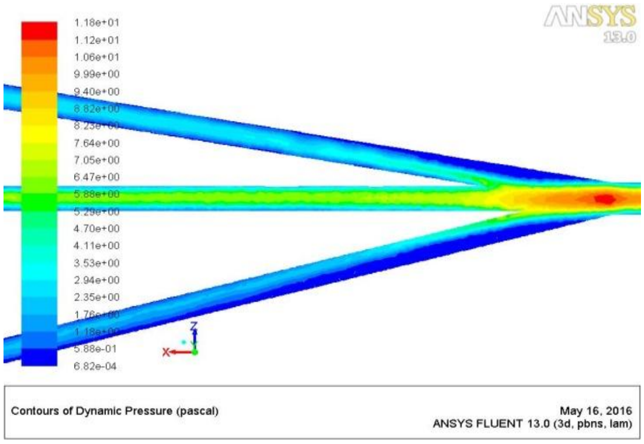


FIG. 11: DYNAMIC PRESSURE CONTOUR-CASE 2 (Pa)

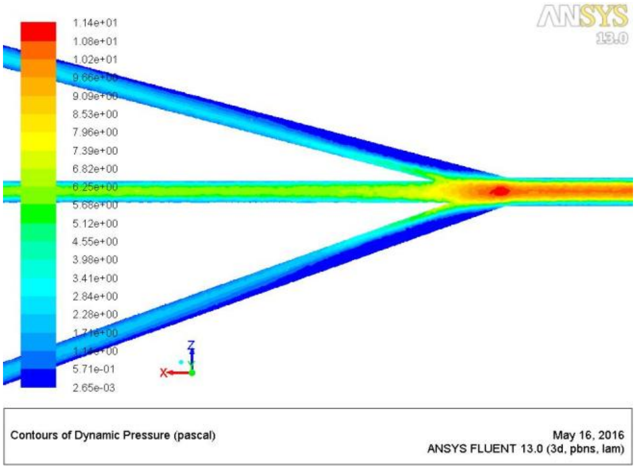


FIG. 12: DYNAMIC PRESSURE CONTOUR-CASE 3 (Pa)

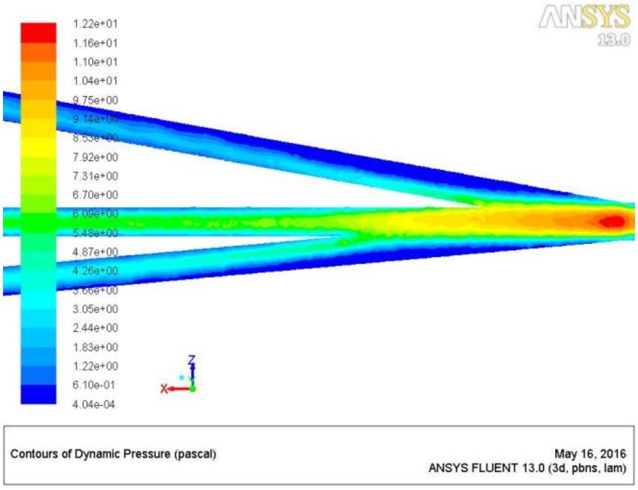


FIG. 13: DYNAMIC PRESSURE CONTOUR-CASE 4 (Pa)

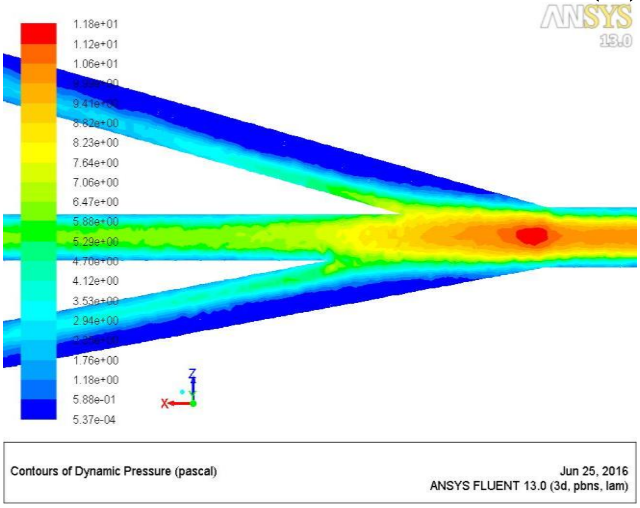


FIG. 14: DYNAMIC PRESSURE CONTOUR-CASE 5 (Pa)

