Optimum Design of Conical Draft Tube by Analysis of Flow Using CFD Simulation

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***Abstract*-The draft tube is a pipe of gradually increasing area, which connects the outlet of the runner to the tailrace. Draft tube helps to convert the exit velocity head into pressure or potential head. Different geometries of draft tube have been created by changing the lengths and diffuser angles. The numerical analysis have been done by using ANSYS 13 CFX code and optimum values of length and diffuser angle are found for the maximum efficiency and head recovery for given boundary conditions. Divergence angles are chosen in such a way that the pressure and potential head varies within the optimal range at angles of 4^0, $5^0$and 6^0. L/D ratio of 4, 10 and 16 has been chosen for flow analysis to check for maximum draft tube efficiency and head recovery that needs to be optimized. The conditions of flow should be so designed that P_1/W shall not become less than vapour pressure head. Ultimately for the model which has shown back flow, the CFD simulation will be terminated.**

CFD simulation has been carried and optimized for L/D ratio. ICEM-CFD software has been used for modeling and meshing, and CFX-13 software has been used for pre processing analysis. Kinetic energy and Turbulence model K- ε and Shear Stress Turbulence (SST) model has been adopted for 4^0, that gives flow analysis results in which head recovery for SST is slightly more, hence for 5^0 and 6^0 divergence angle, SST model for analysis is used. Behavior of flow for various divergence angle have been effectively carried out and results have been obtained, based on the results optimization of design of draft tube model has been done. Significant Improvement has been done and validated with the results of the reference paper published in International Journal of Advances in Engineering, Science and Technology (IJAEST) ISSN: 2249-913X Vol. 2 No. 1 Mar-May 2012, Performance has been enhanced in our research work by optimizing the design of geometry (L/D) ratio.

Keywords: Draft tube, Divergence angle, Potential head, Turbulence model

I. INTRODUCTION

It may be realized that the pressure of water at the outlet of reaction turbine is below the atmospheric pressure and obviously water at such low pressure cannot be discharged directly to the tail race. So, the water leaving the turbine is passed through a gradually diverging pipe leading to the tail race, letting the pressure to rise gradually to reach the atmospheric pressure. This pipe of gradually increasing area is called the draft tube.

The draft tube is a pipe of gradually increasing area, which connects the outlet of the runner to the tailrace.

It is used for discharging water from the exit of the turbine to the tail race. This pipe of gradually increasing area is called a draft tube. One end of the draft tube is connected to the outlet of the runner while the other end is submerged below the level of water in the tail race. The draft tube, in addition to serve a passage for water discharge, has the following two purposes also:

It permits a negative head to be established at the outlet of the runner and thereby increase the net head on turbine. It converts a large proportion of the kinetic energy rejected at the outlet of the turbine into useful pressure energy.

Draft tube helps to convert the exit velocity head into pressure or potential head. The energy recovered in the draft tube is large enough in high speed turbines. Especially, for mixed flow turbines, this exit energy at rotor outlet varies from 4 to 25 % and for axial flow turbines from 20 to 50% of the total available energy. This unused energy can be extracted by the draft tube. The conical type draft tube has the shape of a frustum of a cone with an angle of flare not greater than 80 to avoid separation.

II. METHODOLOGY ADOPTED

A. Geometric Model

ANSYS ICEM CFD is used to build a 3D geometry for CFD analysis is shown in fig. The geometry is created and Meshed. Here ANSYS ICEM CFD 13.0 tool to create the pipe geometry has been used. Modeling has been done in ICEM CFD. The length of pipe is 500mm and inner diameter is 0.038 m.

B. Meshing

Descritization of geometric model is done and an unstructured tetra mesh has been generated from the model using ICEM CFD Software Package.

