HYDRAULIC DRAFT TUBE PERFORMANCE WITH VARYING GEOMETRIC CONFIGURATIONS

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Abstract - *Draft tube is an important component of hydraulic turbine. It has gradual increase in cross sectional area from its inlet to outlet and is located below the runner and connects to the tail race. It converts the major part of kinetic energy coming out of runner into pressure head. The energy recovery depends mainly on the design of draft tube. Therefore, the efficiency of the hydraulic turbine can be improved by increasing the efficiency of draft tube. In order to increase the efficiency of draft tube it is important to identify and optimize the design parameters which effect the performance of draft tube. In present paper, both conical and elbow draft tube performance has been evaluated by varying the geometric configurations. The conical type draft tube with length to inlet diameter ratios 14 and 19 have been modeled by varying diffuser half angle 2˚, 3˚, 5˚ and 7˚ and the elbow type draft tube with constant length to inlet diameter ratios 4.5, 5 and 6 are evaluated by varying the geometry of draft tube. The geometry modeling of elbow draft tube is carried for four different h_1/d_1, b_1/d_1 and b_2/d_1 ratios. The inlet diameter of conical and elbow draft tube is kept constant in all the cases. The inlet boundary condition to the draft tube is mass flow rate and the outlet of draft tube has been defined as atmospheric pressure. The performance of conical and elbow draft tubes has been analyzed using ANSYS CFX.*

1. INTRODUCTION:

A small improvement in performance of turbine components has a lot of significance in generation of power. The efficiency of hydraulic turbine depends on the performance of its each component i.e. casing, stay ring, distributor, runner and draft tube.

Draft tube is an essential component of the reaction turbine. It is a passage with gradually increasing cross sectional area which connects exit of the reaction turbine to the tail race. The draft tube transforms a large part of kinetic energy of exit flow into the pressure energy. It acts as a recuperator of energy. In an impulse turbine the available net head is high and it has no significance on efficiency if the turbine is installed few meters above the tail race. Whereas in reaction turbine the net head available is low and if the turbine is installed above the tail race, there can be appreciable loss in available pressure head to run the turbine. The pressure of fluid at exit of the runner is lower than the pressure of fluid at tail race which leads to backflow of fluid and damages the turbine. The draft tube allows installation of reaction turbine above the tail race without loss of head and permits a negative or suction head at the runner exit. Therefore, draft tube is an important component of reaction turbine. The hydraulic performance of draft tube depends on shape and dimensions of draft tube along with its flow pattern at the entrance.

The geometric configuration of conical and elbow draft tube has a great influence on the efficiency of draft tube. The determination of optimum shape and dimension of draft tube is a difficult problem. It has been observed that height reduction of draft tube from h =1.915d_1 to 1.54 d_1 in Kaplan turbine, efficiency was reduced by 5% and when height is increased from 1.915d_1 to 2.3d_1 efficiency was increased by 3.5%. At Volozsky hydroelectric station, in 1973, it was found that the use of standard draft tube of height h=2.24d_1 instead of 1.915d_1 has made it possible to obtain an additional power output of 100 to 150 kWh[1]. This led to study the influence of geometry on draft tube and desire to find the optimum dimensions of elbow and conical draft tube.

A model test approach had been used to study the influence of draft tube geometry more precisely. However, it was both time consuming and expensive. The Computational fluid dynamics (CFD) became an alternative and very attractive tool for flow simulations. A lot of work and studies have been done on turbines and its components using CFD. It was found that mass flow rate has nearly no effect on efficiency and loss in elbow draft tube [2]. The detailed study on elbow draft tube was carried out using CFD simulations and concluded that the efficiency of draft tube depends on the length and the cross-section area of the draft tube [3]. In 2012, Ruchi Khare, et al., has concluded that both length and diffuser angle have significant effect on performance of straight conical draft tube and there was no significant variation in head loss and efficiency of conical draft tube with length beyond 19 times diameter [4]. Numerical and experimental investigations were conducted on different draft tubes in Francis turbine at different flow conditions, at different turbine speeds and discharge. It was found from the results that the order of error in values were within acceptable limits [5].The performance of mixed elbow draft tube and simple elbow draft tube has been done using experimental and CFD analysis and found that mixed elbow

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draft tube poses improved efficiencies as compared with elbow draft tube [6].

In the present work, computational analysis on effect of varied diffuser half angle on conical draft tube by comparing the pressure contours and velocity streamlines and the efficiencies. Also analyzed the effect of variation in height and width at inlet and outlet sections of diffuser part on elbow draft tube by comparing the pressure contours and velocity streamlines and compared the efficiencies of elbow draft tube of different geometric configurations.

