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The Effect of Head Inflow and Turbine Axis Angle Towards The Three Row Bladed Screw Turbine Efficiency

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Abstract

Archimedes screw applications as water turbine is being developed and researched in the past decade. This kind of turbine excellence is that it can operate at a low head (H <10 m) and does not require a penstock. The screw turbine performance is influenced by the turbine screw shape geometry and the flow characteristics in the screw turbine. This study aims to determine the screw turbine efficiency which is observed by the turbine rotation, turbine torque on a variable head inflow, water flow velocity and the turbine axis specific angle. In this research the screw turbine was made under a laboratory scale and made from flexi-glass.The turbine screw geometry was made of three starts rows screw groove under a 0.54 radius ratio with a 2.4 Ro pitch and a screw angle of 30°. The head inflow (ho) variation is ½ Ro, 2/3 Ro, 1 Ro with an incoming flow velocity (c_o) varied at 0.3 m/s, 0.4 m/s, and 0.5 m/s and an turbine axis angle (α) variation of 25°, 35°, and 45°. The highest efficiency found in this research is about 89%. This performance occurred on the condition of a 50 rpm turbine rotation, at a head in flow (ho) of 1 Ro, a water flow velocity of 0.5 m/s and at a 25° turbine axis angle. The highest turbine rotation on this experiment was 350 rpm, which was reached at a 45°turbine axis angle condition. The water inflow head (ho) and the turbine axis angle (α) variation would strongly affect the turbine efficiency. Because the smaller the head between blades Δh, the greater the ho/Δh ratio thus the higher the efficiency could be.

Keywords: Screw Turbine, head inflow, turbine axis angle, efficiency.

Introduction

This research was done to be one of the electrical energy crisis problems to be solved. Renewable energy sources such as river water streams and irrigation channels can be used for electrical energy through a screw turbine micro hydro power plant. The turbine type was adopted from the Archimedean screw theory that is used as a pump. The advantage in implementing this kind of turbine is that it could operate on a low head (H <10 m) water stream. It does not require a penstock, easy to be installed, easy maintenance and does not disturb the river ecology or it is fish-friendly [1]. Screw turbine is a reaction turbine type that could operate under a low head [2]. Water flow kinetic energy and potential energy was transformed into a mechanical energy to produce a turbine blade screw shaft rotation which can be converted straight forward into electrical energy from a generator through an electricity transmission. The turbine screw could rotate because of the water density. By assuming that there is no loss of all potential energy in the flow, the turbine could generate a maximum efficiency of 100%, [3].

Within the past decade several researchers developed a screw turbine research in terms of both theoretical and experimental design related to the turbine screw efficiency. Numerical design optimization of geometric shapes thread found that the ratio of the range depends on the blades number and the radius ratio (R1/R0) and a 0.54 is the optimal radius ratio [4]. The Archimedes screw theory could be simplified based on the geometric parameters and the ideal energy conversion process for a helical rotation. The research results stated that the screw turbine efficiency is influenced by the screw shape geometry and flow losses [3]. Another research introduces an analytical model of a screw turbine inlet flow by taking into account the flow leaking possibility on the gap between the screw turbine casing and also including the water excess on the center of the pipe [5]. A simulation using MATLAB for screw turbines as a hydroelectric power plant on a lower head has also been done [6]. These three modeling and theoretical observation would later be compared with another experiment done by Brada [7, 8].

It is still necessary to do a further research for deeper information about a screw turbine and to get more real screw turbine information, so that this kind of screw turbine could be applied optimally. The research is focusing on experimental observation to find out the effect of water flow input head and the turbine axis angle toward the three bladed screw turbine efficiency. This research is important because the water flow is the kinetic energy and potential energy source, which are used on a screw turbine power generation system with regard to the geometric and hydraulic power. Besides the turbine screw geometry configuration, the water flow input and the turbine axis angle would strongly govern the turbine hydraulic power which works for the power generation and thus affecting the turbine efficiency. The screw turbine made for this research is designed under a laboratory scale with flexi-glass as the base material. As mentioned before that the purpose of this study is to determine the screw turbine efficiency seen from the turbine rotation variation and the turbine torque result.