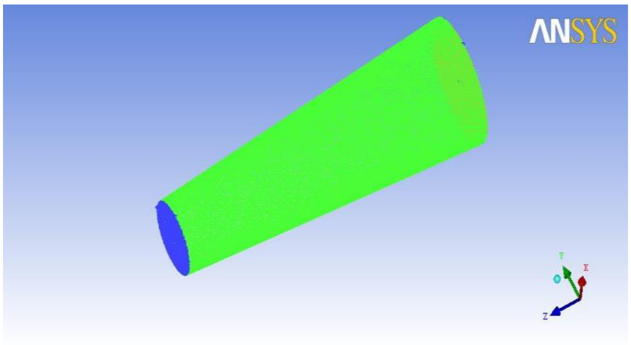
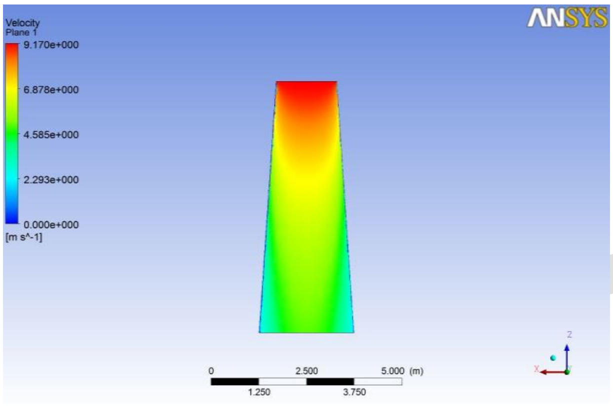


Figure 1: Draft tube meshed model

III. RESULTS AND DISCUSSIONS

A). Results From Post CFD (Model-1 K-ε, Divergence angle = 4^o , L/D = 4)



1).Calculation of draft tube efficiency and recovery of pressure head for (MODEL-1 k-ε, Divergence angle = 4^o, L/D=4)

Recovery of head H = $(v_1^2 - v_2^2)/2g - 0.25v_2^2/2g$

H = $(9.17^2 - 3.75^2)/2*9.81 - (0.25*3.75^{2)}/2*9.81$

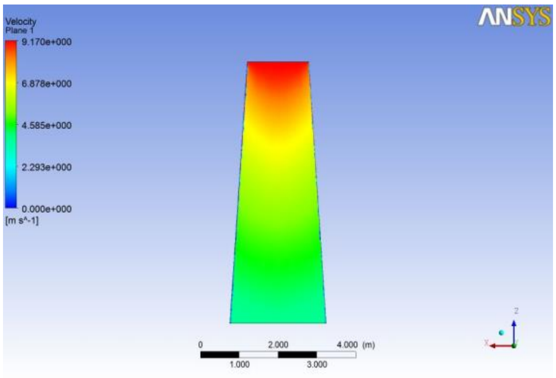
H = 3.381 m

Draft Tube Efficiency η = $\dfrac{\frac{(V1^2-V2^2)}{2g}-\frac{0.25V2^2}{2g}}{\frac{(V1^2-V2^2)}{2g}}$

η = $\dfrac{\frac{(9.17^2-3.75^2)}{2*9.81}-\frac{0.25*3.75^2}{2*9.81}}{\frac{(9.17^2-3.75^2)}{2*9.81}}$

Draft tube efficiency =94.90%

B). Results From Post CFD (Model-2 SST, Divergence angle = 4, L/D=4)



1). Calculation of draft tube efficiency and recovery of pressure head for (MODEL-2 SST, Divergence angle = 4^o, L/D=4)

Recovery of head H = $(v_1^2 - v_2^2)/2g - 0.25v_2^2/2g$

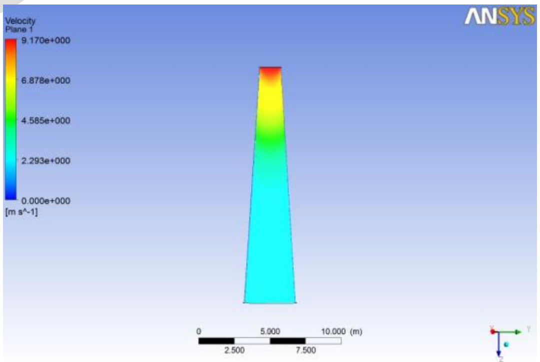
H = $(9.17^2 - 3.60^2)/2*9.81 - (0.25*3.60^2)/2*9.81$

H = 3.450 m

Draft Tube Efficiency = $\dfrac{\frac{(V1^2-V2^2)}{2g}-\frac{0.25V2^2}{2g}}{\frac{(V1^2-V2^2)}{2g}}$