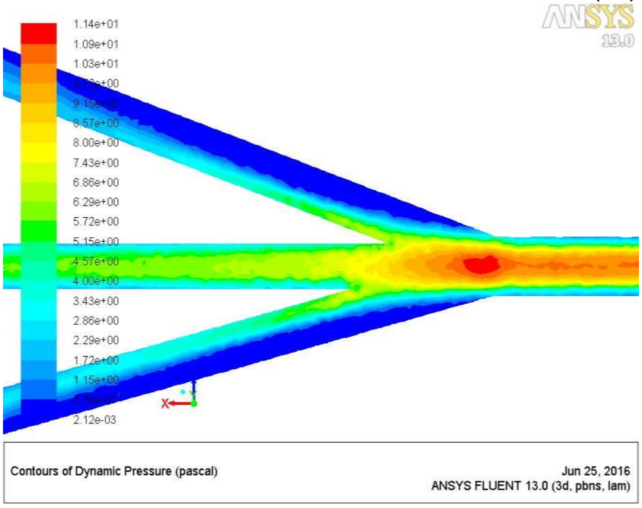


FIG. 15: DYNAMIC PRESSURE CONTOUR-CASE 6 (Pa)

VI. TOTAL PRESSURE CONTOURS

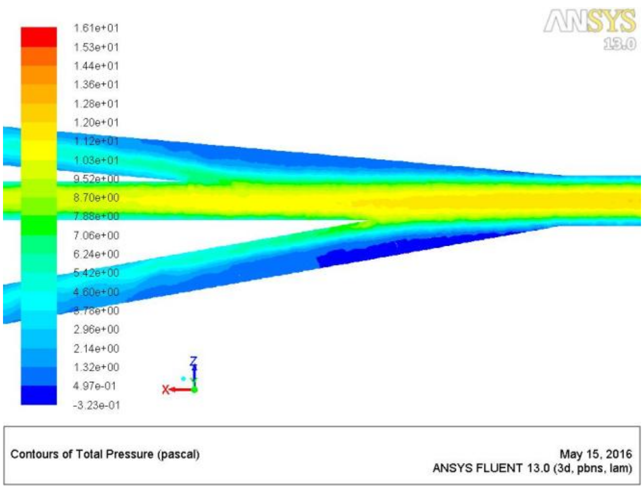


FIG. 16: TOTAL PRESSURE CONTOUR-CASE 1 (Pa)

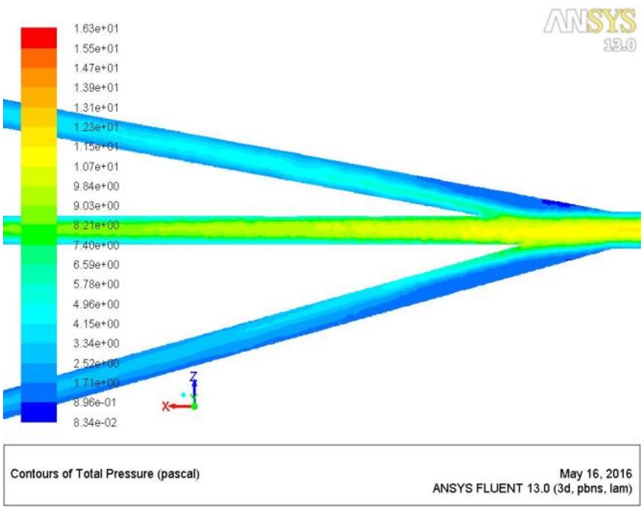


FIG. 17: TOTAL PRESSURE CONTOUR-CASE 2 (Pa)

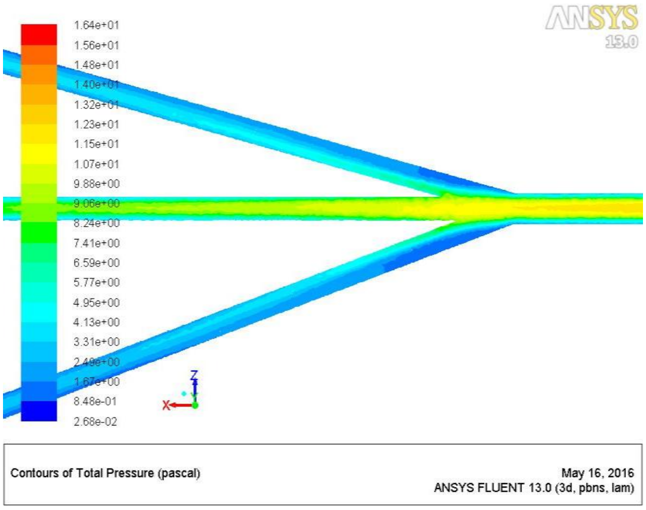


FIG. 18: TOTAL PRESSURE CONTOUR-CASE 3 (Pa)