MATERIAL AND METHODS

The test bed installation

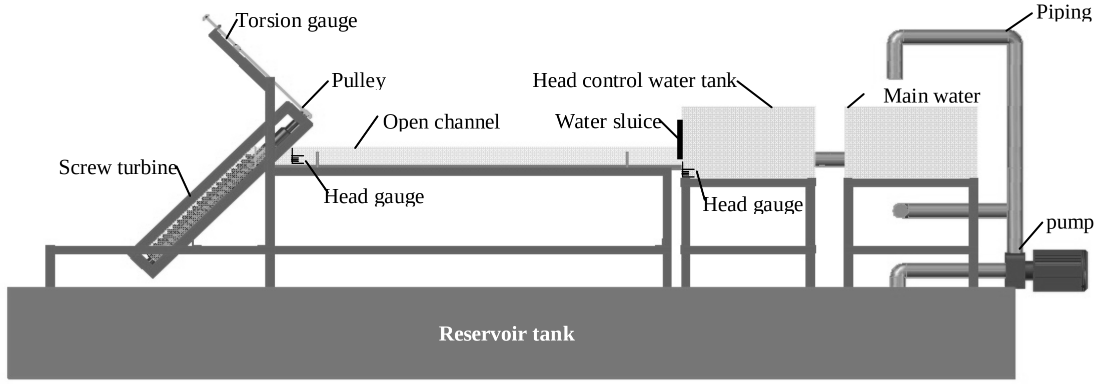


Figure 1: The screw turbine test bed installation

Table 1: Screw turbine model parameters

Parameter	Value	Description
R_o	0.055 m	Outer radius
R_i	0.030 m	Inner radius
S	0.132 m	Pitch
N	3	Number of flights
m	21	helix turns
β	30°	Fixed inclination angel
λv	0.059	Normalized volume per turn
α	25°, 35°, 45°	turbine shaft slope
h_o	$1/2R_o$, $2/3R_o$, $1R_o$	inflow head
c_o	0.3 m/s, 0.4 m/s, 0.5 m/s	inflow velocity

Experimental Procedure

The screw turbine model has a specific dimension. The turbine screw is a three bladed type screw made from flexi-glass and has a 60 mm diameter shaft, a 25 mm blade height with a 2.4 Ro blade screw pitch, a radius ratio (R1/Ro) of 0.54 and a screw angle of 30°. Before the data collection, all measuring devices had been calibrated.

The water flow test running was firstly proceed by pumping water from the water reservoir goes into the main water tank. The flow rate was set through a head controller in the in the sedative tank at the exit of the tank. Secondly, the water flow into the rectangular open channel was arranged into a certain turbine head inflow (ho). This rectangular open channel is the guide for the water inflow going inside the turbine, passing through the turbine blades, pushing the turbine blade to rotate and finally producing the turbine torque. The water output from the turbine was then catch back to the reservoir and ready to be pump back to the water reservoir tank. The next step is preparing for the data collection where the data variation is adjusting the turbine axis angle (α), setting the turbine head inflow by adjusting the small water gate on the water tank bottom to get a steady state water flow. The data taken are the turbine rotation using a tachometer, the water flow visualization using a camera and turbine torque using a small prony brake. All the data was taken at a head ho variation of 1Ro, 2/3Ro and 1/2Ro respectively under a flow rate variation of 0.3 m/s, 0.4 m/s, 0.5 m/s at an turbine axis angle α of 25°, 35°, 45° respectively. The data measurement was repeated three times for each variable.

Result and Discussions

Before discussing the results of this experiment, it is necessary to define some screw turbines parameters which was calculated based on the research data. From Figure 2, H is the total head and Δh is the head flow between the blades. Hydraulic energy that can be converted into screw rotation energy is the water volume in each turbine bucket Vb. The total water flow rate passing through the turbine are the water flow rate hitting straight forward to the turbine blade (Q_w) plus the water flow rate that is passing through the gap between the turbine screw and the turbine casing (Q_G). The Q_G flow rate which produces turbine torque expressed is as follows [5]:

$$Q_w = V_u \frac{n}{60} \; \left(m^3/s \right) \tag{1}$$

V_u is the volume of every NV_b bucket. The V_u value depends on the turbine blade number, the radius ratio and the screw lead ratio.

$$V_u = \frac{2\pi^2 R_a^3}{tan\beta} \lambda \nu \tag{2}$$

The leakage fraction is the ratio between the flow that passes through between the turbine screw and the turbine casing Q_G and water flow rate that produces turbine torque Q_w. The leakage fraction value Q_G/Q_w is equal to between 0.02 and 0.06 [4, 5]. The total flow rate equation is as follows:

$$Q = Q_w + Q_G \tag{3}$$

The screw turbine hydraulic power is:

$$P_{hyd} = \rho \, . \, g. \, Q. \, H = \rho \, . \, g. \, Q \, .m \, .\Delta h \tag{4}$$

m is the thread winding number.

