NUMERICAL STUDY OF ARCHIMEDEAN SCREW TURBINE

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Abstract – *A numerical study of an Archimedes screw turbine is the focus of this work. This is an alternative solution to small scale hydropower as it exploits unused resources such as small rivers or streams. Archimedes screw plants uses the reverse principle of the screw pump and exploit the available stream power for energy production in very low head application. Based on the previous studies, the optimal sizing of Archimedes screws is chosen .The study is done on screw turbine to study mechanical efficiency according to its geometrical parameters, its rotational speed, slope angle, number of blades etc. This work has been done to find the parameters which influence the working of screw turbine and therefore it is found that torque and efficiency increases with increasing mass flow rate and number of blades whereas it increases upto a point then decreases in case of angle of inclination*

Key Words: ***Archimedes screw turbine, screw pump, mechanical efficiency, low head, rotational speed, slope angle, number of blades, etc***

1. INTRODUCTION

In our current scenarios, we only utilize renewable energy sources for 22.8% of our global electricity production. For achieving a truly sustainable energy for the future generation, we need to utilize the renewable energy in more useful ways in electricity generation. Hydropower, which is the most often applied on a large scale, representing the principal source of renewable energy throughout the world, since the water is renewable source. Although most of the large-scale European hydropower opportunities have already been exhausted due to their geographical limitations, a strong potential has arisen to exploit unused resources for small-scale hydropower like small rivers or streams.

Micro hydro is a type of hydroelectric power that typically produces from 5 kW to 100 kW of electricity using the natural flow of water. Installations below 5 kW are called Pico Hydro, whereas upto 10000 kW it is called as Small Hydro. They can provide power to an isolated home or small areas, or are sometimes connected to electric power networks, particularly where net metering is offered. There are many of these installations around the world, mostly in developing nations as they can provide an economical source of energy without the purchase of fuel. Micro hydro systems complements solar PV power systems because in many areas, water flow highest in the winter when solar energy is at a minimum. Micro hydro is frequently accomplished with a Pelton wheel for high head, low flow water supply. The installation is often just a small dammed pool, at the top of a waterfall, with several hundred feet of pipe leading to small generator housing. In low head sites, generally water wheels and Archimedes screws are used.

In earlier days, the Archimedes screw was used for pumping water from a lower to a higher level or for conveying in a horizontal or inclined plane, liquid or solid materials. Nowadays, a new trend in Archimedes screw plants, that is it uses the reverse principle of the pump and exploits the available stream power for the energy production in a very low head application. The generator receives the mechanical energy from the stream of water and it is converted into electrical energy which can be supplied directly to the grid or by using step up or step down transformers. The Archimedes screws can be used for the application of head ranges from 1 to 6.5 m and low flow rates rate such as between 0.25 and 6.5 m^3/s.

Research on screw turbine has been started in Europe around the year of 2000s.C.Rorres in the year 2000 lays out an analytical method to optimize design Archimedes screw geometry for pumping application[1]. The main aim of his study was to maximize the volume of water lifted in one turn of the screw by combination of inner radius and pitch of screw.

Muller and Senior created a simplified model for Archimedes screw turbine that idealizes the turbine's blades as moving weirs[2]. They conclusion was that Archimedes screw turbine's efficiency is a function of both turbine geometry and mechanical losses, and that efficiency increases with an increased number of flights (N) as well as with decreased installation angle (β).

Nurenberg and C. Rorres in 2013 derived analytical model for water inflow of Archimedes screw turbine to get the optimal value of the inflow parameters[3]. For getting efficiency, they considered leakage between the flights and the trough and leakage from overflow. Their analytical model compared with experimental measurement.

In 2015, there was an article about compilation of Archimedes screw in application as a pump and as a turbine (S. Waters, G.A. Aggidis)[4]. They said there is currently a lack of research on the topic due to infancy of technology as a turbine. Screw turbine that was developed is visually similar to the inclined pump and often treated the same during the design. When it comes to creating and optimizing a pump device, the key is to increase the amount of water moved during each turn of device. For the turbine, the maximum amount of energy in the flow needs to be extracted.