η = $\dfrac{\frac{(9.17^2-3.60^2)}{2*9.81}-\frac{0.25*3.60^2}{2*9.81}}{\frac{(9.17^2-3.60^2)}{2*9.81}}$ **; η = 95.44%**

C). Results from Post CFD (Model-3 K-ε, Divergence angle = 4^o, L/D=10)



1).Calculation of draft tube efficiency and recovery of pressure head for (MODEL-3 K-ε, Divergence angle = 4^o, L/D=10)

Recovery of head H = $(v_1^2 - v_2^2)/2g - 0.25v_2^2/2g$

H = $(9.17^2 - 1.90^2)/2*9.81 - (0.25*1.90^2)/2*9.81$

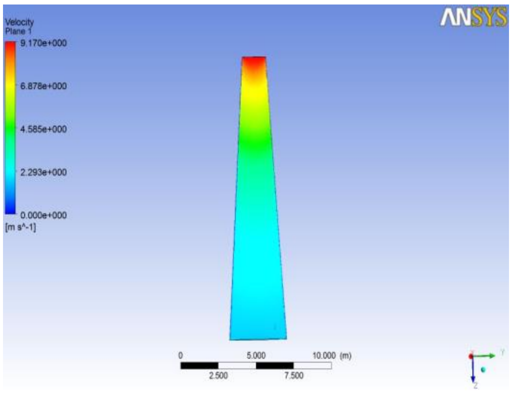
H = 4.05 m

Draft Tube Efficiency η = $\dfrac{\frac{(V1^2-V2^2)}{2g}-\frac{0.25V2^2}{2g}}{\frac{(V1^2-V2^2)}{2g}}$

$$\eta = \frac{\frac{(9.17^2-1.90^2)}{2*9.81}-\frac{0.25*1.90^2}{2*9.81}}{\frac{(9.17^2-1.90^2)}{2*9.81}}$$

η = 98.00 %

D). Results from Post CFD (Model-4 SST, Divergence angle = 4 ^{o}, L/D=10)



1). Calculation of draft tube efficiency and recovery of pressure head for (MODEL-4 SST Divergence angle = 4^o, L/D=10)

Recovery of head H = (v_1^2-v_2^2)/2g- 0.25v_2^2/2g

H = (9.17^2-1.80^2)/2*9.81-(0.25*1.80^2)/2*9.81

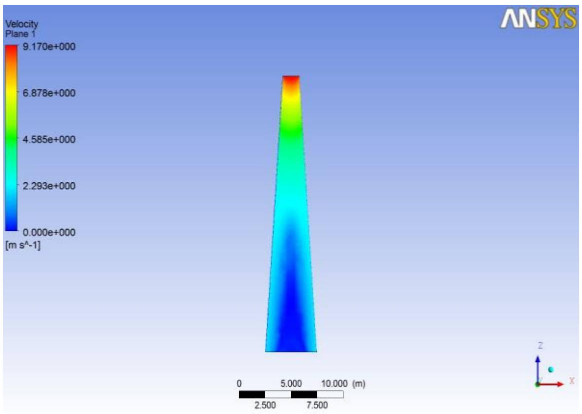
H = 4.122 m

Draft Tube Efficiency $\eta = \frac{\frac{(V1^2-V2^2)}{2g}-\frac{0.25V2^2}{2g}}{\frac{(V1^2-V2^2)}{2g}}$

$$\eta = \frac{\frac{(9.17^2-1.80^2)}{2*9.81}-\frac{0.25*1.80^2}{2*9.81}}{\frac{(9.17^2-1.80^2)}{2*9.81}}$$

η = 99.00 %

E). Results from Post CFD (MODEL-5 k-ε, Divergence angle = 4^o, L/D=15)



1). Calculation of draft tube efficiency and recovery of pressure head for (MODEL-5 k-ε, Divergence angle = 4^o, L/D=15)

