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Study on Effect of Flow Rate and Number of Blades on Sizing of Archimedes Screw Turbine

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Abstract
The study of Archimedes Screw Turbine (AST) as a micro and Pico hydro turbine is in increasing trend. This turbine is applied to low water flow conditions and for head lesser than 10 meters. The purpose of this study is to assess the effect of flow rate and number of blades on the sizing of an AST. The research is done by reviewing the existing empirical relations relating flow rate with design parameters such as inner radius, outer radius and pitch. It also presents the effect of flow rate on torque and efficiency of an AST through Computational Fluid Dynamics (CFD) simulation in ANSYS software.The highest torque of 5.63 Nm and the highest efficiency of 52.1 % are obtained at the flow rate of 40 litres per second. It is found that the trendline of flow rate vs torque curve is a line with positive slope. The trendline of flow rate vs efficiency curve also is a line but with less positive slope.

Keywords
Archimedes, Computational-flow-dynamics, Flow-rate, Screw Pump

1. Introduction

Archimedes Screw Turbine has been used throughout history for many purposes, as pump in earlier days and as generator in modern ages. Archimedes Screw consists of a helical array of blades (flights) that are wrapped around a central core with certain diameter. The blades are welded to a cylindrical extrusion that forms the inner diameter of the turbine. The screw may either be fully encased in outer cylinder or supported within a fixed trough with an open top. The Archimedes screw pump was first pointed by Diodorus of Sicily, Atheneus of Naucratis, Moschino, etc. [1] [2]. Konard Kyser was the first to illustrate the device in the western world [3]. Later the patent for the Archimedes screw generator was filed by Karl-August Radilik [4] . Most of the information published so far is based on the empirical design rules and the optimization of the screw geometry is with the respect to the maximum volume that a bucket can contain. Calculation of mechanical efficiency for an Archimedes screw turbine gave efficiencies between 79 and 84 percent. This makes AST a plausible alternative for turbines in low head hydropower applications [5] [6].

Advantages of AST include its ability to run to operate without any harm to aquatic life [7], it has a low environmental impact [8], less civil works required [9] and can be set up in irrigation canals.

AST is driven by two forces: water weight and hydrostatic pressure. The schematic representation of AST is shown in Figure 1. Recently, it has been verified that the contribution of gravity in energy conversion is not significant in AST [10]. Therefore, the force acting on the Archimedes Turbine is the hydrostatic pressure. Water gets filled in the volumes between the blades and the inner cylinder (called as buckets) [11] . A generator is placed at the top of the screw turbine shaft which rotates when the hydrostatic forces of water strike the helical blades tangentially, causing the screw to rotate. Due to the rotation of the screw, the potential energy possessed by the fluid is converted to mechanical energy in this process.

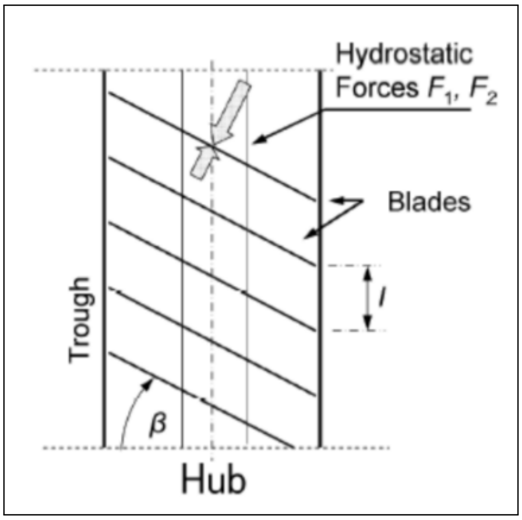

Figure 1: Schematic Representation of AST [10]

