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# Electric Power Generation from Low Head Simple Turbine for Remote Area Power Supply

Erinofiardi[a*], Muhammad Syaiful[a], Adhy Prayitno[b]

[a]Mechanical Engineering Department, Engineering Faculty, University of Bengkulu, Indonesia
[b]Mechanical Engineering Department, Engineering Faculty, University Riau, Indonesia

*Corresponding author: riyuno.vandi@gmail.com

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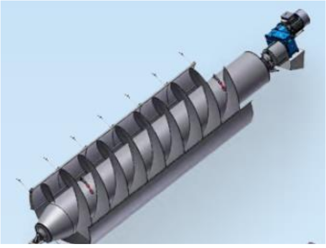
**Graphical abstract**



**Abstract**

Over recent years, there has been an explosive growth of interest in the development of micro-hydropower generationturbine based on low head. Initial investment in building huge dams and large power stations is needed for high head turbine, beside these large dams are not environment friendly. Particularly in lower head, screw turbine is suitable for environment reason where this turbine has high efficiency, relatively lower cost and low environmental impact. Screw turbine can be applied in remote area which has water resource and no grid connection available. This paper reports experimental results examining the relationship between rotation speed and power. Laboratory scale of screw turbine is made by using locally available materials. Test results show that different speed of generator caused by different diameter of pulleys has great discrepency.

*Keywords*: Screw turbine; low head; remote area

## ■1.0 INTRODUCTION

Environmental issue and diminishing sources of energy like fossil fuel and coal encourage researcher to pay attention in finding another sources of green energy nowadays. A lot of research have been conducted by using natural energy sources suh as geothermal, biomass, solar, wave, wind and water. [1]It has been recognised that from all of those sources, energy from water is one of the biggest source in our planet beside energy from the sun.[2] Hydropower is a good example of renewable energy and its potential application to future power generation cannot be underestimated. Water energy a clean, cheap and environmentally friendly source of power generation is a great importance for sustainable future, because this resource can be found around the globe.

Using water energy as source of power generation has been growth over recent years. High head turbine is developed to generate electricity in a few decades and it can be applied in some sites. Due to head limitation, researchers try to find another suitable turbine for lower head and can cover some drawbacks of high head turbine. In addition, most of the low head water sources are not explored yet. The cost of the comercially available low head water turbines is considerably high per kilowatt output, more research need to be done on lowering the cost of these low head hydro-power systems. Use of these low head water sources will help in de-centralization of power supply and helping remote area power supply.[3,4]

The annual global hydropower production is very small in comparison to the global power consumption. However the technically expoitable hydro power potential available throughout the world is far more than the one which is actually been used as illustrated by the data from Sterngerg, Kaygusz and Tailor.[5,6,7,8] The world hydro power scenario show that the technically exploitable potential of hydro energy is about 14000 TWh/year and economically exploitable potential is about 8000 TWh/year, whereas the present global hydro power generation stands at 2800 TWh/year.[5,7,8,9]

Looking at the above estimate it is clear that there is a large potential of hydropower waiting to be exploited. Furthermore there is a large gap between technically exploitable and economically exploitable potential,[5,8,10] which creates a need for further research in hydropower technology to make it more economic and help to reduce this gap. Until now most of the large hydropower sites have been exploited.[5,11] However, most of the small and micro hydro site are yet to be exploited.

Thus keeping in mind that the world currently is still heavily dependent on non-renewable energy sources (fossil fuels) such as coal, oil and natural gases, which are rapidly diminishing and becoming increasingly more expensive, the role of renewable has been recognized to be significantly important in sustainable future development.

An interest in micro-hydropower turbine has grown year by year. The feasibility of micro-hydropower by using axial flow turbine was examined. However, this kind of turbine has several weaknesses such as the need of high head and lack of environmentally friendly causing fish cannot pass through that turbine blade. Due to low head hydro resources, other kinds of turbine, split pipe reaction turbine and cross pipe reaction turbine are examined. However, these turbines need more cost to install intake pipe,[5] and fish cannot pass trough these turbine.