Recovery of head H = (v_1^2-v_2^2)/2g - 0.25v_2^2/2g

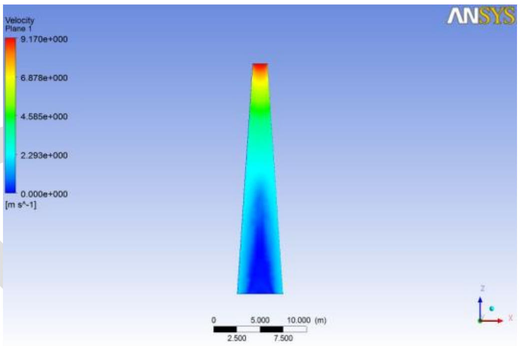
H = (9.17^2-1.00^2)/2*9.81-(0.25*1.00^2)/2*9.81

H = 4.22 m

Draft Tube Efficiency $\eta = \frac{\frac{(V1^2-V2^2)}{2g}-\frac{0.25V2^2}{2g}}{\frac{(V1^2-V2^2)}{2g}}$

$$\eta = \frac{\frac{(9.17^2-1.00^2)}{2*9.81}-\frac{0.25*1.00^2}{2*9.81}}{\frac{(9.17^2-1.00^2)}{2*9.81}} = 99.00\%$$

F). Results from Post CFD (Model-6 SST, Divergence angle = 4^o, L/D=15)



1). Calculation of draft tube efficiency and recovery of pressure head for (MODEL-6 SST, Divergence angle = 4^o, L/D=15)

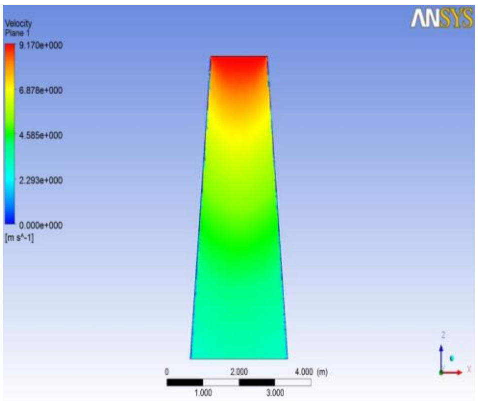
Recovery of head H = (v_1^2-v_2^2)/2g - 0.25v_2^2/2g
H = (9.17^2-0.97^2)/2*9.81-(0.25*0.97^2)/2*9.81 =4.23 m

Draft Tube Efficiency $\eta = \frac{\frac{(V1^2-V2^2)}{2g}-\frac{0.25V2^2}{2g}}{\frac{(V1^2-V2^2)}{2g}}$

$$\eta = \frac{\frac{(9.17^2-0.97^2)}{2*9.81}-\frac{0.25*0.97^2}{2*9.81}}{\frac{(9.17^2-0.97^2)}{2*9.81}}$$

η = 99.00%

G).Results from Post CFD (Model-7 SST, Divergence angle = 5^o, L/D=4)



1). Calculation of draft tube efficiency and recovery of pressure head for (MODEL - 7 SST, Divergence angle = 5^o, L/D=4)

Recovery of head H = $(v_1^2 - v_2^2)/2g - 0.25v_2^2/2g$

H=$(9.17^2-3.10^2)/2*9.81-(0.25*3.10^2)/2*9.81$

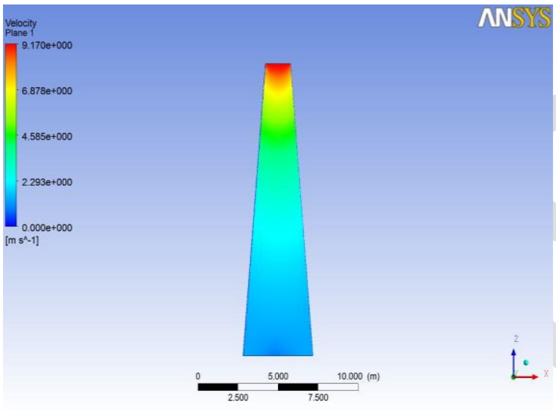
H =3.66 m

Draft Tube Efficiency $\eta = \dfrac{\frac{(V1^2 - V2^2)}{2g} - \frac{0.25V2^2}{2g}}{\frac{(V1^2 - V2^2)}{2g}}$

$$\eta = \frac{\frac{(9.17^2-3.10^2)}{2*9.81} - \frac{0.25*3.10^2}{2*9.81}}{\frac{(9.17^2-3.10^2)}{2*9.81}}$$

