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Determination of Optimum Pressure Loss Coefficient and Flow Distribution at Unsymmetrical Pipe Trifurcation Using Experimental and Numerical Technique

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Abstract: The branching of pipes is common in fluid distribution system, in penstocks of hydroelectric power plants. Junction introduces extra energy losses due to deviation of flow direction and change in magnitude of velocity and flow rate and separation the flow at the sharp corner. Hydraulic analysis is needed to optimize the head losses occurring pipe junctions. Flow prediction at pipe trifurcation junction due to combining streamlines, curvature, turbulence, anisotropy and recalculating region at high Reynolds number is complex. An attempt is made to study the pressure loss (‘K= ΔP’) for unsymmetrical pipe trifurcation (15°-45°, 30°-15°and 35°-20°) using experimental and numerical techniques. It is found that the turbulence and unequal angle of trifurcation are the main reasons for losses and separation of flow. Combined trifurcation loss coefficient (K) and branch loss coefficients have been correlated between split flow ratios.

Keywords: Trifurcation, Split Flow Ratio, Optimum Loss Coefficient

1. Introduction

Pipe networks are very common in industries, water supply schemes where fluid or gases to be transported from source to the receiver. The trifurcation junction is a part of the hydroelectric plant which together with other parts and equipment has the purpose to produce electricity using the hydraulic potential. The losses must be reduced to obtain the best operating condition with stable flow. These conditions can be known from tests in preliminary models to obtain appropriate geometries with controlled load losses and variations of flow supplying the turbines.

Minor losses occur in pipe fittings, expansions, contractions etc. Pipe fittings include bends, tees, elbows, unions, valves and branching.The pressure loss may vary depending on the type of components in the network, material of the pipe, fluid that is being transported through the network, pipe fittings, and placement of valves, pumps, turbines and geometry pipe fittings.

The branching of flow in to streams of different velocities in turbulent region with high Reynolds number results in the exchanges of fluid momentum, energy transfer from low to high velocity. There is a need to account for flow parameter for the distribution of flow between the junction legs.

2. Literature Review

Early experimental and numerical investigation of local losses in piping system was started with Blaisdell [2]. WanngHau [14] has carried an experimental analysis with several wyes configurations and manifolds for head losses in the dimensionless form quantified with the average flow velocity in the pipe.

Albert [1] presented that, in the power plant sever power oscillations were encountered at the outer turbine in the range of +/-10% of nominal power. Vortex instability forming in the sphere starting at the top and extending in to the side branch after a certain period it changes it behavior and extends to the opposite side branch and after some time jumps back, this unpredicted movement of the vortex causes power fluctuations and head loss in the branch. These losses reduce the head of the turbine and consequently the power output. For the flow simulations in pipe trifurcation he has recommends adaptive turbulence model based on the extended K- ε model instead of RANS methods.

Buntic [6] presents has presented that, the turbulent flows in piping system are characterized by the transport of mass,momentum and energy. Malik [11] has carried out 3D flow modeling of the trifurcation to find out the most efficient profile of the trifurcation in the given constraints of pressure, velocity and layout.

Bohuslav [5] has presented the calculation methods of pressure drop in pipe line components such as elbow, tube fittings and various valves etc. The comparison methods are equivalent length method, Crane method, loss coefficient method, Idelchik method and Blevins method and considering the diameter ratio and Reynolds number he has recommended the Blevins method for pressure drop in pipe line components with wide range of hydraulic parameters. Aguirre has determine the loss coefficient in the adduction system type symmetrical trifurcation, by dividing the geometry in to structure and unstructured volumetric elements using CFD tool and concluded that hexahedral (structured) mesh is more sensitive to quantify the head losses mean while the tetrahedral (unstructured) mesh shows similar behavior comparing its results with reduced model tests.

Most of the above studies are concentrating on branch angles beyond 45°. Hence, these formulas and results cannot be applied for pipe bifurcations/trifurcations with lesser angles of pipe branching. In many countries number of theoretical and experimental investigation is carried out on hydraulic behavior of branch pipe system but no exact solution to the problem is arrived.

