Determination of Optimum Pressure loss and Flow Distribution at Pipe Trifurcation"

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Abstract

The friction losses in pipe branching and trifurcation are important in flow distribution of plumbing pipes pipes and penstocks. The design of a efficient trifurcation with desired flow distribution with minimum hydraulic loss need to be developed. An experimental approach is selected to evaluate the losses at the junction of the pipe trifurcation 'K = ΔP'. It is desired to know the split flow ratio and pipe junction geometry for which the pressure loss at trifurcation junction is minimum. The paper focuses in determination of pressure losses and flow distribution of pipe trifurcation using the experimental and numerical techniques at various flow rates and pressures.The complexity of pressure drop at trifurcation is high particularly at high Reynolds number. An attempt has been made to study experimentally, the pressure loss at pipe trifurcation with three different angles of trifurcations 20°, 25°, and 30°. The pipe line pressure is varied between 50 KPa to 200 KPa. The experimental data and analysis for 25.40 mm main and 19.60mm trifurcated pipes show the correlation between pressure loss coefficient (K) with a split flow ratios $\left(\frac{Q_2}{Q_1}\right)$, $\left(\frac{Q_3}{Q}\right)$, $\left(\frac{Q_4}{Q_1}\right)$. It is found that the turbulence at pipe trifurcation junction, angle of trifurcation, and diameter ratio are mainly responsible for losses and separation of flow. The overall trifurcation loss coefficient (K) and individual branch loss coefficients (K_{12}, K_{13}, K_{14}) have been computed and correlation between pressure ratio, split flow ratio and loss coefficients have been developed. The optimum value of overall pressure loss coefficients are obtained for different flow ratios. The experimental findings also suggest that the head loss at the trifurcation junction will be minimum when nearly equal rate of flow in branched pipes. New correlations have been developed. The experiments conducted at different pipeline pressures also indicate that the overall trifurcation loss coefficient (K) is high for higher line pressures.

Keywords: *Trifurcation, split flow ratio, optimum loss co-efficient.*

1. Introduction

Pipe networks are very common in industries, where fluid or gases to be transported from one location to the other. The pressure loss may vary depending on the type of components coming across in the network, material of the pipe, and the fluid that is being transported through the network. The placement of valves, pumps and turbines is important to overcome the pressure loss caused by the other components in the network. This is one of the important reasons why this study was conducted.

The union of two streams of different velocities results in mixing of the streams and changes in both velocity and pressure of both streams. The exchanges of fluid momentum results energy transfer from faster moving to lower components with a single flow path. There is also a need for flow parameter to account for the distribution of flow between the junction legs.

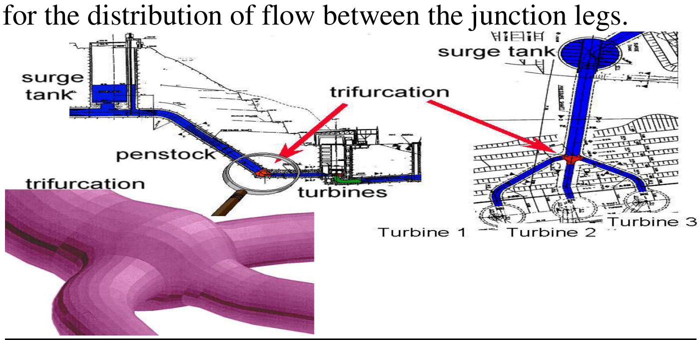

Fig 1. General layout of pipe trifurcation.

Major energy losses due to combining and dividing flow arise separation and subsequent turbulent mixing. Under study should meet maximum flow efficiency under the physical constraints of fabrication. The flow efficient profile was then analyzed to capture the stress amplification near junction.

Minor loss is a term used to describe losses that occur in fittings, expansions, contractions etc. Fittings commonly used in the industry include bends, tees, elbows, unions, and of course, valves used to control flow. Major losses of head in a piping system are the direct result of fluid friction in pipes and ducting. The resulting head losses are usually computed through the use of friction factors. Friction factors for ducts have been compiled for both laminar and turbulent flows.

The trifurcations are part of the architectural complex that forms the hydroelectric plant, which together with others, parts and equipment has the purpose to produce electricity using the hydraulic potential existing in a damming or a river. Whereas the optimal operating point of the pipeline systems, the losses must be reduced to obtain the best operating condition, with fields of stable flow. These conditions can be defined from tests in preliminary models to obtain appropriate geometries, with controlled load losses and variations of flow supplying the turbines.

This practice leads to high pressure losses occurring at the pipe junction and reduces the available head (H_{net}) to turbine for power generation (P), and thereby reducing the overall efficiency the hydro power plant as given by Eq.(1)

$$P = \frac{\gamma_w Q H_{net}}{75} \eta_o \qquad (1)$$

1.1 Objectives

- *T*o compute the pressure loss coefficients 'K' at pipe trifurcation.
- The loss co-efficient and flow ratio for trifurcation for a given pressure ratio and geometry.
- To investigate the pressure losses occurring at the pipe trifurcation and develop general guidelines for determination of split flow ratios.
- To draw nomograms for best operation of the penstock system.
- Design of good trifurcation with desired flow distribution with minimum hydraulic loss.
- To determine the profile which gives maximum discharge and minimum head loss

2. Methodology

The friction losses in the penstocks while conveying water from the overhead reservoir to the power house are of considerable importance. It is a common practice to use larger diameter pipes for trifurcation at the power house to feed the water to individual turbines.