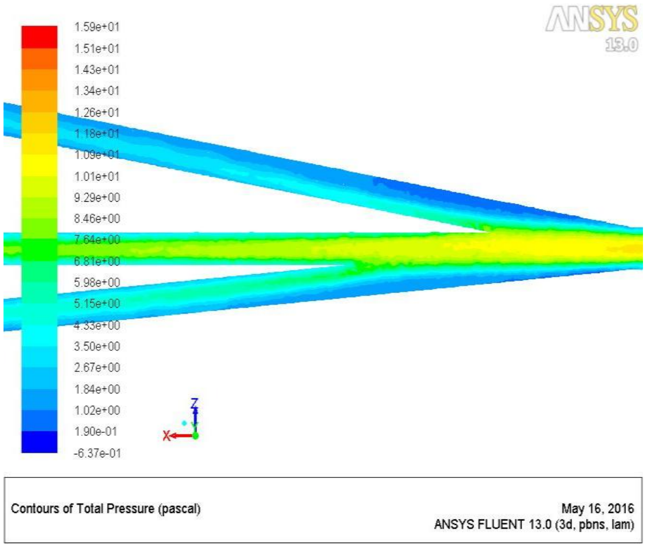


FIG. 19: TOTAL PRESSURE CONTOUR-CASE 4 (Pa)

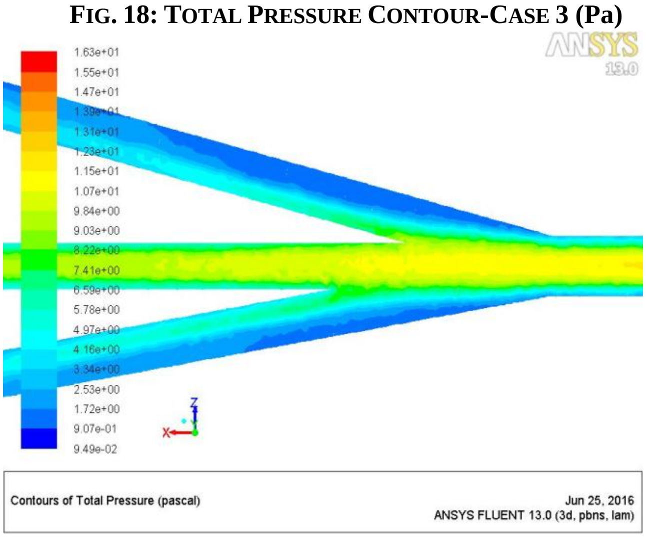


FIG. 20: TOTAL PRESSURE CONTOUR-CASE 5 (Pa)

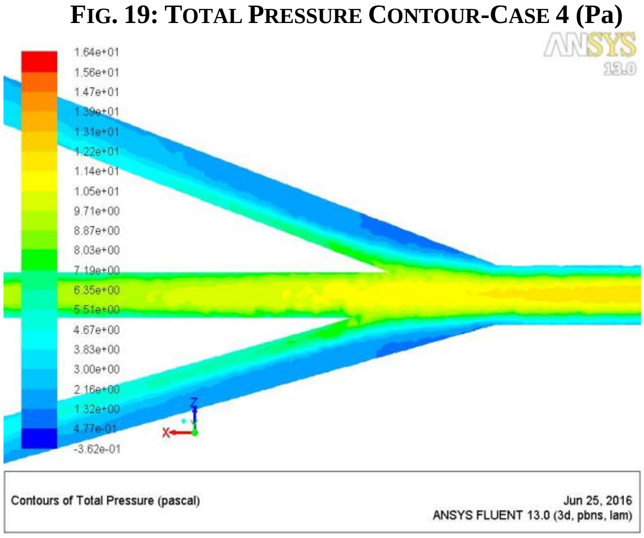


FIG. 21: TOTAL PRESSURE CONTOUR-CASE 6 (Pa)

