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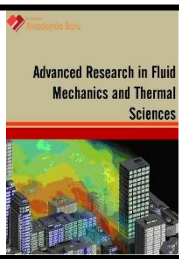

Experimental Study on the Effect of Flow rate on the Performance of Two-Blade Archimedes Screw Turbine

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ABSTRACT

The double blade Archimedes screw turbine has been developed in recent years in countries that have river flow potential, because it is capable of working under conditions of low flow and heads smaller than 10 meters. In order to obtain information in determining the turbine design that has good performance, the research aims to investigate the performance of Archimedes screw turbines because of the effect of flow rates on torque, power and efficiency. The screw turbine model is a two-blade, made of stainless steel with 2Ro pitch, the inner radius of 0.077 m, the outer radius of 0.1435 m and a length of 2 m. The measured and observed variables are turbine rotation, torque, and flow discharge. Tests were conducted on three variations of flow discharge are 0.025 m^3/s, 0.0125 m^3/s, and 0.0044 m^3/s. According to the test results, the highest rotation and turbine power occur at 0.025 m^3/s flow rate are 295 rpm and 116.10 Watt and maximum turbine efficiency is 55% at 0.0125 m^3/s. The results of this study indicate that to obtain maximum torque and power, flow conditions must be maintained at the highest water flow rate conditions, even though the efficiency obtained is not the maximum value.

Keywords:
Water energy, Archimedes screw turbines; rotation; power; efficiency

1. Introduction

The application of sustainable and renewable energy is one of the main challenges throughout the world, especially in overcoming dependence on fossil energy. Renewable energy is an energy that can be renewed and obtained from sustainable natural processes. Renewable energy has become one of the alternative energies in the future, because the use of fossil fuels continues to increase significantly but the source is very limited [1]. The abundant renewable energy in Indonesia is water energy that is used as a micro-hydro power plant. But in general, the existing river flow has a head and a low flow rate. The flow that has a low head and low flow rate is a challenge in terms of utilizing the existing energy potential [2].

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Various renewable energy sources such as solar energy, wind energy, geothermal energy and hydropower energy have been developed in the world [3, 4] and have been developed to the level of nanotechnology and nanomaterials as well as in photovoltaic panels [5].

Micro-hydro power plants with a maximum power of 5 kW can be one of the solutions to the electricity crisis in isolated areas by utilizing the available water potential. Micro hydro-scale power plants usually operate on river streams that have a low head or waterfall, either by using irrigation channels, rivers or waterfalls [6]. While several other researchers examined the potential of various types of Pico Hydro power plants mainly by utilizing channels in the pipe, but have not produced a possible result to be applied because the power produced is very small [7-9].

The Aceh region itself has many sources of water energy in the form of river currents or irrigation with an average waterfall of 1 - 2 meters with a water flow rate of around 0.05 m^3/s. The type of turbine that is suitable to be applied to areas that have water potential with the head and discharge is the type of Archimedes Screw turbine. This type of turbine is usually applied to micro-hydro power plants in rivers with low elevations [10].

Various studies have been conducted to find the turbine design in accordance with the existing potential. The numerical optimization of screw geometries by Rorres states that the geometry of Archimedes Screw can be found by determining the external and internal parameters with the optimum pitch ratio depending on the number of blades and the radius ratio (R_1/R_0) equal to 0.54. This type of turbine is able to work in the range of 1 to 10 meters, with a water flow rate ranging from 0.01 m3 / s to 0.10 m^3/s [11].

Mueller simplified the theory of Archimedes screw based on geometrical parameters and ideal energy conversion process for one helical turn. They stated the efficiency of the screw turbine is influenced by geometric shape and its flow losses [12].

Although there are some researchers who use CFD to study the performance of screw turbines [12-17], some researchers also conduct experiments [18, 19]. However, this experimental study of Archimedes screw turbines only tests on a laboratory scale.

This paper is aimed to investigate the performance of double blade screw turbines experimentally, which are examined from several flow rate conditions. In order to obtain the performance data, measurements of turbine rotation, torque, and efficiency were carried out, in the Archimedes two-blade screw turbine model made of stainless steel. According to the flow conditions that might occur in the field, is expected that a clearer how turbine inflow rate can affect the performance of Archimedes screw turbines used by the generating system.