J. Rohmer et al researched about modeling and experimental results of an Archimedes screw turbine in 2016 [5]. Their model based on what C. Rorres (2000) did for Archimedes screw pump with some developments. Their research shows upstream level, mechanical efficiency and mechanical torque, as a function of the rotational speed and flow rate. Comparison between numerical and experimental data shows the same trend and tends to slightly different.

Guilhem Delinger et al also did experimental research of Archimedes screw turbine in 2016 [6]. They derived some formulas based on C. Rorres (2000). Their conclusion was that both theoretical and experimental values of efficiency decrease when screw inclination increases.

Erinofiardi et al (2016) did experimental study on Archimedes screw turbine[8]. Their research shows the torque and the power as a function of rotational speed and inclination angle (β).They concluded that maximum efficiency occurs at lowest slope among the three slopes angle

1.1 Working Principle of Screw turbine

The working principle used in the working of screw turbine is the reverse of the working of the Archimedes screw – As water flows through the blades the kinetic energy converted to the blades of the screw. As the water flows through the screw turbine alone its length, the kinetic energy of the water imparts torque on the blades of the screw turbine; it causes the blades to rotate in order to convert kinetic energy of the moving water to mechanical or rotational energy of the blades [9]. The mechanical energy is then converted to electrical energy using a generator. We use gearbox for increasing the speed of the motor.

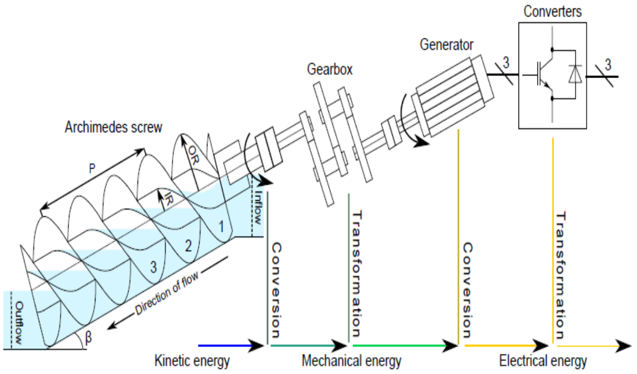

Fig-1: General principle of screw turbine

2. NUMERICAL MODEL

2.1 Geometry

The geometry of the screw turbine consist of the screw and along with its casing. The material used for screw is aluminium where as the fluid passing through is simply water. The model of the Archimedean screw turbine is modeled in ANSYS FLUENT. Cylindrical type uniform enclosure is used to define the fluid domain.

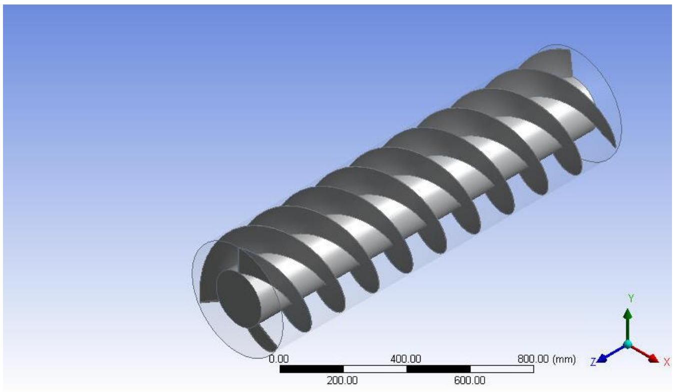

Fig 2 : 3 Bladed screw turbine with enclosure

2.2. GOVERNING EQUATIONS:

Based on the above assumptions, the governing equations for mass and momentum for a steady three-dimensional flow in the fluid domain and the energy equation in the solid region are as follows,

2.2.1 Conservation of Mass

Continuity equation is,

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}=0$$

2.2.2 Conservation of Momentum

X- Momentum equation;

$$u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+w\frac{\partial u}{\partial z}=\nu\left\{\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}+\frac{\partial^2 u}{\partial z^2}\right\}-\frac{1}{\rho}\frac{\partial P}{\partial x}$$

Y- Momentum equation;

$$u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+w\frac{\partial v}{\partial z}=\nu\left\{\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}+\frac{\partial^2 v}{\partial z^2}\right\}-\frac{1}{\rho}\frac{\partial P}{\partial y}$$

