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Design and performance evaluation of a double-bladed Archimedean screw turbine for low-head hydropower generation

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Abstract

Archimedean screw turbines are a type of low-head hydroelectric turbine that can provide a simple and economical option for small-scale hydropower generation. This study focuses on the design and performance evaluation of a double-bladed Archimedean Screw Turbine (AST) for low-head hydropower generation in rural environments, specifically in irrigation canals for agricultural lands. The twin-bladed AST is designed to harness hydrokinetic energy from low head levels and flow rates of water, fabricated using Polyvinyl Chloride (PVC). The turbine was tested in irrigation canal in Misamis Oriental, Philippines, with an average inlet water level of 0.377 m and an inclination angle of 13°. A contracted rectangular weir was designed to regulate water flow and optimize the turbine's performance. The study analyzed the relationships between total water flow, rotational speed, torque, mechanical power, and turbine efficiency. The performance analysis showed that the double-bladed AST performed well, particularly at high inlet water levels enabled by the weir. The simulated and actual results demonstrated a maximum rotational speed of 240 rpm and efficiencies of approximately 19.85% and 19.69% at a total flow of 18 L/s, with a corresponding hydropower of 48.71 Watts. The fabricated AST successfully powered two 12V-6W DC LED light bulbs, demonstrating its potential for small-scale rural electrification. This study highlights the potential of the double-bladed AST as a cost-effective solution for low-head hydropower generation in rural areas, providing electricity for lighting and other basic needs in communities with limited access to power sources.

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Introduction

The global energy landscape is undergoing a significant transformation as the depletion of fossil fuel reserves and the urgent need to mitigate carbon dioxide (CO_2) emissions drive the search for sustainable alternatives (Esposito and Romagnoli, 2023). Hydropower, a mature and widely accepted form of renewable energy, has emerged as a promising solution to meet the growing global energy demand while reducing environmental impact (Liu *et al.*, 2022). This technology harnesses energy from various water bodies, including rivers, waterfalls, and irrigation canals, offering a versatile approach to clean energy production (Nuramal *et al.*, 2017). In off-grid areas with access to elevated running water, small and micro-hydropower systems present particularly suitable renewable energy solutions (Aviso *et al.*, 2020).

However, conventional hydropower turbine designs often pose significant threats to aquatic biodiversity. To address this concern, innovative approaches such as the Archimedes screw turbine (AST) have been developed, providing a safer alternative for generating hydropower in ecologically sensitive areas (YoosefDoost and Lubitz, 2020).

The AST design, was inspired by the ancient Archimedean screw historically used for water elevation, offers several advantages over traditional hydropower systems (Waters and Aggidis, 2015). Its unique design allows for efficient operation in low-head conditions, making it particularly well-suited for implementation in rural areas. Moreover, ASTs demonstrate high efficiency (60% to 80%) across a wide range of flow rates, enhancing their versatility and applicability (YoosefDoost and Lubitz, 2020; Waters and Aggidis, 2015). This high-performance potential underscore the technology's promise for effective energy generation in suitable locations. The design of ASTs is a complex process that requires careful consideration of various parameters. One crucial factor is the number of blades, which significantly influences the turbine's performance. Erinofiardi *et al.* (2022) conducted a study to determine the effect of the number of blades on an Archimedes screw turbine. In an experiment conducted, it was observed that the effect of flow rate on the speed of a screw turbine with two blades showed that the speed increased with an increase in water flow rate (Waters and Aggidis, 2015). The design of AST highly depended on the location, and there was no general standard for the optimal hydraulic design. Rorres (2000) obtained an empirical formula for design purposes where the description of mechanical, hydraulic, and water leakage losses had been explained.

The theoretical model was developed by considering geometrical parameters and idealized energy conversion and was then compared with the experimental results (Müller and Senior, 2009). Efficiency losses in ASTs are primarily attributed to factors such as rotational speed, hydraulic loss, water leakage, and friction losses in the bearings (Rorres, 2000). The study of Brada *et al.* (1999) found that variations in rotational speed and water flow exceeding 20% had minimal impact on AST efficiency. Typically, AST efficiency ranges between 80% and 90% (Lyons and Lubitz, 2013), highlighting the technology's potential for high-performance energy generation. One of the key advantages of ASTs is their relatively simple manufacturing process compared to conventional hydro turbines. This simplicity, combined with their ability to operate efficiently in low-head conditions and at low rotational speeds, makes them an attractive option for small-scale hydropower projects (Zhou and Deng, 2017).

The objective of the study was to conduct an experimental assessment of an AST, with practical test performed on irrigation canals in Misamis Oriental, Philippines. The research focuses on examining the effect of the number of blades on turbine performance while maintaining a constant inlet water flow. Due to environmental constraints, certain assumptions were made, including steady water flow, negligible water leakage, and minimal changes in physical properties, specifically; this study aims to addresses, first, to fabricate an Archimedes Screw Turbine suitable for the irrigation canal at Zone 1 Camaroc, Brgy.