2. Archimedes Screw Turbine

The Archimedes Screw turbine consists of a screw that rotates in a channel and utilizes the flow of water that is converted into electrical energy through a turbine to the generator. The screw turbine design begins to calculate the dimensions of the main parts of the turbine itself (see Figure 1). The calculation of the main dimensions of the turbine in this study refers to the method in a previous study developed by Chris Rorres [12].

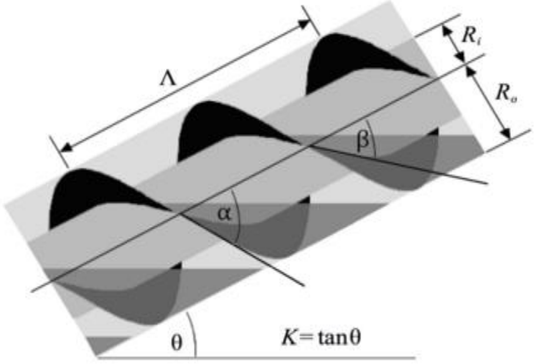

Fig. 1. Profile of two-blade screw turbine [11]

The length of the screw shaft can be calculated by the equation

$$L = \frac{H}{K} \tag{1}$$

Torres offers a formula to determine the dimensions of the Archimedes screw turbine based on the calculation of the water volume in one round screw

$$V_T = \pi R_o^2 \Lambda v \tag{2}$$

The inner diameter of the turbine is obtained using the equation

$$R_i = \rho R_o \tag{3}$$

We define the range screw from the screw turbine blade using the following equation:

$$\Lambda = \frac{2\pi Ro \lambda}{K} \tag{4}$$

The pitch ratio of the screw turbine is equal to

$$\lambda = \frac{K \Lambda}{2\pi Ro} \tag{5}$$

Then, we have number of screw blades as much

$$m = \frac{L}{\Lambda} \tag{6}$$

Eq. (1) to (6) are used to determine the dimensions of the Archimedes screw turbine in this study. The power provided by the Archimedes screw turbine is given by

$$P_{input} = \rho g Q H \eta \tag{7}$$

where ρ = the density of water (kg/m^3), Q = the flow rate (m^3/s), g = the Gravitational constant (m/s^2), the system head (m), η = the efficiency of the whole system (%).

By using the values of friction force (F) and rotation (n), the torque acting on the turbine is the multiplication of the frictional force with the pulley radius [20].

$$T = F \times r \quad (9)$$

Turbine power is obtained by multiplying torque with angular velocity, namely

$$P_{output} = T \times \omega \quad (10)$$

Angular velocity (ω) is obtained by the equation

$$\omega = 2 \pi n / 60 \quad (11)$$

where T = Torque (Nm), F = friction (N), r = pulley radius (m), ω = angular velocity (rad/s), n = rotation (rpm). The turbine efficiency is then equal to

$$\eta = \frac{P\ Output}{P\ Input} \times 100\% \quad (12)$$

3. Experimental Method

3.1 Turbine Dimension

An experimental system with Archimedes screws has been calculated, built and tested in the field to investigate its performance. The device that was designed was the turbine Archimedes screw 2-blade with 1 meter head, 30° angle of laying and a flow rate of 0.05 m^3/s.

The length of the screw turbine is obtained by Eq. (1), namely

$$L = \frac{H}{K} = \frac{1}{\sin 30°} = \frac{1}{0,5} = 2 \text{ meter}$$

While the outer diameter of a turbine thread is calculated by the following equation.

$$D_o = \left(\frac{Q \tan \theta}{K1\ \lambda\ v}\right)^{3/7}$$

$$D_o = \left(\frac{0,05 m^3/s\ \tan 30^{\circ}}{10,362\ x\ 0,0512}\right)^{3/7}$$

D_o = 0,287 meter, R_o = 0,1435 meter.

The inner radius of the turbine thread is obtained from the multiplication between the outer radius and the pitch ratio, as in Eq. (3), namely

$R_i = \rho R_o$

R_i = 0,5369 x 0,1435 meter

R_i = 0,077 meter

The pitch calculation refers to Chris Rorres's journal as in Eq. (4), namely

$$\Lambda = \frac{2\pi\ Ro\ \lambda}{K}$$

$$\Lambda = \frac{2 \text{ x } 3{,}14 \text{ x } Ro \;\; 0{,}1863}{\tan 30^{\circ}}$$

Λ = 2 R_o = 0,287 meter

3.2 Testing Equipment

There are two variables in the testing of this screw turbine experiment, namely: independent variables such as flow discharge and dependent variables which include rotation, torque, power and efficiency. Data collection carried out in this study includes two stages: field data collection related to rotation and torque, and calculations through computing devices. Determination of the flow rate in the field conditions is measured by knowing the altitude of the falling water from the tip of the 90-degree V-notch weir discharge (Figure 2) [21].

