The effect of substantive parameters on the efficiency of Archimedes screw microhydro power: a review

A Nurul Suraya¹, N M M Ammar¹ and J Ummu Kulthum¹
¹Faculty of Mechanical Engineering, Universiti Malaysia Pahang, 26600 Pekan, Pahang, Malaysia.

Email: surayanurul@gmail.com

Abstract. Due to the increasing demands in electricity and decreasing in fossil fuels sources, then hydropower are being developed and most of the project involve with large dams construction and may cause the people live surrounding to be flooded. Hence, the construction of Archimedes screw runner blade turbine can be the best option to generate energy without cause too much environmental impact like a fish friendly turbine and low maintenance cost. This review focus on the parameters that affected the performance of turbine. Besides the review also presented a methodologies based on parameters studied by previous researcher and from that review, it has been found that the uses of external parameter have an effect on the internal parameter in terms of efficiency. In further investigation, another parameter such as gap leakage, velocity of water, blade thickness should be considered to investigate the relationship of efficiency.

1. Introduction

Renewable energy has become one of the important medium for future needs as demand for fossil fuels keep increasing progressively [1]. Renewable energy sources that are commonly used by people nowadays to solve diminishing of fossil fuels include as solar, geothermal, biomass, biofuel wind, water and fuel cells. All these sources of energy will not diminished as it will always be renewed naturally and have high potential to produce a clean environment and reduce the greenhouse gas emission as well as produce a little of waste products that can give unscrupulous effect to earth.

About 71% of this earth is covered by water. So that means the innovation on generating the power from water sources can be expand rapidly. There are several ways on how to generate energy from the water source. For example, energy can be created by using the tidal waves, ocean waves and hydropower. The hydropower can be classified into four categories in terms of power output, such as large, small, mini, micro and Pico hydropower. Table 1 below shows the classification of hydropower plant. Large hydropower can achieved about more than 1000kW of electricity, small hydropower range is of 500kW to 1000kW, mini hydropower have capacity between 100kW to 500kW and micro hydropower installed that can have output power between 5kW to 100kW [2, 3]. Micro hydropower power output can be used in rural areas specifically for small or medium houses.
Table 1. Classification of Hydropower plant [2, 3].

| Classification of Hydropower | Power Output                              |
|-----------------------------|-------------------------------------------|
| Large                       | More than 1000kW                          |
| Small                       | Installation range between of 500 to 1000kW |
| Mini                        | Power output of 100 to 500kW              |
| Micro                       | Installation range of 5kW to 100kW        |

As the electricity demand increasing year by year, the hydropower is one of the best alternative way to generate energy and have many advantages in many aspects which is highly stable, economical, accomplished of generating reliable energy needed, minimal civil works, suitable on low head scheme. Classification of Hydropower can also be describes in terms of head difference and flow rate required. Figure 1 below explains the graph of head, \( H \) (m) difference against the flow rate, \( Q \) (m\(^3\)/s) for each hydropower [4, 5].

![Figure 1. Classification of hydropower for head vs. flow rate [4, 5].](image.png)

In this study, the main purpose of the research is to determine the suitable hydropower to install in rural areas, specifically the remote areas [6]. The study on scope of the area is more focus in the rural region in Malaysia. Since the opportunity of exploring the low head hydropower for generation power output in Malaysia have been given slight responsiveness, the introduction of Archimedes micro hydro screw could be a way to response to the assessment. The Archimedes micro hydro power assists the rural topology with its small head range and lower flow rate. The benefit of selecting Archimedes screw runner also is that environment impact has very small impression on the efficiency of the turbine. Although the output electricity only can achieve about less than 100kW, it may become one of best ways in generating electricity to small house and small resorts at the rural areas.

The aspect of generating power with small flow rate and head arrangement is highly suitable to install Archimedes Screw micro hydro power in rural areas, specifically the remote area. Water sources such as river, pond, and water fall and river stream condition area in generous in remote area [7]. According to figure 1 above, the Archimedes screw Micro Hydro Power head difference ranges from 1 to 10 meter in height while the flow rate required is approximately between speeds of 0.5 m\(^3\)/s.
to 6 m$^3$/s. Flow rate on the current flow rate on River Pahang in Malaysia can generate to the flow rate of that amount and remote area can produce heads as required [8]. Each turbine may produce different efficiencies if the topology of the area and climate change. The Archimedes screw is also similar. It can be describe as a gravity machine [9]. It is comparable to waterways turbine but it can produce higher efficiency as presented in figure 2 below compared to a water wheel and a low speed radial turbine for smaller and moderate flow rate. In fact, hydro screw can sustain its efficiency at high rates. Even without the disturbances from torrential river waterway [9]. As for environmental effect, the Archimedes screw is much proven friendly toward marine animals. The slow rotational speed as well as the gap between the blades produces small hydrodynamic forces, and creates minimal contact with moving obstacles[9].

