The Effect Of The Ratio Of The Hub Diameter (d) To The Diameter Of The Screw (D) To The Performance Of The Archimides Screw

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Abstract. The potency of the ultra-low head hydro resource is quite huge in the world. In Indonesia, only 1.8% of the Pico hydro potency with head of less than 5m is utilized as electric resource [1]. Archimedes screw is one of the promising technology that could be used to extract this low head hydro resource. One prominent factor which is affecting the performance of the Archimedes turbine screw is the ratio of the hub diameter (d) to the diameter of the screw (D). In this paper, the ratio d/D were varied as 0.22, 0.29, 0.33, 0.42. In addition, flow rate (Q), were varied as well as 1.8 l/s, 1.4 l/s, 1.0 l/s. The blade configuration that used in this test is a single blade. The result shows that the highest efficiency is achieved with the diameter ratio of d/D = 0.42 with the efficiency off 40.23%.

1. Introduction

In 2017 the percentage of Indonesians who do not have access to electricity is around 4.65 % [2]. One frequent cause for this problem is the large number of dispersed rural locations with challenging geographical conditions [3]. An additional cause is the uneven distribution of population which has led to an ineffective electrical distribution infrastructure [4]. A micro hydro installation is a solution for this problem. In Indonesia, the amount of installed micro/mini hydro power is around ≈98.47 MW [5], whereas the potential is 450 MW [6]. There are several kinds of micro hydro power converter have been developed nowadays. Archimedes screw is one of the technology developing which is potentially used to exploit small scale hydropower resource. There are several parameters identified play important role to determine the performance of Archimedes screw, such as inclination angle (Ø), diameter of the screw (D), hub diameter (d), etc. This paper, highlights the effect of the ratio of hub diameter (d) to the screw diameter (D). This paper reports screw performance based upon experimental work. Furthermore, the flow rate incoming water was also varied.

The Archimedes screw is also called the Archimedian screw or screw pump. In brief, an Archimedean screw consists of a cylinder containing several continuous helical walls that, when the entire cylinder is rotated on its longitudinal axis, scoop up water at the open lower end and dump it out the upper end [7]. Some scientist stated that this machine was used during the reign of the Assyrian king Sennacherib (704–681B.C.) and that the design was put to use in spectacular fashion to water his palace garden at Nineveh (was an ancient Assyrian city) [8]. However, another scientist said that this machine was invented by Archimedes (287–212 B.C.) [9] [10] [11]. Who invented this machine still under debate see [7], however most people agree to name this machine as an Archimedes Screw. In recent years, the Archimedes Screw has been used working in reverse as a hydropower machine. If water is poured into the top of an Archimedes' screw, the water is lowered within cells which form between the blades and the trough, then it will force the screw to rotate. The rotating shaft which the screw attached then drives an electric generator. Such an installation has the same benefits as using the screw for pumping: the ability to handle very dirty water and widely varying rates of flow at high
efficiency. However this machine operates at low rotational speeds, which requires a complex gearbox to connect it to the generator.

Several previous research has been done relating with *Archimedes screw turbine*. [1] Performed experimental work, the inclination angle of the screw ($\beta$) was varied, and the effect to the efficiency of the machine investigated. It was found that the Increasing of inclination angle affect to rise the rotational speed of turbine. Yet, it tend to decrease the torque. Furthermore from 3 variations of angle ($22^\circ$, $30^\circ$ and $40^\circ$), it was found that $22^\circ$ angle has the highest efficiency.

[12] Reports experimental results, the relationship between torque, rotational speed and power was examined. The downstream water level was varied, and it was found that the higher the downstream water level (the lower the head), the lower power output for the same Torque. In addition, the rotational speed is higher as the downstream water level decreases for the same torque. In addition, Archimedes screw are relatively tolerant to changes in flow and varying water levels, maintaining reasonably high efficiency over relatively wide ranges of these parameters.