3. Methodology

Experiments are carried out in the closed loop test rig as shown in the figure1. Test trifurcation junction is made by GI pipe of 25.40 mm diameter main pipe and 19.60 mm diameters GI branching with different angle of trifurcation. Branching pipes are carefully joined for required angle of trifurcation. Flow meters are installed at downstream of the pressure gauges in each of the branching to quantify the flow. Valves are installed to control the flow distribution in each of the branch pipe and main pipe. Flow is continuous and driven by pump of 2HP capacity supplied with constant head tank at collecting sump. Temperature of the re circulated water is also noted. Water temperature variation during each test run was within +/-0.5°C because of large volume of water in the test rig tank. Pressure gauges in the main pipe and each of the three branching are installed at 400 mm from the trifurcation junction. Pressure measurements were noted for each branching pipes to obtain the flow parameters by controlling of line pressure from 50 KPa. to 400 KPa.

Figure 1. *Experimental Setup.*

4. Experimental Results and Discussion

Pressure at the trifurcation is reduces due to recirculation at this zone, but there is a small region near the junction where negative pressure is developed due change in direction of flow resulting in the pressure drop at downstream and increase in the velocity at the out let.

Figure 2: Combined loss coefficient (K) is optimum at 0.50 for at least 40% flow in center pipe and remaining 60% at the extreme branch pipes and much fluctuating from 0.50 to 0.60 for different angle of trifurcations.

Figure 3: Branch loss coefficient (K_{14}) with the split flow ratio (Q_4/Q_1) varies from 0.60 to 0.80 and it is optimum at split flow ratio (Q_4/Q_1) =0.4 for unsymmetrical trifurcation angles. Branch loss coefficient (K_{14}) for 30% to 40% of the main flow through it varies from 0.6 to 0.86 for unsymmetrical trifurcations. It shows that as the angle of trifurcation increases the loss coefficient also increases in parabolic manner.

Figure 4: For fully developed flow at inlet when the Reynolds Number (Re_1) is more than 10000, the loss coefficient is independent from the Reynolds Number (Re_1).

Figure 5: Branch loss coefficient (K_{13}) varies linearly as the velocity in the branch pipe 3 increase and attains the max value of 0.6 when the flow is fully diverted to pipe 3. Branch loss coefficient (K_{13}) for the branch 3 varies linearly and attains optimum value of 0.6 when full flow is diverted to that branch andindependent of the branch angle.