Fig. 2. Measurement of v-notch weir dimensions

The tool used to measure the turbine shaft rotation is a sensor speed connected to Arduino Mega 2560. Tests were also carried out to analyze the power of turbine rotation power by measuring torque (T). Torque measurement is done by a disc brake dynamometer method that uses load cells as shown in Figure 3. When the turbine rotates, loading starts and the frictional force will work on the turbine, which is defined as the resultant between the loads added to the force read on the sensor. Torque is obtained based on Eq. (9).

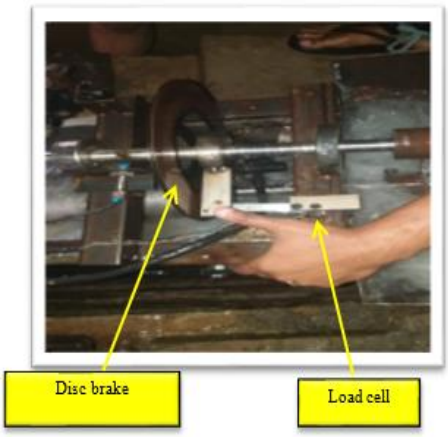

Fig. 3. Measurement of V-notch weir dimensions

4. Results and Discussion

4.1 Experimental Results

From the measurement results obtained the highest water discharge Q_1 is 0.025 m^3/s, medium flow rate Q_2 is 0.025 m^3/s and the lowest water discharge Q_3 is 0.0044 m^3/s as shown in Figure 4.

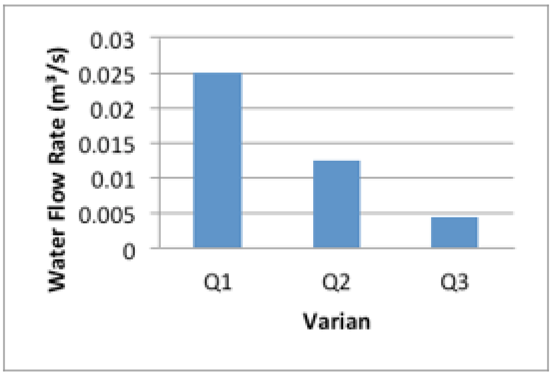

Fig. 4. Water flow rate of the test results

Data obtained from the test results and calculations can be seen in Table 1.

Table 1
Test results and calculation data

	Rotation (rpm)	Torque (Nm)	Power (Watt)	Efficiency (%)
	295	3,33	102,73	42
Q1	236	4,70	116,10	47
	177	5,00	92,56	38
	236	2,05	50,64	41
Q2	177	3,62	67,06	55
	118	4,48	55,33	45
	177	1,16	21,49	49
Q3	118	1,76	21,74	50
	59	2,01	12,41	29

The graph in Figure 5 explains the relationship between shaft rotation (n) and torque (T) in all variations in flow rate (Q). The graph shows that the highest torque value occurs at the flow rate of Q_1 with shaft rotation that occurs in this condition at 295 rpm, followed by the flow rate of Q_2 with a shaft rotation value of 236 rpm and the lowest torque occurs at flow rate Q_3 with 177 rpm.

The maximum torque occurs at the maximum flow rate and occurs in the initial rotation is quite large, meaning that the rotational speed of the shaft is still influenced by the speed of high inlet water. This value is far greater than the other flow conditions on the same shaft rotation.

Compared to the highest flow conditions Q_1, the maximum torque value of the middle flow rate of Q_2 is not too different, but occurs at n = 236 rpm, which means that the turbine wheel rotation is quite low. While the flow rate of Q_3 has a lower torque than other flow conditions.

The Figure 6 below shows that the highest power occurs at the flow rate of Q_1, which is 116.10 Watts, followed by the power generated at the flow rate of Q_2 is 67.06 Watts and the lowest power occurs at the flow rate of Q_3 is 21.74 Watt. It can be seen from Figure 6, where the range of power differences that occur is very large due to a decrease in the flow rate.