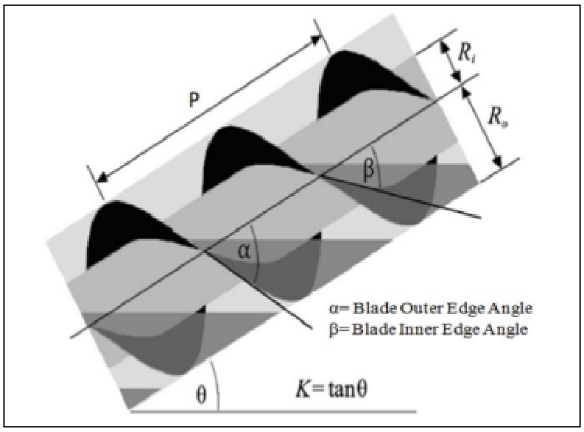

Figure 2: Profile view of a segment of a Two- Bladed Archimedes Screw

2. Methodology

The method of this research is based on field study. The main objective of this research is to figure out the relationship nature between number of blades & design parameters, flow rate & torque and flow rate & efficiency. Firstly, literature review related to project was gathered and reviewed. Then six different sites with different flow rate within Pokhara valley were visited. Those sites were named as Location 1, Location 2, Location 3, Location 4, Location 5 and Location 6. Design parameters shown in Table 1 were extracted for each site. The CAD model of AST for each site was generated. The effect of flow rate and number of blades on sizing of AST was then studied through CFD simulation. According to Rorres, the parameters that define the geometry can be split into internal and external parameters. The site of the installation of the screw and its material type usually determines these external parameters [12]. The profile view of a segment of a two-bladed Archimedes Screw is shown in Figure 2.

Table 1: Parameters governing the geometry of AST

External Parameters	Internal Parameters	Design Range For Internal Parameters
Outer Radius (Ro)	Inner cylinder radius (Ri)	0 ≤ Ri ≤ Ro
Total length of screw (L)	Pitch of blade (P)	0 ≤ P ≤ 2 π Ro/k
Slope of screw (K)	Number of blade (N)	N=1,2,3 ...

$$\text{Flow Rate}(Q) = 0.25 \times \pi \times (2 \times Ro)^2 \qquad (1)$$

The internal parameters are determined by the help of two non-dimensional parameters. They are; [13]

$$Radius\,Ratio, \rho = \frac{Ri}{Ro}(0 \leq \rho \leq 1) \qquad (2)$$

$$Pitch\,Ratio, \lambda = \frac{P}{2\pi Ro}(0 \leq \lambda \leq 1) \qquad (3)$$

The internal parameters values are determined by the optimal ratios for various numbers of blades as shown in Table 2.

Table 2: Optimum Ratio Parameters

No. of Blade (N)	Optimal Radius Ratio (ρ)	Optimal Pitch Ratio (λ)
1	0.5358	0.1285
2	0.5369	0.1863
3	0.5357	0.2217
4	0.5353	0.2456
5	0.5352	0.2630
6	0.5353	0.2763
7	0.5354	0.2869
8	0.5354	0.2957
9	0.5356	0.3029
10	0.5356	0.3092

Flow Measurement Equipment

The velocity of flow at the sites selected were measured by using current meter equipped with the pre-settable revolution and time counter. The specifications of current meter are shown in Table 3.

Table 3: Current Meter Specifications

Current Meter Type	Cup type with fish weight
Model	U.K.ENGINEERING ROORKEE-247 667
Rotor type	Six-cup wheel type
Material	Stainless Steel
Contact	Every one revolution
Range	0.05 to 3.5 m/s
Accuracy	1%FS (for velocities $\leq$ 0.3 0.5% FS (for velocities>0.3
α (constant)	0.6998
β (constant)	-0.0003
Contact Chamber	Magnetic type
Wading rod length	3m long with base plate
Electric cable length	10m
Fish Weight	10, 25kg (made of cast iron)

CFD Simulation Setup

The geometry of an AST was modelled in SolidWorks Software. The CAD model was imported in ANSYS Software. For the ease of meshing and saving computational time, the design model was scaled down with a scale factor of 0.5 using scaling law. Meshing was done till satisfying the Grid Independent Test. Torque value is obtained for each flow rate through the simulation process. The CAD model and meshing is as shown in the figures (3) and (4) below.