Malanang, Opol, Misamis Oriental, based on calculated design parameters (inside and outside diameter, pitch, screw length, and number of blades); and to design a rectangular contracted weir for the turbine, suitable for the desired inclination angle of the turbine setup. By focusing on these objectives, this research aims to contribute to the development of small-scale hydropower solutions that can operate efficiently in low-head and low flow rate conditions, with potential applications in street lighting and other local energy needs.

Materials and methods

Design

The design process of the Archimedes Screw Turbine (AST) and its accompanying frame involved several stages, beginning with the determination of essential turbine parameters. These parameters were based on specific environmental conditions, including water flow rate and the height of the inclination angle. Once the necessary parameters were identified, the design of the screw turbine was developed using SOLIDWORKS software.

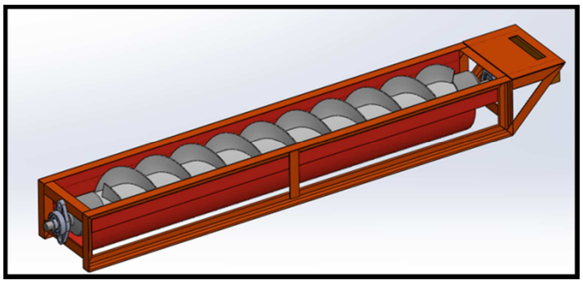

Fig. 1. 3D model of the AST

In this study, the preference was to design the AST (Fig. 1) with the minimum number of blades. For this purpose, a twin-bladed screw configuration was employed, allowing the turbine to operate at a low inclination angle. This design approach served the goal of minimizing production and maintenance costs by reducing material expenses.

Blade

In the design and fabrication of the Archimedes Screw Turbine, several screw/blade parameters were considered and employed to ensure optimal performance and efficiency (Table 1, Fig. 2). These measurements were based on the key design features that were necessary for the successful operation of the turbine.

Table 1. Blade parameters of the design of the screw

Blade Dimensions	Design measurements
Inner diameter (D_i)	0.08255 m
Outer diameter (D_o)	0.1524 m
Trough and screw gap (G_w)	0.002 m
Length of screw (L)	1.10 m
Number of blades (N)	2
Pitch of screw (S)	0.198 m

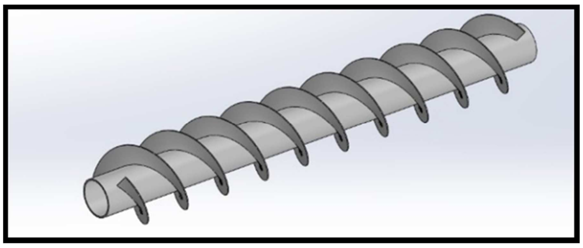

Fig. 2. Archimedes screw model

Frame and trough

The frame primarily consisted of ANSI inch angle bars measuring 1" x 1" x 0.125" and having a length of 1.2 m and a width of 0.21 m. The trough was constructed with plain sheet metal measuring 0.5 mm in thickness. Both the frame and the trough were coated with red oxide primer, to attach the shaft to the frame, the frame was bolted with a UCFL 204 flange bearing (Fig. 3).

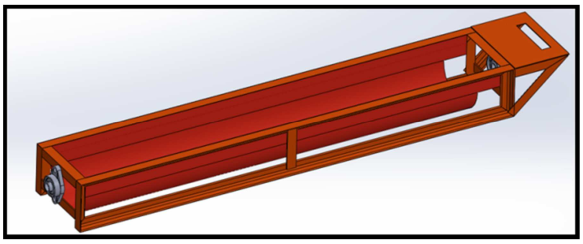

Fig. 3. Frame and trough model

Turbine fabrication procedure

The fabrication of the AST started after the numerical modeling of the turbine was designed and performed using SOLIDWORKS with corresponding simulation runs. The procedure started with the design parameter calculations and fabrication of the blades of the turbine. The blades were then attached to a 1.10 m tube of the turbine. Both the blades and the tube were fabricated using a 3" Polyvinyl Chloride (PVC) pipe. The pipe together with the attached blades was then coupled on the designed composite shaft, a combination of a hollow and solid shaft, with the use of a 2" to ¾" PPR pipe reducer. The reducer was connected to the PVC pipe using a 3" coupler. To reduce the chance of slip between the contact surfaces of the reducer, the coupler, and the hollow tube, a fair amount of PVC cement was used in attaching these parts (Fig. 4).