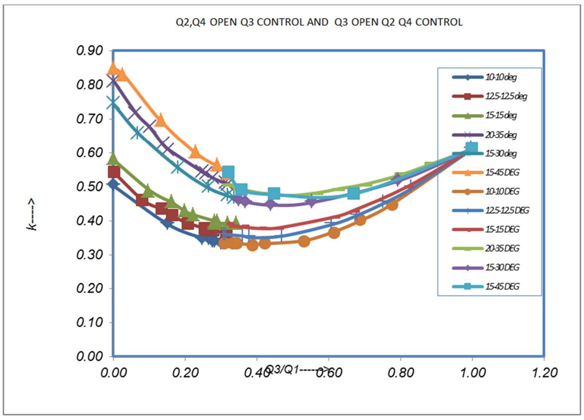

Figure 2. *Combined loss coefficient (K) with Split flow ratio (Q_3/Q_1).*

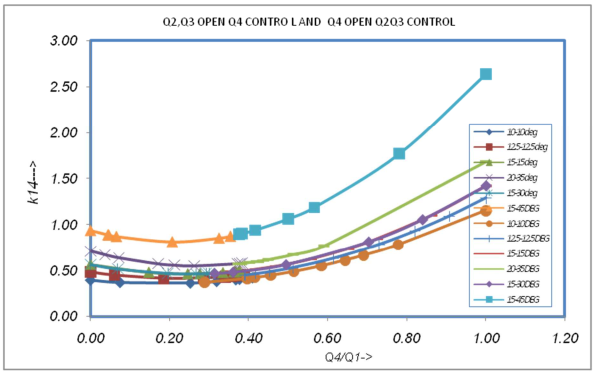

Figure 3. *Branch loss coefficient (K_{14}) with split flow ratio (Q_4/Q_1).*

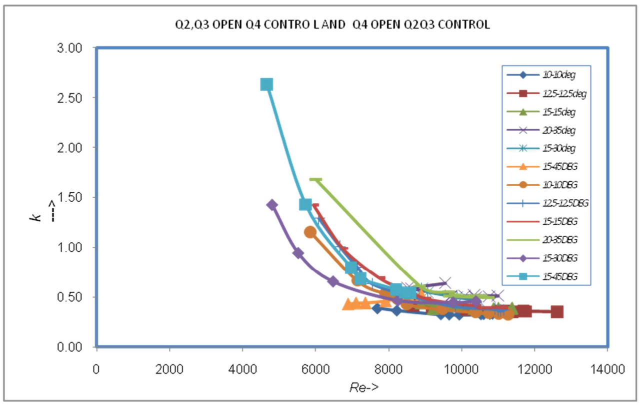

Figure 4. *Combined loss coefficient (K) with. Reynolds number (Re).*

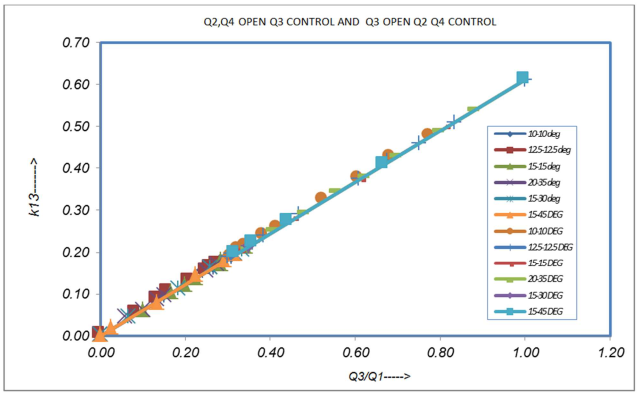

Figure 5. *Branch loss coefficient (K_{13}) with split flow ratio (Q_3/Q_1).*

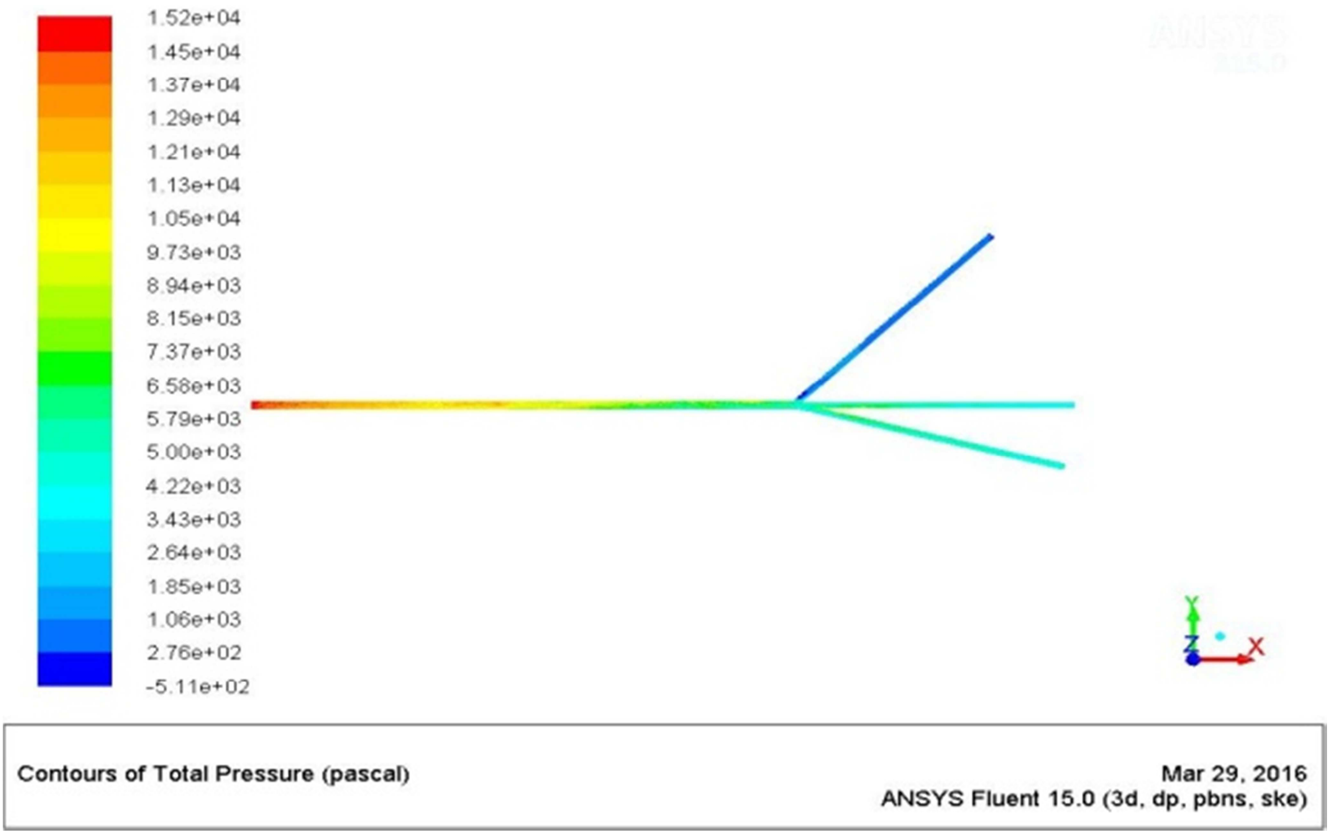

Figure 6. *L-view of total pressure.*

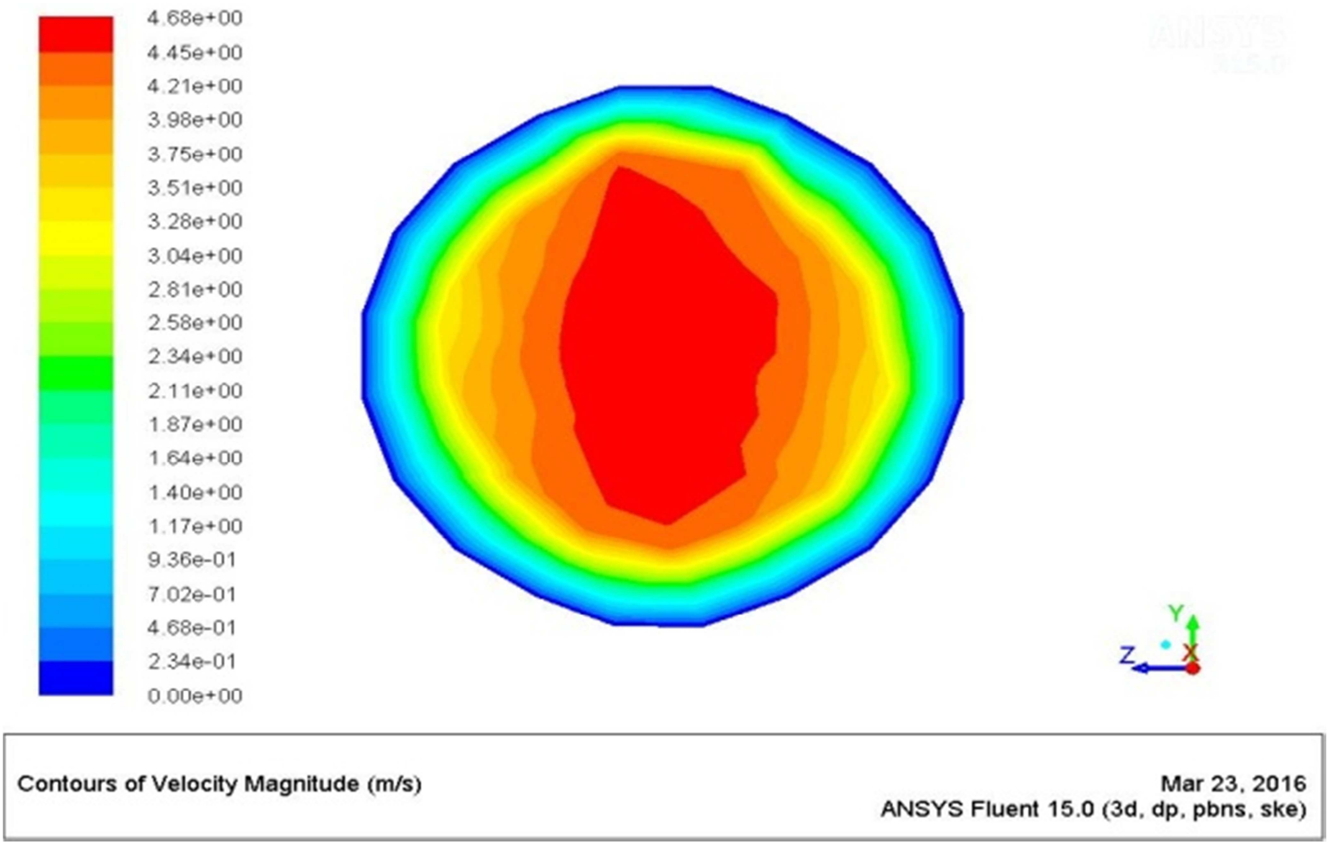

Figure 7. *Velocity magnitude at inlet.*

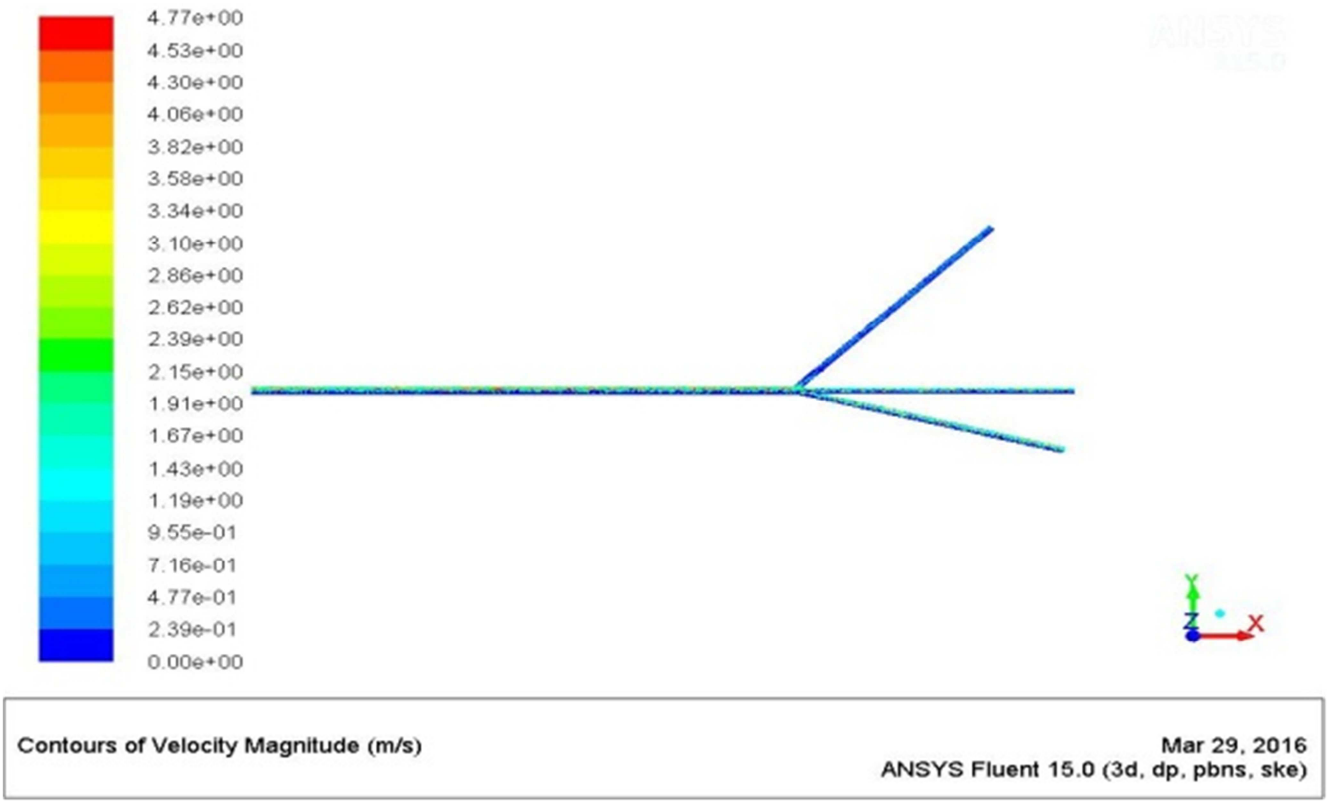

Figure 8. *L-View of velocity magnitude.*

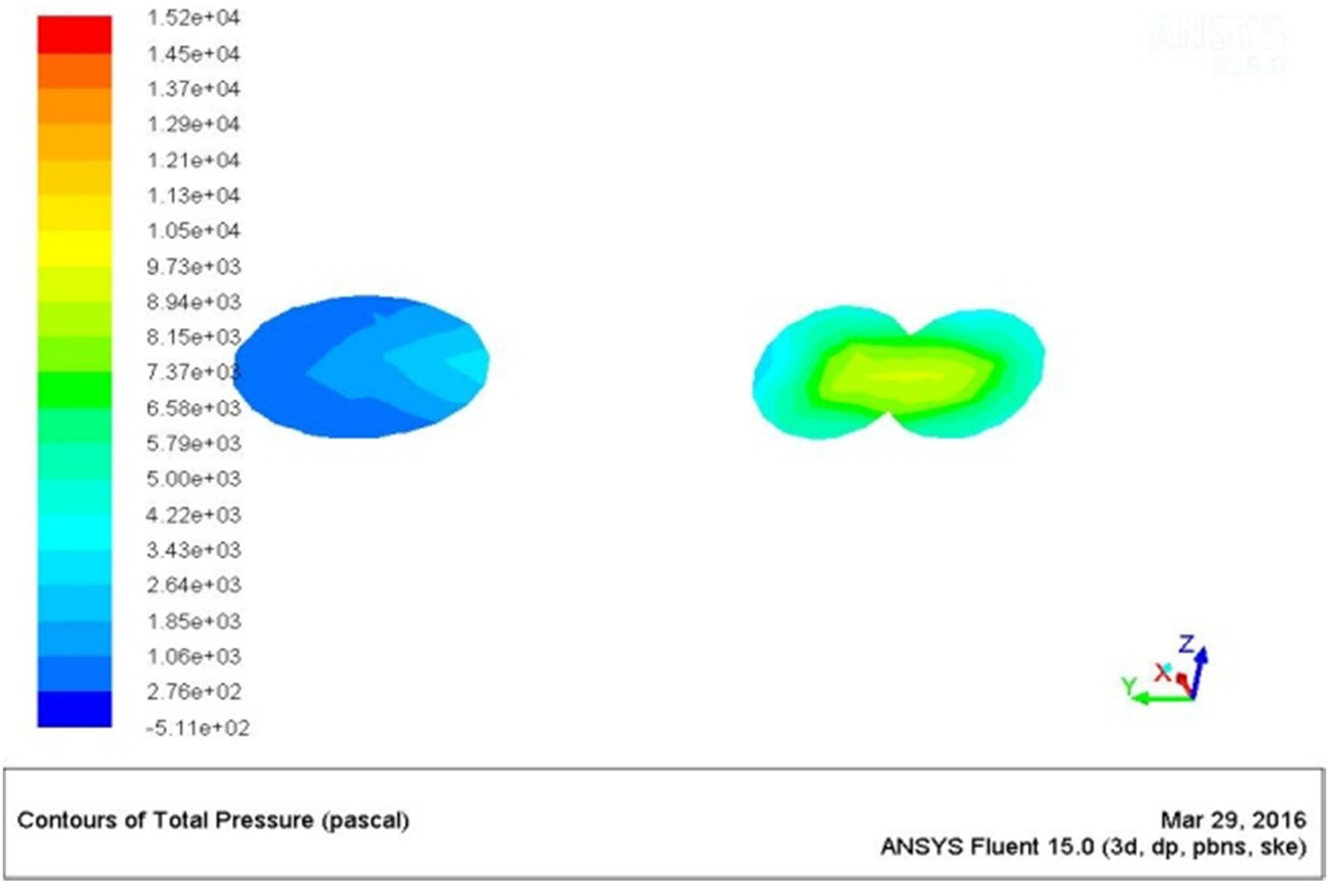

Figure 9. *Total pressure at plane 100mm from the junction.*