Furthermore, in the rapid-change of technology these days, there is an environmental issue for saving fish and other biota on water where water is used as hydro power source. As seen in several developed countries, there is a ban to dam a river that can disturb its ecosytem. There should be a consideration of how to safe them while hydropower system is built. Installation of screw turbine is unlikely to have impact on the quantity and quality of spawning and juvenille coarse fish habitat available there.[12,13,14] Unlike most micro-hydro technologies, an operating screw turbine can be passed through by fish and small debris without causing damage to the screw. Conversely, screw turbine in general does not harm fish. Studies of screw turbine on the River Dart (UK) found that almost all fish, including eels, trout and solenoid, passed through screw turbine unharmed, and that intake screening was not necessary. Laboratory test found fish less than 1 kg were not injured by contact with screw leading edge if the tip speed was less than 4.5 m/s (a speed greater than many operating screw turbine): addition of a rubber leading edge further reduced injuries to larger fish as higher tip speeds.[14]

Some researchs already done about screw turbine. Measurements of screw turbine showed the effect of inflow water level to diameter, and gave efficiencies between 79% and 84%, make this as interesting alternative for turbine in low head hydropower application,[15,16,18,19] where the power is generated by hydrostatic pressure difference and horizontal screw velocity.[15,17]

Because of this kind of turbine has high efficiency, relative lower cost and low environmental impact, screw turbine to be widely used at low head sites in Europe. These same factors, as well as raising policy support for distributing renewable energy generation, are expected to result in a prominent market for screw turbine in Asia.

Available range of micro-hydro generation technologies becomes wider with a recent addition of screw turbine. One of benefit of screw turbine compare to other generation technologies is, it has greatest potential at low head sites (less than about 5 m), and unlike conventional reaction or impulse turbines, screw turbine also has the potential for maintaining high efficiencies even as the head approaches zero.[20]

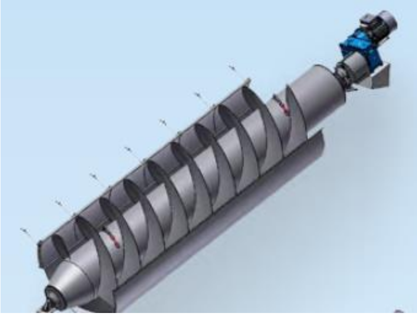


**Figure 1** Screw turbine with open trough[21]

Screw turbine consists of an inner cylindrical shaft, around which one or more helical surfaces (blades) which are wrapped orthogonal to the cylindrical surfaces (Figure 1). The resulting geometry is very much like conventional in (and in some case are fixed to it) a cylindrical trough. This trough may be a tube that encircles the screw, or it may only extend around the lower half of the screw. Water flow into the top of the screw, causes it to turn. Water is bounded by two consecutive blades in a ‘bucket’. The hydrostatic pressure in this body of water exerts on the bucket surfaces causes the screw to turn, lowering the bucket in the process.

Screw turbine used by inversing principle of screw pump. There is enough scientific literature on the use of Archimedean screw as pumps.[22,23,24] However, when Archimedean screw used to extract energy from a flow there is still little English literature addressing engineering of it, and much of what is available is case studies of installations. Most of the case studies are qualitative; however some of the reports sufficiently give detailed performance data from operating screw turbine to be used for engineering modeling.[19,25,26]

An examination of the dynamics of screw turbine in the literature present an efficiency model of an Archimedean screw based on the difference in hydrostatic pressure across the screw surfaces. The model includes the effect of leakage between the gap between screw blade and trough. This research conclude that the efficiency of a screw is theoretically independent of rotational speed.[15] However, to achieve a compact equation, for predicting efficiency, their model simplifies the screw geometry to such a degree that it is not useful as a practical design tool.

The inflow conditions to an Archimedean screw and its analytical model can be used to predict and design for optimal inflow conditions.[27] Another research examined the effect of screw geometry on turbine efficiency, both in lab tests and via a survey of existing screw turbine across Europe.[28] The survey found that plants on the order of 10 kW to 60 kW were most common, and that fixed speed generators are much less tolerant of large flow variations than variable speed generators. Their lab tests also examined the use of rotating trough in an effort to increase efficiency. They found that in most cases, a fixed-trough design is more efficient, and more tolerant to change flow conditions.[29]

Sufficient English literature is not currently available on screw turbine to guide designers seeking to optimize screw turbine for specific site and flow conditions, although there are some non-English literatures related to screw turbine are available.

This paper will focus mainly on the manufacturing and experimentation of a simple screw water turbine working on the same principle of gravity turbine under the micro-hydro range for low head applications. Simple manufacturing methods using locally available material and skills will be presented. The performance of the test unit will be explored and evaluated as well as identify potential areas for improvement. This work is part of a larger research project seeking to develop engineering models of screw turbine that can be used as practical engineering tools.