$$\text{Screw turbine power } P = T \, \omega = T. \, \frac{2\pi n}{60} \tag{5}$$

Where T is the turbine torque and ω is the turbine angular velocity.
Screw turbine efficiency is:

$$\eta = \frac{p}{p_{hyd}} .100 \, \% \tag{6}$$

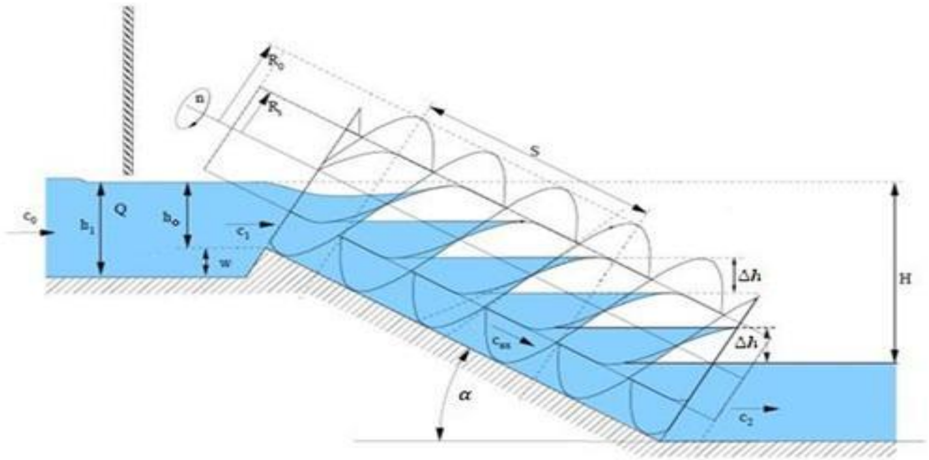


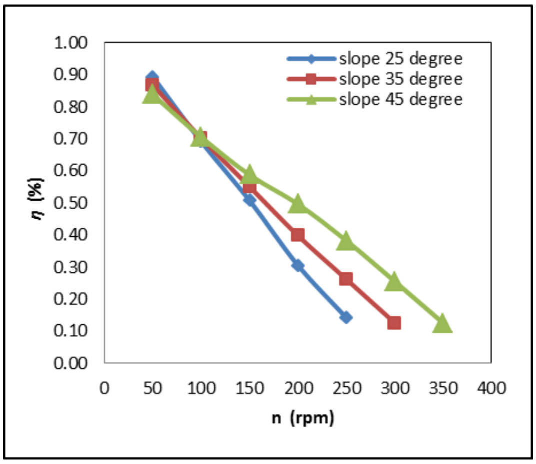
Figure 2: Water flow geometry in an Archimedes screw

The Turbine Efficiency and Turbine Rotation Relationship

The data presented from the research result is based on the ho, 1/2Ro, 2/3Ro, and 1Ro head inflow which was connected with the turbine efficiency and the turbine rotation for every turbine axis slope angle α of 25°, 35°, and 45°. Figure 3 shows that the highest efficiency of 89% occurred on a 50 rpm turbine rotation and a 25° turbine axis slope angle under a head flow of ho = 1Ro. At a 35° axis slope angle and a 50 rpm turbine rotation the turbine efficiency was found as big as 87%. While on a turbine axis angle of 45° the turbine efficiency found was 84%. The highest turbine rotation is 350 rpm at 45° turbine axis slope angle, although the turbine efficiency is nearly the same under a turbine rotation of 300 rpm and at a turbine shaft inclination of 35°. Under a turbine rotation condition of 250 rpm and a turbine shaft inclination of 25° the efficiency was very low, which was 13%. The head flow velocity ho = 1Ro is set at 0.5 m/s.

The experimental results under a head inflow ho = 2/3Ro shows the same trend under a head inflow of ho = 1Ro. From figure 4 it is seen clearly that the turbine efficiency decreases at a turbine rotation of 50 rpm and a turbine axis angle of 25° with an efficiency of 72%, while under a same turbine rotation of 50 rpm and an axis angle of 35° the turbine efficiency become 70%, furthermore on a 45° turbine axis angle the turbine efficiency is 68%. The turbine efficiency and turbine rotation result under a water head inflow of ho = 2/3Ro gives a lower result compare with the result under a water head inflow ho = 1Ro. This is due to the water flow velocity at the inflow head ho = 2/3Ro is about 0.4 m/s which is lower than the flow velocity in ho = 1Ro of 0.5 m/s.