The computation is based on the principle of conservation of mass called continuity equation. Thus for a fluid flowing through a pipe at all the cross section the quantity of fluid per second is constant.

Fig 2. Experimental setup

According to law of conservation of mass, rate of flow at cross section 1-1 = rate of flow at cross section 2-2 $\rho_1 A_1 V_1 = \rho_2 A_2 V_2$

The equation is applicable to the compressible as well as incompressible fluids and is called "Continuity equation". The fluid is incompressible then $\rho_1 = \rho_2$.

The equation reduces to, $A_1 V_1 = A_2 V_2$. If the net head of water and discharge at inlet is 'h' and 'Q' respectively then from the continuity equation for the equal discharge among three branching pipe, expected discharge through each nozzle = $\frac{Q}{3}$ The evaluation of real velocity at the outlet of the jet can help us to evaluate the loss of head by using energy equation. The inlet energy per unit time = Work done by Pressure per unit time + Kinetic Energy

$$Inlet\ Energy/Time = P_1 Q_1 + \frac{\rho Q_1 U_1^2}{2} \quad \text{...(2)}$$

$$Outlet\ Energy/Time = \frac{\rho Q_2 U_2^2}{2} + \frac{\rho Q_3 U_3^2}{2} + \frac{\rho Q_4 U_4^2}{2} \quad \text{...(3)}$$

ρ : Density of water 1g/cm^3
Q_1: Discharge in main pipe
γ_w : Unit weight of water 1000kg/m^3
Q_2, Q_3, Q_4 Discharge in Branching
U_1, U_2, U_3,, U_4: Velocities in branching

The experimental set up is shown in fig 2

3. Observations and Discussion.

The variation between the loss co-efficient with discharge ratio for trifurcation shows decreasing trend in initial range of discharge ratio and increases gradually for higher values of discharge ratio such variations are attributed to flow turbulence.

The loss co-efficient is found to increase for initial discharge ratio and attain a parabolic shape with minimum value of k in the middle range of discharge ratio and increases parabolic ally for higher values of discharge ratios. Hence the effect of line pressure is significant. The effect of stream lining is more pronounced in high pressure. The loss co-efficient for 1HP capacity pump shows parabolic trend for angles of trifurcation 20^0 25^0, and 30^0 shows minimum value of k at middle values of split flow ratio. The split flow discharge to 20^0 25^0, and 30^0 angle of trifurcation shows concluding trend due to high pumping capacity and more pressure developed in distribution system. As the flow increases in the particular branch, split flow ratio of the remaining branch shows same trend for 20^0 25^0, and 30^0 angle of trifurcation.

Table 1

Details	Formula
Pressure loss coefficient K_{12}	$2000(\Delta P)/U_{12}+0.67+0.56(U_2/U_1)^2$
Pressure loss coefficient K_{13}	$2000(\Delta P)/U_{12}+0.67+0.56(U_3/U_1)^2$
Pressure loss coefficient K_{14}	$2000(\Delta P)/U_{12}+0.67+0.56(U_4/U_1)^2$

Table 2

Sl No	Time for flow of 10 ltr of water in the branch pipe No 2	Time for flow of 10 ltr of water in the branch pipe No 3	Time for flow of 10 ltr of water in the branch pipe No 4	Ratio	Velocity in branch No 1	Velocity in branch No 2	Loss coefficient	Loss coefficient	Loss coefficient	Combined k	Ratio
	T_2 (Sec)	T_3 (Sec)	T_4 (Sec)	Q_2/Q_1	U_1 Cm/s	U_2 Cm/s.	K_{1-2}	K_{1-3}	K_{1-4}	K	Q_3/Q_4
1	406.80	25.60	26.36	0.06	161.58	15.56	0.69	1.02	0.99	0.99	1.03
2	204.60	26.39	27.07	0.01	149.05	2.23	0.69	1.06	1.03	1.04	1.03
3	120.30	27.50	28.21	0.04	147.27	8.98	0.70	1.04	1.01	1.01	1.03
4	95.90	28.43	29.23	0.16	163.92	43.55	0.73	0.95	0.93	0.90	1.03
5	73.08	29.30	30.68	0.21	166.81	56.69	0.75	0.92	0.90	0.88	1.05
6	56.14	31.20	32.47	0.25	165.11	66.28	0.78	0.90	0.88	0.86	1.04
7	48.02	32.72	34.06	0.31	170.64	84.51	0.82	0.86	0.85	0.85	1.04
8	37.66	36.50	38.50	0.33	157.71	84.51	0.85	0.86	0.83	0.85	1.05
9	31.24	35.10	42.80	0.38	165.49	101.88	0.90	0.86	0.79	0.85	1.22
10	27.99	42.90	43.90	0.44	161.45	113.71	0.97	0.80	0.79	0.87	1.02
11	16.31	35.60	37.82	0.53	228.59	195.14	1.09	0.76	0.75	0.93	1.06
12	22.34	52.40	51.30	0.54	164.45	142.47	1.11	0.76	0.75	0.95	0.98

