

The Effect of Valve Opening on the Performance of an Archimedes Screw Turbine in a Micro-Hydro Power Generation System

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Water energy is one of the renewable energy resources with considerable potential for development in Indonesia. Micro-Hydro Power Plants (MHPPs) utilize the potential and kinetic energy of water from rivers, irrigation channels, or natural waterfalls to generate electricity based on the available head and water discharge. This study aims to analyze the effect of water discharge, regulated through variations in valve opening, on the performance of an Archimedes screw turbine in order to determine the operating conditions that produce the highest shaft rotational speed, generator output power, and turbine efficiency. An experimental method was employed using five valve-opening variations of 25°, 40°, 55°, 70°, and 85°, corresponding to water discharge rates of 0.00115, 0.00311, 0.00429, 0.00528, and 0.00802 m³/s, respectively. The results show that the maximum shaft rotational speed of 180.3 rpm was achieved at an 85° valve opening with a water discharge of 0.00802 m³/s. The highest generator output power of 5.35 W was obtained at a 70° valve opening with a discharge of 0.00528 m³/s. Meanwhile, the maximum turbine efficiency of 27.34% was achieved at a 40° valve opening with a water discharge of 0.00311 m³/s. These findings indicate that increasing water discharge does not necessarily result in simultaneous improvements in all turbine performance parameters.

Keywords: Archimedes Screw Turbine; Micro-Hydro Power Plant; Valve Opening; Water Discharge; Output Power; Turbine Efficiency

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1. Introduction

The continuous growth of population, industrial activity, and technological development has increased electricity demand and intensified the need for reliable and sustainable energy systems. Indonesia continues to depend substantially on fossil-based energy sources, while its transition toward renewable energy remains an important component of long-term energy security and decarbonization strategies [1]. At the same time, Indonesia possesses significant hydropower resources because of its mountainous terrain, high rainfall, and extensive river networks. Small-scale hydropower has therefore played an important role in the development of distributed electricity generation, particularly in regions where conventional grid expansion is technically or economically difficult [2]. Studies of small hydropower development in Indonesia also emphasize its continuing relevance for improving energy access in remote communities.

Micro-Hydro Power Plants (MHPPs) convert the potential and kinetic energy of flowing water into mechanical and subsequently electrical energy. Their performance depends primarily on the available hydraulic head, water discharge, turbine characteristics, and generator configuration. Because micro-hydro systems can utilize relatively small water resources, they are particularly attractive for decentralized electricity generation in rural and geographically isolated areas [3]. Evidence from Indonesia has shown that

micro-hydro systems can provide reliable electricity where grid access remains constrained, while also supporting local economic and social development [4], [5]. Consequently, micro-hydro development is not only relevant from an engineering perspective but also contributes to broader objectives of sustainable rural electrification.

Among the technologies available for low-head hydropower applications, the Archimedes screw turbine (AST) has attracted considerable attention. Originally developed as a water-lifting device, the Archimedes screw can operate in reverse as a turbine by converting the gravitational energy of water into rotational mechanical energy [6]. Its relatively simple structure, capability to operate under low-head conditions, tolerance to variations in flow, and comparatively low environmental impact make it suitable for small-scale hydropower generation [7]. Recent reviews also identify the Archimedes screw as a promising technology for mini-, micro-, and pico-hydropower applications, particularly at sites where conventional turbines may be less appropriate [8]. Simmons and Lubitz [9] further emphasize its applicability to run-of-river micro-hydropower systems and the importance of understanding its hydraulic and geometric operating parameters.

Water discharge is one of the principal parameters governing the performance of an Archimedes screw turbine. Variations in discharge influence the volume of water retained between screw flights, rotational speed, torque, mechanical power, electrical output, and overall efficiency. Experimental evidence shows that an increase in discharge can improve torque and output power; however, the highest efficiency does not necessarily occur at the maximum flow condition [10]. Indonesian experimental studies have similarly reported that turbine performance changes with variations in water discharge and shaft inclination [11]. Kurniawan [12] obtained a maximum shaft speed of 423.3 rpm and an output power of 0.78 W at a water discharge of 0.001 m³/s, while the maximum efficiency of 13.1% occurred at a lower discharge of 0.0004 m³/s. Syahputra [13] reported a maximum turbine power of 23.02 W and an efficiency of 9.77% at a discharge of 0.04016 m³/s. These results demonstrate that maximum rotational speed, output power, and efficiency may occur under different hydraulic operating conditions.