VII. CALCULATION OF HEAD LOSS COEFFICIENTS

The head losses in the individual branches can be calculated using the following formula [1]:

$$k = \frac{(P_{T\,1,2,3} - P_{T\,Inlet})}{\frac{1}{2}\rho {V^2}_{Inlet}} \tag{1}$$

Where;

$P_{T\,1,2,3}$ → Total Pressure in branches 1, 2 and 3

$P_{T\,Inlet}$ → Total Pressure in Inlet Pipe

$V_{T\,Inlet}$ → Reference flow velocity at Inlet

ρ → Density of air

The velocity magnitudes and pressure values obtained from the fluent analysis are used to carry out the calculations of head losses for all the branches of each trifurcation case. The reference inlet flow velocity (V_{Inlet} = 3 m/s) [2] and density of air (ρ = 1.225 kg/m^3) are constant for all the calculations.

The head loss coefficients have been calculated and their values have been tabulated in the table XII.

The above formula yields negative values of head loss coefficients for all the branches of trifurcations. However, the non-dimensional coefficients (k) can be called energy change coefficients rather than head loss coefficients whenever branching of flows occurs [3]. Thus, the negative sign can be ignored here and head loss coefficients can be considered as energy loss coefficients.

TABLE 12
HEAD LOSS COEFFICIENTS IN THE BRANCH PIPES OF ASYMMETRIC TRIFURCTIONS

Trifurcation Case No.	Head (Energy) Loss Coefficients (k)		
	Branch-1	Branch-2	Branch-3
1	2.60	2.20	2.65
2	2.63	2.23	2.72
3	2.69	2.26	2.73
4	2.67	2.25	2.53
5	2.70	2.26	2.64
6	2.72	2.30	2.69

VIII. DISCUSSION OF RESULTS

The velocity magnitude contours, dynamic pressure contours and the total pressure contours for all the six cases are as shown in the figures 4 to 9, 10 to 15 and 16 to 21, respectively. It has been observed that the velocity magnitudes, dynamic and total pressures in the branch pipes decrease with the increase in the trifurcation angles for all the six cases. And also maximum values have been observed in the branch-2.

From the analysis of the contours for all the above six cases, it can be seen that the values of velocity magnitude, dynamic and total pressures are maximum in the central branch (branch-2) of the trifurcation. The distribution of velocities, pressures and separation of flow in the other two branches of the trifurcation mainly depends upon the turbulence at pipe trifurcation junction, angle of trifurcation, and diameter ratio [4].

The values of energy change coefficients have been calculated for all the six cases of trifurcations and are tabulated as shown in the table XII. It can be observed that the branch-2 head loss coefficients are smaller compared to that of the other two branches. This is because there is only change in the pipe area and more energy dissipation that is taking place is because of the viscous friction at the wall, while the side branches suffer a directional flow change (secondary flow) along with the cross-sectional variation [1].

IX. CONCLUSION

Energy (head) loss analysis has been carried out and volumetric flow rates, velocity magnitudes, and dynamic & total pressures have been determined for all the six cases of asymmetric trifurcations. It is seen that the fluid flow rate, velocity magnitude and dynamic & total pressures are more in the branch-2 compared to the other two branches. Smaller values of head losses have been obtained for branch-2 in all the cases. This is because there is only change in the pipe area and more energy dissipation that is taking place is because of the viscous friction at the wall, while the side branches suffer a directional flow change (secondary flow) along with the cross-sectional variation [1]. The turbulence at pipe trifurcation junction, angle of trifurcation, and diameter ratio are mainly responsible for the losses and separation of flow [4].

REFERENCES

[1] Aguirre C.A, Ramirez R.G, Head losses analysis in symmetrical trifurcations of penstocks - high pressure pipeline systems cfd *CamachoInstituto de Engenharia Mecânica, Universidade federal de Itajubá*.

[2] RK, M., Paras, P., 2009, Flow modeling of the first trifurcation made in Nepal, Hydro Nepal, Kathmandu, Nepal.

[3] "The head change coefficient for branched flows: Why ''losses'' due to junctions can be negative", B. Schmandt, H. Herwig / International Journal of Heat and Fluid Flow 54 (2015) 268–275.

[4] Basappa Meti, Prof. Nagaraj Sitaram, "Determination of Optimum Pressure loss and Flow Distribution at Pipe Trifurcation", Journal of Information, Knowledge And Research in Civil Engineering ISSN 0975–6744 , Impact Factor: GIF: 00.9487 , SIF: 03.495.