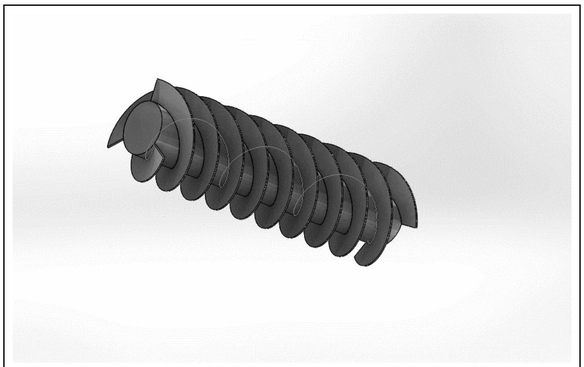

Figure 3: CAD view of AST

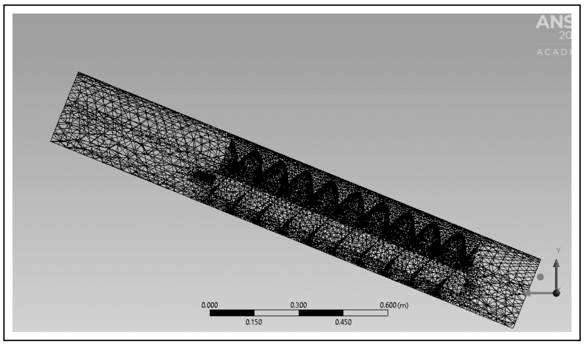

Figure 4: Geometry After Meshing in ANSYS

The settings for the setup of CFD simulation in ANSYS Fluent Solver Software is shown in Table 4.

Table 4: CFD Simulation Setup

General	Solver Velocity Time Gravity	Pressure based Absolute Steady 9.8m/s^2
Model	Viscous k-omega	SST
Material	Liquid	Water
Cell zone	Fluid zone	Water
Boundary Conditions	Inlet Outlet Virtual Turbine	Velocity Pressure (Atmospheric) Rotating (Turbine Axis)
Solution Methods	Pressure-Velocity Coupling Pressure Momentum	Simple Scheme Second Order Second Order
Initialization	Standard Initialization	From inlet

Efficiency calculation

The efficiency of an Archimedes screw turbine is given by;

$$Efficiency(\eta) = \frac{Power\,Output}{Power\,Input} \quad (4)$$

Where, Power Output = T*ω;
T = Torque (Nm)
ω = Rotational Speed (rev/sec)
Power Input = ρ*g*Q*H
η = Efficiency of AST (%),
Q = Flow rate(m^3/s),
g = acceleration due to gravity (m/s^2)
ρ = Density of water (Kg/m^3).

3. Result And Discussion

The flow rate of the water at six different locations were measured using current meter. The highest water discharge of Q_6 = 1.6283 m3/s at location 6 and the lowest water discharge of Q_5 = 0.1049 m^3/s was obtained at location 5.

By applying equation (1), (2) and (3), the outer radius, inner radius and pitch can be obtained for each location. The variation of pitch, inner radius and outer radius for each location (locations 1 to 6) are as shown in figures 5 to 10. Calculations for locations 1, 2 and 3 yielded flow rates (Q) and velocities (V) as Q_1 = 0.1906 m^3/s ,V_1 = 1.7328 m/s; Q_2 = 1.6167 m^3/s, V_2 = 1.7964 m/s and Q_3 = 0.6924 m^3/s, V_3 = 0.6819 m/s respectively. Likewise, obtained values of flow rates and velocities, also represented in graphs, for locations 4, 5 and 6 are found to be Q_4 = 0.1494 m^3/s, V_5= 0.6359 m/s; Q_5 = 0.1049 m^3/s, V_6 = 0.6363 m/s and Q_6 = 1.6283 m^3/s, V_6 = 2.0756 m/s respectively.

