Development of Archimedes Turbine Research: Review Article

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Abstract. Archimedes crew was used as a pump initially, however with time there were many innovations that were done to convert it into power machine. Even though this turbine has been utilized for a considerable time, Archimedes turbine does not have a fixed theory of design. There are several theories that have been developed for this turbine which are related to find out the effects of the angle with the torque that can be absorbed by the turbine. This is done, also to find out the optimum volume of the bucket. These theories are obtained by experimental means. Up to this day, several studies have tried to identify the relationships between optimum angle of screw, effect of pitch and slant to the turbine speed, and relation of rotational speed with friction.

Keywords: Archimedes screw, pico-hydro, renewable energy, water turbine

Introduction

Remote areas are areas that do not have a national grid (Institute Bisnis dan Ekonomi Kerakyatan 2003). Difficult access causes the construction of power grids to connect and transmit electrical energy to the regions it becomes increasingly difficult and costly. The right solution to overcome the electrical energy crisis of electricity is by empowering the potential energy available in each region, especially the rural area by applying the local power station independently (Harsarapama 2012).

To improve the quality of life and economic growth of rural communities, it is undeniable that electrical energy has a very big role. The availability of electricity in rural areas as one form encourages the increase of economic productivity, education and health facilities and no doubt will form a new job field (Institute Bisnis dan Ekonomi Kerakyatan 2003). This is because the electricity in the remote area causes extended lighting time, thus spurring business development and increasing hours of productivity (Ho-Yan 2012).

Developing countries use pico hydro turbines to overcome power crises in remote areas such as Cameroon, Nepal, Laos, Rwanda, Honduras, Bolivia, Peru and Indonesia [3–9]. This is because the pico hydro turbine has the least investment cost and operational cost compared to other independent power plants (Ho-Yan 2012).

Archimedes turbines are considered one of the most suitable turbines to be applied in remote areas. In addition to the turbine efficiency is stable also because based on studies that have been done, aquatic organisms such as fish can still swim through the gaps in the turbine blade so it is seen as a turbine that is friendly to water biota. [10, 11].

The Archimedes Screw is an old hydraulic machine first founded by a scientist and engineer named Archimedes. The Archimedes Screw was first used as a device to pump water and was also called the Archimedes Pump. The Archimedes Screw Pump consists of blades forming a helix around a cylindrical shaft and enclosed by a semi closed or closed circular enclosure (Muller & Senior 2009). The shape of the Archimedes turbine also resembles the Archimedes pump which consists of a circular arranged blade around the main shaft in the form of a cylinder resembling a screw screw.

The function of the Archimedes Screw Turbine has recently been changed into a turbine to generate energy (Hellman 2003). Some of the advantages of the Archimedes Screw Turbine is its ability to operate optimally in a low head condition (Williamson et al. 2011), and and can also operate at large discharge (Lashofer et al. 2012).

Although the Archimedes screw is quite old but until now there is still no theory that explains the relationship between energy conversion process, turbine geometry, and mechanical efficiency.

This paper will review the Archimedes turbine from the characteristics of the Archimedes turbine, basic principles, basic theory and development. It is hoped that will this paper, research and development of Archimedes turbine can be continuously carried out in order to be utilized and implemented as an environmentally friendly electrification plant.

The Basic Theories of Archimedes Turbine

The Archimedes turbine is driven by two forces: water weight and hydrostatic pressure. Initially, it is thought that the main driving forces that rotate the Archimedes turbine are the gravity of the water that flows in the spaces within the Archimedes turbine

(Nagel & Radlik 1988; Brada 1999). However, it has recently been noted that the contribution of gravity to energy conversion is not significant because the water in the bucket is looks silent. In addition, the motion of water caused by the force of gravity with the movement of the turbine rotation has the opposite direction, in contrast to the overshot turbine where the direction of the water weight and the direction of the tangential speed of the turbine are parallel (Muller & Senior 2009). This is the main reason Muller assumes Archimedes turbine are driven by hydrostatic pressure by the water (Senior et al. 2008).

The force acting on the Archimedes turbine is the hydrostatic pressure. It was explened by Muller who model the Archimedes turbine with hydrostatic pressure wheel (Muller & Senior 2009). The hydrostatic pressure formed due to the difference in the water level on each blade along the Archimedes turbine (Muller & Senior 2009).

Terminology of Archimedes Turbine

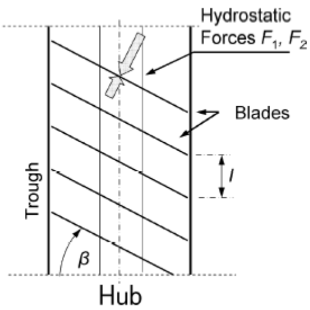
There are several terms that are often used on Archimedes turbines is:

1. Pitch: the length or mileage of the thread each time a lap or a period.
2. Chutes: space bounded by two adjacent blades
3. Bucket: the volume of water that occupies and flows in chutes each time a lap or a period.