![Figure 2. Comparison of low head turbine plots in Efficiency vs Head (m) [5, 10].](image)

Thus, the development of renewable energy in contact of micro hydro power is one of the important source of power generation, but there are such problems that disturb the performance of turbine and at the same time effect the quality of power that can be created by turbine and it is important to study the suitable related parameter based on current situation in order to achieve some improvement in energy production.

2. Controlling parameter
The benefit of improving the design of Archimedes screw runner is to improve its efficiencies and its power output. However, there are many criteria displayed in figure 3 below that are needed to develop better efficiencies. These criteria are the external parameter (the outer radius of the blade $R_0$, length of the blade $L$, Head difference $H$, inflow depth $d_0$ and slope of the penstock, $\alpha$) and internal parameters (hub diameter $D_h$, inner radius $R_i$, number of blades $N$, volume of bucket $V$ and the pitch of the blades $P$). The outer parameters are the controlled parameters of the Archimedes screw runner and the flow rate of the water. The internal parameters are the required characters to optimize the enactment of the screw [11]. In this study, the parameter of the research is to emphasis on the study of the outer diameter of the penstock $D_0$, the slope $\alpha$, head difference $H$ and the length, $L$ as shown in figure 3(a) and 3(b) to control the flow of water thus allow the optimization on design of Archimedes screw runner for micro hydro power. This outer parameter can determine the relationship of internal parameter on the effect of efficiencies.
Figure 3(a). Blade design of Archimedes screw [11].

Figure 3(b). Side elevation of screw blade [12].

Head difference exists as the level of water is differ between top and bottom reservoir. The water flow from the top reservoir and forming a bucket which make the blade rotate along the length of the Archimedes screw blade [13] while the inclination of blade has contribute to the formation of hydrostatics force where the downstream pressure that acting on blade is smaller compared to the upstream level [12]. Because of the hydrostatic force, the blade is rotating (which contribute to kinetic energy) and make turbine turns generator rotor. Lastly, the electrical energy is generated.

3. Parameter evaluation
Several methods of analytical were conducted by controlling the head difference, H, length of the blade, L and the slope of the penstock, α [11, 12, 14, 15]. Some researcher conducted the analytical method by abandoning the slope of the penstock to determine the efficiency of the blade [12]. The first parameter that commonly used as independent parameter is slope inclination angle. Müller and Senior, Yulistiyanto et al., and Stergiopoulou and Kalkani have been considered the effect of slope angle towards the performance of the Archimedes screw runner blade turbine. All of the researchers possess a dissimilar approach on how to collect the data relating to efficiencies. Müller and Senior [12]
proposed that the efficiency of the blade is not consistent with the slope angle. However, Yulistiyanto et al., determined the increasing slope angle is increase with the efficiency, but have optimum efficiency occurred at 350 angle and after 350 angle, efficiency starts to decline [16]. William David Lubitz [17] obtained the results equally with Muller which is lower slope angle is better in performance. Stergiopoulou and Kalkani compared angle between 220, 330 and 440 angle of slope and study on the behavior of hydrodynamics performance and only shows the preliminary results of simulation [18]. Lubitz et al., and Muller have an identical findings where lower angle have a better efficiencies while Yulistiyanto et al., is vice versa.

In head difference aspects, there are two researchers which focus on this parameter. Both of the researchers use a dissimilar methodology. Stergiopoulou and Kalkani have preliminary results which study more on the effected head in terms of hydrodynamics behavior than the efficiency of turbine [18]. On the other hand, Hendra and Indriani consider the head difference with three values of head and compare between these 450mm, 550mm and 650mm on the prototype [19]. The experimental results from Hendra and Indriani formularize that head is directly proportional with the power output. These can be believed that the head difference plays an important role in the turbine’s performance.

Additional parameter that leads to the variation performance of the turbine is the number of turns and the outer diameter of the blade. Based on the study made by Rorres, Muller and Senior, Stergiopoulou and Kalkani and Raza et al., study on the number of turns but in different methods as summaries in table 2. Rorres conclude in terms of volume of water in cycle which increases with the number of blades. Muller identified that efficiency dependable with number of turns while Stergiopoulou and Kalkani studied the behavior of hydrodynamic using one or more blades with various values of flow input. Both Muller and Senior and Raza et al. have the similar results in number of turns, so it can be summaries that to have better efficiencies, then the number of turns should rise depending on the site.

