Jurnal Polimesin
Department of Mechanical Engineering
State Polytechnic of Lhokseumawe
http://e-jurnal.pnl.ac.id/polimesin

e-ISSN	: 2549-1999	No.	: 4	Month	: August
p-ISSN	: 1693-5462	Volume	: 23	Year	: 2025

Processing dates: received on 2025-06-17, reviewed on 2025-08-06, accepted on 2025-08-20 and online availability on 2025-08-31

Performance analysis of a single-blade Archimedes screw turbine for low-head micro hydro applications

Muhammad Ilham Maulana[1,*], **Ahmad Syuhada**[1], **Yusmanizar**[2], **Muhammad Aufa Asyqar**[1,3]
[1]Department of Mechanical Engineering, University of Syiah Kuala, Banda Aceh 23111, Indonesia
[2]Department of Agriculture Engineering, University of Syiah Kuala, Banda Aceh 23111, Indonesia
[3]Department of EPC, PT. PGN Solution, Jakarta Barat 11510, Indonesia
*Corresponding Author: ilhammaulana@usk.ac.id

Abstract

The need for efficient micro-hydro power generation systems for low head locations and the challenges of electrification in remote areas are increasing. The Archimedes Screw Turbine (AST) offers a simple and environmentally friendly technological solution; however, experimental studies on single-blade configurations with heads below 1 meter are limited. This study aims to evaluate the performance of a single-blade AST turbine through experimental testing at varying heads (0.7-1.0 meters) and flow rates (106-1035 L/min). The analyzed parameters include torque, mechanical power, and turbine efficiency, with the application of the Taguchi method for optimization of experimental design and reduction of the number of tests. Results show that flow discharge has a dominant influence on turbine performance compared to head, with the maximum power of 115.89 W and the highest efficiency reaching 68.72% under the condition of 1 meter head and 1035 L/min discharge. This study confirms that the single-blade AST turbine can function optimally at low head conditions and is worthy of further development for small-scale renewable energy systems in irrigation canals and other shallow flow sources.

Keywords:
Archimedes Screw, micro hydro turbine, low head, efficiency, Taguchi method

1 Introduction

According to the 2025–2045 National Medium-Term Development Plan (RPJMN), the Indonesian government aims to achieve a 23% share of renewable energy in the national energy mix by 2025 [1]. However, the country's reliance on fossil fuels remains high, and New and Renewable Energy (EBT) has not emerged as a significant source in the national energy mix. Using widely available and easily accessible local energy potential, such as water energy, is essential to achieving this goal [2].

Water resources in Indonesia are plentiful, encompassing significant river flows, irrigation channels, technical drainage systems, and various small streams. Much of this potential falls into the low-head category (less than 5 meters), which cannot be utilized effectively by conventional turbine systems. Consequently, it is crucial to develop small-scale power generation technologies that operate under low head conditions, particularly to enhance electrification in remote areas and regions lacking reliable electricity access [3], [4]. An appropriate technological solution for the condition is the Archimedes Screw Turbine (AST). This turbine has advantages, including operation at low heads, a straightforward design, environmental compatibility with aquatic biota, and ease of maintenance [5], [6], [7], [8]. Numerous studies indicate that AST may attain high efficiency across diverse flow rates and geometries, rendering it a viable choice in micro-hydro systems [9], [10].

Numerous research studies have been conducted to evaluate the performance of AST, employing both experimental and simulated methodologies. Stergiopoulou [11] conducted a preliminary experimental investigation on horizontal Archimedes turbines, which later served as a foundation for developing similar turbines designed for flat flow. Rorres [12] created an ideal geometric design model, while other researchers [13], [14], [15], [16] compiled a technical design guide for the practical implementation of AST. In Indonesia, several studies by Maulana et al. [9], [17] examined the effects of blade quantity and flow rate on the effectiveness of double-blade AST. Some other research [18], [19], [20], [21], [22] demonstrated the considerable efficiency potential of AST in micro-hydro applications.

Most prior research has concentrated on medium to high heads or testing in large-scale test channels without optimizing operational parameters. However, the AST has been thoroughly examined in the context of micro-hydro power generation. Research on single-blade AST turbines functioning at extremely low heads (<1 meter) remains scarce, particularly in regions such as Indonesia, characterized by numerous irrigation channels and flat-water flows. Also, the Taguchi technique for optimizing test parameters has not been widely used in AST, even though it could significantly help understand how different operational factors affect performance with fewer tests needed.

This study evaluates the performance of a single-blade AST operating at low heights (0.7–1.0 meters) and varying water flow rates (106–1035 L/min). It examines how different operational variables affect performance by analyzing torque, mechanical power, and turbine efficiency. Additionally, the experimental design utilizes the Taguchi method to optimize the combination of test parameters systematically. The results of this study aim to support Indonesia’s efforts to electrify using renewable energy sources and provide a scientific basis for developing simple, practical micro-hydro devices, particularly in areas with low-head water energy potential.

