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DESIGN AND FLOW ANALYSIS OF ENHANCED KAPLAN TURBINE

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ABSTRACT

*This paper presents the study of fluid flow analysis in enhanced **Kaplan turbine**. By changing the blade design, we consume the more energy even at low pressure of water flow in the Turbine. This turbine works on the principle of **Archimedean screw** that convert's the potential energy of water on an upstream level into kinetic energy. Water flows into the turbine and its weight presses down onto the blades of the turbine, which in turn forces the turbine to turn. Water flows freely off the end of the turbine into the river. Also this study focused to found the variations of velocity components and the pressure by average circumferential area (ACA) from inlet to outlet of the blades and used as factors to analyzed the flow inside the blades, the results of this analysis shows a good prediction of the flow behavior inside the blades and this lead to acceptable blade design, which can be used in Kaplan turbine. Blade complex geometry and design have been developed by using the coordinates point system on the blade in **PRO-E /CREO software**. Based on the flow rate and heads, blade profiles are analyzed using **ANSYS software** to check and compare the output results for optimization of the blades for improved results which show that by changing blade profile angle and its geometry can be optimized using the computational techniques with changes in CAD models.*

Key words: Ansys, Blades, CFD, Creo, Energy, Kaplan turbine.

I. INTRODUCTION

The demand for increasing the use of renewable energy has risen over the last few years due to environmental issues. The high emissions of greenhouse gases have led to serious changes in the climate. Although the higher usage of renewable energy would not solve the problems over night, it is an important move in the right direction. The field of renewable energy includes, for example wind power, solar power and waterpower. The first use of waterpower as an energy source dates back centuries. The energy was utilized, for instance, to grinding grain. The applied machinery for this purpose was based on simple water wheels. Hydropower was the first renewable source which was used to generate electricity over 100 years ago. Today, hydropower is an important source of producing electrical energy; approximately 20% of the world electricity is supplied by hydroelectric power plants. Depending on the head and discharge of the sites, the

II.DESIGN OF KAPLAN TURBINE

Mainly the Kaplan turbine is used to create the power from the low head turbines. Large flow rate is required from the Kaplan turbine. The main purpose of the Kaplan turbine is used to provide loading at large flow rates. The design of the Kaplan turbine and Francis turbine are very much similar. The water flow in the Kaplan turbine is in the radial direction the flow is entered and exists axially. In the inlet of the turbine guide vanes are fixed. We can see the passage in between the rotor and guide vane which the flow is in the radial direction. Initially the flow must be in radial direction but the radial direction is forced to move in the axial direction. We can observe the similarity in between the rotor and propeller of a ship. To the central shaft of the turbine rotor blades are attached. With the help of moveable joints blades are connected to the shaft. The blades are rotated according to the water flow rate and the water head available. Compared to the other axial flow Turbines, the blades of the Kaplan turbine are not planer. So they are designed with a twist along the total length so it allows rotation of the water flow at the inlet and leaves at the axial flow.

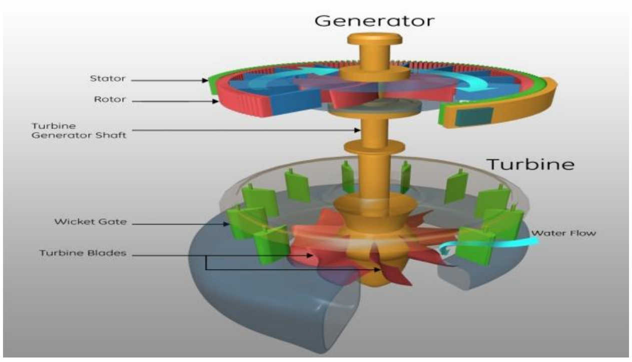

Fig.2.1 Kaplan Turbine

III.ARCHIMEDEAN SCREW

The screw turbine is a water turbine which uses the principle of the Archimedean screw to convert the potential energy of water on an upstream level into kinetic energy. It may be compared to the water wheel, though the screw turbine has a much higher efficiency. The turbine consists of a rotor in the shape of an Archimedean screw which rotates in a semicircular trough. Water flows into the turbine and its weight presses down onto the blades of the turbine, which in turn forces the turbine to turn. Water flows freely off the end of the turbine into the river. The upper end of the screw is connected to a generator through a gearbox.

By way of hydropower introduction, *'small hydropower'* actually means less than 1 MW power output, while *'micro hydropower'* is less than 100 kW. Typically a small hydro system could power 1,000 homes, and a micro hydro system could power 100 homes, which by most people's standards is actually quite big.