## ■2.0 EXPERIMENTAL

Water weight is generally assumed enclosed by the screw’s blades while drives the turbine.[15,19] If no losses are assumed, all potential energy contained in the flow can be extracted giving such a machine the teoritical maximum efficiency of 100%. However, most of the water weight in the screw rests on the trough, which does not move. Power is generated by force and velocity as shown in Figure 1, and since the velocity vector of the rotating screw acts tangentially to the screw, only a small part of the water weight enclosed in the screw)the part which is resting on the inclined outer section of the blade) contributes to energy conversion. Unlike the water in the cells of an overshoot water wheel, weight force direction of the complete water mass coincides with the downward direction of the cell movement. The contribution of the weight force is therefore neglected.

Measurement of screw turbine performance across a wide range of conditions and parameters, such as screw slope, rotation speed, and fill point can be done by laboratory experiments in which are not easily obtained from field measurements of operating screw turbine. Currently, only two research group have reported results of screw turbine laboratory studies in the English literature.[26,28,29] Laboratory studies of screw turbine were initiated at the University of Bengkulu before it applied in remote area around Bengkulu province to generate electricity.

**Figure 2** Turbine screw experimental apparatus

This turbine has diameter 0.106 m (106 mm). Total length of turbine is 0.7 m, consist of 9 blades screw with pitch screw 0.08 m as a distance between blade screw. Flow rate of water passing through the turbine is 0.68 l/s (0.00068 m$^3$/s). A series of laboratory scale turbine screw were custom made by using locally available materials. The lab screw was tested in a custom built experimental apparatus capable of providing a range of controlled head and flow conditions (Figure 2). During a test, the screw is suspended at each end on bearings within a cylindrical trough. Two pairs of pulleys are used to continue rotation from turbine shaft to generator, and also white acrylic plastic is joined on the top of trough to allow for future studies involving flow visualization (Figure 3). Because of limitation in producing, the nominal gap thickness between the screw and trough is made around 5 mm. This gap is necessary to prevent friction between the screw blades and the trough, but also allows for leakage losses. An upper reservoir supplies water to the screw. Water is supplied by two electric pumps that operate continuously, and also those pumps are used to control reservoir depth.

**Figure 3** Acrylic cover and pulleys

While the lower end of screw turbine is completely submerged (flooded) will cause decreasing effective head, so low end of trough is put just over the top of lower reservoir, the effective head will decrease. Flow exiting the screw is collected in a lower reservoir which supplies the pumps that feeds the upper reservoir. Water depths within the upper and lower reservoirs were measured by manual sight tubes.

At this time there are no sufficient measurement devices available at Mechanical Engineering Department University of Bengkulu. Therefore, the power output of the screw does not measure torque to get mechanical power, however it use multi-meter to show how much current and voltage generated. To show this turbine really generate electricity, bicycle generator and also some led lamps are used (Figure 4).Rotational velocity was measured using a tachometer located on the outer side of pulley affixed to screw turbine shaft.

**Figure 4** Bicycle generator and led lamps

**Figure 5** Turbine blades

Screw turbine is made by using locally available materials. PVC pipe with 4 inches diameter is used as duct or trough of turbine, aluminum is used as screw blade and joined by using rivet (Figure 5). Turbine is installed with $45^0$ elevations ($\alpha$) to horizontal.

## 3.0 RESULTS AND DISCUSSION

By using flow rate of water (Q) 0.68 l/s (0.00068 $m^3/s$), this turbine can generate electricity. This turbine uses two pairs pulley reduction. At first pair of pulley, tachometer measured that rotation at generator is 560 rpm and at turbine is 232 rpm. As showed in Figure 6, measuring current and voltage by using multimeter get 33.1 mA and 2.97 volt respectively. It can be said that in this experiment power can be generated maximum at 0.098 Watt. Furthermore, at second pair of pulley, big gap in pulleys diameter used to increase rotation, so that tachometer measured rotation at generator is 2457 rpm and at turbine is 946 rpm. Measuring current and voltage by using multimeter get 61.6 mA and 4.50 volt respectively. It can be said that this experiment power maximum can be generate at 0.2772 Watt.