2. NOMENCLATURE:

θ – Diffuser half angle
L – Length of draft tube
d_1 – Throat diameter or initial diameter
h_1 – Height of conical section
h_2 – Height of elbow section
h_3 – Height of exit section of elbow
h_4 – Height of exit section of diffuser
b_1 – Width of the exit section of elbow
b_2 – Width of exit section of diffuser
η – Efficiency of draft tube
H_L – Head Loss in draft tube
P_{01} – Total pressure at inlet of draft tube
P_{04} – Total pressure at outlet of draft tube
V_1 – Velocity at inlet of draft tube
V_4 – Velocity at outlet of draft tube
g – Acceleration due to gravity
p – Density of water

3. GEOMETRIC MODELLING AND BOUNDARY CONDITIONS:

The geometry modeling of conical draft tube is done for L/d_1= 14 and L/d_1= 19 and for diffuser angles 2˚, 3˚, 5˚ and 7˚. The inlet diameter (d_1) in all the cases is 1.6m.

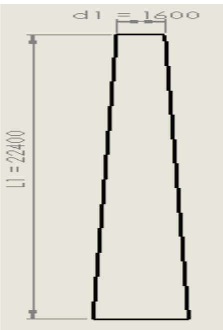

Fig – 1: Conical draft tube (dimensions are in mm)

The elbow draft tube consists of three parts namely cone, elbow and diffuser as shown in the Fig 2. Design of elbow draft tube was made according to inlet diameter of elbow draft tube and by using non dimensional parameters h_1/d_1, b_1/d_1, b_2/d_1. The geometry modeling of elbow draft tube is carried for four different h_1/d_1, b_1/d_1, and b_2/d_1ratios for each L/d_1 equal to 4.5, 5 and 6. In all the cases inlet diameter of the draft tube is kept constant. Total 12 elbow draft tubes with different geometric configurations are modeled.

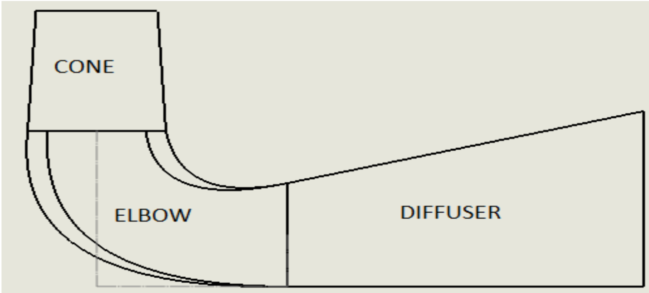

Fig – 2: Parts of elbow draft tube

The geometry modeling of elbow draft tube is carried for four different h_1/d_1, b_1/d_1 and b_2/d_1 ratios for each L/d_1 ratio 4.5, 5 and 6. The Fig. 3 shows the dimensions of elbow draft tube where d_1=1.6 m, h_1/d_1 = 1.304, b_1/d_1 = 1.111, b_2/d_1 = 2.11.

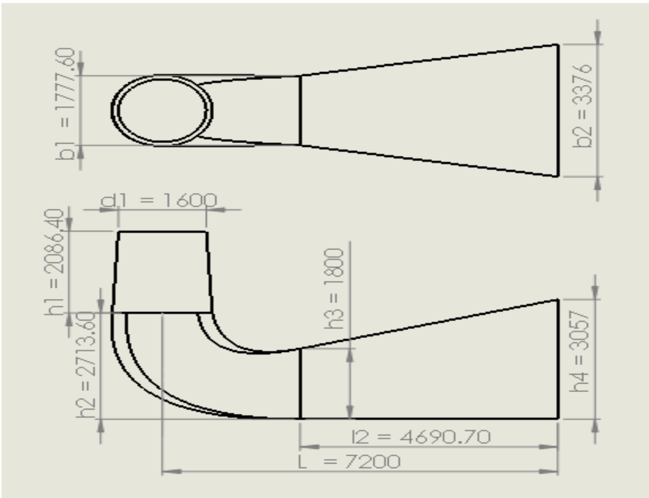

Fig – 3: Geometric parameters of elbow draft tube (dimensions are in mm)

The Geometric modeling of conical draft tube and elbow draft tube are done using SolidWorks. The flow analysis for all geometric models of conical and elbow draft tubes are carried out using ANSYS CFX.

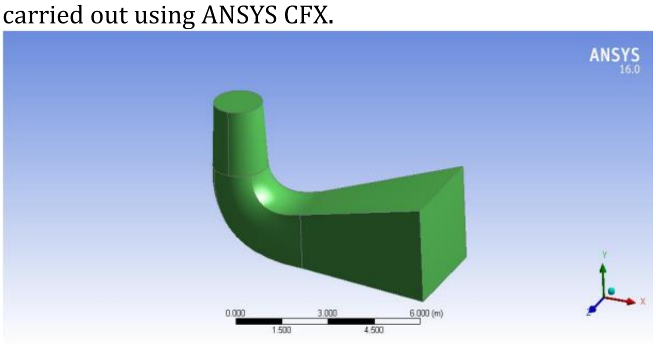

Fig – 4: Geometry of elbow draft tube

Meshing of the draft tube flow domain is generated in ANSYS CFX. The mesh generation is done using method patch forming with tetrahedrons. The unstructured triangular elements on surfaces and tetrahedral in flow domain are adopted in draft tube meshing.