2 Research methodology

2.1 Experimental system design

The experimental setup consists of an upper reservoir, a water channel, an Archimedes screw turbine, a loading system (rope brake), a water circulation pump, a V-notch for measuring flow, and a closed-loop installation. The turbine is made of stainless steel, with a total length of 2.0 m, an outer diameter of 110 mm, and an inner shaft diameter of 25.4 mm. It contains 14 helical turns. The head is adjusted by changing the channel slope, and the pump regulates the flow rate, and verified with a 70° V-notch. Fig. 1 shows the geometry of the single-blade Archimedes screw turbine, while Fig. 2 presents the Experimental Setup Diagram used for torque, power, and efficiency measurements.

This study uses two independent variables: head (H) with values of 0.7 m, 0.8 m, 0.9 m, and 1.0 m; and flow rate (Q) with values of 106.7 L/min, 291.1 L/min, 594.4 L/min, and 1035.3 L/min. Water from the upper reservoir passes through the V-notch to measure the discharge, flows along the water channel toward the turbine, and exits into the lower reservoir. As the water flows, it rotates the Archimedes screw turbine, which is loaded by a rope brake connected to a pulley, with a rope tied to a digital scale. The pump recirculates the lower reservoir water to the upper reservoir.

The Taguchi orthogonal array approach was applied to reduce the number of experiments while obtaining representative results. Each combination of variables was tested five times. Only the single-blade configuration was tested to isolate the effects of head and flow rate.

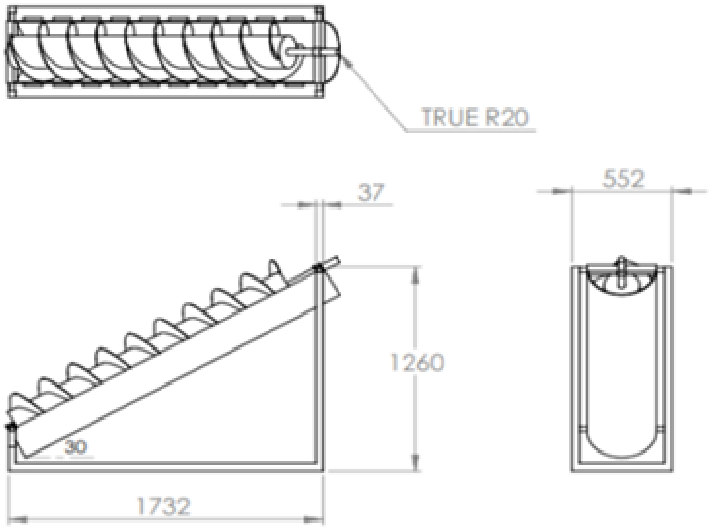


Fig. 1. Design of a single blade of the archimedes screw water turbine

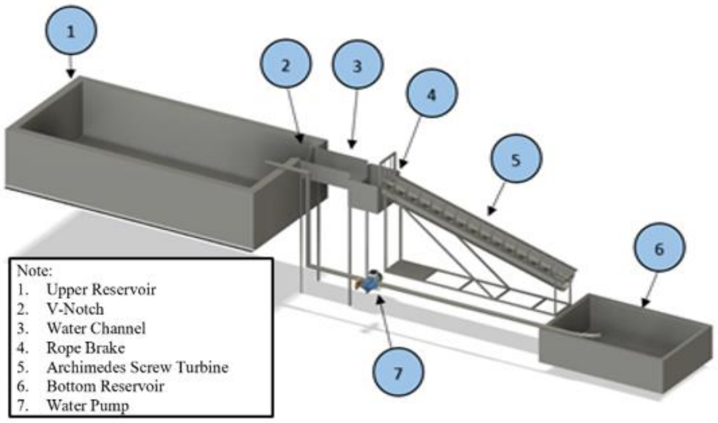


Fig. 2. Experimental setup diagram

2.2 Measurement and instruments

Measurements focused on three parameters: torque, rotational speed, and flow rate. Torque was measured using the rope brake method, where the applied force (read from a digital scale) was multiplied by the pulley radius. Rotational speed was measured in revolutions per minute (rpm) and converted to angular velocity (rad/s). Flow rate was measured with a 70° V-notch, using the corresponding empirical equation based on water head above the notch crest. Voltage and current measurements were also taken with a digital multimeter, though the analysis focused primarily on mechanical shaft power. All data were recorded manually, and each test condition was repeated five times.