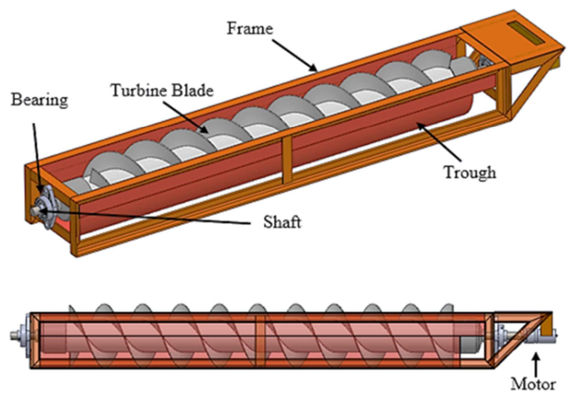

Fig. 4. Design of the AST setup

After the completion of the fabrication of the turbine, it was coupled to the composite metal shaft in which the inside shaft was made up of ¾" Aluminum shaft. This hollow shaft was fastened and coupled with a ¾" solid cast iron (CI) shaft on both ends which was then connected to the bearings of the frame. The fabrication of the frame followed with certain dimensions and tolerances appropriate for the turbine and the location of the study. After the fabrication of the turbine with the frame, the design of a rectangular contracted weir followed, which had to be suitable with the dimensions obtained from the site survey of the proposed irrigation canal.

Fabrication of blades

The Archimedean screw turbine's blade dimensions were determined for the turbine to be fabricated according to the design made using SOLIDWORKS software. The design formulas were similar to the calculations made in fabricating a screw conveyor.

Calculation of blade parameters

The concept of utilizing and calculating the screw flight was the same as it is on inclined screw conveyors. The calculations for the AST blades were obtained using the formulas stated by Rajesh and based on the design guidelines for auger conveyors of Duraipandi. Small pitch auger flight or short pitch screw flight was employed in the study. They were also used to control the feed at the entrance and to prevent free flowing items from being flushed. The necessary screw flight calculations were used to identify the blank plate cutting layout of a screw flight that was utilized in the fabrication of the Archimedean screw turbine (Fig. 5).

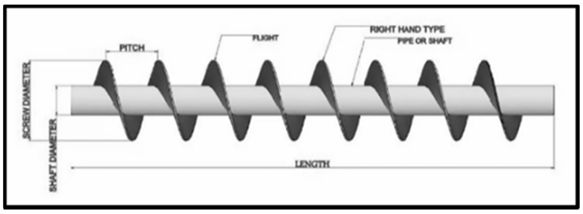

Fig. 5. AS turbine nomenclature

The formula to determine the developed outside diameter is:

$$L = \sqrt{(\pi D_o)^2 + S^2} \quad (1)$$

Where L is the developed outside diameter (m), D_o is the screw diameter (m), and S is the pitch of the screw (m). Developed inside diameter of the turbine should also be calculated. It is a necessary variable to obtain the dimensions of the ring-like structure of the blade. The developed inside diameter of the screw blade can be calculated using the following formula:

$$\ell = \sqrt{(\pi D_i)^2 + S^2} \quad (2)$$

Where ℓ is the developed inside diameter (m), D_i is the pipe diameter (m), and S is the pitch of the screw (m). The blades must be fabricated first in a ring-like configuration, with outer and inner rings to be identified. The inside diameter of the ring can be calculated using the formula:

$$d' = \frac{D_o - D_i}{\left(\frac{L}{\ell}\right) - 1} \quad (3)$$

Where d' is the inside diameter of the ring (m), D_o is the screw diameter (m), D_i is the pipe diameter (m), L is the screw flight (m), and ℓ is the developed inside diameter (m). The outside diameter of the ring can be calculated using the formula:

$$D' = (D_o - D_i) + d' \qquad (4)$$

where D' is the outside diameter of the ring (m), D_o is the screw diameter (m), D_i is the pipe diameter (m), and d' is the inside diameter of the ring (m). The cutting degree, denoted as θ, is the angle in which the ring-like structure should be cut in order to obtain the necessary configuration for the blade of the AST. The formula used for the calculation of the cutting degree is the following:

$$\theta = \frac{L}{\left(\frac{\pi D'}{360}\right)} + 360° \qquad (5)$$

Where θ is the cutting degree (°), L is the screw flight (m), D' is the outside diameter of the ring (m). Overall radius that was developed in the design of the turbine was also identified in the procedure. It can be calculated using the formula:

$$R_o = \frac{D_o - D_i}{2} \qquad (6)$$

Where R_o is the overall radius of of the Archimedean screw turbine (m), D_o is the screw diameter (m), and D_i is the pipe diameter (m). Finally, the cylindrical screw flights is important for the fabrication of the turbine. It serves as the guides in which the blades will be attached to the hollow pipe. It can be calculated by:

$$F_{screw} = \frac{\ell R_o}{L - \ell} \qquad (7)$$

Where F_{screw} is the cylindrical screw flight (m), D_o is the screw diameter (m), R_o is the overall radius of the Archimedean screw turbine (m), L is the screw flight (m), and ℓ is the developed inside diameter (m). Typically, cylindrical screw flights can also be obtained simply by just half of the D' that was previously calculated.