Z- Momentum equation;

$$u\frac{\partial w}{\partial x}+v\frac{\partial w}{\partial y}+w\frac{\partial w}{\partial z}=\nu\left\{\frac{\partial^2 w}{\partial x^2}+\frac{\partial^2 w}{\partial y^2}+\frac{\partial^2 vw}{\partial z^2}\right\}-\frac{1}{\rho}\frac{\partial P}{\partial z}$$

2.3 Grid Independency study

SI No	Element size (in mm)	Number of elements (in lakh)	Skewness (maximum)	Net force (in N)
1	5	27.42	0.885	1068.88
2	5.5	22.69	0.8805	1064.67
3	6	19.5	0.887	1072.146
4	6.5	17.44	0.8879	1068.713

5	7	15.98	0.889	1077.8706
6	7.5	15.09	0.890	1070.522
7	8	14.38	0.892	1080.45
8	8.5	13.75	0.8904	1111.3982

Table 1: Grid Independency study

From the study we can see that even though the elements size increases the output value changes less and it only requires less time to converge. Finally we take element size 7.5 mm for our numerical study as its value is almost equal.

2.4 BOUNDARY CONDITIONS

Name	Type
Inlet	Mass flow inlet
Outlet	Pressure outlet
Wall	Wall

Table 2 : boundary conditions

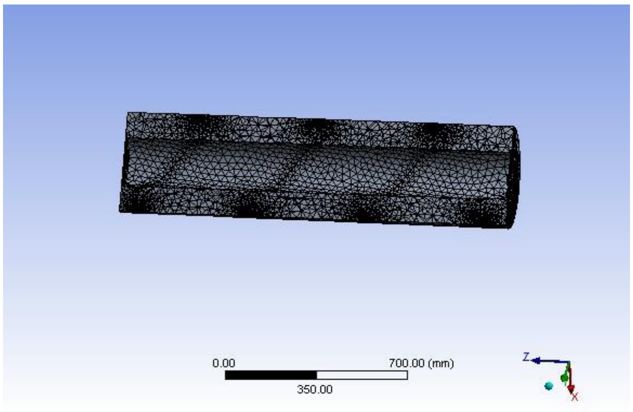

Fig 3 : Meshed model of fluid domain

3. RESULTS AND DISCUSSIONS

3.1 Effect of variation of mass flow rate:

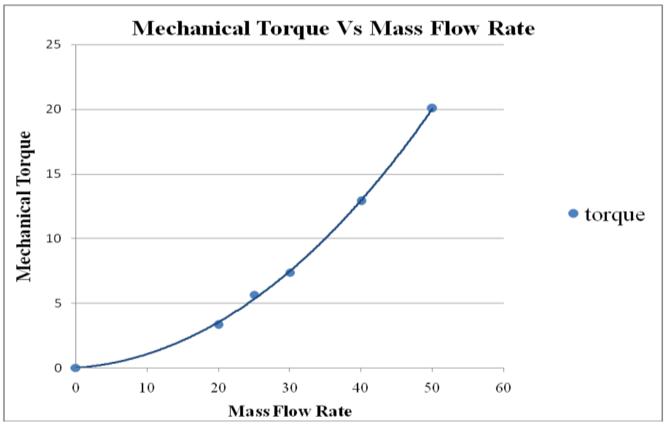

Fig 4: Mechanical torque Vs mass flow rate

The figure 4 shows the graph between mechanical torque versus mass flow rate. It is clear from the curve that as the mass flow rate increases the mechanical torque developed on the shaft due to the rotation is increasing. The trend line is seen to be almost like parabolic in nature. The reason for the rise in torque is that as the mass flow rate increases more force will get impinged on the blades of the screw also more energy to rotate the blades