Figure 5 shows the experimental results on a head inflow ho = 1/2Ro, a decrease in efficiency was seen, compared to the turbine efficiency and turbine rotation on a head inflow of ho = 1Ro and ho = 2/3Ro. The highest efficiency is 42% and was reach at ho = 1/2Ro and a rotation of 50 rpm. The head inflow velocity ho = 1/2Ro is equal to 0.3 m/s. Highest turbine rotation attainable is 200 rpm at 45° turbine axis angle. Meanwhile, on a turbine angle axis of 35° and 25° the turbine rotation reaches just 150 rpm.



ho=1/2Ro**Figure 3:** η vsturbine rotation

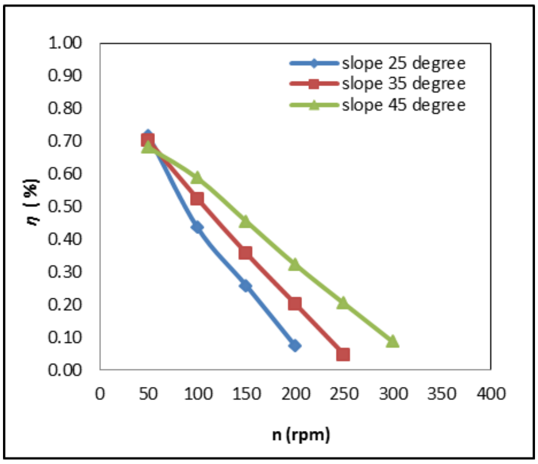


Figure 4: η vsturbine rotation on

The relationship between the turbine efficiency and turbine rotation of the three variations of head inflows ho=1/2Ro, 2/3Ro, and 1Ro at each turbine axis angle produces a linear relationship. The bigger the turbine axis angle the higher the turbine shaft rotation produced but the lower the turbine efficiency. On a turbine axis angle of 45° and a total water inflow head H of 0.54 m, resulting a turbine wheel of 350 rpm but the turbine efficiency is 13%, which is little bit lower than if the turbine axis angle is 35° and 25° with a total head H of 0.44 m and 0.32 m respectively. This result explains that the water flow potential energy value from a high total head is not really affecting the turbine efficiency.

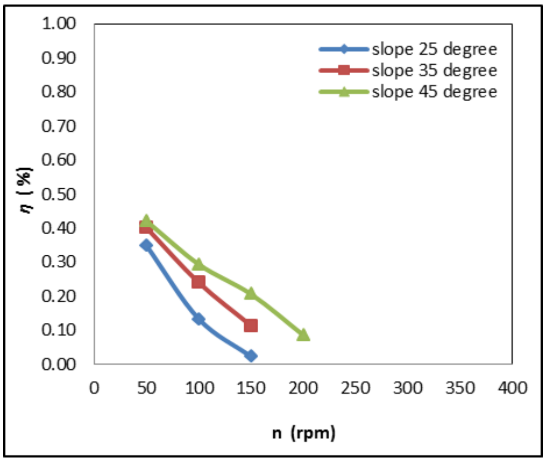


Figure 5: η vsturbine rotation on

Figure 6: The screw turbine research

The Turbine Efficiency and Turbine Axis Angle Relationship

The water inflow head (ho) determine the water flow rate and the hydraulic power value to rotate the turbine blade (Figure 2). While Δh will be high as the turbine axis angle rising higher. The ho and Δh ratio will be great when the turbine axis angle is low and the turbine efficiency will be high. The same data as figure 3 to figure 5 are presented based on the relationship between the turbine efficiency and the turbine axis angle at every water inflow head variation in figures 7 to figure 9. The water inflow head ho=1Ro on a turbine axis angle of 25° in Figure 7 shows a large increase in efficiency an average of 18.7% with a decrease in turbine rotation of 50 rpm. At a 35° turbine axis angle, the average turbine efficiency increase about 15.3% with a similar turbine rotation decrease. At a turbine axis angle of 45° with a same turbine reduction of 50 rpm, the turbine average efficiency increase is about 11.5%.