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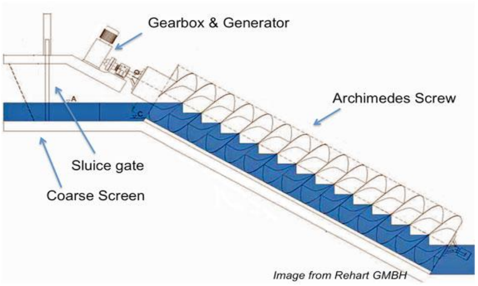

Fig3.1 Archimedean screw Turbine

3.1. Advantages of Archimedean screw turbine

- ❖ Cutting of trees & displacement of people are not needed.
- ❖ Suitable for power consumption of small villages or one or more than one families.
- ❖ Small canals, ponds & rivers etc. can be utilized as resources.
- ❖ Negligible maintenance & operational cost. Fish friendly. Easy & fast installation.
- ❖ Less civil work required.
- ❖ Efficient for low & variable water heads (min. 1m head).
- ❖ To improve blade design of Kaplan turbine and analyze its performance using the CFD.
- ❖ To increase the efficiency of Archimedean screw.
- ❖ To decrease the frictional losses, runner losses and draft tube losses.

3.2 OBJECTIVE OF RESEARCH WORK

- ➢ To improve blade design of Kaplan turbine and analyze its performance using the CFD.
- ➢ To increase the efficiency of Archimedean screw.
- ➢ To decrease the frictional losses, runner losses and draft tube losses.

IV.DESIGN CALUCUALTIONS

From the above chapter the problem has been identified and design calculations are done for the Kaplan turbine and modified Archimedean screw turbine.

Most turbine are works only in high water flow, conditions it can be made to work under low head by changing the design and velocity of flow.

The design of the runner is based on the main parameter such as heads. To calculate, the forces on the blade or to determine the dimensions of the adaptation mechanism the parameters of the turbine are needed.

4.1 TURBINE DESIGN

Design specifications are taken from the reference journal titled "Modelling and Analysis of a very Low Head Kaplan Turbine Runner Blades for Rural Area of Punjab" and the "Blade angles are taken form the "Blade Profile Optimization of Kaplan Turbine Using CFD Analysis".

4.1.1 Power

A water turbine is a rotary machine that converts kinetic energy and potential energy of water into mechanical work. Thus power of the runner can be calculated with the following equation:

$$P = Q\, H\, \eta_h \rho\, g \qquad - 4.1$$

Where,

Q – Discharge m^3/s

H – Gross head m

η_h – Hydraulic efficiency %

ρ – Water density kg/m^3

g – Acceleration of gravity m/s^2

4.1.2 Specific speed

The specific speed is defined as the revolution per minute or second.

$$n_s = \frac{n\sqrt{Q}}{E^{\frac{3}{4}}} \qquad - 4.2$$

Where,

E –Specific hydraulic energy of machine J/kg

n –Rational speed of the turbine s^{-1}

The specific hydraulic energy of machine can be determined with the following equation:

$$E = H_n\, g$$

Where,

H_n– Net head m

$$n_s = \frac{2.294}{H_n^{\,0.486}} \qquad -4.3$$

4.1.3 Rational speed

The rational speed is the rotation of blade with specific speed, thus resulting equation has to be re-arranged to the rational speed of the turbine.

$$n = \frac{E^{\frac{3}{4}}}{n_s\sqrt{Q}} \qquad -4.4$$

4.1.4 Runway speed

The runway speed is the maximum speed which the turbine can theoretically attain. It is achieved during a load rejection. Depending on the regulation of the Kaplan turbine, the following guidelines can be used to determine the runaway speed.

Table 4.1Selection of Runway speed

(International Journal of Scientific & Engineering Research July-2014)

Turbine Type	Runway speed (n_{max})
Single regulated Kaplan turbine	2.0-2.6
Double regulated Kaplan turbine	2.8-3.6

4.1.5 Runner diameter

The runner diameter D_e can be calculated by the following equation:

$$De = 84.5 (0.79 + 1.062\ n_s)\frac{\sqrt{Hn}}{60*n} \qquad - 4.5$$

4.1.6 Hub diameter

The hub diameter Di can be calculated with the following equation:

$$D_i = 0.25 + \frac{0.0951}{ns} D_e \qquad - 4.6$$

4.2 BLADE DESIGN

The blade dimension has been selected from the (**National Advisory Committee for Aeronautics)**NACA airfoil of the chamber and also reference from the journal of the ISSN 0254-7821.