The variability of these findings highlights the need for further experimental investigation into the relationship between water-flow regulation and Archimedes screw turbine performance. In practical micro-hydro installations, valve opening provides a straightforward mechanism for controlling the discharge supplied to the turbine. Nevertheless, studies specifically examining how progressive valve-opening variations affect shaft rotation, electrical output, and efficiency under a common experimental configuration remain relatively limited. Therefore, this study investigates the performance of an Archimedes screw turbine under different valve openings and corresponding water discharges. The objective is to determine the operating conditions that produce the highest shaft rotational speed, generator output power, and turbine efficiency, thereby providing an experimental basis for improving the operation of small-scale Archimedes screw micro-hydro systems.

2. Literature Review and Problem Statement

Micro-hydropower represents a mature renewable energy option capable of converting locally available water resources into electricity without the direct combustion of fossil fuels. In Indonesia, its relevance is particularly evident in rural and remote areas, where geographical conditions can make conventional grid extension costly or impractical [2], [4]. Technical and economic assessments have also shown that the feasibility of micro-hydro systems is strongly dependent on local hydrological conditions, electricity demand, infrastructure, and system configuration [3]. Beyond electricity production, successful micro-hydro implementation can provide broader socioeconomic benefits to rural communities [5].

The Archimedes screw turbine is particularly relevant to low-head hydropower because it operates differently from conventional impulse and reaction turbines. Water entering the screw creates a pressure difference between successive flights, producing torque that rotates the screw and drives the generator. Its performance is therefore determined not only by available head and discharge but also by geometric and operational factors such as screw diameter, pitch, inclination angle, number of blades, rotational speed, and filling level [6]–[9]. Practical AST installations have demonstrated that these turbines can achieve relatively high efficiency when their geometry and operating conditions are appropriately matched to the available hydraulic resource.

The theoretical relationship between screw geometry, filling level, and turbine performance was investigated by Lubitz et al. [14], who developed a performance model based on the pressure generated by water trapped between successive screw flights. Rohmer et al. [15] subsequently combined mathematical modeling with experimental testing and demonstrated that mechanical efficiency depends on geometry, rotational speed, and the degree of screw filling. Dellinger et al. [16] also found that leakage, friction, and downstream immersion influence turbine efficiency. These studies establish that AST performance results from a complex interaction among hydraulic conditions, turbine geometry, and mechanical losses rather than from water discharge alone.

Experimental research has further confirmed the sensitivity of Archimedes screw performance to flow conditions. Dedić-Jandreć and Nižetić [17] examined variations in water-flow ratio, rotational speed, and inclination angle and demonstrated substantial changes in power, torque, and efficiency. Maulana et al. [10] found that a higher flow rate could produce greater turbine power, while peak efficiency occurred at a different flow condition. This distinction is particularly important because turbine optimization cannot be based exclusively on maximum discharge or maximum rotational speed. The most appropriate operating condition depends on whether the main objective is maximum power production, maximum hydraulic efficiency, or a compromise between the two.

Hydraulic and mechanical losses provide an additional explanation for nonlinear turbine performance. Kozyn and Lubitz [18] identified several important loss mechanisms in Archimedes screw generators, including bearing friction, internal hydraulic friction, outlet losses, and losses associated with downstream submergence. Consequently, increasing water discharge beyond the optimum operating range may not produce a proportional increase in useful output power. Instead, excessive filling, overflow, leakage, or mechanical resistance can reduce overall conversion efficiency. Optimizing an AST therefore requires matching the turbine design and operating parameters to the actual site conditions [19].

Inclination angle and blade configuration are also closely associated with turbine performance. Dellinger et al. [20] showed through experimental and computational analysis that moderate inclination angles can produce better performance and that changes in the number of blades affect power production and hydraulic losses. Similarly, previous Indonesian research has shown that simultaneous variations in water discharge and shaft inclination influence rotational speed, torque, power, and efficiency [11]. These findings reinforce the conclusion that optimum Archimedes screw operation involves interacting hydraulic and geometric parameters rather than a single independent variable.