The fabrication of the turbine began by sectioning the 3" PVC tubing. To save manufacturing costs, these sections were reduced by 0.210 m with a 5 mm allowance on both sides for the ring's outer diameter. The portion was then cut lengthwise on one side. It enabled the flattening of the PVC piece into a sheet by the use of a fire torch. The torch allowed the PVC to be easily formed into sheets. Since there were five sets in each blade section, a total of ten (10) plates were made.

Blade installation

When the blade of the turbine had been fabricated, it was attached to the hollow tube, a 3" PVC pipe, which was the same material as the blade. It was attached using an all-purpose grab adhesive as a primary attachment of the blades to the pipe. After the pre-treatment, a PVC cement was then coated or applied on the contacted or joined surfaces of the blade and of the pipe, which was only applied after the grab adhesive solidified. PVC cement was used since most PVC-based materials such as pipes in plumbing were joined and connected with this adhesive as a primary bonding solvent for pipes and fittings. This allowed the blades to be attached to the turbine with better adhesion than the all-purpose grab adhesive. This solvent was also used in the attachment of the fittings used in the turbine. By allowing the treatment to dry for 24 hours, it showed a better bonding result of the attachment of the fabricated blades and the PVC pipe. As a final treatment for the blades to be attached to the turbine, an all-purpose structural adhesive epoxy was applied to the contact surfaces of the blades and the surface of the pipe where the surfaces would mate. This allowed a secured bonding of the components and more grip strength of the blades. By allowing the epoxy to dry for another 24 hours, the PVC turbine blades had been joined with the pipe that finalized the fabrication of the turbine.

Rectangular weir dimensions

The rectangular contracted weir was designed so that the desired inclination angle would be within the required parameters set in the design of the turbine. The guidelines set from the recommendations of Nagel, which were further utilized by Rorres, had specific conditions for the pitch-to-outside diameter ratio based on the inclination angle.

$$\frac{S}{D_o} = \begin{cases} 1.2, if\ \beta < 30° \\ 1, if\ \beta = 30° \\ 0.8, if\ \beta > 30° \end{cases}$$

The chosen factor for the pitch-to-outside diameter ratio (S/D_o) was 1.2 if the inclination angle, β, was configured to be below 30°. This means that it would be ideal for the study so that the rise of water caused by the placement of the rectangular weir in the irrigation canal would not flow out of its walls, thus preventing the overflowing of water on the outside portion of the setup that prevents data discrepancies. To determine the inclination angle, it needs to determine the length of the screw and the height in which it was desired to be inclined. The formula for the inclination angle was the following:

$$\beta = \frac{X}{L} \quad (8)$$

Where β is the inclination angle, X is the inclination height, and L is the length of the screw.

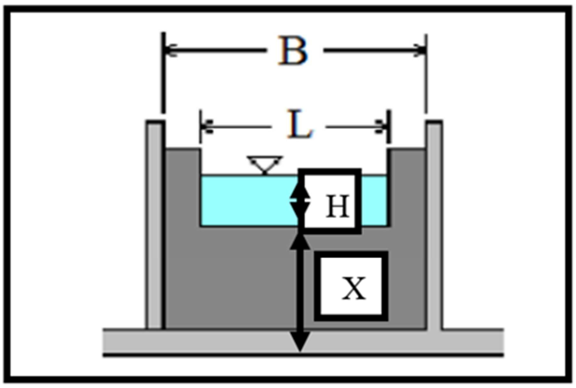

Fig 6. Visualization of the rectangular weir dimensions

Fig. 6 shows the parameters that the contracted rectangular weir has been designed by the irrigation canal. The L represents the length of the weir crest in meters, the B represents the average width of the approach channel in meters, and X is the height of the weir crest relative to the ground in meters, and H is the change in the measured head above the weir crest in meters.

Simulation procedure

Fluid dynamics is a branch of mechanical engineering that studies fluid flow. The fluid motion can be investigated by using numerical methods. The numerical method can be approached based on the results shown in Computational Fluid Dynamics (CFD). The project's simulation of the AST would be performed by using the SOLIDWORKS software. With the finalized design, the model of the AS is then tested into the SOLIDWORKS Flow Simulation add-in. With the experimental set-up parameters input below into the flow simulation wizard (Table 2).