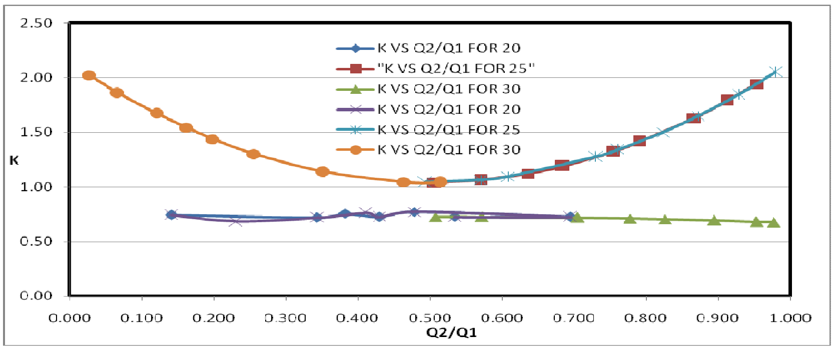

Fig 3. Loss co-efficient Vs Discharge ratio.

The fig 3 shows the variation of combined loss co-efficient K and branch loss coefficient K_{12} with discharge ratio Q_2/Q_1. The value of K and K_{12} decreases as the discharge ratio increases in the initial stage and higher the angle higher is the loss and attains the min value of 1.00 for the discharge ratio of 0.5 for both loss coefficient of combined k as well as loss coefficient between main pipe and branch No 2.and the loss coefficient increases as the discharge ratio further increase decreases turbulence and eddies formation.

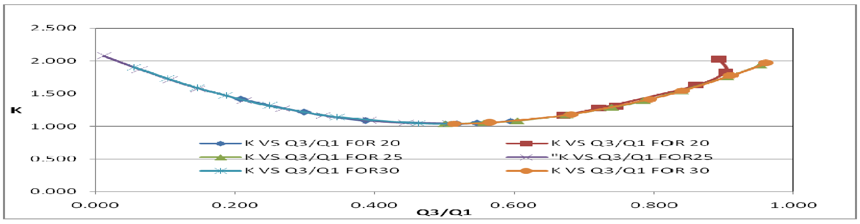

Fig 4: Loss co-efficient Vs Discharge ratio

The fig 4 shows the variation of combined loss co-efficient K with discharge ratio Q_3/Q_1. The value of K decreases as the discharge ratio increases in the initial stage and attains the value of min 0.45 and further increases in the split flow ratio the combined k increases and attains the value of 1.20.Whereas the loss coefficient between the main pipe and branch pipe No 3 increases exponentially and attains the value of 1.20 for all angle of trifurcations.

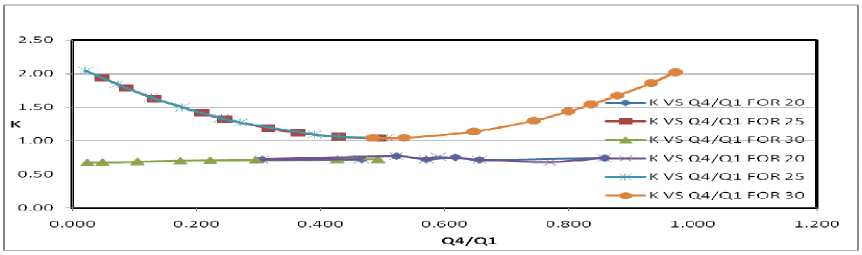

Fig 5: Loss co-efficient Vs Discharge ratio

The fig 5 shows the variation of combined loss co-efficient K with discharge ratio Q_4/Q_1. The value of K decreases as the discharge ratio increases in the initial stage and attains the value of min 0.45 and further increases in the split flow ratio the combined k increases and attains the value of 1.20.Whereas the loss coefficient between the main pipe and branch pipe No 4 increases exponentially and attains the value of 2.0 for all 20^0 25^0 and $30^{\ 0}$ angle of trifurcations.

4. Conclusion

The Distribution of flow in the pipes has been studied in pipe trifurcation for different line pressures, flow rates and trifurcation angles. The experimental analysis shows that the pressure loss coefficient increases as the flow increases in the main pipe and the increase trifurcation angles, and it attains optimum value when the discharge is nearly equal in branch pipes. The Reynolds number of flow for the experiment is from transition to fully turbulent region. The effect of pipe line pressure for the value of loss coefficient is under study. The loss coefficient behavior of the right side branch pipe is similar to the left side branch pipe for symmetrical trifurcation.

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