Despite these developments, relatively little attention has been given to valve opening as an operational control variable in small laboratory-scale Archimedes screw systems. Valve position directly regulates the amount of water supplied to the turbine and therefore provides a practical means of controlling turbine loading without modifying the turbine geometry. Previous studies have established the importance of discharge, inclination, rotational speed, filling level, and blade configuration [10], [14]–[20], but the

performance response associated with progressive valve openings remains worthy of further experimental investigation.

Accordingly, the problem addressed in this study is whether increasing valve opening and water discharge continuously improves Archimedes screw turbine performance or whether different performance indicators reach their optimum values at different operating conditions. The study evaluates valve openings of 25°, 40°, 55°, 70°, and 85° and examines their effects on water discharge, shaft rotational speed, generator output power, and turbine efficiency. By identifying the valve setting associated with maximum rotational speed, maximum electrical output, and maximum efficiency, the study contributes practical experimental evidence for improving the operation of Archimedes screw turbines in micro-hydro power generation systems.

3. Method

This study employed an experimental method to investigate the effect of valve opening on the performance of an Archimedes screw turbine used in a micro-hydro power generation system. The experiment focused on changes in water discharge produced by different valve-opening settings and their effects on turbine performance, particularly shaft rotational speed, generator output power, and efficiency. The experimental apparatus consisted of an Archimedes screw turbine connected to a water circulation system using a 4-inch PVC pipe. The configuration of the experimental turbine and its supporting components is presented in the turbine design and prototype shown in the research document.

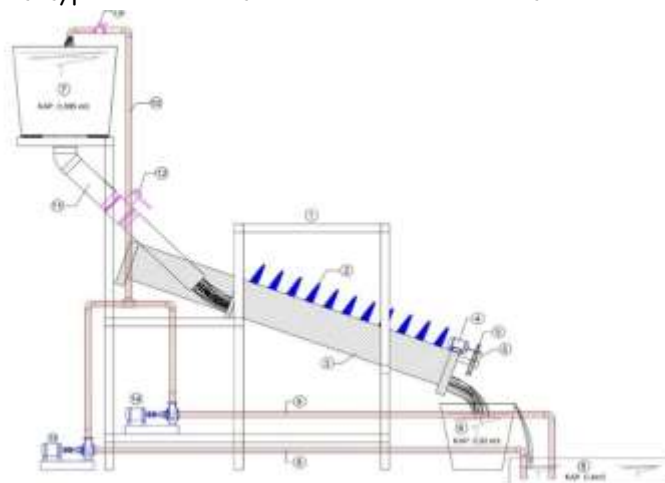


Figure 1. Archimedes Screw Turbine Design

Five experimental conditions were applied by setting the valve opening at 25°, 40°, 55°, 70°, and 85°. These settings produced water discharge values of 0.00115, 0.00311, 0.00429, 0.00528, and 0.00802 m³/s, respectively. Each valve position was tested to determine how increasing water flow affected the operating characteristics of the turbine.

During each test, the water discharge was regulated through the valve before being directed toward the Archimedes screw turbine. The resulting turbine operation was then observed and measured. Electrical performance was evaluated using generator voltage, electric current, and output power, while turbine efficiency was calculated for each operating condition. Shaft rotational speed was also recorded to identify the maximum rotational response generated by the variation in water discharge.



Figure 2. Archimedes' screw turbine

The collected data were analyzed descriptively by comparing turbine performance at each valve-opening condition. The analysis focused on identifying changes in shaft rotation, generator output power, and turbine efficiency as the water discharge increased. The operating condition that produced the highest output power and the condition that produced the maximum efficiency were then identified to determine the most favorable performance characteristics of the Archimedes screw turbine.

4. Results And Discussion

The experimental results show that changes in valve opening produced different water discharge rates and directly affected the performance of the Archimedes screw turbine. The tests were conducted at valve openings of 25°, 40°, 55°, 70°, and 85°, corresponding to water discharge values of 0.00115, 0.00311, 0.00429, 0.00528, and 0.00802 m³/s, respectively. The analysis focused on the electrical output and turbine efficiency under each operating condition.