Another parameters which have an important role as controlling parameter is the length of the blade. Rorres, Muller and Senior, Yulistiyanto et al., Raza et al., Stergiopoulou and Kalkani, Lubitz et al., and Ammar et al. control the length as constant parameter as the length did not contribute most in feature of efficiency.

Consequently, by considering the above parameters such as slope angle, length of the blade, head difference, number of turns and diameter of blade would not be improved if the associated problem is not identified including the climatic change, the prototype cost such as material structure and material joining, installation cost, the suitability of the site and etc.
Table 2. Summary of parameter from previous researchers.

| Researcher                  | Method of analysis | Control parameter                                    | Independent parameter          | Results/ Findings                                                                 |
|-----------------------------|--------------------|------------------------------------------------------|-------------------------------|-----------------------------------------------------------------------------------|
| Rorres (2000) [11]          | Analytical         | 1. Diameter 2. Length, L                            | 1. Number of blade, N         | 1. Volume of bucket depend on slope angle. 2. Volume of water in cycle increase with number of blade. |
| G. Müller and J. Senior (2009) [12] | Analytical        | 1. Length, L, 2. Outer diameter, 3. Head, H       | 1. Inflow depth over radius, d1/R 2. Slope Angle, α 3. Number of turns, N. | 1. Inflow depth over radius increase, efficiency, η increase. 2. Angle increase, efficiency, η decrease. 3. Number of turns increase, efficiency, η increase. |
| Yulistiyanto et al., (2012) [16] | Experimental      | 1. Length, L, 2. Outer diameter, D0 3. Head, H, 4. Pitch diameter, P | 1. Slope angle, α 2. Water discharge, Q | 1. At angle 25°-40°, efficiency increase, at 41°-50°, start to decrease, have maximum efficiency and power at 35° angle. 2. Water discharge increase, then efficiency and power increase too. |
| Raza et al., (2013) [20]    | Numerical          | 1. Head, H, 2. Length, L, 3. Outer diameter, D0 4. Head, H, 5. Pitch diameter, P | 1. Water discharge, Q 2. Outer radius screw 3. Blade portion length of screw | 1. Simulate to obtain electrical power output. |
| Researcher                  | Method of analysis | Control parameter | Independent parameter | Results/ Findings                                                                 |
|-----------------------------|-------------------|------------------|-----------------------|--------------------------------------------------------------------------------|
| Strgiopoulou and Kalkani    | Computational     | 1. Length, L     | 1. Slope angle, α     | 1. Inlet pressure was set to zero under homogenous Neumann condition.          |
|                             |                   | 2. Diameter      | 2. Number of rotation, N |                                                                        |
|                             |                   |                  | 3. Water discharge, Q  |                                                                        |
|                             |                   |                  | 4. Head, H            |                                                                        |
| Lubitz (2014) [13]          | Experimental      | -                | 1. Rotational speed    | 1. All friction losses at entry and exit effect are neglected.               |
|                             |                   |                  |                       | 2. Reducing the speed does not minimize the gap leakage.                    |
| Lubitz et al., (2014) [17]  | Analytical and experimental | 1. Pitch diameter, P | 1. Fill level (full, under full and overfull) | 1. All friction losses at entry and exit effect are neglected.               |
|                             |                   | 2. Outer diameter, D0 | 2. Gap leakage between flights | 2. Gap leakage decreases the efficiency.                                   |
|                             |                   | 3. Length ,L     | 3. Slope angle, α     | 3. Gap leakage decreases the rotational speed.                              |
|                             |                   | 4. Head, H       | 4. Pitch ratio        |                                                                        |
|                             |                   | 5. Number of rotation, N | 5. Water discharge, Q |                                                                        |
| Ammar et al., (2014) [21]   | Computational     | 1. Length, L     | 1. Water discharge, Q | 1. Obtain pressure contour and velocity contour to determine particle impact prediction for Archimedes screw design. |
|                             |                   | 2. Outer diameter, D0 | 2. Velocity streamline |                                                                        |
|                             |                   | 3. Head, H       |                       |                                                                        |
|                             |                   | 4. Pitch diameter, P |                       |                                                                        |
| Researcher       | Method of analysis | Control parameter          | Independent parameter | Results/ Findings                                      |
|------------------|--------------------|----------------------------|------------------------|-------------------------------------------------------|
| E. Fiardi        | Experimental       | Slope Angle, $\alpha$     | -                      | 1. Efficiency for analytical is 50% and power output is 0.236W.  
|                  | comparison         | Length, $L$                |                        | 2. Efficiency of experiment is 41% and power output is 0.098W.  
|                  |                    | Head, $H$                  |                        |                                                       |
|                  |                    | Outer diameter, $D_0$      |                        |                                                       |
| Hendra and A. Indriani | Experimental     | 1. Pitch diameter, $P$    | 1. Head, $H$           | 1. Flow rate increase, rotation increase.               
| (2014) [19]      |                    | 2. Outer diameter, $D_0$  | 2. Water discharge, $Q$| 2. Head increase as the rotation increase.               
|                  |                    | 3. Length, $L$             |                        |                                                       |