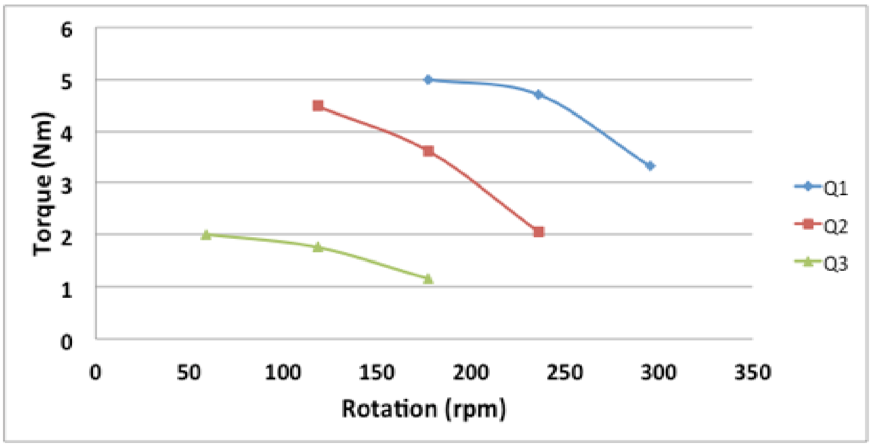

Fig. 5. Graph of rotation and torque relationships based on variations in flow rates

While the graph in Figure 7 explains the relationship between the rotation and efficiency in all conditions of variation in water flow rates. The graph shows that the highest efficiency occurs at the flow rate of Q_2 which is 55%, followed by efficiency at the flow rate of Q_3, which is 50%, and the lowest efficiency occurs at the flow rate of Q_1 which is 47%.