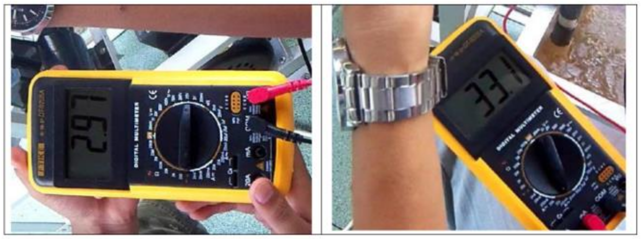


**Figure 6** Voltage and current generated in first pair of pulleys

Most interestingly, the comparison of two experiments has a profound effect on the voltage and current generated to produce electricity. Different pair of pulley diameter which produce different speed of pulley. This discrepency is interesting.

**Figure 7** Voltage and current generated in second pair of pulleys

Actually, mechanical power produced by screw turbine is $P = \omega.T$, where $\omega$ is the rotational speed of the turbine in rad/s and T is the torque in Newton meter, however, at this time we do not have torque measurement equipment so the torque cannot be measured.

The maximum power $P_{max}$ available to a hydroelectric turbine is given by

$$Pmax = \rho.g.Q.H \qquad (1)$$

Where Q is the flow rate, H is the head drop across the turbine, $\rho$ is the water density and g is the gavitational constant. The efficiency n of the Archimedean screw generator can be written as

$$\eta gen = Pgen/Pmax \qquad (2)$$

During testing, a nominal flow rate of 0.68 l/s and head of 45 mm was used, giving a typical $P_{max}$ of 0.3002W. While this power is compare to power of generator, this turbine has 33% efficiency on first data of experiment, and it has 92% efficiency on second experiment. This results show that higher rotation on generator will produce higher power.

Study of the impact of rotational velocity on screw turbine performance was initiated after the prototype screw turbine was observed to have a substantial drop in performance as lower velocity of generator. The results in Figure 7 show that peak efficiencies were gotten while rotational velocity of generator is 2457 rpm. This suggests that one of the impact on power output caused by changing velocity of generator. Lower speed of generator does reduce the range of power that the screw turbine can achieve. Effectively, as the speed of generator is increased, the efficiency of the screw remains high, however, the pulleys diameter that used on generator and turbine shaft must have big discrepancy.

## 4.0 CONCLUSION

Screw turbine is built succesfully with locally simple materials. Lab tests were performed to quantify the performance of screw turbine under two different operation conditions, notably changes in rotational velocity of pulleys used in experiment. and at second experiment this turbine can generate power 0.2772 Watt. By considering equipments and measurement tools used, this result is promising to be continued.In addition, data was collected from a prototype screw turbine to examine the effects of changing pulleys. The results suggest that screw turbine can be expected to operate efficiently across a range of head and flow conditions in small-scale run-of-river applications for remote area power supply.

Future research plans is to consider the impact of varying other parameters, including the effects of inlet and outlet geometry, installed slope and pitch.

## References

[1] Erinofiardi. 2014. Preliminary Design of Archimedean Screw Turbine Prototype for Remote Area Power Supply. *Journal of Ocean, Mechanical and Arospace–Science and Engineering*. 5: 30–33.

[2] EIA, Electric Power Monthly. March 2001. *Renewable Energy Sources.* Wisconsin Valley Improvement Company.

[3] Date, A., Akbarzadeh, A. 2005. Design Analysis and Investigation of a Low Head Simple Reaction Water Turbine. In: *43rd ANZSES Conference*. Dunedin, New Zealand.

[4] Date, A., Akbarzadeh, A. 2009. Design and Cost Analysis of Low Head Simple Reaction Hydro Turbine for Remote Area Power Supply. *Renewable Energy*. 34: 409–415.

[5] Date, A., Date, A., Akbarzadeh, A., Alam, F. 2012. Examining the Potential of Split Reaction Water Turbine for Ultra-Low Head Hydro Resources. *Procedia Engineering*. 49: 197–204.

[6] Sernberg, R. 2008. Hydropower: Dimensions of Social and Environmental Coexistence. *Renewable and Sustainable Energy Reviews.*, 12(6): 1588–1621.

[7] Taylor, R. 2004. Hydropower In: *Survey of Energy Resources*, (ACJ Trinnaman). Oxford, Elsevier Science. 199–232.

[8] Kaygusuz, K. 2004. Hydropower and the Worlds Energy Future. *Energy Sources*. 26(3): 215–224.