4.2.1 Peripheral Velocity

The peripheral velocity at inlet and outlet are equal with relative to blades adjacent rows, with respect to each other are calculated below equation:

$$u_1 = u_2 = \frac{\pi D_i N}{60} \qquad -4.7$$

Where,

D_o – Outer diameter of the runner blade m

N – Speed of the blade rpm

u_1- inlet of the peripheral velocity m/s

u_2- outlet of the peripheral velocity m/s

4.2.2 Velocity of the Flow

The flow velocity perpendicular to the tangential direction remains constant throughout and is equal to that at the inlet to the draft tube.

$V_{f1} = V_{f2}$ -4.8

Where,

V_{f1} – inlet velocity flow m/s

V_{f2} – outlet velocity flow m/s

4.2.3 Area of Flow

Area of flow is the volume of fluid which passes per unit time of velocity

$A = \frac{\pi}{4} (D_e^2 - D_i^2)$ -4.9

Where,

A – Area of the inlet and outlet m

D_e – runner diameter m

D_i – hub diameter m

4.2.4 Discharge flow rate

The guide vanes regulate the rate of water flow through the turbine by changing the opening between them is discharge flow rate.

$Q = \frac{\pi}{4} (D_e^2 - D_i^2) V_{f1}$ -4.10

Where,

Q – Discharge flow rate m^3/s

4.2.5 Hydraulic Efficiency

The Kaplan turbine is a propeller-type water turbine which has adjustable blades with automatically adjusted wicket gates to achieve efficiency over a wide range of flow and water level.

$\eta_h = \frac{V_{w_1} u_1}{gH}$ - 4.11

Where,

V_{w_1} - Inlet velocity triangle m/s

V_{w_1} - Outlet velocity triangle m/s

H -Head of the Kaplan turbine m

4.2.6 Flow ratio

The flow ratio is the efficiency of turbine water flow with velocity at height is calculated below equation:

$$V_{f1}/\sqrt{2gH} \quad - 4.12$$

4.2.7 Speed ratio

The speed ratio is the efficiency of turbine speed with velocity from the height is calculated below equation:

$$u_1/\sqrt{2gH} \quad - 4.13$$

4.2.8 Overall Efficiency

The overall efficiency is defined as shaft power to water power of output is calculated below:

$$\eta_o = \frac{Shaft\ power}{Water\ Power} \quad - 4.14$$

$$Water\ power = \frac{\rho\, g\, Q\, H}{1000} \quad - 4.15$$

4.3 DRAFT TUBE

The draft-tube is a pipe of gradually increasing area which connects the outlet of the runner to the tail race. 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.

4.3.1 Efficiency of draft- tube

$$\eta_d = \frac{\left(\frac{Vf_1^2}{2g} - \frac{Vf_2^2}{2g}\right) - h_f}{\frac{V_1^2}{2g}} \quad - 4.16$$

Where,

h_f – loss of energy between sections m

4.4 FORCE CALCULATION

The various types of forces are applied in the turbine as calculated below:

4.4.1 Centrifugal force

An inertial force which tends to pull an object outward when it is in orbit or is rotating around a center is centrifugal force.

$$F_c = mr\omega^2 \quad - 4.17$$

Where,

m – Mass of the blade kg

r – Radius of the runner m

ω – Angular velocity rad/s

4.4.2 Water force

The rotary machine that converts kinetic energy and potential energy of *water* since the runner is spinning, that force acts through a distance. It as the two types of forces are tangential and axial component of water force.