2.3 Torque, power, and efficiency calculations

Calculations are based on fundamental mechanics relationships. The Eq. (1) calculates torque, which is the force that causes an object to rotate, where F is the measured force (N) and r is the pulley radius (m) [23].

$$T = F \times r \tag{1}$$

The power generated by the turbine, also known as Turbine shaft power ($P_{turbine}$), is calculated using Eq. (2), where ω is the angular velocity (rad/s) [24].

$$P_{turbine} = T \times \omega \tag{2}$$

Turbine efficiency is defined as the ratio of the turbine's performance in converting the kinetic energy of flowing water into electrical energy. Efficiency (η) calculated using Eq. (3). In Eq. (3), $P_{turbine}$ signifies the turbine power, while $P_{hydraulic}$ represents the hydraulic power of the fluid, with both measured in Watts.

$$\eta = \frac{P_{turbine}}{P_{hydraulic}} \times 100\% \tag{3}$$

Data is collected using variables designed through the Taguchi method. Three factors, head height, flow discharge, and blade type, are identified. Table 1 presents the values determined by these factors.

Table 1. Research variables for the Archimedes screw single-blade turbine

Head (meter)	Flow Rate (L/min)
0.7	106.7
0.8	291.1
0.9	594.4
1.0	1035.3

2.4 Parameter optimization strategy – Taguchi method

The Taguchi method is utilized to optimize the combination of test parameters, specifically head and flow rate, with the goal of minimizing the number of trials while still achieving meaningful experimental results. This method involves finding the important factors and their levels, creating a structured matrix, and calculating the signal-to-noise (S/N) ratio for each output variable, like torque, power, and efficiency. The S/N analysis helps identify the optimal combinations of parameters and assesses the relative contribution of each variable to the performance of the turbine system.

2.5 Experiment procedure

Before data collection, the entire system was inspected and tested without load to ensure flow integrity, operational stability, and the absence of leaks. All components, including the turbine shaft, bearings, and rope brake assembly, were checked for proper alignment and function. Calibration of measurement instruments was conducted: the V-notch weir was cleaned and levelled before use; the digital scale was zeroed and verified with known weights; the pulley radius was measured with callipers; and the tachometer was tested on a reference rotating device. The experimental matrix followed a Taguchi orthogonal array, with head values of 0.7, 0.8, 0.9, and 1.0 m, and flow rates of 106.7, 291.1, 594.4, and 1035.3 L/min, tested in randomized order to minimize systematic bias.

The channel slope was adjusted for each test point to achieve the desired head, while pump speed was fine-tuned to reach the target discharge within ±2% tolerance, verified using the V-notch. The turbine was operated without load for 60 seconds to eliminate transients, and steady-state operation was defined as a variation of no more than ±2% in rotational speed and flow rate over 30 seconds. The load was applied gradually using the rope brake system, with the load force measured by a digital scale. Torque was calculated as the product of force and pulley radius, rotational speed was measured with a tachometer, and shaft power was obtained from torque and angular velocity. Hydraulic power was calculated from the measured head and flow rate, and efficiency was determined as the ratio of shaft power to hydraulic power.

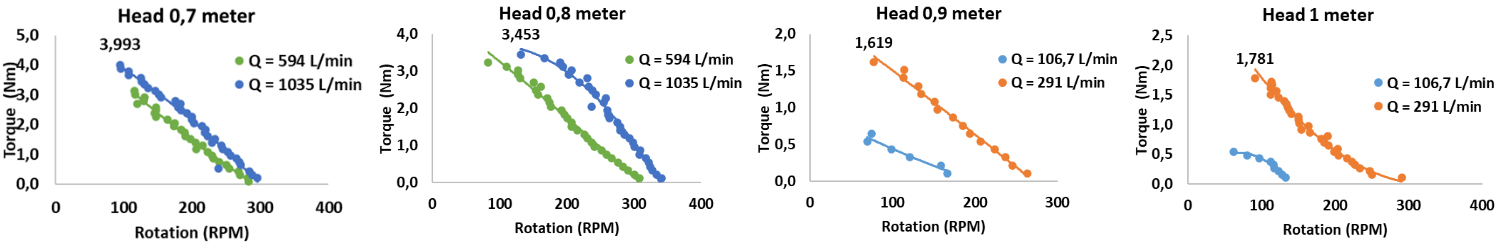
Each head flow combination was tested five times, with the average used for analysis. Any trial deviating by more than three standard deviations was repeated. The Taguchi method was applied to calculate signal-to-noise ratios for torque, power, and efficiency, identify optimal parameter combinations, and evaluate factor contributions. Between test blocks, the brake was released, the pump was stopped, and the V-notch was cleaned to maintain measurement accuracy.