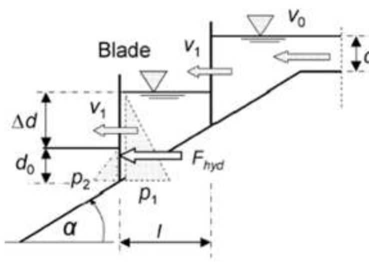
The complete terminology in the Archimedes turbine is available in Table 1:

Table 1. Terminologys of Archimedes turbine

Terminology	Definition
α	turbine angle slope
R_o	radius outer
D_o	diameter outer
M	number of rotation of screw helix
R_i	radius inner
V_u	volume of water over a period
L	total length
S	pitch length
P_{hydro}	potential power
P	total power turbine
P_o	power one blade
l	horizontal distance between blade
Δd	difference of water level between two blade
V_1	velocity water in turbine
V_o	velocity inlet
ρ	Ratio Ro to Ri
λ	Ratio pitch
ν	Ratio volume



(a)



(b)

Figure 1. (a) fornt view, (b) side view of Archimedes turbine scheme (Muller & Senior 2009)

Power Output Calculation

Based on the modeling done by Muller and Senior, the efficiency (η) of Archimedes turbines can be searched by using Eq. 1 (Muller & Senior 2009):

$$\eta = \frac{2n+1}{2n+2} \quad (1)$$

Where the value of $n = \text{do}\,\Delta\text{d}$ and its magnitude $\Delta d = \frac{h}{m} = \left(\frac{L}{m}\right) \tan\alpha$. Then, the output power of the turbine is $P = \eta\, P_{hydro}$, where $P_{\text{hyrdro}} = \rho.\text{g.do}.V_o.\text{m}.\Delta\text{d}$. So it can be seen that the efficiency of the turbine Archimedes is influenced by the turbine slope and the number of screw rotations (pitch).

The determination of the dimensions of Archimedes turbine still can not be found by using the efficiency equation which has been triggered by Muller and Senior, so the method of volume optimization can be used as an alternative way. There are three non-dimensional parameters in the Archimedes turbine, namely (Rorres 2000):

$$\nu = \frac{V_U}{V.Ro^2.\Lambda} = volume\ ratio \quad (2)$$

$$\lambda = \frac{\Lambda}{2.\pi.R_o} = pitch\ ratio \quad (3)$$

$$\rho = \frac{Ri}{R_o} = radius\ ratio \quad (4)$$

Rorres determines three parameter values by varying the number of blades to obtain the optimal bucket volume using Matlab software, (Rorres 2000):

Table 2. Optimum number for ratio Ro to Ri, pitch and volume

N	(ρ)	(λ)	(ν)
1	0,5358	0,1285	0,2811
2	0,5369	0,1863	0,2747
3	0,5357	0,2217	0,2697
4	0,5353	0,2456	0,2667

Previous Investigations of the Archimedes Turbine

To date, research on turbine archimedes has been widely practiced. This paper will discuss the results of studies that has been done. Havendri and Arnif (2010) conducted an experiment to determine the optimal screw angle values (A. Havendri, I. Arnif 2010). Experimental done on the head of 1.1 meters and using 3 prototypes with each angle of 23^0, 26^0, 29^0. From the experimental results, founded the relationship between output power and discharge with the angle slope of the thread, and also have the relationship between efficiency and discharge to the angle of the thread slope. The result shows that the best inclination angle is 29^0.

Khamdi and Akhyan (2014) conducted experiments to determine effect of pitch and rotation turbine (Nur Khamdi, Amnur Akhyan 2014). From the experimental results it was found that the highest turbine rotation was reached at angle of 35^0 on pitch length of 1,6 R_o and $2R_o$. While the on the pitch $2R_o$ produces a higher rotational speed compared with pitch of 1,6 R_o. But Khamdi and Akhyan have not been able to conclude whether the longer the pitch will increase the rotational speed of the turbine screw.

Erinofiardi (2014) conducted experimental testing, turbines designed using the simplification theory initiated by Muller (Erinofiardi 2014). Based on the experimental results, it was found that turbine efficiency was lower than the theoretical efficiency. This is due to other loss factors that are not considered in the simplification theory.

Yulistiyanto, Hizar, and Lisdiyanti. (2012) conducted experimental research on the influence of flow discharge and turbine shaft slope (Lisdiyanti et al. 2012). The experimental results show that there is a correlation between the turbine rotation speed and the turbine slope variation. Turbine Archimedes with 30^o and 40^o slopes produce the highest spin in large flow. While at low flow, turbines with a slope of 45^o produce the highest rotation. In addition, the turbine rotation speed will be higher with increasing flow rate. The power generated on the turbine will increase as the turbine rotation speed increases until it reaches its maximum power point, before the power has decreased significantly until the power produced is 0 when turbine rotation reaches the maximum. This is due to the higher rotation of the turbine, the torque will decrease to a value of 0. Usually it occurs when the turbine is not loaded or disconnected.