$F_w = \rho Q r \pi$ - 4.18

4.4.3 Tangential component of water force

The force calculated in tangential direction of water flow with angle

$F_{wt} = F_w \cos\theta$ - 4.19

4.4.4 Axial component of water force

The force calculated in axial direction of water flow with angle

$F_{wa} = F_w \sin\theta$ - 4.20

V.THEORITICAL CALCULATION

5.1 Turbine Design

5.1.1 Power

$P = Q\, H\, \eta_h \rho\, g$ **$\rho = 998\ Kg/m^3$, $g = 9.81\ m/s^2$**

P = 7.07x1.16x0.75x998x9.81

P = 60.23 kW

5.1.2 Specific speed

$n_s = \frac{n\sqrt{Q}}{E^{\frac{3}{4}}}$ $E = H_n x\ g$

$n_s = \frac{2.294}{{H_n}^{0.486}}$ $n_s = \frac{2.294}{1.16^{0.486}}$

$n_s = 2.13$

5.1.3 Rational speed

$$n = \frac{n_s E^{\frac{3}{4}}}{\sqrt{Q}}$$

$$n = \frac{2.13 \ X \ 11.37^{\frac{3}{4}}}{\sqrt{7.07}}$$

$$\mathbf{n = 5s^{-1}}$$

5.1.4 Runway speed

$n_{max} = n \times 2.6$ - Turbine type is single regulated Kaplan 2.0-2.6

$n_{max} = 5 \times 2.6$

$$\mathbf{n_{max} = 13s^{-1}}$$

5.1.5 Runner diameter

$$D_e = 84.5\,(0.79 + 1.062\ n_s)\frac{\sqrt{Hn}}{60 * n}$$

$$D_e = 84.5\,(0.79 + 1.062 \times 2.09)\frac{\sqrt{1.16}}{60 * 5}$$

$$\mathbf{D_e = 1.25\ m}$$

5.1.6 Hub diameter

$$D_i = 0.25 + \frac{0.0951}{ns} D_e$$

$$D_i = 0.25 + \frac{0.0951}{2.09}\ 1.25$$

$$\mathbf{D_i = 0.36\ m}$$

5.2 BLADE DESIGN

5.2.1 Velocity Flow

$$\mathbf{V_{f1} = V_{f2}}$$

$$Q = \frac{\pi}{4}\,(D_e^2 - D_i^2)\ V_{f1}$$

$$V_{f1} = \frac{7.07 \ X \ 4}{(1.25^2 - 0.36^2)\pi}$$

$$\mathbf{V_{f1} = 4.19\ m/s}$$

5.2.2 Inlet velocity triangle,

$$\text{Tan}\alpha = \frac{V_{f2}}{V_{w1}}$$

$$V_{w1} = \frac{V_{f2}}{\tan\alpha}$$

$$V_{w1} = \frac{4.19}{\tan 21.23^{\circ}}$$

$$\boldsymbol{V_{w1}} = \mathbf{5.98\ m/s}$$

5.2.3 Inlet peripheral velocity

$$\eta_h = \frac{V_{w_1} u_1}{gH}$$

$$0.75 = \frac{5.98 X u_1}{9.81\ X\ 1.16}$$

$$\mathbf{u_1 = 1.427\ m/s}$$

5.2.4 Flow ratio

$V_{f1}/\sqrt{2gH}$ = **0.87**

5.2.4 Speed ratio

$u_1/\sqrt{2gH}$ = **0.299**

5.2.5 Overall Efficiency

$$\eta_o = \frac{Shaft\ power}{Water\ Power}$$

$$\text{Water power} = \frac{\rho\, g\, Q\, H}{1000}$$

$$\text{Water power} = \frac{998 \times 9.81 \times 7.07 \times 1.16}{1000}$$

$$\eta_o = \frac{60}{80.3}$$

$$\boldsymbol{\eta_o} = \mathbf{0.74}$$

5.2.6 Efficiency of draft- tube

$$\eta_d = \frac{\left(\frac{Vf_1^2}{2g} - \frac{Vf_2^2}{2g}\right) - h_f}{\frac{V_1^2}{2g}}$$

$$\eta_d = \frac{\left(\frac{4.19^2}{2\ X\ 9.81} - \frac{4.19^2}{2\ X\ 9.81}\right) - 11}{\frac{4.19^2}{2\ x\ 9.81}}$$

η_d= **0.54**

5.3 FORCE CALCULATION

5.3.1 Centrifugal force

$F_c = mr\omega^2$

$F_c = mr\omega^2 \quad = \omega = 2\pi n$

$= 2\pi 5 = 31.41 s^{-1}$

$F_c = 525 \times 0.625 \times 31.4^2$

$\mathbf{F_c = 323518.125\ N}$

5.3.2 Water Force

$F_w = \rho Q r \pi$

$F_w = 998 \times 7.07 \times 0.625 \times \pi$

$\mathbf{F_w = 13854.14871\ N}$

5.3.3 Tangential component of water force

$F_{wt} = F_w \cos\theta$

$F_{wt} = 13854.14871 \cos (19.1^\circ)$

$\mathbf{F_{wt} = 13084.82594\ N}$

5.3.4 Axial component of water force

$F_{wa} = F_w \sin\theta$

$F_{wa} = 13854.14871 \sin (19.1^\circ)$

$\mathbf{F_{wa} = 4533.325\ N}$

Thus model of existing Kaplan turbine of theoretical calculation are calculated and it as modeling and analysis is below process.