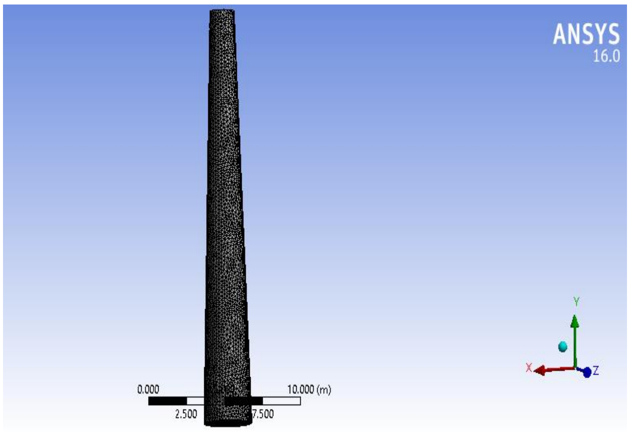

Fig – 5: Meshing of conical draft tube with L/d_1= 14 and diffuser half angle 3˚

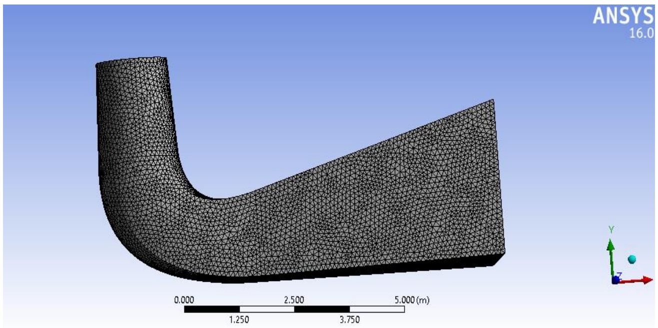

Fig – 6: Meshing of elbow draft tube with L/d_1= 4.5, h_1/d_1 = 1.304, b_1/d_1 = 1.111, b_2/d_1 = 2.11.

The walls of draft tube are assumed to be smooth with no slip. Shear Stress Transport (SST) κ-ω turbulence model in Ansys CFX code has been used for analysis due to boundary curvature in conical draft tube and elbow draft tube. The mass flow rate normal to surface at inlet of draft tube cone is specified as inlet boundary condition. The static pressure at outlet of draft tube is specified as outlet boundary condition.

Working fluid of draft tube has been taken as water. Isothermal flow with fluid temperature 25˚C and turbulence model SST κ-ω has been taken for the domain. Density of water has been considered as 997 kg/m^3. The outlet of draft tube is considered as atmospheric pressure.

For conical draft tube the inlet mass flow rate is taken as 20296.96 kg/s. For elbow draft tube the inlet mass flow rate is taken as 20000 kg/s. The walls of the conical draft tubes and elbow draft tubes are assumed to be smooth with no slip.

4. FORMULAE FOR CALCULATING HEAD LOSS AND EFFICIENCY OF DRAFT TUBE:

The efficiency of the draft tube is defined as actual conversion of kinetic head into pressure head to kinetic head available at the inlet of the draft tube.

$$\text{Efficiency } (\eta) = \frac{\frac{V_1^2}{\rho g} - \frac{V_4^2}{\rho g} - H_L}{\frac{V_1^2}{\rho g}}$$

$$\text{Head loss in Draft tube } (H_L) = \frac{P_{01} - P_{04}}{\rho g}$$

5. RESULTS AND DISCUSSION:

5.1 Results of Conical Draft Tube with Different Geometric Configurations:

The flow analysis is carried out in conical draft tube with length 22.4m (L/d_1=14) and diffuser half angle (θ) 2˚, 3˚, 5˚ and 7˚.The velocity at the inlet to all conical draft tubes is 10.1m/s as inlet diameter is fixed. For conical draft tube with length 22.4m and diffuser half angle (θ) 2˚, 3˚, 5˚ and 7˚ the outlet velocities obtained are 2.42 m/s, 1.66 m/s, 0.851 m/s and 0.514 m/s respectively and outlet pressures are 101459Pa, 101386Pa, 101434Pa and 101129Pa respectively.