3 Results and discussion

3.1 Turbine torque analysis

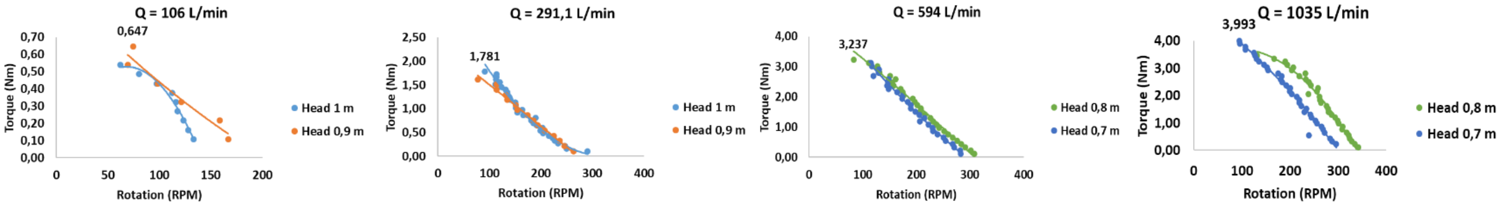
The single-blade Archimedes screw turbine's torque and rotational speed relationship under different head and flow rate variations is depicted in Fig. 3 and Fig. 4. According to the statistics, greater flow rates yield the maximum torque; at a head of 0.9 meters and a flow rate of 1035 L/min, the torque is 8.633 Nm. Given that a higher flow rate increases the fluid's thrust on the turbine blade surface, this relationship suggests that the flow rate significantly affects the turbine's capacity to produce torque.

These results align with a study by Arifin et al. [25] that discovered that, even in multi-blade turbines, the increase in thrust force on hydro turbine blades is precisely proportional to the increase in flow rate. However, variations in blade configuration impact the ability to absorb fluid forces. This study significantly adds value by showing that a single-blade layout can still generate the best torque under high-flow conditions, even at low head. It suggests that it might be used in flat areas or irrigation channels.



(a) (b) (c) (d)

Fig. 3. The relationship between rotation and torque of Archimedes' single screw water turbine at various heads



(a) (b) (c) (d)

Fig. 4. Rotation and torque relationship of the Archimedes screw single-blade water turbine at various flow rates

Fig. 5 illustrates the relationship between the torque and spin of the Archimedes Single Screw turbine at a steady flow rate. An issue arises when excess flow causes water to fill the gaps between the blades, potentially reducing rotational performance. Even though we expect the highest torque at the most excellent head and flow rate, we noted that this can cause water to get trapped in specific shapes at very high flow rates, which leads to lower efficiency.

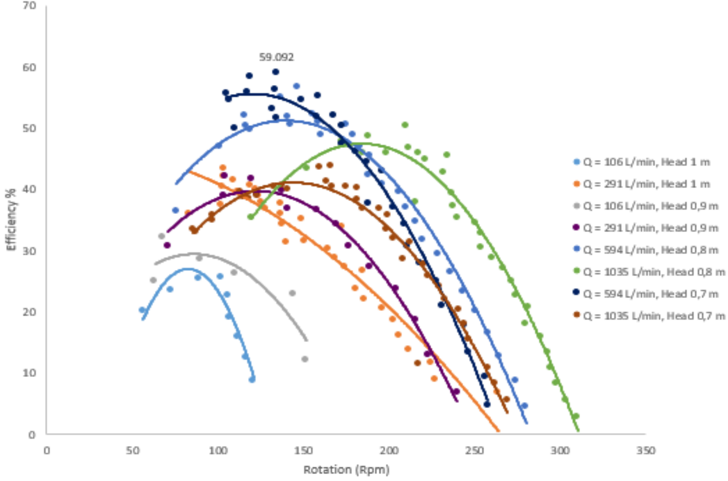
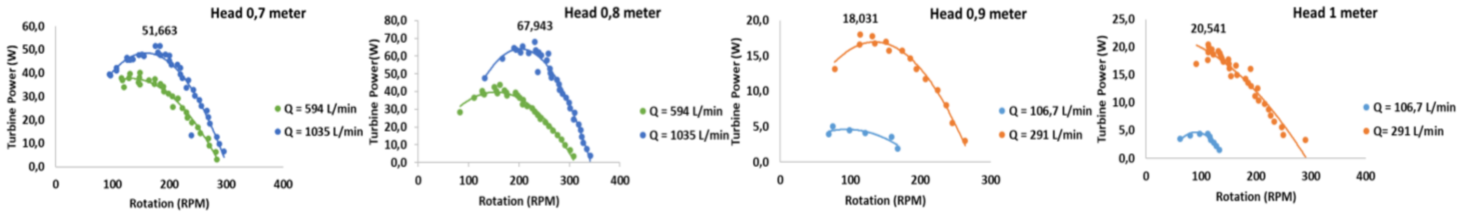


Fig. 5. Relationship between Toque and rotation of a single-blade Archimedes screw water turbine at varying head and flow rate