VI. MODELING AND ANALYSIS

Modeling:

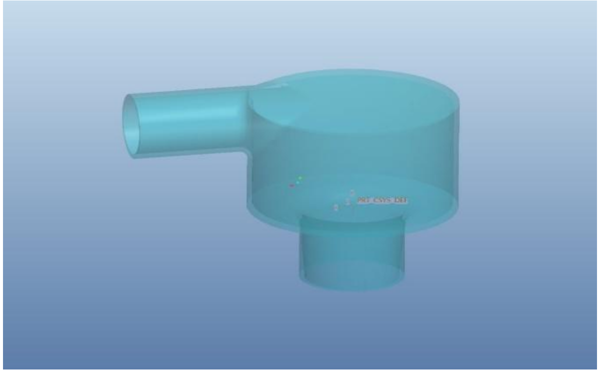

Fig6.1 Kaplan Turbine Casing 3D Model

Archimedean screw Turbine Casing 3D Model

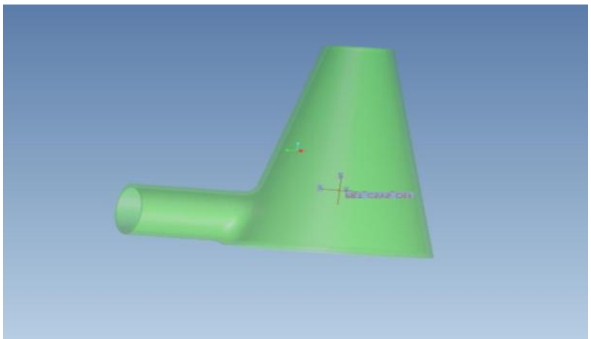

Fig 6.2 Archimedean screw Turbine Casing 3D Model

Kaplan Turbine Vane 3D Model

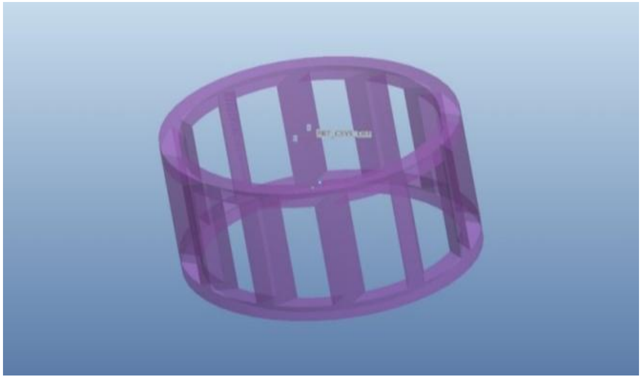

Fig 6.3 . Kaplan turbine Vane Design 3D model

Kaplan turbine Blade Design 3D Model

Blade rotates by the force of water from inlet and the rotating blade runners to the draft tube. It discharge water outlet with the same velocity of inlet to outlet in particular angle of blade are shown in fig 5. and fig 6.

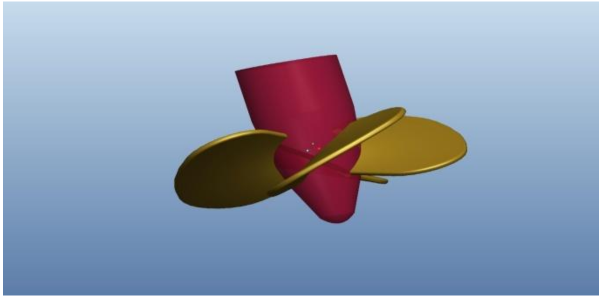

Fig.6.4 Kaplan turbine Blade Design 3D Model

Archimedean screw blade Design 3D Model

The spiral rotation of blade to flow water easily from inlet to outlet with low head flow of water to outlet discharge

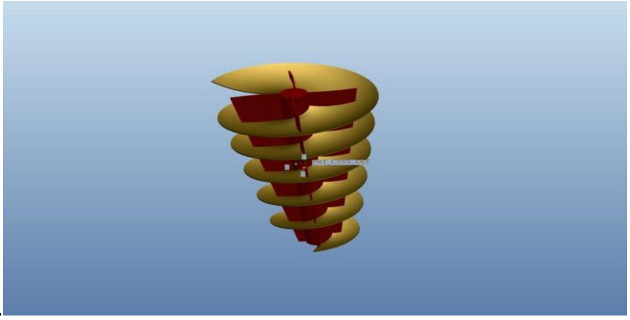

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Fig.6.5 Archimedean screw turbine Blade Design 3D Model

Kaplan turbine Design (Assembly 3D model)