[9] Sommers, G. L. 2004. Appendix 4 Selected Energy-Related Tables In: *Encyclopedia of Energy*, (C J Cleveland). New York, Elsevier. 721–775.

[10] Khennas, S., and Barnett, A. 2000. Chapter 313–Micro-hydro Power: AN Option for Socio-economic Development In: *World Renewable Energy Congress VI*, (AAM Sayigh). Oxford, Pergamon. 1511–1517.

[11] Bartle, A. 2002. Hydropower Potential and Development Activities. *Energy Policy*. 30(14): 1231–1239.

[12] W. H. Turnpenny *et al.* 2000. Risk Assessment for Fish Passage Through Small Low Head Hydro Turbines. ETSU-H/0600054/Rep.

[13] H. Spah. 2001. Fishery Biological Opinion of the Fish Compatibility of the Patented Hydraulic Screw From Ritz Atro, Bielfield, Germany.

[14] P. Kibel, T. Coe 2009. Castleford Mill Hydro Power Fisheries Assesment. Devon, UK.

[15] G, Muller, J. Senior. 2009. Simplified Theory of Archimedean Screws. *Journal of Hydraulic Research*. 47(5): 666–669.

[16] K. Brada, K. A. Radlik. 1996. Water Screw Motor for Micropower Plant. 6th Intl. Symp. Heat Exchange and Renewable Energy Sources. W. Nowak, ed. Wydaw Politecchniki Szczecinskiej, Szczecin, Poland. 43–52.

[17] J. Senior, P. Wiemann, G. Muller, 2008. The Rotary Hydraulic Pressure Machine for Very Low Head Hydropower Sites. Proceedings of Hydrogenia, Bled/Slovenia, European Small Hydropower Association 5B(1).

[18] H. D. Hellman. 2003. Gutachten Zur Wirkungsgradbestimmung Einer Wasserkraftsshnecke Fabrikat Ritz-Atro [Report On Determination Of Hydraulic Screw Efficiency Manufactured By Ritz-Atro Ltd.] Fachbereich Maschinebau Und Verfahren Stechnik. Technical University, Kaiserslautern, Germany.

[19] K. Brada. 1999. Wasserkraftschnecke Ermoglicht Stromerzegung Uber Kleinkraftwerke [Hydraulic Screw Generates Electricity From Micro Hydropower Stations]. Maschinenmarkt Wurzburg, Mitteilung. 14: 52–56.

[20] Williamson, S. J., Stark, B. H., Booker, J. D. 2011. Low Head Pico Hydro Turbine Selection Using a Multi-Criteria Analysis. In: World *Renewable Energy Congress*. 44(0): 1377–1385.

[21] Andritz Atro GmbH leaflet. 2014. Andritz Atro Hydrodynamic Screw Turbine. Nuremberg, Germany.

[22] Rorres, C. 2000. The Turn of Screw: Optimal Design of an Archimedes Screw. *Journal of Hydraulic Engineering*. 80: 72–80.

[23] Koetsier, T., Blauwendraat, H. 2004. The Archimedean Screw-pump: A Note on Its Invention and the Development of the Theory. Proc. Of Int. Symposium on History of Machines and Mechanism (HMM04). Kluwer, Dordercht. 181–194.

[24] Nagel, G. 1968. Archimedean Screw Pump Handbook, Schwabisch Gmud: Ritz pumpenfabrik OHG.

[25] Bard, N. 2007. River Dart Hydro Performance Assessment by Nick Bard Hydro Services for Mannpower Consulting Ltd. Nick Bard Hydro Services, 44(0). Retrieved from http:/www.mannpower-hydro.co.uk/research.php.

[26] Hawle, W., Lashofer, A., Pelikan, B. 2012a. Lab Testing of the Archimedean Screw. Hydroenergia.

[27] Nuernbergk, D., Rorres, C. 2013. Analytical Model for Water Inflow of an Archimedes Screw Used in Hydropower Generation. *Journal of Hydraulic Engineering*. 139(2): 213–220.

[28] Hawle, W., Lashofer, A., Pelikan, B. 2012b. State of Technology and Design Guidelines for the Archimedes Screw Turbine. University of Natural Resources and Life Sciences Vienna (BOKU). 1–8.

[29] M. Lyons, W. D. Lubitz. 2013. Archimedes Screws for Microhydro Power Generation. In Proc. Of ASME 2013 Minneapolis USA. 1–7.

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