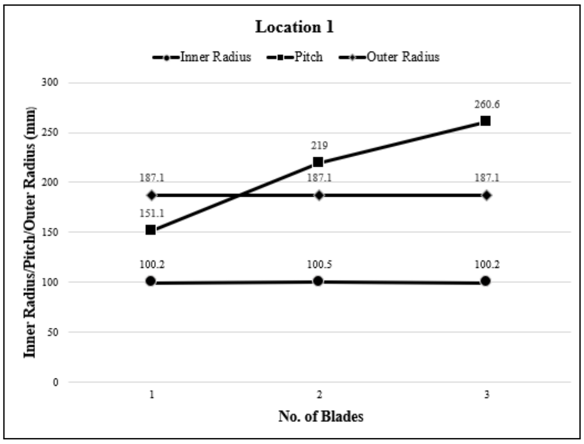

Figure 5: Effect of No. of blades on design parameters at Location 1

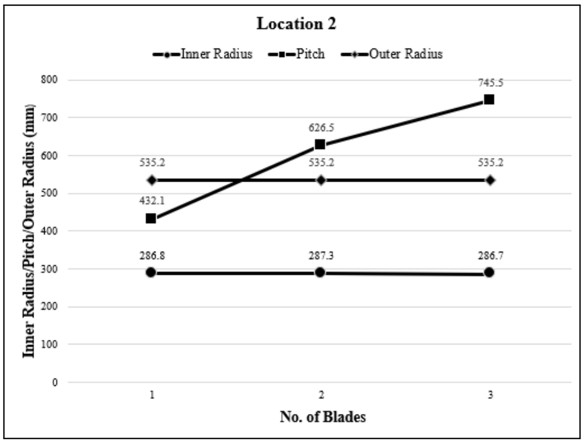

Figure 6: Effect of No. of blades on design parameters at Location 2

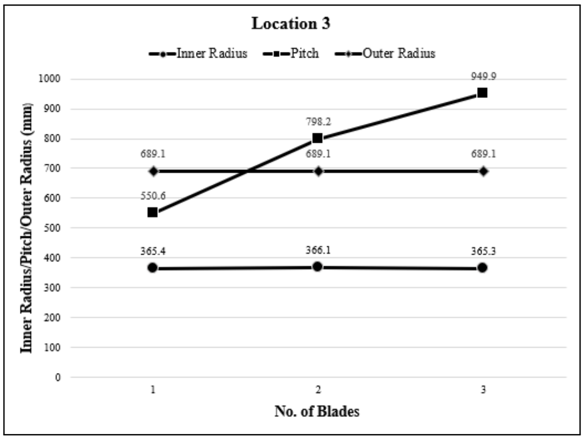

Figure 7: Effect of No. of blades on design parameters at Location 3

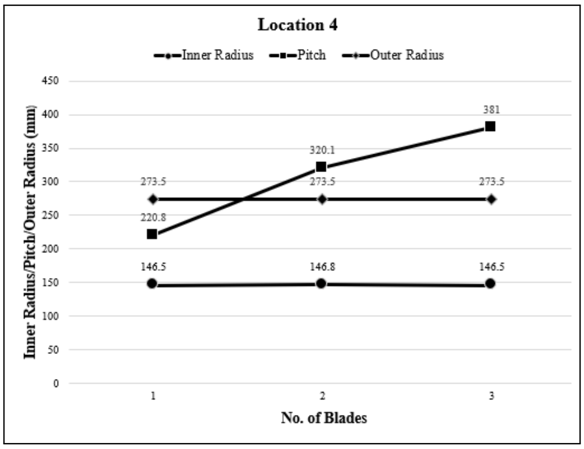

Figure 8: Effect of No. of blades on design parameters at Location 4

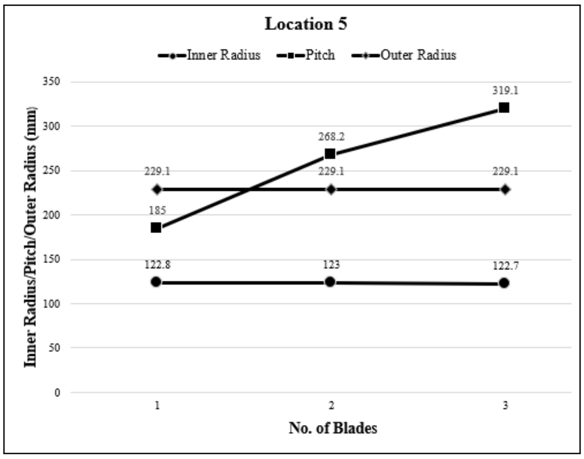

Figure 9: Effect of No. of blades on design parameters at Location 5

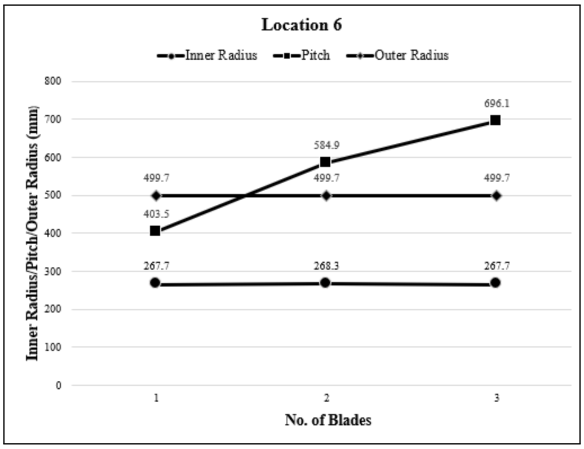

Figure 10: Effect of No. of blades on design parameters at Location 6

Flow rate is varied from 12.6 litres per second to 40 litres per second. For each flow rate input, torque value is received as output by CFD simulation. The effect of flow rate on the torque and efficiency can be seen from the charts obtained after CFD simulation of a CAD model in ANSYS Software.