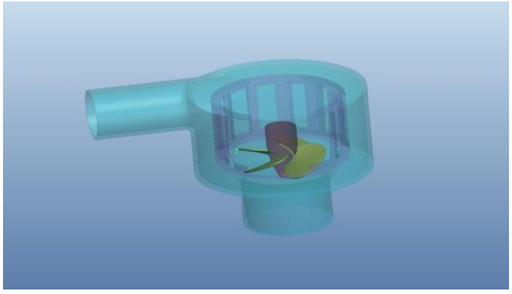

Fig. 6.6 Assembly of Kaplan turbine 3D Model

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Archimedean screw turbine Design (Assembly 3D model)

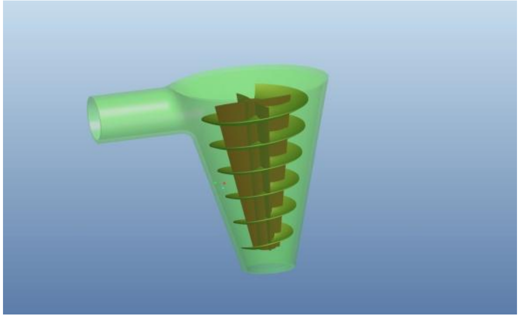

Fig 6.7Assembly of Archimedean screw turbine 3D Mode

VII.RESULTS AND DISCUSSION

At the reference the design specifications and boundary conditions are applied in the above analysis software of ANSYS 14.5 for CFD. Thus the various results are analyzed and output are discussed below:

Fluent flow analysis of velocity on turbines

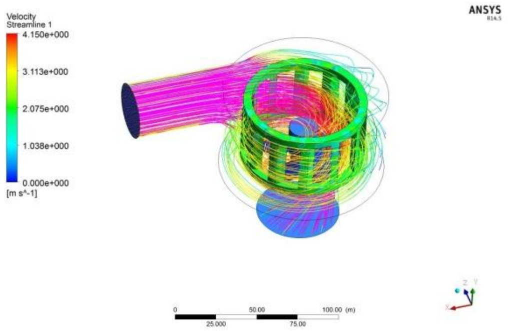

Fig 7.1. Velocity flow analysis on 25% of turbo surface

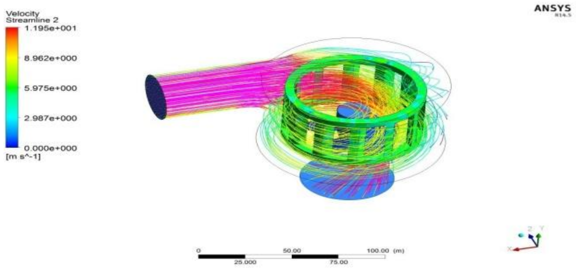

Fig 7.2. Velocity flow analysis on 50% of turbo surface

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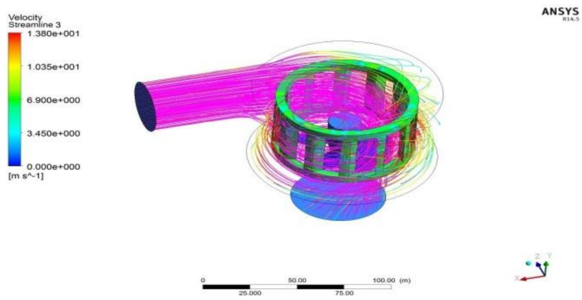