It is noted that as the trifurcation angle increases the value of loss coefficient also increases in parabolic order. Main reason could be whirling of flow, formation of vortex, recirculation (complex flow phenomena) of the flow in the extreme branch pipes of unsymmetrical trifurcation branches due to symmetrical streamlining of flow as visualized in CFD output image.

Numerical model is created using GAMBIT 2.4 with tetrahedral unstructured mesh of 4 mm size for the standard K-ε model. Boundary conditions were set as the velocity at inlet and the outlet parameters are static pressure, mass flow rate, turbulence, pressure coefficient and mean velocity. Model is run through the commercial software ANSYS FLUINT 15 and output of CFD images are shows, It is observed that maximum differences between simulation and experimental results is less than 10% the predicted loss coefficient are validated with the experimental results Sakakibara [15].

5. Conclusions

Distribution of flow in the pipes has been studied in pipe unsymmetrical trifurcation with different line pressures and flow rates for unsymmetrical trifurcation angles. Experimental results show that the pressure loss coefficient increases with trifurcation angles and its optimum value (K= 0.50) is obtained at 30% split flow ratio in each outer branch and 40% in the middle branch. Loss coefficient tends asymptotically towards Reynolds number when Re is more than 10,000. Branch loss coefficient K_{14} varies from 0.60 to 0.80 in parabolic manner for different angles unsymmetrical trifurcation. Experimental findings suggest that the overall trifurcation loss coefficient (K) is more for higher angle of the trifurcation.