Saroinsong, Soenoko, and Wahyudi (2016) conducted research on the inlet and slope with the variation of Froude number (Saroinsong et al. 2016). Based on the results of research conducted, the lower the height of the water on inlet, the efficiency will decrease significantly. In addition, the angle of slope can also effect the efficiency of the turbine. From the experimental result, the greater the angle of slope, the turbine's efficiency decreases. This is due to at the 25^o angle, there is a small vortex, and vice versa. Another factor effect the efficiency is the number of screw rotations. Based on research conducted, it is known that turbines that have a more number of threads will result in higher efficiency.

Lyons Murray (2015) conducted research with experimental method. It was observed that the effect of immersion level on the turbine outside (Lyons 2015). Based on the data obtained, it was found that the highest efficiency was achieved when 22% of the turbine was submerged (at the outlet). However, the resulting power achieves the highest value of which the turbine is not submerged at all.

Table 3. Summary of the previous investigations

Researcher	Activity
G Muller and J, Senior	The basic theory of the working principle of Archimedes turbine with the principle of hydrostatic pressure
Ali Raza, Muhammad Saleem Mian and Yasir Saleem	Design and test performance with parameter variation with MATLAB Simulink
Daniyan, Adaramola and Dada	Designed 3-blade Archimedes turbine with geometry parameters (from Rorres and Muller and Senior)
Kyung Tae Lee, Eung-Seob Kim, Won-Shik Chu and Sung-Hoon Ahn	Designing turbine Archimedes with a pitch that is not constant
C. Rorres	Geometry optimization using Matlab software, taking into account the radius ratio, pitch ratio, volume specific ratio for the Archimedes pump
Murray William Keith Lyons	Optimization of Archimedes turbine geometry by computation method, total torque calculation using

	meshing, and optimum bucket volume computationally and comparable with Solidworks
Tineke saroinsong, Rudy Soenoko and Slamet Wahyudi	Archimedes turbine modeling with the concept of water linear momentum, ie hydrostatic pressure force. Then, consider the effects of Froude numbers, slope, and inlet depth (y), as well as flow phenomena that occur, to the efficiency of Archimedes turbine
Herman Budiharja, Halim Abdurrahim and Sigit Yoewono	Design Archimedes turbine, using simplified theory, determining dimensions with Table Rorres, but taking into account the gravity of water to power conversion.
Nur Khamdi and Ammur Akhyan	Looking for Pitch distance relationship, external diameter effect and gap influence on Archimedes turbine
Nur Khamdi and Ammun Akhyan	Relationship Effect of pitch on turbine RPM
Andrew Kozyn and William David Lubitz	Conduct a losses analysis on Archimedes turbines
Zachary Kraybill	Mechanical analysis on Archimedes threads uses FEA and CFD
Filo Christian Surbakti	Explains The process of manufacturing Archimedes turbines

Discussions

A Romanian engineer named Vitruvius provides detailed illustrations and detailed information about the screw construction of Archimedes through his work called De Architecture (Vitruvius, circa first century BC). In 1968, Nagel and Radlik published a book on how to design the Archimedes screw pump comprehensively, including how they are manufactured, based on their experience in the field (Nagel & Radlik 1988). Then, in 2000, Rorres optimized the volume of water transport through analytical methods (Rorres 2000).

The Archimedes screw used as a power plant is also called Archimedes turbine, while the Archimedes turbine assembly that has been equipped with a gearbox and generator is also called Archimedes screw generator (Lyons 2015). In 2000, Brada undertook a series of experimental testing of Archimedes turbine to generate energy (Brada 1999). Then, in 2009, Muller theorize simplification Archimedes turbine, known as the simplified theory of the Archimedean screw (Muller & Senior 2009). Muller compared the results of experimental tests conducted by Brada with his theory. Rorres and Nuenberg (2012) are modeling and calculating Archimedes turbines to find out the right inflow head value for optimal filling point value (Nuernbergk & Rorres 2012). In 2017, Lubitz and Kozyn modeled the losses of Archimedes turbines, in which there are several factors that cause losses to Archimedes turbines such as friction, expansion at the outlet and soaking the turbines at the outlet (Kozyn & Lubitz 2017).

Conclusion

The Archimedes turbine is a turbine capable of operating with high efficiency under low head conditions with moderate discharge. So that suitable Archimedes turbines are implemented to power remote areas of Indonesia in mountainous and hilly terrain that are difficult to access by PLN, as there are many water courses which has a low head height in the area.

But until now there is no standard theory that explains the relationship between energy conversion process, turbine geometry, and mechanical efficiency. Various models and theories about Archimedes turbine design have been developed such as the simplified theory of Archimedes screw developed by muller and the volume optimization model by Rorres. However, testing needs to be done both experimentally and numerically to test the accuracy of the theories and the modeling.

Various experiments on archimedes turbines are still continuing to this day. However, the experiments carried out only apply in accordance with the condition constraints determined by the examiner or researcher. In addition, there is no mathematical equation derivative that explains in detail the relationship of turbine geometry, such as pitch, inner diameter, number of blades, and number of screw rotation to the efficiency and power generated. Thus, further study and research is required on the Archimedes turbine.

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