4. Conclusions
The Archimedes screw runner blade turbine is one of most guaranteed alternative solution to overcome the lacking of fossil fuels source and environmental impacts. A suitable Archimedes screw runner blade turbine efficiency is depending on the function of screw parameters. Therefore, this review is focused on parameters study by comparing the effect of parameters in aspect of efficiency. The uses of external parameter have an effect on the internal parameter and the external parameter data can be collected for the prototype. Besides, the effect of climate change, material selection and cost installation also should be considered to build an Archimedes screw runner blade turbine with good performance and have benefits to the people especially to those people who lives in rural areas.

Acknowledgements
The authors would like to be obliged to University Malaysia Pahang for providing laboratory facilities and financial assistance under project no. RDU140348.

References
[1] Kandpal J B, Madan M 1995 Renewable Energy 6 159-60
[2] Mohibullah M, Radzi A M, Hakim M I A, Basic design aspects of micro hydro power plant and its potential development in Malaysia. Power and Energy Conference, 2004 PECon 2004 Proceedings National; 2004 29-30 Nov. 2004.
[3] Keawsuntia Y 2014 Frontiers of Manufacturing and Design Science IV 496-500
[4] Fraenkel P P O, Bokalders V, Harvey A, Brown A, Edwards R. 1999 Micro-hydro power: a guide for development workers IT Publications)
[5] Elbatran A H, Yaakob O B, Ahmed Y M, Shabara H M 2015 Renewable and Sustainable Energy Reviews 43 40-50
[6] Date A. Akbarzadeh A 2009 Renewable Energy 34 409-15
[7] Tushar K. Ghosh M A P 2011 Energy Resources and Systems 2 Springer)
[8] Muhamad Barzani Gasim M E T, Mushrifah Idris, Pan Ian Lun, M. K. A. Kamarudin, A. A. Nor Azlina, Mazlin Mokhtar and S. A. Sharifah Mastura 2013 *American Journal of Applied Sciences* **10** 42-57
[9] Barelli L, Liucci L, Ottaviano A, Valigi D 2013 *Energy* **58** 695-706
[10] Williamson S J, Stark B H, Booker J D 2014 *Renewable Energy* **61** 43-50
[11] Rorres C 2000 *Journal of Hydraulic Engineering* **126** 72-80
[12] Müller G, Senior J 2009 *Journal of Hydraulic Research* **47** 666-9
[13] Lubitz W D 2014 *Proceedings of The Canadian Society for Mechanical Engineering International Congress 2014* 1-6
[14] Fiardi E 2014 *Journal of Ocean Mechanical and Aerospace Science and Engineering* **5** 1-12
[15] Brada K 1999 **14** 52-6
[16] Bambang Yulistiyanto Y H, and Lisdiyanti 2012 *Dinamika TEKNIK SIPIL* **12** 1-5
[17] William David Lubitz M L a S S 2014 *Journal of Hydraulic Engineering* **140** 04014050
[18] Alkistis Stergiopoulou E K 2013 *International Journal of Engineering Research & Technology* **2** 193-9
[19] Hendra H a I, Anizar 2014 *International Conference on Mechanical Design, Manufacture and Automation Engineering*
[20] Ali Raza M S, Yasir Saleem 2013 *International Journal of Engineering Research & Technology* **2** 2471-7
[21] Mutasim M A N A, N.S.: Adam, A.A.A., Prediction of Particle Impact on an Archimedes Screw Runner Blade for Micro Hydro Turbine. 4th international conference (ICME 2013); 2014; Bangi-Putrajaya, Malaysia: Trans Tech Publications, Durnten-Zurich.