Table -1: Head loss in conical draft tube (m) and Efficiency of conical draft tube with length 22.4m

Diffuser half angle (θ)	Head loss in meter	Efficiency (η)
2˚	0.3894	0.8677
3˚	0.5401	0.8691
5˚	0.6663	0.8532
7˚	0.8641	0.8312

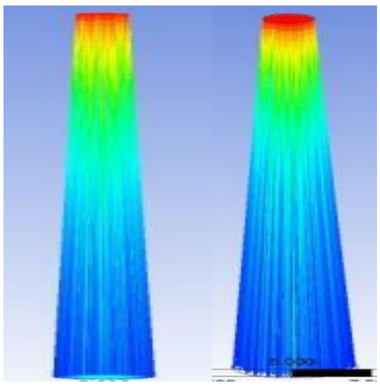

Fig – 7: Velocity distribution in conical draft tube with length 22.4 m and diffuser half angle θ = 2˚ & 3˚

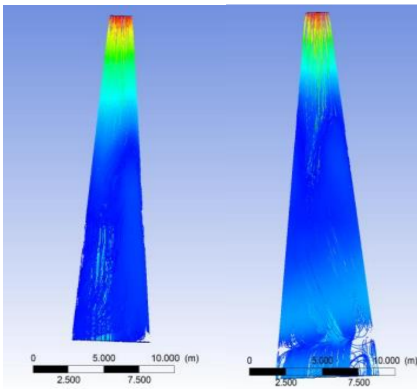

Fig – 8: Velocity distribution in conical draft tube with length 22.4 m and diffuser half angle, θ = 5˚ & 7˚

The flow analysis is carried out in conical draft tube with length 30.4m (L/d_1=19) and diffuser half angle (θ) 2˚, 3˚, 5˚ and 7˚.The velocity at the inlet to all conical draft tubes is 10.1m/s as inlet diameter is fixed. For conical draft tube with length 30.4m and diffuser half angle (θ) 2˚, 3˚, 5˚ and 7˚ the outlet velocities obtained are 1.378m/s, 1.13m/s, 0.5414m/s and 0.3154m/s respectively and outlet pressures are 101459Pa, 101386Pa, 101100Pa and 101106Pa respectively.

Table -2: Head loss in conical draft tube (m) and Efficiency of conical draft tube with length 30.4m

Diffuser half angle (θ)	Head loss in meter	Efficiency (η)
2˚	0.5997	0.86603
3˚	0.6663	0.8532
5˚	0.796	0.8411
7˚	0.9147	0.823

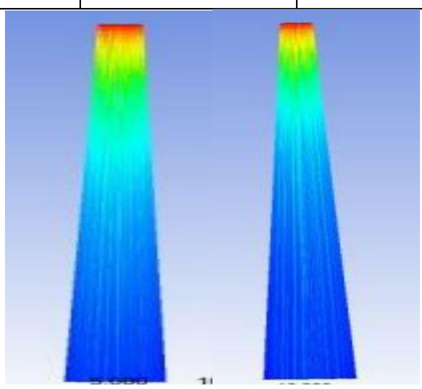

Fig – 9: Velocity distribution in conical draft tube with length 30.4 m and diffuser half angle, θ = 2˚ and 3˚

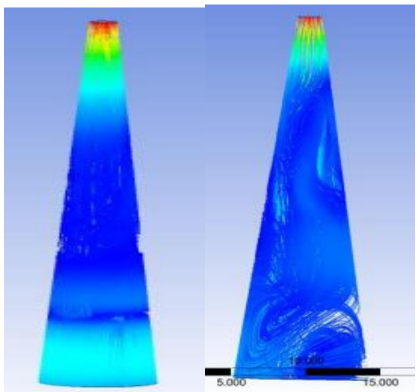

Fig – 10: Velocity distribution in conical draft tube with length 30.4 m and diffuser half angle, θ = 5˚ and 7˚

Losses in the draft tube increase as the diffuser angle increases. Fig. 11 shows swirling motion at the outlet of the conical draft tube with large diffuser angles. Swirling motion is one of the main problem that occurs in draft tube. This swirling motion rotates and generates a rotating oscillatory pressure field. These pressure oscillations can lead to severe vibrations and other losses in the draft tube.

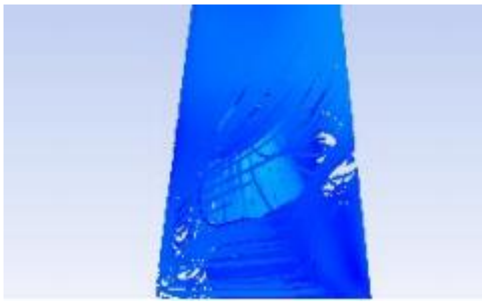

Fig – 11: Swirling motion in the draft tube at diffuser half angle, θ = 7˚

From the graph shown in chart 1 it is concluded that conical draft tube with L/d_1 = 14 and diffuser half angle (θ) 3˚ has more efficiency compared to the other geometric configurations. As the diffuser angle increases, efficiency of the conical draft tubes were found to be decreasing. This is due to swirling motion in the conical draft tube.