Effect of Valve Opening on Generator Output Power

The electrical performance of the system was evaluated through voltage, current, and generator output power. The results are presented in Table 1.

Table 1. Effect of Valve Opening on Generator Output Power

No.	Valve Opening (°)	Water Discharge (m ³ /s)	Voltage (V)	Current (A)	Output Power (W)
1	25	0.00115	4.34	0.32	1.4
2	40	0.00311	6.62	0.59	3.9
3	55	0.00429	7.62	0.64	4.87
4	70	0.00528	8.5	0.63	5.35
5	85	0.00802	8.56	0.52	4.45

Source: Experimental data processed by the authors.

Table 1 shows that generator output power generally increased as the valve opening and water discharge increased. At a valve opening of 25°, the turbine produced only 1.40 W of electrical power. The output increased to 3.90 W at 40° and continued to rise to 4.87 W at 55°. The highest output power, 5.35 W, was obtained at a valve opening of 70° with a water discharge of 0.00528 m³/s. However, when the valve opening was increased further to 85°, the output power decreased to 4.45 W even though the water discharge reached its highest value of 0.00802 m³/s.

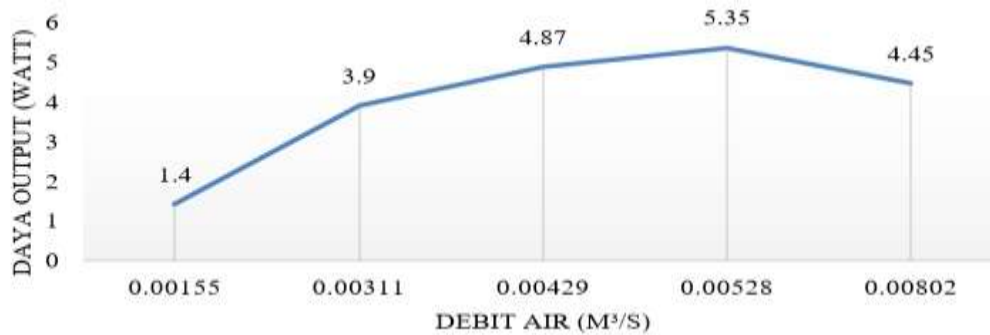


Figure 3. Graph Showing The Effect Of Valve Opening On Output Power

This result indicates that increasing water discharge does not always lead to a proportional increase in electrical output. Up to a certain operating point, a larger water discharge provides greater hydraulic energy to drive the turbine and generator. Beyond that point, however, additional water flow may increase hydraulic and mechanical losses. The original study explains that excessive water discharge may increase friction between the water and turbine components, thereby reducing the amount of energy that can be converted into electrical power.

The result therefore suggests that the valve opening of 70° provided the most favorable condition for maximizing generator output in the tested system. The decline in power at the largest valve opening also demonstrates the importance of controlling water flow rather than simply operating the turbine at the maximum available discharge.

Effect of Valve Opening on Turbine Efficiency

The effect of valve opening on turbine efficiency is shown in Table 2.

Table 2. Effect of Valve Opening on Turbine Efficiency

No.	Valve Opening (°)	Water Discharge (m³/s)	Turbine Efficiency (%)
1	25	0.00115	8.75
2	40	0.00311	27.34
3	55	0.00429	11.03
4	70	0.00528	9.85
5	85	0.00802	5.4

Source: Experimental data processed by the authors.

The efficiency results show a different pattern from the electrical output. The turbine efficiency increased sharply from 8.75% at a valve opening of 25° to a maximum value of 27.34% at 40°. After this point, efficiency decreased progressively to 11.03% at 55°, 9.85% at 70°, and only 5.40% at the largest valve opening of 85°.

These findings indicate that the highest water discharge does not correspond to the highest turbine efficiency. The most efficient operating condition was obtained at a moderate water discharge of 0.00311 m³/s. At this condition, the turbine was able to convert a relatively large proportion of the available hydraulic energy into useful output.