η = 96.70%

H). Results From Post CFD (Model-8 SST, Divergence angle = 5^o, L/D=10)



1). Calculation of draft tube efficiency and recovery of pressure head for (MODEL-8 SST, Divergence angle = 5^o, L/D=10)

Recovery of head H = $(v_1^2-v_2^2)/2g - 0.25v_2^2/2g$

H = $(9.17^2-1.25^2)/2*9.81-(0.25*1.25^2)/2*9.81$

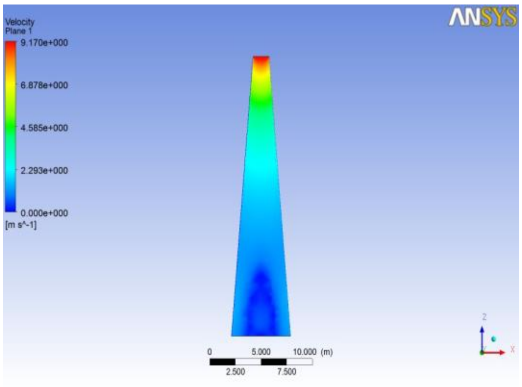
H = 4.187 m

Draft Tube Efficiency $\eta = \dfrac{\frac{(V1^2 - V2^2)}{2g} - \frac{0.25V2^2}{2g}}{\frac{(V1^2 - V2^2)}{2g}}$

$$\eta = \frac{\frac{(9.17^2-1.25^2)}{2*9.81} - \frac{0.25*1.25^2}{2*9.81}}{\frac{(9.17^2-1.25^2)}{2*9.81}}$$

η = 99.50%

I). Results from Post CFD (Model-9 SST, Divergence angle = 5^o, L/D=15)



1). Calculation of draft tube efficiency and recovery of pressure head for (MODEL-9 SST, Divergence angle = 5^o, L/D=15)

Recovery of head H = $(v_1^2-v_2^2)/2g - 0.25v_2^2/2g$

H = $(9.17^2-0.8^2)/2*9.81-(0.25*0.8^2)/2*9.81$

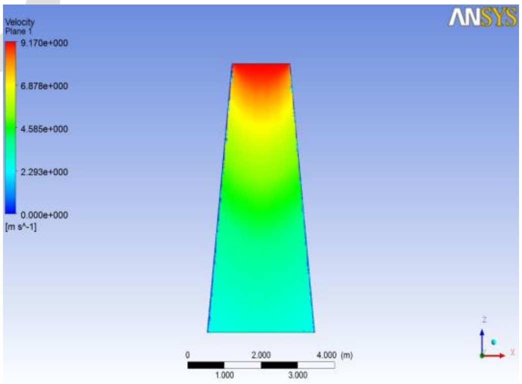
H = 4.244 m

Draft Tube Efficiency $\eta = \dfrac{\frac{(V1^2 - V2^2)}{2g} - \frac{0.25V2^2}{2g}}{\frac{(V1^2 - V2^2)}{2g}}$

$$\eta = \frac{\frac{(9.17^2-0.8^2)}{2*9.81} - \frac{0.25*0.8^2}{2*9.81}}{\frac{(9.17^2-0.8^2)}{2*9.81}}$$

η = 99.60%

J). Results from Post CFD (Model-10 SST, Divergence angle = 6^o, L/D=4)



1). Calculation of draft tube efficiency and recovery of pressure head for (MODEL-10 SST, Divergence angle = 6^o, L/D=4)

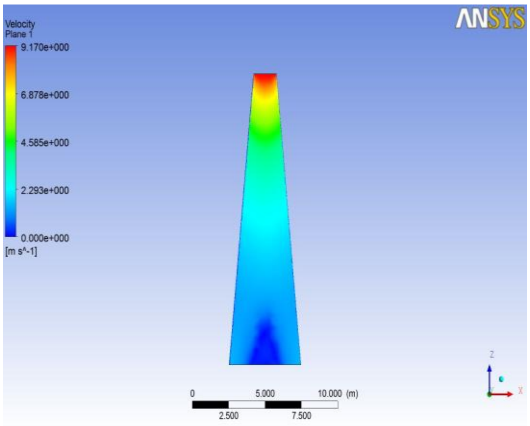
Recovery of head H = $(v_1^2-v_2^2)/2g - 0.25v_2^2/2g$
H = $(9.17^2-2.70^2)/2*9.81-(0.25*2.70^2)/2*9.81$ =3.822 m