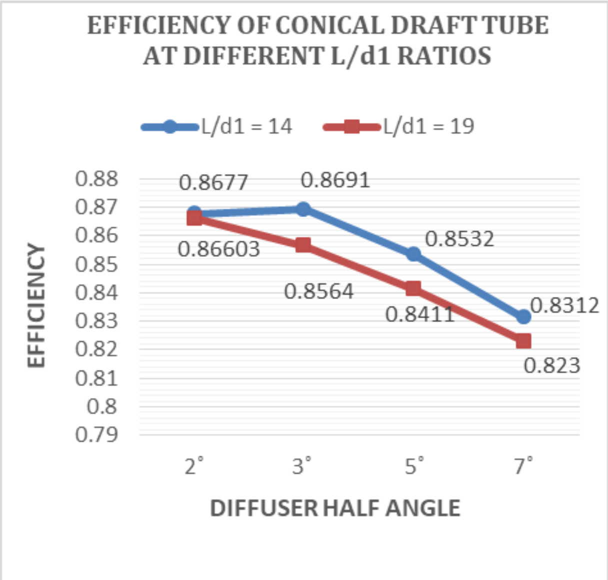

Chart -1: Efficiency of conical draft tube at different length to diameter ratios

5.2 Results of Elbow Draft Tube with Different Geometric Configurations:

Results of four geometric configurations of elbow draft tube are presented here.

5.2.1 Geometric Configuration 1: Elbow draft tube with initial diameter d_1= 1.6m, h_1/d_1 = 1.304, b_1/d_1 = 1.111, b_2/d_1 = 2.11 ratios. These ratios are kept constant for three L/d_1 ratios of 4.5, 5 and 6.

The velocity at the inlet of the elbow draft tube is 9.977 m/s and is same for all geometric configurations as mass flow rate and diameter at the inlet are unchanged.

From the velocity vectors shown in Fig. 12, 13 and 14, it is found that elbow draft tube with geometric configuration 1 for length 7.2 m, 8 m and 9.6 m, the outlet velocities obtained are 1.943 m/s, 1.81656 m/s and 1.6059 m/s respectively and outlet pressures are 101416 Pa, 100875 Pa and 101475 Pa respectively.

Table -3: Head loss in elbow draft tube (m) and Efficiency of elbow draft tube with geometric configuration 1

L/ d_1	Head loss in meters	Efficiency (η)
4.5	0.8755	0.7894
5	1.346	0.7015
6	1.595	0.6596

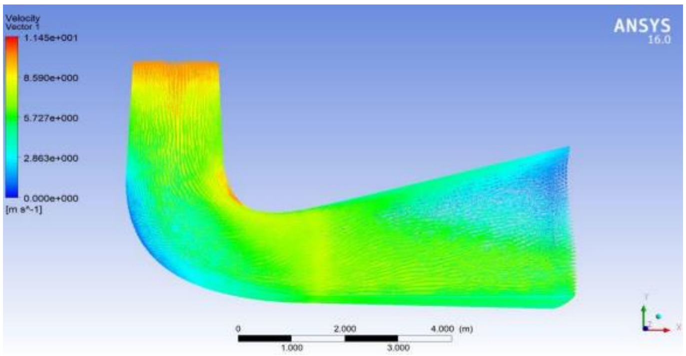

Fig – 12: Velocity vector of elbow draft tube of length 7.2m for geometric configuration 1

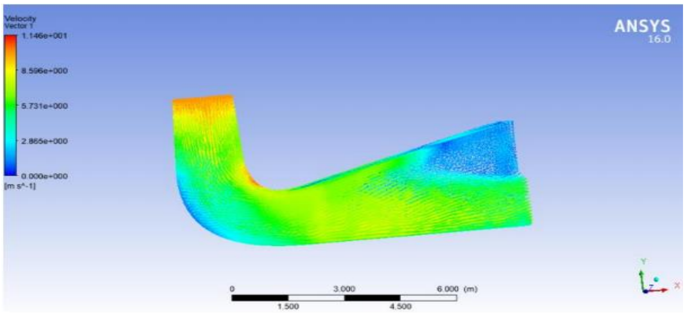

Fig – 13: Velocity vector of elbow draft tube of length 8m for geometric configuration 1

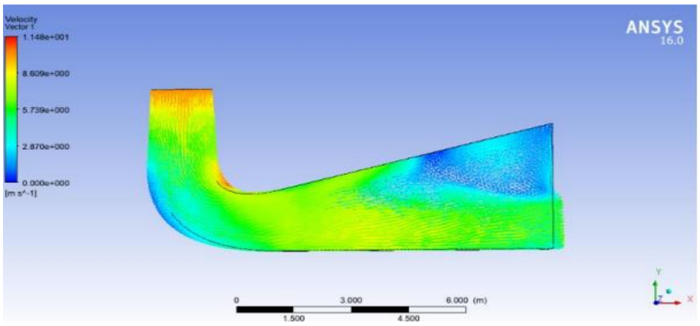

Fig – 14: Velocity vector of elbow draft tube of length 9.6m for geometric configuration 1

It is found that as length of the draft tube is increasing its efficiency decreased, when length of the draft tube is increased from 7.2 m to 8 m, the efficiency in the draft tube is decreased by 8.79%. The geometric configuration 1 with L/d_1= 4.5 is found to have more efficiency compared to L/d_1 =5 and 6 and its efficiency is 78.94 %.