Table 2. Archimedean screw turbine simulation setup

Turbine dimensions	Estimates
Average velocity	2.8 m/s
Weir height	0.24 m
Inlet water height (Δh_i) *	0.30~0.42 m
Turbine inclination (β)	13°
Rotational speed ranges**	160 – 325 rpm

*The range is given as the change of the height of water is transient

** The range is given as the change of the rotational speed of the screw is affected by the height of water

When creating a new flow simulation project, the researcher adjusted the computational domain of the simulation to cover the screw assembly. It is important so that we can ensure the results of the CFD simulation are accurate and in line with what the researchers are aiming for. Then, after inputting the parameters, the researcher selected a face in the screw assembly where the torque would be measured. The measured torque would then be contrasted with the experimental results.

Data gathering

For data gathering, the first data that had to be collected were the inlet and outlet water head levels, as this was the determining factor for hydropower. Water head level was the height of water before it passed through the weir (indicated as inlet water head level) and after it passed the weir (indicated as outlet water head level). The inlet water head level was measured in the weir using a tape measure. The outlet water head level was measured in the discharge zone of the water located at the bottom of the turbine. The rotational speed was measured using the RS Pro Tachometer with an accuracy deviation of ± 0.05%. It was measured at the same location as the dynamometer with slight deviation to the bottom, with the reflective tape on the turbine. The rotational speed was measured after measuring the water head level. The data measured by the tachometer were the no-load rotational speed and the loaded rotational speed. The data was gathered at intervals of 5 minutes. Torque, one of the required parameters for mechanical power, was measured using a dynamometer set up on the turbine that used a rope brake method. Two digital hook scales with an accuracy deviation of ± 0.5% for numerical readings of the weight in terms of kilogram force were used. These scales were attached to a rope that was wrapped around the modified end of the turbine to be used as the pulley. This served as a brake that the scales would read the output forces (in kilograms of force). It was then converted to Newtons to be used as a centrifugal force for the identification of the torque output of the turbine. Mechanical power was calculated using the formula of power transmission. The torque needed for the calculation of mechanical power was used from the gathered data in both actual and simulation results. Hydropower was calculated using the total flow, water density, gravity, and the difference in water head levels, with the total flow serving as the biggest factor affecting the value of hydropower.

Results and discussion

Torque simulation

The performance of the Archimedean Screw Turbine (AST) in this study was evaluated through a combination of Computational Fluid Dynamics (CFD) simulations and experimental testing, an approach that has become standard in hydropower research due to its ability to provide accurate predictions of turbine performance (Williamson *et al.*, 2019). The CFD analysis, conducted using SOLIDWORKS Flow Simulation, yielded torque values ranging from 0.291 N-m to 0.382 N-m, corresponding to rotational speeds between 169 rpm and 240 rpm. These results align with previous studies on small-scale ASTs, such as those conducted by Nuernbergk and Rorres (2013), who reported similar torque ranges for low-head applications. The simulation is an important phenomenon affecting turbine efficiency, including backflow and gap leakage (Table 3, Fig. 7 and 8).

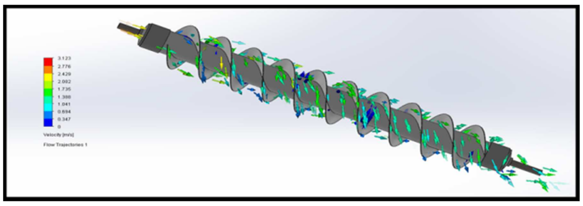

Fig. 7. Simulated water flow of the Archimedean screw turbine

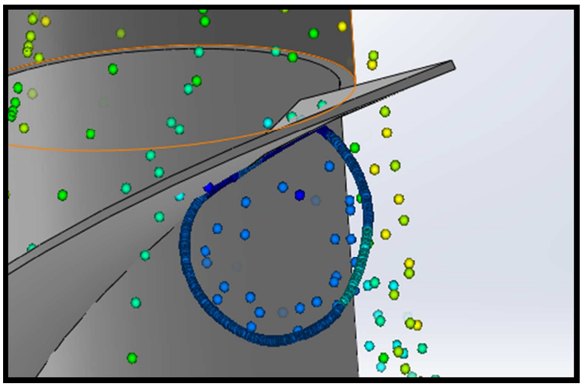

Fig. 8. Backflow phenomenon on the start of the screw turbine

Table 3. Torque Simulation results

Total Flow (L/s)	Rotation speed	Torque (N-m)
12	169	0.298
13	186	0.291
14	198	0.326
15	212	0.331
16	213	0.353
17	232	0.367
18	240	0.382

The simulation revealed two critical phenomena affecting turbine efficiency: backflow and gap leakage. The observed circulation of water behind the turbine blades, resulting in backflow, is a well-documented issue in AST design. This phenomenon causes velocity loss in the screw, leading to reduced efficiency. Rohmer *et al.* (2016) identified this backflow as a critical factor in AST performance optimization. The gap leakage observed between the blades and the frame's trough corroborates the findings of Kozyn and Lubitz (2017), who reported that such losses can account for up to 15% of total flow in some AST designs. This observation highlights the critical importance of manufacturing and design optimization of blade design and minimizing gaps to improve overall turbine efficiency in AST development. These findings align with the comprehensive review of AST design principles by Dellinger *et al.* (2019), emphasizing the potential for significant efficiency improvements through innovative design solutions that address these specific loss mechanisms.