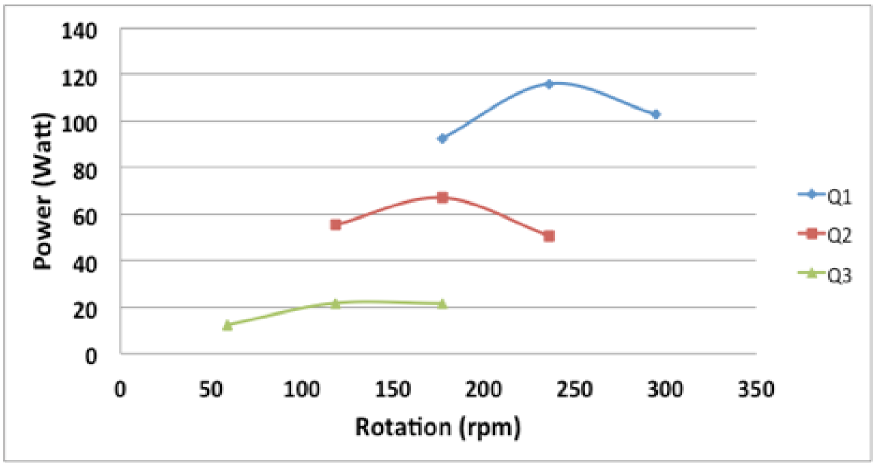

Fig. 6. The relationship of rotation to power based on variations in flow rates

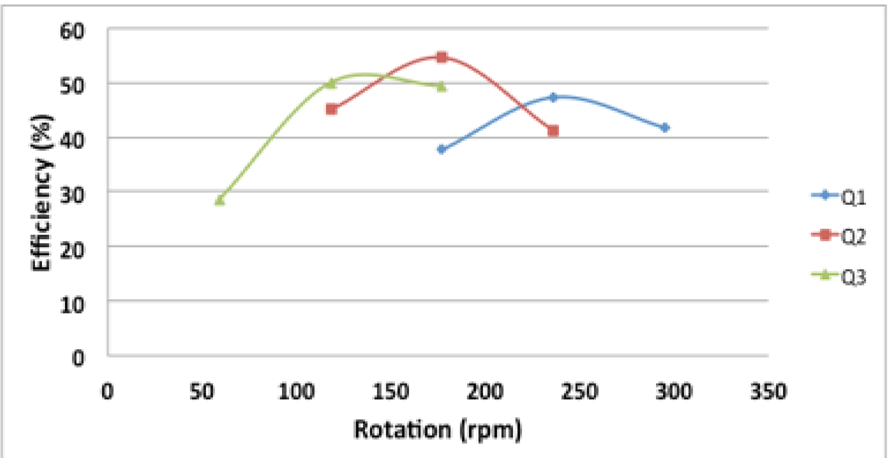

Fig. 7. Relationship between power and efficiency with variations in flow rates

4.2 Discussion

Figure 4 shows the variation of water flow rates used in the study. Variations in the flow rate of water are obtained by opening the valve at the end of the reservoir. The increase in water discharge occurs because of the addition of valve openings in each variation. This is intended to condition testing on different flow conditions that may occur in the field. The larger the valve is opened, the higher the distance of the water falling from the v-notch end so that the flow rate will increase. The flow rate of water entering the turbine also shows how many parts of the turbine will be submerged in the water. The higher the water discharge, the greater the turbine submerged in water.

Based on the graph in Figure 5, it can be seen that the higher the water flow rate (Q), the higher the maximum rotation achieved from the turbine, because the torque will decrease as the turbine rotation increases. The highest torque obtained due to braking force will produce the lowest rotation at each flow rate. This shows that the energy provided by the shaft will be higher, because the greater the torque that occurs so the greater the energy that will be carried by the turbine to rotate the generator. This condition results in a lower turn on the turbine shaft. Adding too much load will cause the turbine to not be able to rotate. So that it takes an appropriate load for each turbine based on the rotation power of the water that can be transmitted to the shaft.

At the same rotation condition, which is a rotation of 177 rpm, the largest torque is obtained by the flow rate of Q_1. Torque rise is inversely proportional to turbine rotation. The higher the torque, the lower the turbine shaft rotation. At first glance it looks as if the conditions of this test are different from previous studies conducted by Yulistianto *et al*., [22], and Erinofiardi *et al*., [23]. This is because the recorded rotation is the residual rotation that occurs after the turbine has been loaded to produce torque and power. The same trend will appear when the load is converted to rotate, because high rotation will produce a large torque. Increasing the water discharge will also increase the power of the turbine.

This event can be seen in Figure 6. This shows that the water discharge in Q_1 conditions produces higher power than the others. Mechanical power is greatly affected by the torque acting on the rotation. High rotation will generally produce higher power, but the mass of water entering the turbine will also affect the momentum that occurs in the turbine blades. This is what makes turbine efficiency different.

In the second test condition in every variation of water flow rate, there is a phenomenon of increase in power which is due to the significant increase in torque, so the power has increased from the previous one. Conditions like this are highly desirable, where the turbine still has a high rotation when torque is also higher.

The performance of 2 blade screw turbines depends on their efficiency through Eq. (12). Figure 7 shows the relationship between efficiency and rotation in each variation of flow rate. From the graph in Figure 7, the highest efficiency is 55%, which occurs at 177 rpm rotation and the flow rate Q_2 is 0.0125 m^3/s. While the largest discharge can only reach 47% efficiency at 236 rpm rotation and the maximum rotation of the turbine only has an efficiency of 42%.

Turbines with high power do not necessarily have high efficiency, because there are several factors that affect the performance, such as torque, pressure, and losses [24]. This trend has similarities with some of the previous studies conducted by Tineke Saroinsong *et al*., [25] where the highest efficiency is produced by turbines with low rotation.

Based on Figure 7 it can be explained that the highest efficiency conditions of a power turbine are only 67.06 Watts, while for the highest power is produced when the turbine has an efficiency of 47% in the flow discharge of Q_1. In other words, the turbine with the highest power is obtained on the condition of the flow rate of Q_1, and the turbine with the highest efficiency is obtained in the flow rate condition of Q_2.

5. Conclusions

The turbine model used in this study is Archimedes two-blade screw turbine, with a pitch of 2Ro, external radius (R_o) = 0.1435 m, and internal radius (R_i) = 0.077 m. This turbine was tested in the field with a range of average flow discharge of 0.025 m3 / s to 0.0044 m^3/s. The test results provide conclusions

i. To obtain maximum torque and power, flow conditions must be maintained at the highest conditions. This requires very good flow control considering the conditions on the field that change frequently.
ii. The highest efficiency is achieved not in the higher flow rate (Q_1), but in the condition of the medium flow rate (Q_2). However, the rotation range obtained is lower than Q1. This will result in lower power output.

So, the best in this test is to maintain the flow rate at the highest condition (Q1), even though the efficiency obtained is slightly lower but the power produced can reach 116. 10 watts. This value is almost twice the value obtained in Q_2, which is only 67.06 Watts.

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