3.2 Turbine power analysis

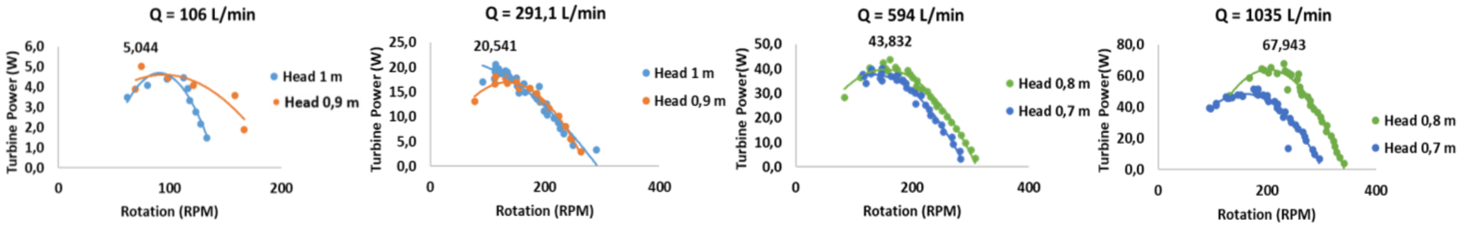
The power and rotation graph of the Archimedes Single Screw water turbine at a constant head is shown in Fig. 6. In contrast, Fig. 7 illustrates the relationship between rotation and a constant flow rate. Fig. 6 and Fig. 7 show that the most power is produced when the head is 1 meter and the flow rate is 1035 L/min. In general, power goes up when the head and flow rates go up, which aligns with the ideas behind fluid potential energy. However, there is a limit to how power and rotational speed are related; torque starts to go down at greater speeds. The graph in Fig. 8 shows that the highest power value occurs at the same head height at a greater flow discharge. Similarly, tests conducted at the exact flow discharge yield the most incredible power value at a higher head.

The decrease in power after this peak point is associated with a trade-off between torque and angular velocity, as confirmed by Maulana et al. on a two-blade turbine [17]. The results of this study confirm that the single-blade configuration is efficient, also efficient, and competitive in generating power at low flow rates, which were previously more often associated with multi-blade turbines. This experimental method is developed from Stergiopoulou's work, which only focused on the horizontal geometry of large test channels, by providing experimental evidence on a smaller scale and with a smaller head [26].



(a) (b) (c) (d)

Fig. 6. Rotation and power relationship of a single screw Archimedes turbine at various heads



(a) (b) (c) (d)

Fig. 7. Rotation and power relationship of a single screw Archimedes turbine at various flow rates

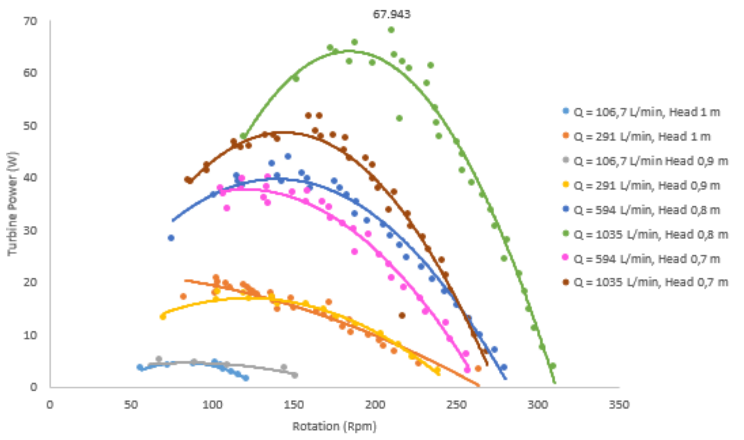


Fig. 8. Relationship between turbine power and rotation of Archimedes' single screw water turbine at varying head and flow discharge

3.3 Turbine efficiency analysis

The research results indicate that the highest efficiency recorded was 68.72% at a head of 1 meter and a flow rate of 1035 L/min, as shown in Fig. 9 and Fig. 10. The general pattern produced shows that efficiency increases with the increase in flow rate and head, but decreases at extreme combinations due to the disruption of pressure distribution caused by turbulent flow that is not fully captured by the blades. The results achieved on turbine efficiency (Fig. 11) show encouraging results where the efficiency obtained is relatively high for an AST. Irwansyah [27] reported a 65% efficiency for a similar flow rate using a two-blade system without optimizing the parameters.

The proposed single-blade AST system demonstrates superior performance compared to conventional configurations, particularly when optimized using the Taguchi method. The results of this study demonstrate that employing the Taguchi method in a testing plan can yield optimal results with fewer tests.

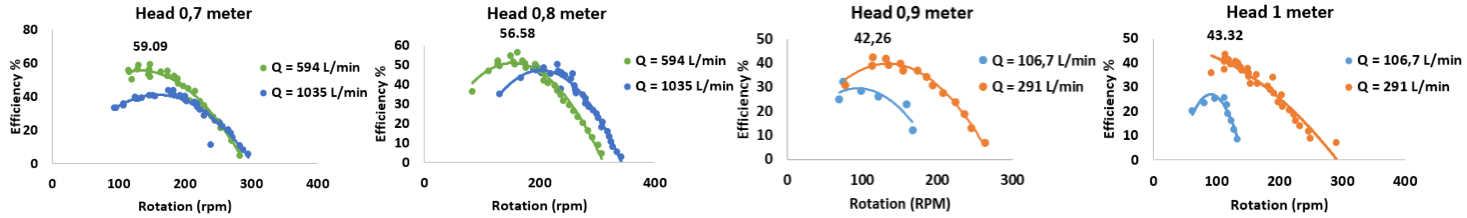


Fig. 9. Rotation and efficiency relationship of a single screw Archimedes turbine at various heads