The simplification theory of the Archimedes screw was developed by [13]. Based on the idealization, a comparison is made to the hydrostatic pressure wheel. The Efficiency of the Archimedes screw was stated as function of blade geometry (angle, the number of turns and the ratio of inflow depth and radius) and leakage losses. Efficiency increases with increasing number of turns, as well as increasing ratio of inflow depth and radius. Decreasing screw angle also could increase efficiency.

[14] Suggests that increasing the ratio between pitch and diameter (P/D), there is a decrease in volume per bucket, and a proportional decrease in force acting on each bucket. This situation tend to reduce efficiency eventually.

2. Methodology

The experiment was done on irrigation channel in the Batu roto Village, Bengkulu Utara Region. The water from inlet is flowed to the screw via a valve (to control water flow rate) then exits to outlet. The ratio between hub diameter to the screw diameter (d/D) was varied as follow 0.22, 0.29, 0.33, 0.42. The decision to choose these ratio are based on the availability of the material. The dimension of the screw is provided in fig 1. The gap clearance between screw and housing is 5mm whereas, the slope angle of the screw $\beta$ is $22^\circ$.

![Figure 1. Dimension of the Archimedes Screw](image)

**Note**
- d = 32mm; 42mm; 48mm; 60mm
- D = 142mm
- P = 54mm
- L1 = 648mm
- L2 = 760mm
L3 = 860mm

Figure 2. Schematic diagram of the experimental setup.

The mechanical power Ps available at the turbine shaft can be determined by measuring the torque T at a corresponding angular speed \( \omega \). The torque is found by measuring the tangential force F on a pony brake with moment arm radius of pulley r.

\[
T = F \, r \tag{1}
\]

\[
Ps = T \, \omega = \frac{T \, 2 \, \pi \, n}{60} \tag{2}
\]

The efficiency in this case is the ratio between output mechanical power \( Ps \) and the hydraulic power available, which is calculated as
\[ \eta = \frac{P_s}{P_w} \]

\[ P_w = \rho Q g h \]

The torque was measured by using Pony brake. Whereas the rotational speed is determined by using stopwatch for 10 times rotational speed then it is converted into rotational speed. The flow rate of incoming water was varied 1.8 l/s, 1.4 l/s, and 1.0 l/s by using valve control. The effect of variation of the d/D and incoming flow water to the torque, power and efficiency then investigated.

3. Result and Discussion

3.1 The relationship between torque, rotational speed, and flow rate at various of d/D

Figure 4 shows the torque as output of varying rotational speed, flow rate and d/D. It shows that the higher the flow rate, the higher the torque. The highest torque is occurred at the rotational speed of 60rpm for all variations of d/D. All these torques are 0.182Nm, 0.177Nm, 0.176Nm and 0.174Nm as result of d/D of 0.42, 0.33, 0.29 and 0.22 respectively. Furthermore at any variations of flow rate, the smaller d/D, the torque tends to be smaller as well.

As d/D is bigger, the arm of the torsional moment occurred on the screw is bigger. Therefore the resultant tangential force on the cell which is filled up with water produces the higher torque as d/D higher. This is alleged to be the cause of the occurrence of greater d / D, the greater the torque produced for various variations of rotation.

In Figure 4 it is also can be seen that the larger the water flow rate, the greater the torque produced in any various of d/D or rotational speed. This phenomenon can be explained as follows, with the increasing of flow rate, the mass of water inside the screw cell is also increasing. Result in the tangential forces (hydrostatic forces within the cells in the tangential direction) are also getting bigger.

Torque Spectrum for d/D=0.42 is shown in figure 5. In general, the torque spectrum pattern for variations d/D=0.42, 0.33, 0.29 and 0.22 is similar to figure 5. The biggest torque always occurs at low

![Figure 4. Torque output as function of rotational speed and flow rate at variations of d/D](image-url)
rotation (60rpm), largest water discharge (1.8 l/s), and at a small rotational speeds. This pattern is common in various water wheels.