Fig 7.3 Velocity flow analysis on 75% of turbo surface

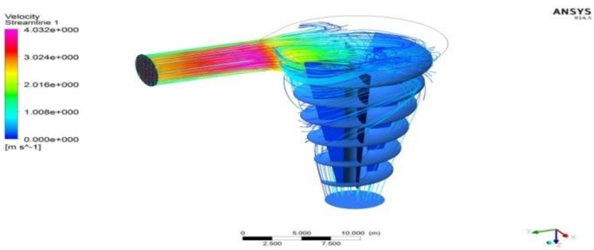

Fig 7.4 Velocity flow analysis on 25% of turbo surface

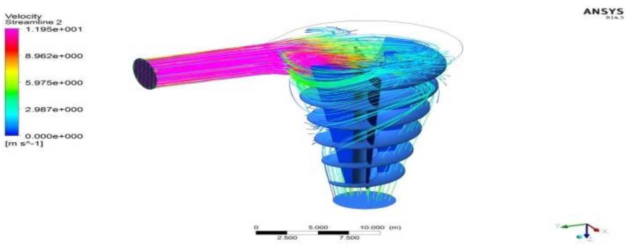

Fig 7.5 Velocity flow analysis on 50% of turbo surface

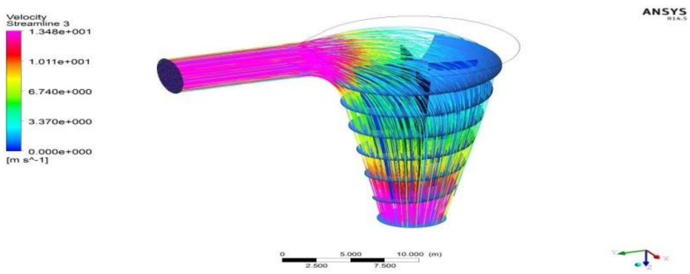

Fig7.6 . Velocity flow analysis on 75% of turbo surface

Fluent flow analysis of Pressure counter on urbines

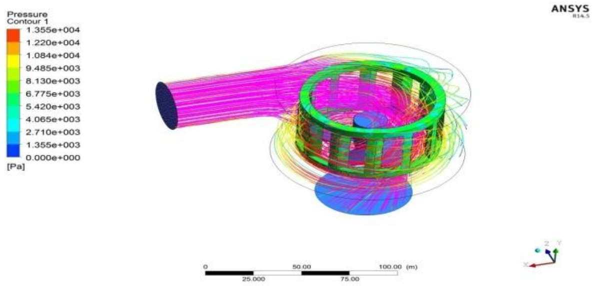

Fig7.7 Pressure Counter analysis on 25% of turbo surface

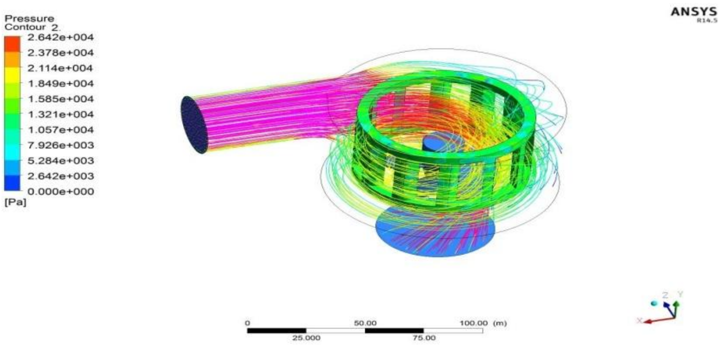

Fig7.8 Pressure Counter analysis on 50% of turbo surface

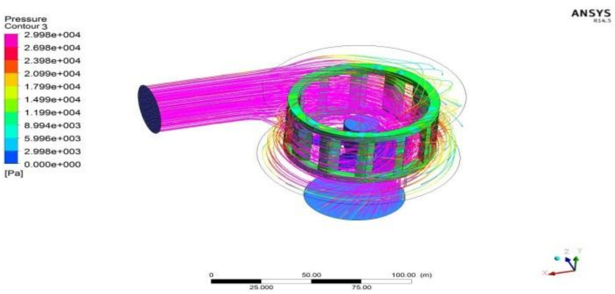

Fig 7.9 . Pressure Counter analysis on 75% of turbo surface

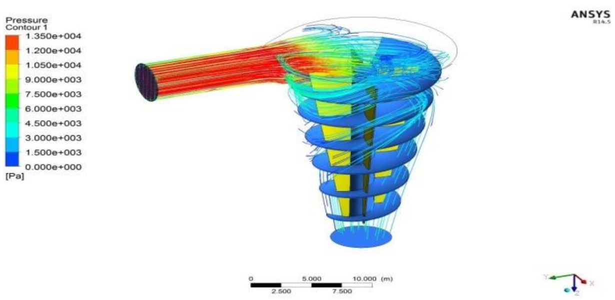

Fig7.10. Pressure Counter analysis on 25% of turbosurface

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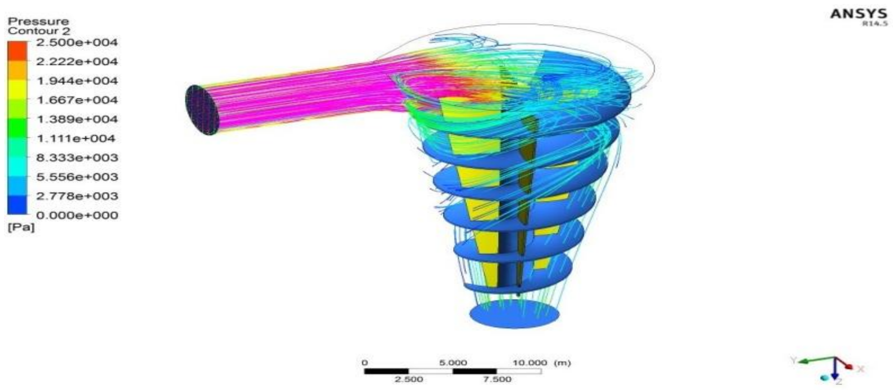