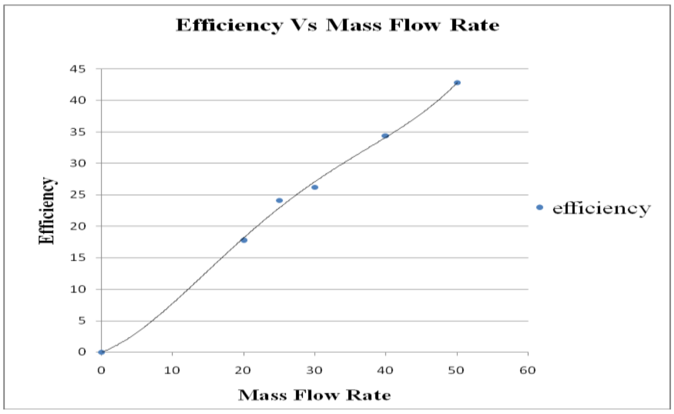

Fig 5: Efficiency Vs mass flow rate

The figure 5 shows the behavior of the efficiency curve when mass flow rate is changing. The efficiency is increasing as the mass flow rate is increasing as the output increases. It is to be noted that the frictional losses were neglected or are not taking in considerations which affects the efficiency curve. The curve is seen to be almost linear in nature. The input power also increases as the mass flow rate increases as it is directly depending on the mass flow rate. That is both input power and output power is increasing, may be that is the reason why the efficiency curve seen to be almost linear in nature.

3.2 Effect of variation of angle of inclination (β):

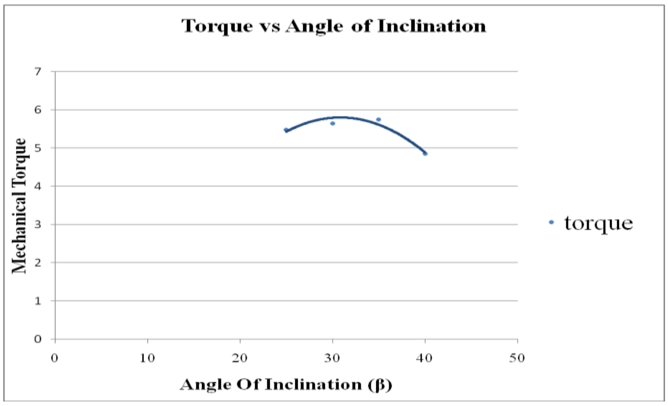

Fig 6: Mechanical torque Vs angle of inclination

The figure 6 shows the relationship between mechanical torque and the angle of inclination of the screw turbine at constant mass flow rate of 25 m^3/s. The torque increases as the angle increases upto a point then it decreases as the inclination increases. This is because as the angle increases beyond the optimum angle, there may be chance that the water will not fully impart its kinetic energy on the blades and also there is a chance that water may flow over the blades without giving energy to the blades causing overflow loss. Also as the angle at which water hits the blades changes affects the amount of transferring energy taking place. The water over flow imparting maximum torque is seen to be 31.5 ^{0} from the graph.

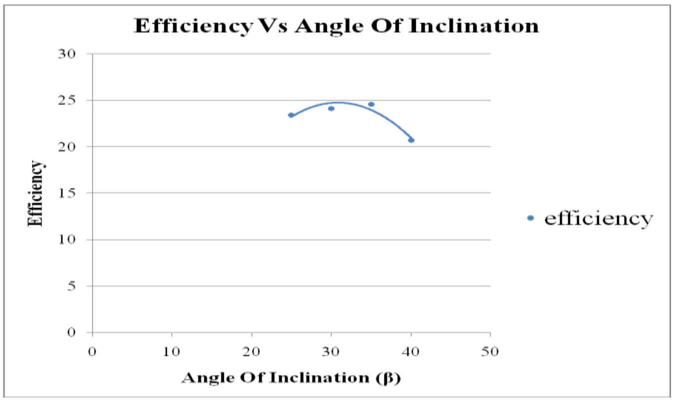

Fig 7: Efficiency Vs angle of inclination

The figure 7 shows the trend of efficiency of the screw turbine at constant mass flow rate of 25 m^3/s, as the angle of inclination (β) increases. The curve is seen almost similar curve to torque vs angle of inclination curve. The efficiency increases as the angle of inclination increases upto an optimum point then it seems to be decreasing. As the mass flow rate, head is kept constant; there is no change in the input power, making it a steady value over the study time. As the angle of inclination is more than the optimum value, that will causes overflow loss, that is the water will flow above the outer edge of the blades freely and without transferring it flow energy to the blades. As the output power will decrease as the torque decreases as it is directly depending on torque, also as the losses increases. As the output decreases the efficiency will also increase as the input power is a constant value