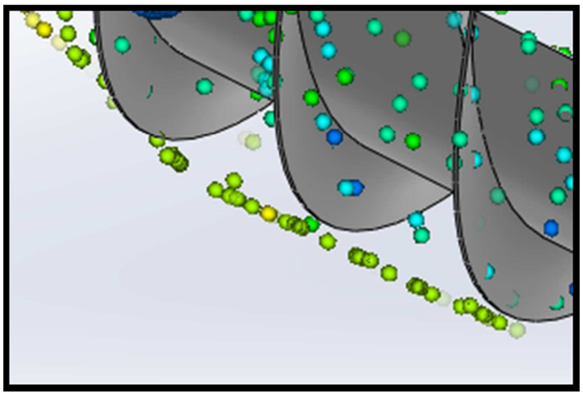

Fig. 9. Gap leakages

Total flow and rotational speed

The relationship between total flow and rotational speed is a crucial aspect of Archimedean Screw Turbine (AST) performance, providing insights into the turbine's efficiency and power generation capabilities across varying hydraulic conditions. The analysis on the total flow and the rotational speed has been used instead of the comparison of water velocity and the rotational speed of the turbine, these two shows the effects of a sudden increase or decrease of the amount of water flowing into the blades of turbine would affect the speed of rotation that would directly affect the mechanical power of the turbine. This relationship is fundamental to AST operation and aligns with the theoretical principles of hydropower generation (Lyons and Lubitz, 2013).

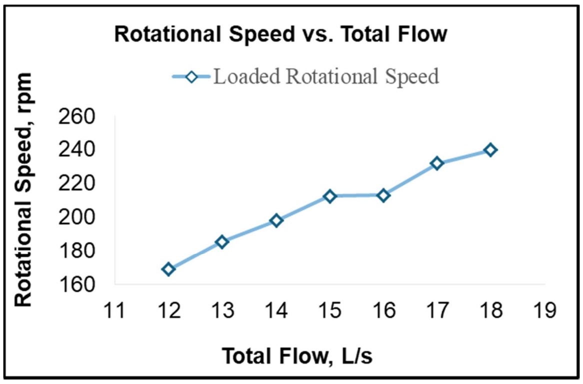

Fig. 10. Rotational speed and water flow comparison data

Fig. 10 shows that the simulation and the experimental result that the rotational speed increases, as the flow of water coming out of the weir increases. The highest loaded rotational speed achieved was 240 rpm at 18 L/s total flow, while the lowest was 169 rpm at 12 L/s of total flow. This linear relationship between flow rate and rotational speed is typical for ASTs and has been reported in similar studies (Dellinger *et al.*, 2016). Muller and Senior (2009) observed that at very high flow rates, the linear relationship may break down due to increased turbulence and overflow losses. Conversely, at very low flow rates, friction and startup torque can become significant factors, potentially leading to non-linear behavior. While the achieved rotational speeds are relatively low compared to conventional reaction turbines, they are well-suited for low-head applications. As Williamson *et al.* (2019) noted, this low-speed operation can offer several advantages, including reduced wear on components, simpler gearing requirements, and improved ecological compatibility.

Total flow and torque

The following shows the results of the recorded brake torque and the estimated water flow rate into the turbine.

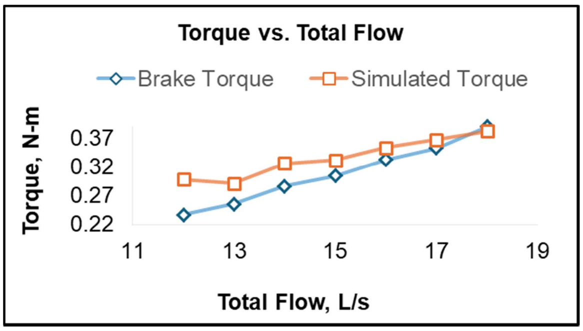

Fig. 11. Torque and water flow comparison data

Fig. 11 above shows the comparison between the simulation and brake torque results. It shows the relationship between the torque and total flow with an estimated angle of inclination of 13°, demonstrates a positive correlation, with both simulated and experimental results showing increasing torque with increasing water flow rate. The result in the minimum brake torque is at 0.24 N-m and the minimum simulated torque is at 0.29 N-m. The maximum brake torque at 0.389 N-m and simulated torque at 0.382 N-m both at 18 L/s of total flow is consistent with theoretical expectations and previous studies on ASTs of Nuernbergk and Rorres, 2013. The close alignment between simulated and experimental torque values in the CFD model accurately captures the torque generation mechanisms in the AST. However, the CFD model that may not fully capture low-flow dynamics, particularly at lower flow rates where measurement errors may have a more significant relative impact.