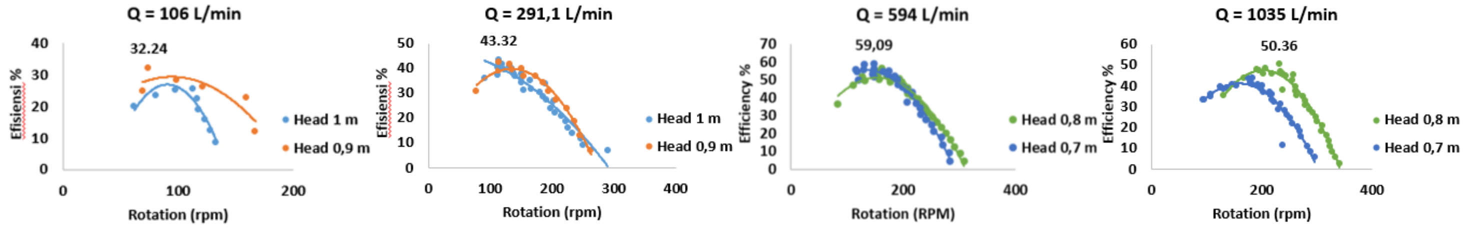


Fig. 10. Rotation and efficiency relationship of a single screw Archimedes turbine at various flow rates

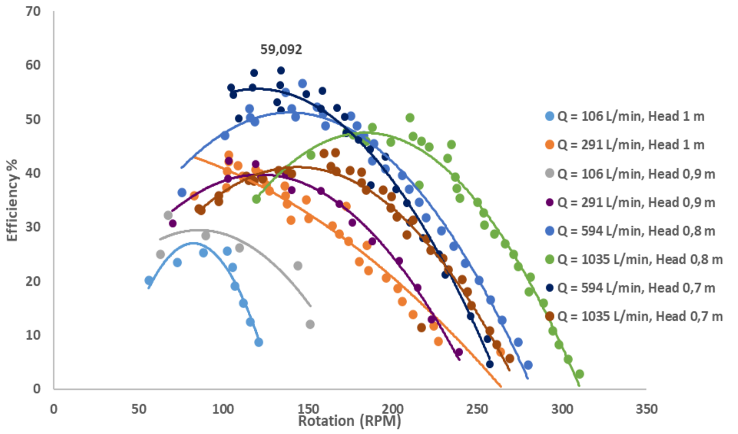


Fig. 11. Relationship between Turbine Power and Rotation of Archimedes' Single Screw Water Turbine at varying Head and Flow Discharge

These findings align with those of Yoosefdoost and Lubitz [28], who illustrate the importance of enhancing geometry and operational parameters in the design of screw turbines. Microhydro systems with heads under 1 meter exhibit excellent performance in regions with irrigation and drainage channels, provided the installed system achieves an efficiency of over 60%.

3.4 Validation of research results and contributions

The results of this study were compared with relevant previous research on the AST to evaluate both the performance and the originality of the conducted work. The tests indicated that the highest efficiency recorded was 68.72%, with a maximum power output of 115.89 W. These results show that the single-blade turbine performs well, achieving efficiency values close to those reported for multi-bladed turbines under similar conditions [17], despite having a simpler construction and lower manufacturing cost. Compared to the findings of Yoosefdoost and Lubitz [14], who emphasize optimizing turbine geometry and operational parameters, the present study confirms that careful parameter selection, achieved through the Taguchi method, can yield competitive performance even with a reduced blade count. Similarly, Irwansyah et al. [27] reported comparable efficiency levels for multi-blade designs, suggesting that the single-blade configuration can be a viable alternative for ultra-low-head (<1 m) applications, particularly in irrigation and drainage channels where installation simplicity and cost-effectiveness are crucial.

The practical implication of these results is that a single-blade AST can be effectively deployed in small hydropower systems to harness energy from low-flow water sources while reducing complexity and maintenance requirements. The strengths of this study include the experimental validation of a simplified turbine geometry under extremely low-head conditions and the application of the Taguchi method to optimize performance with fewer tests. However, limitations remain, as the experiments were conducted in a controlled laboratory environment without accounting for debris, sedimentation, or long-term operational wear, and electrical generation performance was not assessed. Addressing these factors in future research through field trials, durability assessments, and integrated electrical performance analysis will further validate the applicability of the single-blade AST in real-world micro-hydro installations.

This study's turbine designs utilize geometries and sizes specifically tailored to the technical conditions in Indonesia, including agricultural irrigation and open drainage systems, which differ from the theoretical models and laboratory-scale experiments reported by Stergiopoulou [11] and Rorres [12]. The achieved efficiency supports the argument that a simplified, small-scale AST remains highly relevant for meeting local energy demands in remote or off-grid communities. Furthermore, aligning these results with the conclusions of Yoosefdoost and Lubitz [28] reinforces the notion that AST performance is more strongly influenced by the compatibility between flow rate and turbine geometry than by the number of blades alone. The novelty of this work lies in being among the few experimental evaluations of a single-blade AST under ultra-low-head conditions, systematically optimized using the Taguchi approach, and benchmarked against multi-blade configurations from existing literature.