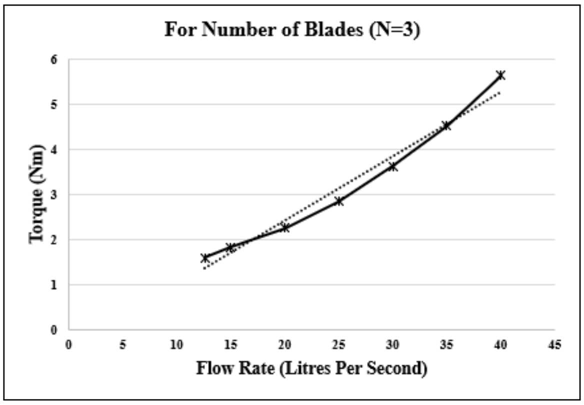

Figure 11: Effect of flow rate on Torque for N=3

The curve shown in Figure 11 shows the relationship between flow rate and torque value for an AST. It is found that the torque value is 1.59 Nm at the flow rate of 12.6 litres per second. The trendline shows the positive slope i.e., torques value increases with the increase in flow rate of water. The highest torque of 5.63 Nm is obtained at a flow rate of 40 litres per second.

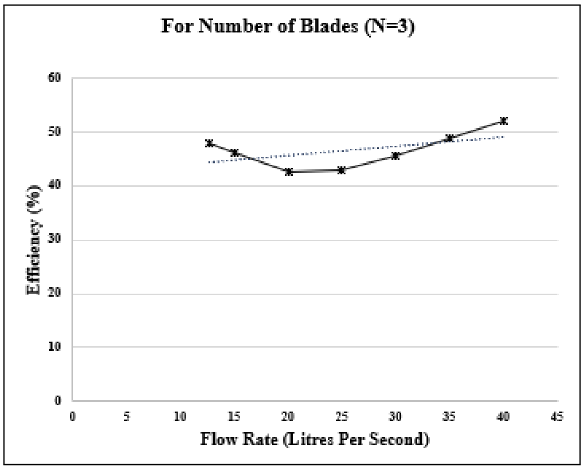

Figure 12: Effect of flow rate on Efficiency for N=3

The curve shown in Figure 12 shows the relationship between flow rate and efficiency. It is found that the efficiency value is 47.85% at the flow rate of 12.6 litres per second. The highest efficiency of 52.1% is obtained at the flow rate of 40 litres per second. Despite the efficiency decreases slightly at first, the trendline shows that the efficiency increases with the increment of flow rate. For validation, reference work of CFD simulation of Rabin Dhakal et al. was taken. The maximum efficiency obtained in that paper was 53.3% [9].The deviation with is 1.34 which yields 2.25% error. This deviation is within the acceptable range. Hence, the results are considered valid.

4. Conclusion

The results of this simulation-based study indicate the effect of number or blades on the sizing and the effect of flow rate on sizing, torque and efficiency of an Archimedes Screw Turbine. Six different sites with different flow rate were visited and the discharge was measured at each location by the help of current meter. By studying empirical relations, design parameters were extracted from the flow rates of each site. CFD simulation was then performed to obtain torque value. Then efficiency was calculated and the effect of flow rate was studied.

From the results of this simulation-based study, following conclusions could be drawn:

- The number of blades on an AST does not influence the outer diameter at all. But it affects the inner radius slightly and pitch considerably. With the increase in number of blades, pitch value increases considerably.

- The relationship between flow-rate and torque is justified by the positive slope of the trendline. The highest torque value of 5.63 Nm was obtained at the flow rate of 40 litres per second.
- The relationship between flow-rate and efficiency is justified by the less positive slope of the trendline. The highest efficiency of 52.1% was obtained at the flow rate of 40 litres per second.

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