Total flow and mechanical power

The relationship between total flow and mechanical power exhibits a clear positive correlation, as demonstrated by both actual and simulated experiments in Fig. 12. This correlation is supported by the fundamental principles of fluid dynamics and mechanical systems, where flow rate, rotational speed, and torque are interrelated (Zhao *et al.*, 2022). As the flow increases, the rotational speed of the turbine increases, as mechanical power output increases.

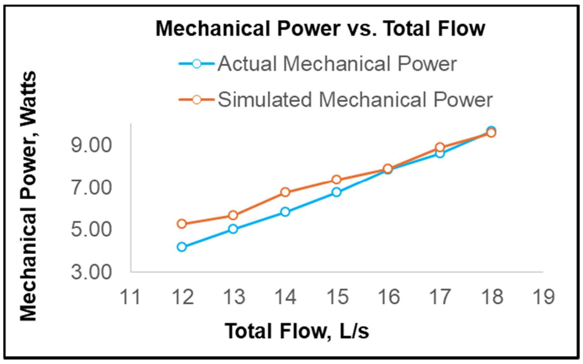

Fig. 12. Mechanical power and water flow comparison data

In Fig. 12, the mechanical power increases as the weir flow increases due to the increase of rotational speed of the turbine. The data show that at a total flow of 12 L/s, the actual mechanical power is 4.180 watts, whereas the simulated mechanical power is slightly higher at 5.270 watts. At a total flow of 18 L/s, the maximum mechanical power recorded for the actual experiment is 9.669 watts, with the simulated value at 9.588 watts. Despite the minor deviations between the actual and simulated data, the trend of increasing mechanical power with higher flow rates remains consistent. However, it is crucial to critically assess the factors contributing to the slight deviations between actual and simulated power outputs. Simulated systems often assume ideal conditions, such as perfect fluid flow without turbulence or energy losses due to friction or inefficiencies in the turbine's mechanics. These factors could explain why simulated mechanical power consistently slightly exceeds actual values, especially at lower flow rates. According to Wang and Chen (2022), real-world energy systems often experience losses that are difficult to model perfectly, which may result in discrepancies between actual performance and theoretical simulations. Moreover, the increase in mechanical power with the rise in total flow is indicative of the turbine's efficiency in converting kinetic energy from the water flow into mechanical energy. As highlighted by Tsujimoto (2019), turbines operating at higher flow rates typically experience increased efficiency consistent rises the mechanical power with increasing flow rates.

Total flow and turbine efficiency

The relationship between total flow and turbine efficiency is crucial in evaluating the performance of Archimedean Screw Turbines (ASTs) for hydropower applications.

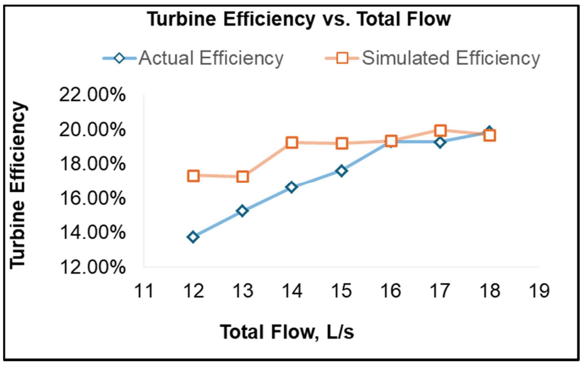

Fig. 13. Turbine efficiency and total flow comparison data

Fig. 13 shows the correlation between total flow and turbine efficiency, both simulated and experimental results. As the total flow increases, the turbine efficiency also increases, at the maximum flow rate of 18 L/s, we observed turbine efficiencies of 19.85% and 19.69% for actual and simulated conditions, respectively. These findings align with recent research in the field of small-scale hydropower generation. A comprehensive study by Kozyn and Lubitz (2017) on AST performance reported efficiencies ranging from 15% to 30% for similar-sized turbines, placing our results within the expected performance range. Nuernbergk and Rorres (2013) explain, higher flow rates lead to increased filling of the screw's buckets, reducing losses and improving overall efficiency. However, Rohmer *et al.* (2016) found that efficiency peaks at an optimal flow rate, beyond which overflow losses and increased turbulence can lead to efficiency declines. This finding underscores the importance of proper sizing and design for specific site conditions.