5.2.2 Geometric Configuration 2: Elbow draft tube with initial diameter d_1= 1.6m, h_1/d_1 = 1.304, b_1/d_1 = 1.222, b_2/d_1 = 1.666 ratios. These ratios are kept constant for three L/d_1 ratios of 4.5, 5 and 6.

From the velocity vectors shown in Fig. 15, 16 and 17, it is found that elbow draft tube with geometric configuration 2 for length 7.2 m, 8 m and 9.6m,the outlet velocities obtained are 2.461 m/s, 2.6542 m/s and 2.3005 m/s respectively and outlet pressures are 102665 Pa, 102075 Pa and 100980 Pa respectively.

Table -4: Head loss in elbow draft tube (m) and Efficiency of elbow draft tube with geometric configuration 2

L/d_1	Head loss in meters	Efficiency (η)
4.5	0.7631	0.78905
5	1.453077	0.6427
6	1.4488	0.6614

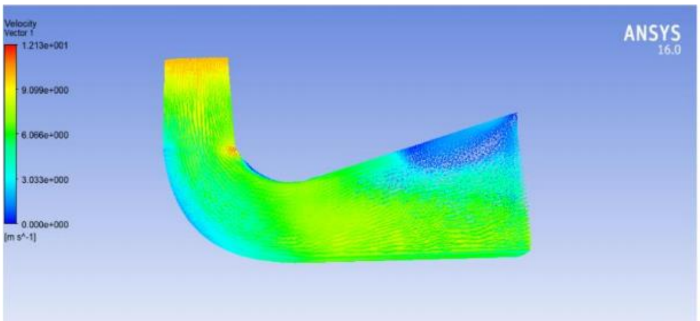

Fig – 15: Velocity vector of elbow draft tube of length 7.2m for geometric configuration 2

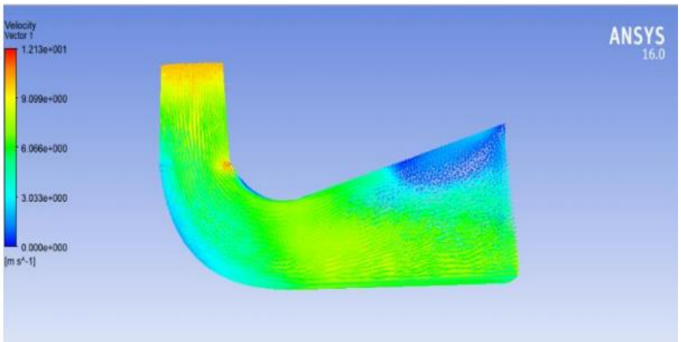

Fig – 16: Velocity vector of elbow draft tube of length 8m for geometric configuration 2

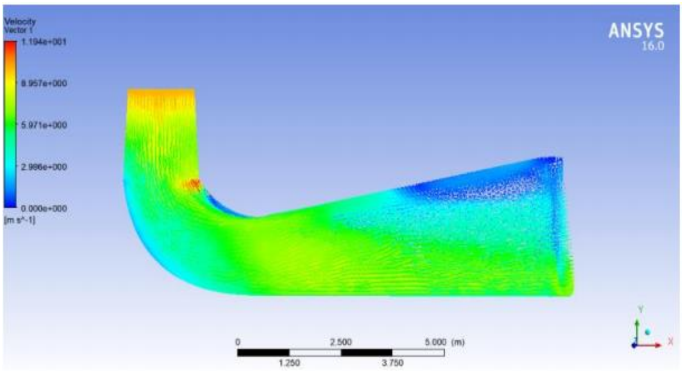

Fig – 17: Velocity vector of elbow draft tube of length 9.6m for geometric configuration 2

As the length of the draft tube is increased from 7.2 m to 8 m, the efficiency in the draft tube is decreased by 14.635%. The geometric configuration 2 with L/d_1= 4.5 is found to have more efficiency compared to L/d_1 =5 and 6 and its efficiency is 78.905 %.

5.2.3 Geometric Configuration 3: Elbow draft tube with initial diameter d_1= 1.6m, h_1/d_1 = 1.193, b_1/d_1 = 1.111, b_2/d_1 = 1.444 ratios. These ratios are kept constant for three L/d_1 ratios of 4.5, 5 and 6.

From the velocity vectors shown in Fig. 18, 19 and 20, it is found that for elbow draft tube with geometric configuration 3 for length 7.2 m, 8 m and 9.6 m, the inlet pressures are 59500 Pa, 64620 Pa and 62696.6 Pa respectively, the outlet velocities obtained are 2.55 m/s, 2.6542 m/s and 2.3005 m/s respectively and outlet pressures are 102100 Pa, 102400 Pa and 101600 Pa respectively.