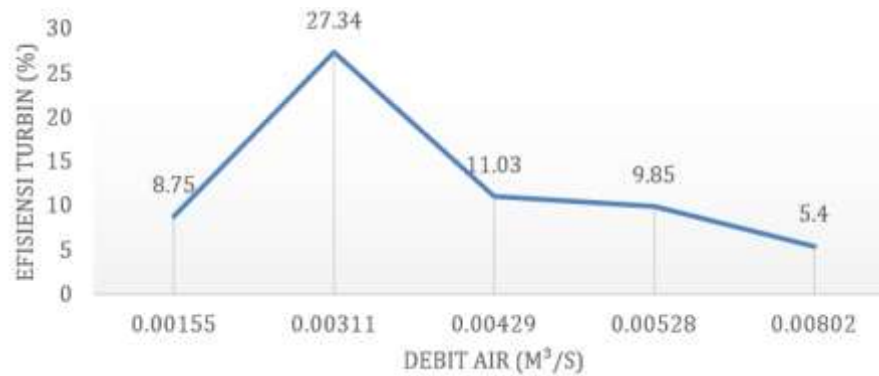


Figure 4. Graph Showing The Effect Of Valve Opening On Efficiency.

The reduction in efficiency at higher discharge levels can be associated with increasing mechanical and hydraulic losses. The study explains that excessive water flow increases the load on turbine components, including the shaft, bearings, and seals. This condition can increase friction, wear, vibration, and energy losses, thereby reducing overall turbine efficiency.

The result is also consistent with the earlier finding reported by Kurniawan (2021), in which maximum shaft speed and maximum efficiency were obtained at different flow rates. This confirms that the operating condition that produces the greatest rotational speed or electrical output is not necessarily the condition that produces the highest efficiency.

Overall Turbine Performance

A comparison of the main performance indicators is presented in Table 3.

Table 3. Summary of Maximum Turbine Performance

Performance Indicator	Maximum Value	Valve Opening (°)	Water Discharge (m ³ /s)
Shaft Rotational Speed	180.3 rpm	85	0.00802
Generator Output Power	5.35 W	70	0.00528
Turbine Efficiency	27.34%	40	0.00311

Source: Experimental data processed by the authors.

Table 3 demonstrates that each performance indicator reached its maximum value under a different operating condition. The highest shaft rotational speed of 180.3 rpm occurred at the largest valve opening of 85°. In contrast, the maximum generator output power of 5.35 W was achieved at 70°, while the highest turbine efficiency of 27.34% was obtained at only 40°.

This difference is important because it shows that Archimedes screw turbine performance cannot be evaluated using a single parameter. A larger valve opening can increase water flow and rotational speed, but this does not automatically provide the best electrical output or the highest efficiency. In the present experiment, the 85° condition produced the highest shaft speed but did not generate the highest power and resulted in the lowest efficiency. Conversely, the 40° valve opening provided the highest efficiency even though its electrical output was lower than that obtained at 55° and 70°.

The findings therefore indicate that turbine optimization should depend on the intended operational objective. If the primary objective is to maximize electrical output, a valve opening of 70° appears to be the most suitable among the tested conditions. If energy conversion efficiency is the principal consideration, the 40° valve opening is preferable. The results confirm that proper regulation of water discharge is essential for achieving stable and efficient operation of an Archimedes screw turbine in a micro-hydro power generation system.

5. Conclusion

This study demonstrates that valve opening has a substantial influence on the performance of an Archimedes screw turbine in a micro-hydro power generation system. Increasing the valve opening generally increases water discharge and improves turbine performance up to a certain operating point. However, the results show that the highest water discharge does not necessarily produce the highest electrical output or the best efficiency. The maximum shaft rotational speed was obtained at a valve opening of 85°, while the highest generator output power was achieved at a valve opening of 70°. In contrast, the highest turbine efficiency was obtained at a valve opening of 40°. These findings confirm that different performance indicators reach their optimum values under different operating conditions.

The results also indicate that excessive water discharge may increase hydraulic and mechanical losses, causing output power and efficiency to decline. Therefore, effective regulation of water discharge through appropriate valve adjustment is essential for achieving optimal turbine operation. For the tested system, a 70° valve opening is preferable when the main objective is to maximize electrical output, whereas a 40° valve opening is more suitable when efficiency is the primary consideration. Future studies are recommended to conduct experiments under actual river-flow conditions and to include additional operating parameters such as turbine inclination, screw geometry, torque, head variation, and mechanical losses to obtain a more comprehensive understanding of Archimedes screw turbine performance.

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