Conclusion

This study successfully designed, built, and tested an Archimedean Screw Turbine (AST) for low-head hydropower generation in irrigation canals. The turbine showed promising results for rural electrification. With an average inlet water level of 0.377 meters and a 13° inclination angle, the AST achieved a maximum mechanical power of 9.669 Watts and an efficiency of 19.85%. The experimental results closely matched the simulation data, demonstrating the reliability of the turbine design. The AST was able to power two 12V-6W DC LED bulbs, potentially for small-scale and real-world applications. For future research and development, the study recommended to improving the design by incorporating guiding vanes or paddles and screw covers to optimize water flow and reduce spillage; using advanced simulation software like ANSYS FLUENT for more detailed analysis; exploring alternative composite materials for fabrication and more suitable dynamos for power generation; integrating power management systems including batteries and controllers; and utilizing advanced data collection methods such as Arduino-based systems for real-time performance monitoring. These enhancements aimed to improve the efficiency, durability, and applicability of ASTs in rural electrification projects, furthering the development of sustainable and accessible renewable energy solutions.

References

Aviso KB, Mayol AP, Promentilla MAB, Santos JR, Tan RR, Ubando AT, Yu KDS. 2020. Allocating human resources in organizations operating under crisis conditions: A fuzzy input-output optimization modeling framework. Resources, Conservation and Recycling **128**, 104751.

Brada K, Radlik K. 1999. Water screw motor for micropower plant. Proceedings of the 6th International Symposium on Heat Exchange and Renewable Energy Sources, 43-52.

Dellinger G, Garambois PA, Dellinger N, Dufresne M, Terfous A, Vazquez J, Ghenaim A. 2016. Computational fluid dynamics modeling for the design of Archimedes Screw Generator. Renewable Energy **118**, 847-857.

Dellinger G, Simmons S, Lubitz WD, Garambois PA, Dellinger N. 2019. Archimedes screw turbines: A review of the state of the art. Renewable and Sustainable Energy Reviews **117**, 109479.

Erinofiardi, Nuramal A, Bismantolo P, Date A, Akbarzadeh A, Mainil AK, Suryono AF. 2022. Experimental study on the effect of number of blades of Archimedes screw turbine on its performance. Energy Reports **3**, 006-013.

Esposito S, Romagnoli A. 2023. The role of renewable energy in decarbonizing the power sector: A review. Renewable and Sustainable Energy Reviews **174**, 113176.

Kozyn A, Lubitz WD. 2017. A power loss model for Archimedes screw generators. Renewable Energy **108**, 260-273.

Liu D, Liu H, Wang X, Kremere E. 2022. World small hydropower development report 2022. United Nations Industrial Development Organization; International Center on Small Hydro Power.

Lyons M, Lubitz WD. 2013. Archimedes screws for microhydro power generation. In ASME 2013 7th International Conference on Energy Sustainability.

Muller G, Senior J. 2009. Simplified theory of Archimedean screws. Journal of Hydraulic Research **47**(5), 666-669.

Nagel G. 1968. Archimedean screw pump handbook. RITZ-Pumpenfabrik OHG, Schwäbisch Gmünd, Germany.

Nuernbergk DM, Rorres C. 2013. Analytical model for water inflow of an Archimedes screw used in hydropower generation. Journal of Hydraulic Engineering **139**(2), 213-220.

Nuramal A, Bismantolo P, Date A, Akbarzadeh A, Mainil AK, Suryono AF. 2017. Experimental study of screw turbine performance based on different angle of inclination. Energy Procedia **110**, 8-13.

Rohmer J, Knittel D, Sturtzer G, Flieller D, Renaud J. 2016. Modeling and experimental results of an Archimedes screw turbine. Renewable Energy **94**, 136-146.

Rorres C. 2000. The turn of the screw: Optimal design of an Archimedes screw. Journal of Hydraulic Engineering **126**(1), 72-80.

Tsujimoto T. 2019. Review of turbomachinery flow phenomena. Journal of Thermal Science **28**(5), 815-838.

Wang L, Chen J. 2022. Efficiency analysis and optimization of small hydropower systems: A comprehensive review. Renewable and Sustainable Energy Reviews **153**, 111782.

Waters S, Aggidis GA. 2015. Over 2000 years in review: Revival of the Archimedes screw from pump to turbine. Renewable and Sustainable Energy Reviews **51**, 497-505.

Williamson SJ, Stark BH, Booker JD. 2019. Performance of a low-head pico-hydro Turgo turbine. Applied Energy **102**, 1114-1126.

YoosefDoost A, Lubitz WD. 2020. Archimedes screw turbines: A sustainable development solution for green and renewable energy generation—A review of potential and design procedures. Sustainability **12**(18), 7352.

Zhao Y, Zhang Y, Zhang Y. 2022. Archimedes screw turbine: A review of the main technical challenges and future research direction. Renewable and Sustainable Energy Reviews **158**, 112092.

Zhou D, Deng ZD. 2017. Ultra-low-head hydroelectric technology: A review. Renewable and Sustainable Energy Reviews **78**, 23-30.