CFD analysis for total pressure, velocity, loss coefficient is validated with the experimental results. This extraction leads to show a good accuracy in predicting pre-defined physical condition. It can be said that the correlation obtained in this studyreflects the recommendation.

Nomenclature

ρ	Density of water, 1000 kg/m^3
Q_2, Q_3 and Q_4	Discharge in branching
γ_w	Unit weight of water, 9810N/m^3,
V_2, V_3, and V_4	Velocities in branching
(K_{12}, K_{13}, K_{14}, and K)	Branch loss coefficient and combined loss coefficient

(Q_2/Q_1), (Q_3/Q_1) and (Q_4/Q_1)	Split flow ratio
Wb and Ws	Mean velocity in the branch and main passage m/s,
ξ ξcb and ξcs	Resistance coefficient of branch and main pipe
Q_1	Discharge in main pipe
V_1	Velocities in main pipe
p	Static pressure
Θ_1, Θ_2	Branch angle in degree
Re_1, Re_2, Re_3 and Re_4	Reynolds Number in main, branching
Fb, Fs and Fc	Areas of the cross section of the branch, straight passage and common pipe m^2
Qc, Qb and Qs	Discharge in common and branch and straight pipe.

Governing equations:

Computation is based on the principle of conservation of mass, momentum and energy.

Expected discharge through each nozzle = Q/3.

Inlet energy per unit time = Work done by Pressure per unit time + Kinetic Energy

$$Inlet\ \ Energy\ \ /\,Time\ = P_1Q_1 + \frac{\rho Q_1U_1^{\,2}}{2}\ \dots \quad (1)$$

$$Outlet\ \ Energy\ /\,Time\ = \frac{\rho Q_2U_2^2}{2} + \frac{\rho Q_3U_3^2}{2} + \frac{\rho Q_4U_4^2}{2}\ \dots \quad (2)$$