Draft Tube Efficiency $= \dfrac{\frac{(V1^2 - V2^2)}{2g} - \frac{0.25V2^2}{2g}}{\frac{(V1^2 - V2^2)}{2g}}$

$$\eta = \frac{\frac{(9.17^2-2.70^2)}{2*9.81} - \frac{0.25*2.70^2}{2*9.81}}{\frac{(9.17^2-2.70^2)}{2*9.81}}$$

η = 97.60%

K). Results from Post CFD (Model-11 SST, Divergence angle = 6^o, L/D=10)



1). Calculation of draft tube efficiency and recovery of pressure head for (MODEL-11 SST, Divergence angle = 6^o, L/D=10)

Recovery of head H = $(v_1^2-v_2^2)/2g - 0.25v_2^2/2g$

H = $(9.17^2-0.95^2)/2*9.81-(0.25*0.95^2)/2*9.81$

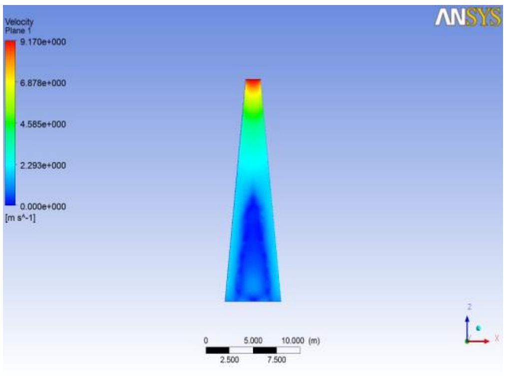
H = 4.228 m

Draft Tube Efficiency η = $\dfrac{\frac{(V1^2-V2^2)}{2g}-\frac{0.25V2^2}{2g}}{\frac{(V1^2-V2^2)}{2g}}$

$$\eta = \frac{\frac{(9.17^2-0.95^2)}{2*9.81}-\frac{0.25*0.95^2}{2*9.81}}{\frac{(9.17^2-0.95^2)}{2*9.81}}$$

η = 99.60%

L). Results from Post CFD (Model-12 SST, Divergence angle = 6^o, L/D=13)



1). Calculation of draft tube efficiency and recovery of pressure head for (MODEL-12 SST, Divergence angle = 6^o, L/D=13)

Recovery of head H = $(v_1^2-v_2^2)/2g - 0.25v_2^2/2g$

H = $(9.17^2-0.65^2)/2*9.81-(0.25*0.65^2)/2*9.81$

H = 4.258 m

Draft Tube Efficiency η = $\dfrac{\frac{(V1^2-V2^2)}{2g}-\frac{0.25V2^2}{2g}}{\frac{(V1^2-V2^2)}{2g}}$

$$\eta = \frac{\frac{(9.17^2-0.65^2)}{2*9.81}-\frac{0.25*0.65^2}{2*9.81}}{\frac{(9.17^2-0.65^2)}{2*9.81}}$$

η = 99.80%

IV. CONCLUSIONS

It is seen from the numerical simulation of conical draft tube that both length and diffuser angle has significant effect on performance of straight conical draft tube. There is no significant variation in head loss, recovery and efficiency of draft tube with length to diameter aspect ratio beyond 13 (**L/D=13)**. Therefore, increase in length to diameter aspect ratio of draft tube beyond 13 (**L/D=13)** will not be economical and also increase in length leads to problem of cavitations in turbine. Secondly maximum efficiency is achieved at diffuser angle of 6 degree. Hence the aspect ratio of draft tube corresponding to **L/D=13** is the optimum length to diameter aspect ratio of draft tube. Most of the hydel power plants have used straight conical draft tube with the aspect ratio equal to 13 (**L/D=13)**, diffuser angle ranging from 4° to 6° and hence the results from numerical simulation are validated corresponding to the available literature.

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