Fig 7.11. Pressure Counter analysis on 50% of turbo surface

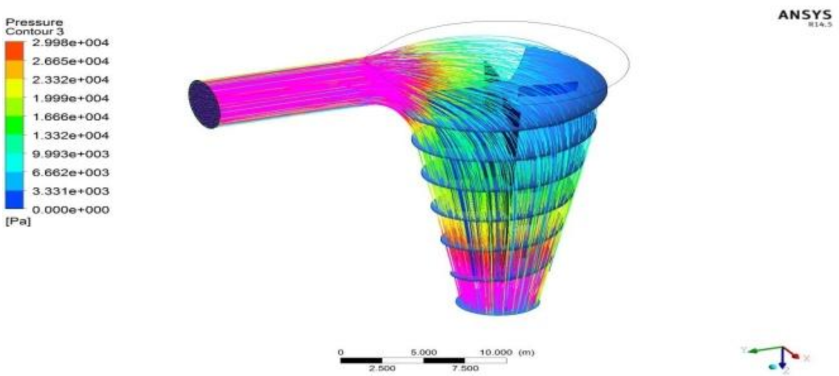

Fig7.12. Pressure Counter analysis on 75% of turbo surface

Common turbine chart from the standard journals reference

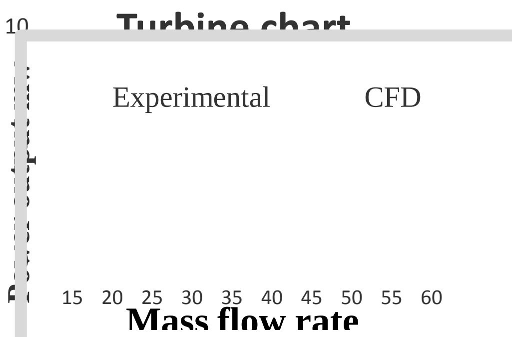

Fig 7.12. Comparison of Power output vs Flow rate

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Comparison of Kaplan turbine chart

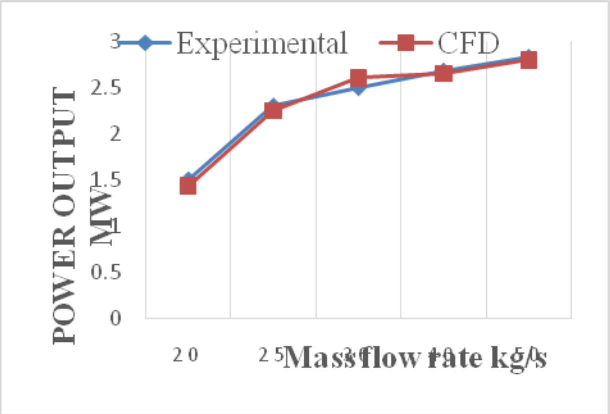

Fig 7.13. Comparison of Kaplan turbine Power output vs Flow rate

Comparison of Archimedean screw turbine chart

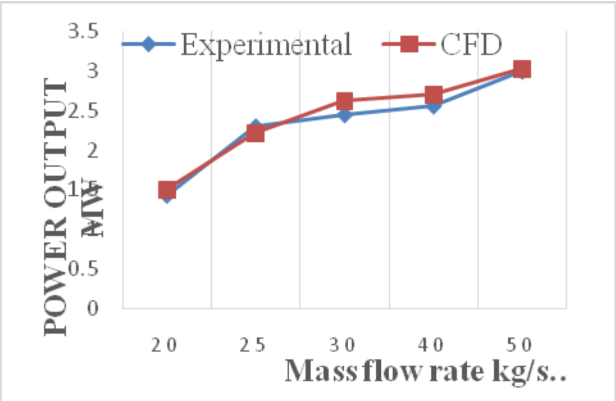

Fig 7.14. Comparison of Archimedean screw turbine Power output vs Flow rate

VIII.CONCLUSION

From the above results of both Kaplan and Archimedean screw turbines, the velocity flow and pressure counter with density of water 998.23 kg/$m^3$is compared. The result shows that Archimedean screw turbine is the best to implement for power generation and safe to run with low cost and maintenance. When the blade angles were changed,the increase in power and flow of velocity of the turbine with more efficiency. As compared with the Kaplan turbine can generate 2.83Mw and Archimedean screw turbine can generate 3.03Mwpower output. Thus the Archimedean screw turbine as given as 83% efficiency

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