The relationship between the turbine efficiency and the turbine axis angle for every water inflow head ho, clearly clarifying the water inflow head and the turbine axis angle affecting the screw turbine efficiency. The maximum turbine efficiency of 89% occurred at 25° turbine axis angle on a water inflow head of ho=1Ro. This is happen because the head between the blade shaft Δh at a 25° turbine angle is 0,016 m smaller than Δh at 35° turbine axis angle which is 0.021 and Δh on a turbine axis angle of 45° is as big as 0.026. So that the biggest ho/Δh ratio is as big as 3.44 and producing which occurs at an inclination turbine axis of 25° ho=1Ro. The bigger the turbine axis angle α the bigger the head between the blades and decreasing the ho/Δh ratio and consequently decreasing the turbine efficiency. From the data presented and the relation between the turbine efficiency and the turbine axis angle it is seen that on a turbine axis angle of 25° potential energy influence occurs in at a ho/Δh value of 3.44 resulting 89% maximum efficiency. Likewise, on a turbine axis angle of 25° the kinetic energy influence due to the water flow velocity occurs at a water flow input speed of of 0.5 m/s produces the a efficiency of 89%.

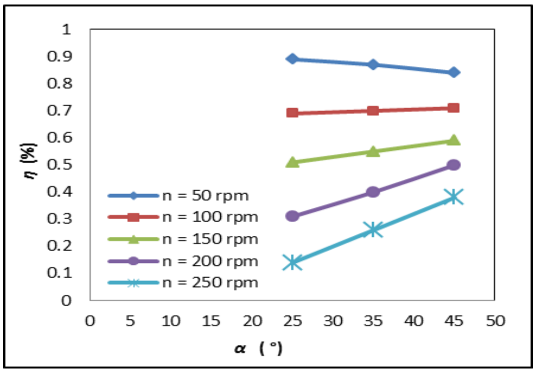


Figure 7: η and turbine rotation at

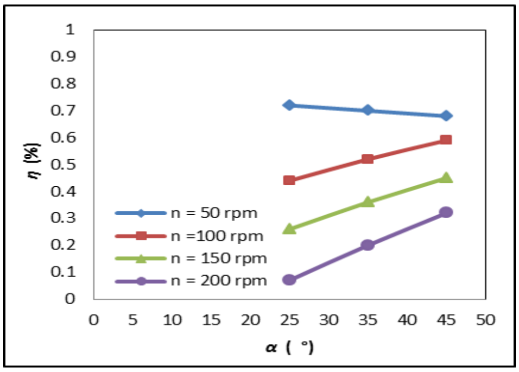


Figure 8: η and turbine rotation at

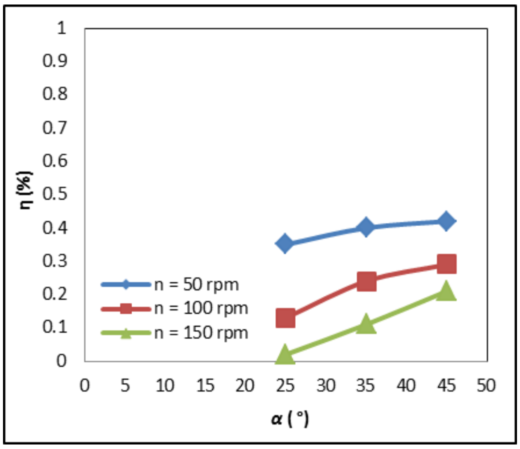


Figure 9: η and turbine rotation at

Figure 10: Screw turbine flow

Conclusion
From the results and discussion, it can be concluded as follows:

1. The maximum turbine efficiency is 89%, it occurs on a water inflow head ho=1Ro at a water flow speed of 0.5 m/s, on a turbine rotation of 50 rpm and a turbine axis angle α = 25°.
2. A Turbine axis angle of α = 45° produces a maximum turbine rotation of 350 rpm. The turbine efficiency of 87% was reach at a turbine rotation of 50 rpm, speed water flow of 0.5 m/s with ho 1Ro. The bigger the turbine axis angle, the larger head between the blade and turbine casing gap Δh so that efficiency will drop down.
3. The water inflow head ho and a turbine axis angle α would strongly affect the three bladed screw turbine efficiency, because the ho/Δh ratio determined by the ho and α parameters. The smaller the head between the blades Δh the bigger the ho/Δh ratio so that the efficiency value is higher.
4. The flow kinetic energy a result of speed flow and potential energy as a result of head flow would strongly affect the screw turbine efficiency.

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