4 Conclusions

This study evaluated the performance of a single-blade AST for ultra-low-head micro-hydro applications (0.7–1.0 m) under varying flow rates, applying the Taguchi method to optimize parameters and minimize experimental runs. Results showed that flow rate had a greater impact on performance than head, with optimal operation achieved at 1.0 m head and 1035 L/min flow rate, producing 115.89 W of power and 68.72% efficiency. These findings demonstrate that a simplified single-blade configuration can operate efficiently in low-head conditions, making it suitable for micro-hydro installations in irrigation channels and shallow flows.

The research offers a practical and low-cost solution for rural electrification by proving that single-blade ASTs can deliver performance comparable to multi-blade designs when parameters are correctly optimized. The successful use of the Taguchi method highlights its effectiveness in identifying optimal conditions with fewer trials, contributing to more efficient experimental design in turbine optimization studies.

Limitations include testing in controlled laboratory conditions without accounting for debris, sedimentation, seasonal variations, or long-term wear, and without assessing electrical generation performance. Future work should involve field trials, durability and maintenance studies, and integration with electrical generators to evaluate full system performance. By confirming the viability of a single-blade AST for ultra-low-head applications, this study adds to the micro-hydro knowledge base. It provides a valuable reference for engineers, researchers, and policy-makers developing sustainable energy solutions for remote and off-grid communities.

References

[1] Kementerian PPN/Bappenas, “UU_RPJPN-2025-2045_P20AUG_2024,” 2023, Accessed: Aug. 11, 2025. [Online]. Available: https://drive.google.com/file/d/1BvGbA2pC7O8pGKiYmRHT9KWVD7FSQbG5/view

[2] IESR, “Indonesia Energy Transition Outlook 2022,” Iesr, pp. 1–93, 2021.

[3] R. Luz, T. Antunes, J. De Souza, E. G. Rossini, and A. Beluco, “Pico Hydro for power generation with Small-scale hydroplants,” vol. 10, no. 3, pp. 6–12, 2020, doi: 10.6084/m9.figshare.12616709.

[4] R. Sahay, M. Rachna, and E. Institutions, “Micro-hydro power-harnessing the potential energy of water for small-scale electricity generation,” no. August, pp. 12–17, 2024, doi: 10.71143/4p12n447.

[5] A. Khomsah, Sudjito, Wijono, and A. S. Laksono, “Pico-hydro as a renewable energy: Local natural resources and equipment availability in efforts to generate electricity,” IOP Conf Ser Mater Sci Eng, vol. 462, no. 1, 2019, doi: 10.1088/1757-899X/462/1/012047.

[6] R. K. Chaulagain, L. Poudel, and S. Maharjan, “A review on non-conventional hydropower turbines and their selection for ultra-low-head applications,” Heliyon, vol. 9, no. 7, p. e17753, 2023, doi: 10.1016/j.heliyon.2023.e17753.

[7] C. Purece and L. Corlan, “Archimedean screw as fish-friendly turbines for harnessing hydropower potential,” E3S Web of Conferences, vol. 286, p. 02007, 2021, doi: 10.1051/e3sconf/202128602007.

[8] A. T. Piper, P. J. Rosewarne, R. M. Wright, and P. S. Kemp, “The impact of an Archimedes screw hydropower turbine on fish migration in a lowland river,” Ecol Eng, vol. 118, no. October 2020, pp. 31–42, 2018, doi: 10.1016/j.ecoleng.2018.04.009.

[9] M. I. Maulana, A. Syuhada, Y. Yusmanizar, and M. A. Asyqar, “Performance of a double-blade archimedes screw turbine with head and flow configuration for low-head applications,” Advanced Engineering Forum, vol. 56, pp. 51–63, Jun. 2025, doi: 10.4028/p-n35lot.

[10] M. Zamani, R. Shafaghat, and B. Alizadeh Kharkeshi, “Enhancing performance evaluation of archimedes screw turbines under optimal conditions: a focus on flow rate analysis, empirical equations, and comparative scaling methods,” Iranica Journal of Energy and Environment, vol. 15, no. 2, pp. 123–134, 2024, doi: 10.5829/ijee.2024.15.02.01.

[11] A. Stergiopoulou and V. Stergiopoulos, “Back to the future: Towards innovative low and zero head archimedean hydropower turbines in irrigation networks,” Journal of Multidisciplinary Engineering Science and Technology (JMEST), vol. 2, no. 9, pp. 3159–3199, 2015, [Online]. Available: www.jmest.org

[12] C. Rorres, “The Turn of the Screw: Optimal design of an archimedes screw,” Journal of Hydraulic Engineering, vol. 126, no. 1, pp. 72–80, 2000, doi: 10.1061/(asce)0733-9429(2000)126:1(72).