3.3 Effect of variation of number of blades:

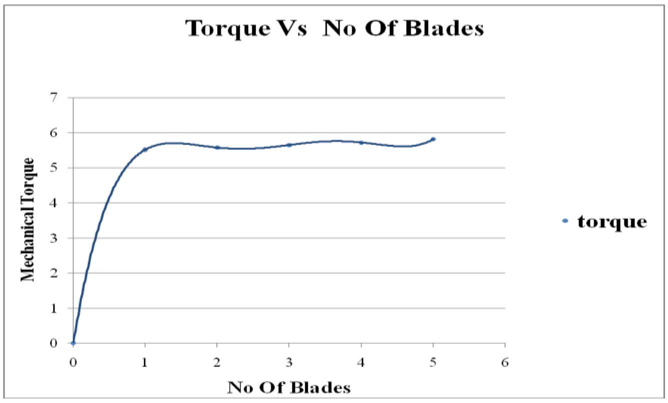

Fig 8: Mechanical torque Vs angle of inclination

Figure 8 show the relation between mechanical torque and number of blades of the screw turbine. From the curve we can see that as the number of blades increases the generating torque increases. This is because as more blades come in there is more surface area for water to transfer energy. But the increase in the value of torque is not appreciatable because the torque values for blades 3 and 4 seem to have a small difference in the value of torque obtained. Also as the number of blades increases the fabrication process will become more complex and also the cost for the fabrication also increases very highly.

Figure 9 show the curve between efficiency and number of blades of the screw turbine. From the curve we can conclude that as the number of blades increases the efficiency increases. This is because as more there are more number of blades, more surface contact for water to transfer energy to obtain more torque in the shaft. But the increase in the value of torque is not appreciatable when comparing values of the torque obtained at different number of blades. Even though, as the torque increases the output power increases as there is no other losses. As the factors influencing the input power is constant, input power will also be a constant. So the efficiency will increases in a smaller value as the number of blades increases.

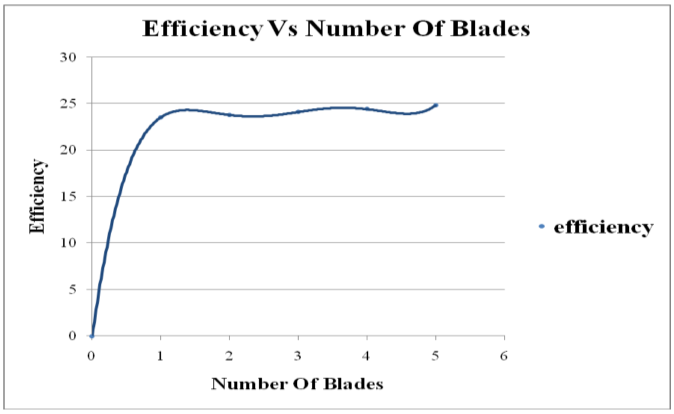

Fig 9: Efficiency Vs Number of blades

It seems to have a small difference in the value of torque obtained. Also as the number of blades increases the fabrication process will become more complex and time for fabrication also increases. Also the cost for the fabrication also increases very highly. It will a deciding factor for the fabrication of screw turbine whether it to make it a economical turbine.

4. CONCLUSION

We have studied the characteristics of the Archimedes screw turbine using numerical study method using Ansys Fluent software by varying its parameters like mass flow rate, inclination angle and the number of blades. We have obtained results according to the various conditions of the screw turbine.

We can see from the result that in the case of mass flow arte the behavior of the efficiency and the torque generated is directly proportional to the mass flow rate that is as the mass flow rate increases the efficiency increases linearly where as the torque is parabolically changes with mass flow rate increment.

In the case of varying the angle of inclination of the screw turbine, the efficiency and the torque obtained increases upto optimum point then decreases. In the case of efficiency, maximum efficiency of 24.9 % occur at 31.5^0 and maximum torque of 5.8599 N at $31.5^{\,0}$

In the case of changing the number of blades, both the efficiency and torque generated is increasing as the number of blades increases, but the increase in torque and efficiency is not appreciable also as the number of blades increases cost of the fabrication process as well as the time for fabrication increases. Its a deciding factor what number of blades do our turbine should have.

Even though the study is done, we had made numerous assumptions. There is still huge scope for this type of micro turbines. By considering the frictional losses which is effecting efficiency at higher speed and considering other losses like over flow losses. There is still significant scope for studying this turbine by taking these losses

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