Loss coefficient equations

Idlechik [8]

$$1+(\frac{Q1}{Qc}\circ\frac{Fc}{Fb})\hat{}\,\mathbf{2}-8(\frac{Q1b}{Qc})x\frac{(\frac{Qc}{Q1b}-(1+\frac{Q2b}{Q1b})}{4-(1+\frac{Q2b}{Q1b})\frac{Q1b}{Qc}}\hat{}\,2-1.93(\frac{Q1b}{Qc})2\frac{Fc}{F1b}\left[1+(\frac{Q2b}{Q1b}\right]\hat{}\,2=.\zeta 1cb.\dots \quad (3)$$

$$1+(\frac{Qs}{Qc}-(\frac{Qs}{Qc})\hat{}\,\mathbf{2}\,x\frac{(1+\frac{Qs}{Qc})}{(0.75+0.25\frac{Qs}{Qc})2}\hat{}\,2-1.93(\frac{Qs}{Qc})2\frac{Fc}{F1b}\frac{\left[1+(\frac{Q2b}{Q1b}\right]\hat{}\,2.}{(1+\frac{Q2s}{Q1s})2}(\frac{Qc}{Qs}-1)\hat{}\,2=\zeta cs.\dots \quad (4)$$

Blevins [3]

$$K_{ij}= 0.96\sin^2\theta_j+ \alpha_j\,(\cos\theta_j/U_1)^2+\beta_jU_j/U_1 \dots \quad (5)$$

$\alpha_j = 0.22\ \theta_j\cos\theta_j+1.2\sin\theta j.\ \mathrm{Sin}\ (60-\theta j)$

$\beta_j= \{0.00698(45-\theta j)+0.075Aj/A1+0.0262\ \theta j\}\sin(75-\theta j)$, ɵ in degree

Combined loss coefficient:

$$K= (Q_2/Q_1)\ x\ K_{12} + (Q_3/Q_1)\ x\ K_{13}+ (Q_4/Q_1)\ x\ K_{14} \dots \quad (6)$$

Table 1. *Split flow ratio and Total energy.*

Trifurcation Angle(°)		Split flow ratio			Head (m)	
Θ_1	Θ_2	Q_2/Q_1	Q_3/Q_1	Q_4/Q_1	inlet	head loss
35	20	0.30	0.32	0.38	11.62	6.79
35	20	0.32	0.30	0.37	12.17	7.40
35	20	0.32	0.30	0.38	12.06	7.19
35	20	0.31	0.31	0.38	12.52	7.65
35	20	0.33	0.41	0.26	13.08	6.57
30	15	0.36	0.34	0.30	12.58	8.21
30	15	0.36	0.34	0.29	12.59	7.82
30	15	0.38	0.36	0.27	13.06	7.84
30	15	0.42	0.39	0.20	13.51	6.81
30	15	0.48	0.45	0.07	14.41	5.82
15	45	0.39	0.40	0.21	7.63	4.34
15	45	0.46	0.47	0.07	8.58	4.44
15	45	0.47	0.48	0.05	8.55	3.93
15	45	0.47	0.48	0.04	8.55	3.90
15	45	0.49	0.51	0.00	9.04	4.08

Table 2. *Loss coefficient and Reynolds number.*

Trifurcation angle(°)		Loss coefficient				Reynolds number
Θ_1	Θ_2	K_{14}	K_{13}	K_{12}	K	Re
35	20	0.57	0.20	0.75	0.51	10745
35	20	0.57	0.19	0.76	0.52	10987
35	20	0.57	0.18	0.76	0.52	10336
35	20	0.58	0.19	0.75	0.51	10071
35	20	0.55	0.25	0.76	0.50	10372
30	15	0.47	0.21	0.71	0.47	10411
30	15	0.47	0.21	0.72	0.47	10458
30	15	0.46	0.22	0.72	0.47	10237
30	15	0.47	0.24	0.75	0.50	9875
30	15	0.52	0.28	0.81	0.55	9077
15	45	0.88	0.20	0.47	0.53	8878
15	45	0.86	0.21	0.47	0.51	8548
15	45	0.82	0.25	0.50	0.46	7901
15	45	0.87	0.29	0.54	0.44	7349
15	45	0.89	0.29	0.55	0.44	7095

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