[13] K. Shahverdi, “Modeling for prediction of design parameters for micro-hydro Archimedean screw turbines,” Sustainable Energy Technologies and Assessments, vol. 47, p. 101554, Oct. 2021, doi: 10.1016/J.SETA.2021.101554.

[14] A. Yoosefdoost and W. D. Lubitz, “Archimedes screw design: An analytical model for rapid estimation of Archimedes screw geometry,” Energies (Basel), vol. 14, no. 22, 2021, doi: 10.3390/en14227812.

[15] M. A. B. A.I. Siswantara, M.H.G. Syafei, “Design Procedure Of Archimedes Hydro turbine,” Journal Of Southwest Jiaotong University, vol. Vol. 56 No, 2021.

[16] Z. Abbas, M. Waqas, S. S. Khan, R. Khatoon, S. Larkin, and L. Zhao, “Numerical and experimental investigation of an Archimedes screw turbine for open channel water flow application,” Energy Sci Eng, vol. 12, no. 4, pp. 1317–1336, Apr. 2024, doi: 10.1002/ese3.1649.

[17] M. I. Maulana, A. Syuhada, and R. Kurniawan, “Experimental study on the effect of flow rate on the performance of two-blade Archimedes screw turbine,” Journal of Advanced Research in Fluid Mechanics and Thermal Sciences, vol. 61, no. 1, pp. 10–19, 2019.

[18] E. Fiardi, “Preliminary design of archimedean screw turbine prototype for remote area power supply,” Journal of Ocean, Mechanical and Aerospace-Science and Engineering, vol. 5, no. March, pp. 30–33, 2014.

[19] R. Kusumanto and M. Noviansyah Nugraha, “Archimedes screw turbine application on portable mini hydropower plant,” the research of mechanical engineering-Jurnal Polimesin, vol. 21, no. 1, pp. 2023–2025, 2023, [Online]. Available: http://e-jurnal.pnl.ac.id/polimesin

[20] M. A. N. Mu’tasim, N. S. Azahari, and A. A. A. Adam, “Prediction of particle impact on an Archimedes screw runner blade for micro hydro turbine,” Applied Mechanics and Materials, vol. 465–466, no. June 2017, pp. 552–556, 2014, doi: 10.4028/www.scientific.net/AMM.465-466.552.

[21] A. Nandar, G. Gunawan, D. Suanggana, and A. Djafar, “Kaji eksperimental pengaruh head terhadap performa turbin ulir Archimedes tiga sudu,” Jurnal Ilmiah Teknologi dan Rekayasa, vol. 28, no. 2, pp. 159–170, 2023, doi: 10.35760/tr.2023.v28i2.5275.

[22] B. Darmono and H. Pranoto, “Archimedes screw turbines (asts) performance analysis using cfd software based on variation of blades distance and thread number on the pico hydro powerplant,” International Journal of Advanced Technology in Mechanical, Mechatronics and Materials, vol. 3, no. 1, pp. 18–25, 2022, doi: 10.37869/ijatec.v3i1.53.

[23] D. M. Nuernbergk and C. Rorres, “Analytical model for water inflow of an archimedes screw used in hydropower generation,” Journal of Hydraulic Engineering, vol. 139, no. 2, pp. 213–220, 2013, doi: 10.1061/(asce)hy.1943-7900.0000661.

[24] M. D. Lee and P. S. Lee, “Modelling the energy extraction from low-velocity stream water by small scale archimedes screw turbine,” Journal of King Saud University - Engineering Sciences, vol. 35, no. 5, pp. 319–326, 2023, doi: 10.1016/j.jksues.2021.04.006.

[25] F. Arifin, A. P. Maulana, and I. Indrayani, “CFD analysis in investigating the impact of turbine blade number on the performance of hydro turbine,” Jurnal Polimesin, vol. 21, no. 3, pp. 311–317, 2023, doi: 10.30811/jpl.v21i3.3671.

[26] A. Stergiopoulou and E. Kalkani, “Towards a First C.F.D. Study of modern horizontal axis archimedean water current turbines,” International Research Journal of Engineering and Technology, pp. 1954–1961, 2015, [Online]. Available: www.irjet.net

[27] I. Syam, M. I. Maulana, and A. Syuhada, “Design and performance of archimedes single screw turbine as micro hydro power plant with flow rate debit variations (Case Study in Air Dingin, Samadua - South Aceh),” Jurnal Inotera, vol. 4, no. 1, p. 13, 2019, doi: 10.31572/inotera.vol4.iss1.2019.id71.

[28] A. YoosefDoost and W. D. Lubitz, “Archimedes screw turbines: A sustainable development solution for green and renewable energy generation-a review of potential and design procedures,” Sustainability (Switzerland), vol. 12, no. 18, 2020, doi: 10.3390/SU12187352.