Table -5: Head loss in elbow draft tube (m) and Efficiency of elbow draft tube with geometric configuration 3

L/d_1	Head loss in meters	Efficiency (η)
4.5	0.3864	0.8585
5	0.85159	0.761354
6	0.87514	0.7722

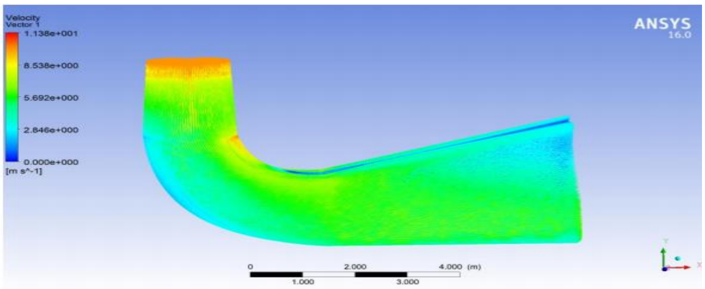

Fig – 18: Velocity vector of elbow draft tube of length 7.2m for geometric configuration 3

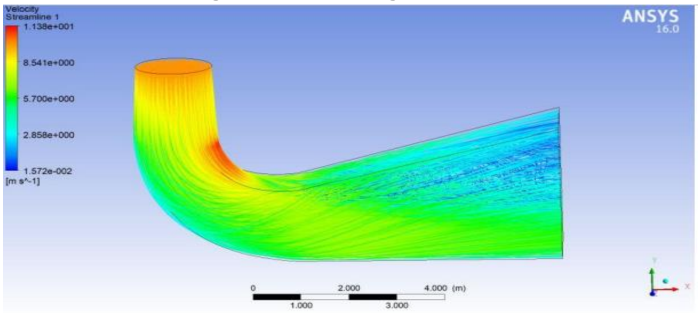

Fig – 19: Velocity vector of elbow draft tube of length 8m for geometric configuration 3

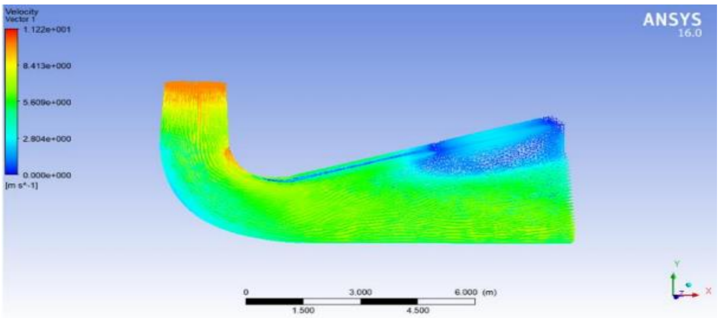

Fig – 20: Velocity vector of elbow draft tube of length 9.6m for geometric configuration 3

It is found that when length of the draft tube is increased from 7.2 m to 8 m, the efficiency in the draft tube is decreased by 9.7146%. The geometric configuration 3 with L/d_1 = 4.5 is found to have more efficiency compared to L/d_1 =5 and 6 and its efficiency is 85.85 %.

5.2.4 Geometric Configuration 4: Elbow draft tube with initial diameter d_1= 1.6m, h_1/d_1 = 1.193, b_1/d_1 = 1.222, b_2/d_1 = 1.666 ratios. These ratios are kept constant for three L/d_1ratios of 4.5, 5 and 6.

From the velocity vectors shown in fig. 21, 22 and 23, it is found that elbow draft tube with geometric configuration 4 for length 7.2 m, 8 m and 9.6 m, the outlet velocities obtained are 2.46 m/s, 2.3005 m/s and 2.0341 m/s respectively and outlet pressures are 101300 Pa, 100775 Pa and 100505 Pa respectively.

Table -6: Head loss in elbow draft tube (m) and Efficiency of elbow draft tube with geometric configuration 4

L/d_1	Head loss in meters	Efficiency (η)
4.5	0.7284	0.7956
5	1.597	0.632
6	1.525	0.6578

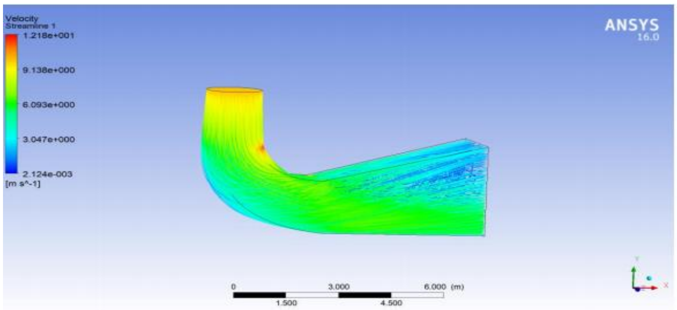

Fig – 21: Velocity vector of elbow draft tube of length 7.2m for geometric configuration 4