![Figure 5 Torque Spectrum Based upon flow rate and rotational speed for d/D=0.42](image)

3.2 The relationship between power output, rotational speed, and flow rate at various of d/D

The graph of power output as varying rotational speed, water flow rate and d/D is presented in figure 6. It shows the tendency of the turbine power to increase as the flow of water increases. This is because a large discharge makes the amount of hydraulic power input greater, therefore the mechanical power output produced is also enlarged, this is similar to what was stated by [15].
Figure 6. Power output as function of rotational speed and flow rate at variations of d/D

Spectrum power data for d/D=0.42 is shown in figure 7. From the graph, it appears that the largest power output occurs at around 120rpm and the largest discharge (1.8 l/s). The spectrum pattern that occurs at d/D=0.22, 0.29 and 0.33 is similar to what happened at d/D=0.42.

Figure 7. Power output spectrum as function of rotational speed and flow rate at d/D of 0.42

Besides, the bigger the d/D makes the power produced is also enlarged. The greatest power always occurs at d/D=0.42 for various variations of flow rate. At 1.8 l/s discharge the largest output power is 1.60W, occurring at 120 rpm. While for the discharge of 1.4 l/s, the largest power of 1.03W occurs at 100 rpm. Output power of 0.98W is produced at 100 rpm for flow rate of 1.0 l/s.

The power that occurs at d/D=0.42 which is greater than the other diameter ratios which is very closely related to the torque that occurs as explained previously. Where at d/D=0.42 produces the largest torque. this large torque is also closely related to the larger torque arm for larger d/D, which results in a large amount of power in the end.

3.3 The relationship between efficiency, rotational speed, and flow rate at various of d/D

Figure 8 shows a graph of the relationship between efficiency, rotation and flow rate of water entering Archimedes screw. For all discharge variations and screw rotation speeds, the highest efficiency is always achieved at d/D=0.42.
Figure 8. Efficiency as function of rotational speed and flow rate at variations of d/D

At 1.8 l/s flow rate, the highest efficiency occurs at 120 rpm with an efficiency of 35.20%. While the lowest efficiency occurs in variations of screw d/D=0.29 with an efficiency value of 30.73% at 100 rpm. For flow rate of 1.4 l/s the maximum efficiency is 30.08% at 100 rpm while at d/D=0.22, the maximum efficiency value is 20.65% which is also at 100 rpm. Furthermore at the discharge of 1.0 l/s, the efficiency is 40.23% at 100 rpm. While for screw variations of d/D=0.22, the maximum efficiency is 27.82% at 80 rpm.

In general, efficiency increases with an increase in the value of d/D, and this occurs in almost all variations of flow rate. Increasing the d/D ratio means narrowing the cell space filled with water, which means the closer the distance between the hub and the surface of the water in the cell. This tendency is similar to what was conveyed by [13] which states that the closer the water surface to the hub (d0), the higher the efficiency, as shown in Figure 9. In the graph it is stated that the greater d0 / R then the efficiency increases (or the more the water level approaches the hub, the more efficiency increases). The results of this study are in accordance with the research conducted (13).

Figure 9. Efficiency graph as a function of d0/R [13]

4. Conclusion
This literature review aims to identify and analyze the trends, datasets, methods and frameworks used in the topic of attribute independence assumption assumptions on NB between 2010 and 2018. Based
on the inclusion and exclusion criteria designed, it shows 71 study studies of attribute independence assumptions on the published NB between January 2010 and December 2018 are investigated in this literature review have been conducted as a review of systematic literature. A systematic literature review is defined as the process of identifying, assessing, and interpreting all available research evidence in order to provide answers to specific research questions.

The results of this study identified three of the most commonly used and influential framework methods in the topic of attribute independence on the NB. They are Menzies et al. Framework, Lessmann et al. Framework, and Song et al. Framework. They are Langley et al [16], Friedman et al [17], and Wu et al [18].

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