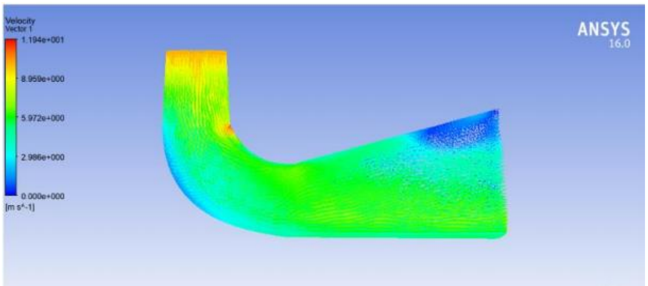

Fig – 22: Velocity vector of elbow draft tube of length 8m for geometric configuration 4

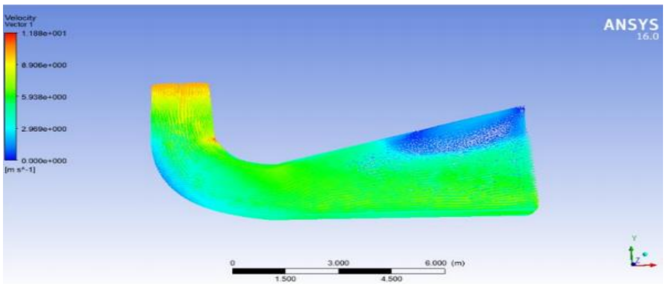

Fig – 23: Velocity vector of elbow draft tube of length 9.6m for geometric configuration 4

As length of the draft tube is increased from 7.2 m to 8 m, the efficiency in the draft tube is decreased by 16.36%. The geometric configuration 4 with L/d_1= 4.5 is found to have more efficiency compared to L/d_1 =5 and 6. Its efficiency is 79.56 %.

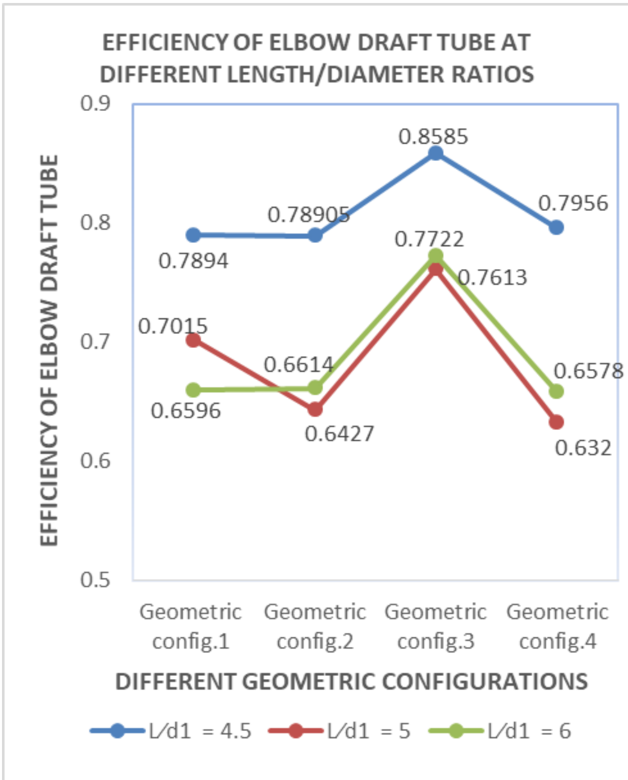

Chart -2: Efficiency of elbow draft tube at different length to diameter ratios

From the graph shown in Chart 2, it is observed that the Elbow draft tube with geometric configuration of initial diameter d_1= 1.6m, h_1/d_1 = 1.193, b_1/d_1 = 1.11, b_2/d_1 = 1.444 for all L/d_1 ratios 4.5, 5 and 6 is found better than other geometric configurations and the elbow draft tube with h_1/d_1 = 1.193, b_1/d_1 = 1.11, b_2/d_1 = 1.444 and L/d_1= 4.5 is more efficient and its efficiency is 85.85%.

6. CONCLUSIONS:

From computational analysis of conical draft tube, it is seen that both length and diffuser angle have significant effect on performance of conical draft tube. The conical draft tube with cone angles greater than 6˚ resulted lesser efficiency due to back flow. The conical draft tube with length to diameter ratio 14 and diffuser half angle 3˚ is better than other geometric configurations.

From the numerical simulations carried out for different geometrical configurations of Elbow draft tube, it is observed that height, length and width at inlet and exit of diffuser have significant effect on performance of elbow draft tube. The Elbow draft tube with geometric configuration initial diameter d_1= 1.6m, h_1/d_1 = 1.193, b_1/d_1 = 1.11, b_2/d_1 = 1.444 for all L/d_1 ratios 4.5, 5 and 6 is found better than other geometric configurations.

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