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EVALUATING EFFECT OF BLADES MATERIAL ON ARCHIMEDES SPIRAL HYDRO TURBINES: A COMPARATIVE STUDY FOR SUSTAINABLE HYDROPOWER

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Abstract:
This paper presents a comparative performance analysis of PVC and MS blades in Archimedes Spiral Hydro Turbines (ASHT) for sustainable hydropower generation. There are two types of ASHT prototypes fabricated based on a three-dimensional (3D) design by varying the blade material; one was Poly Vinyl Chloride (PVC) made screw ASHT, and another was Mild Steel (MS) made ASHT. The thickness of PVC and MS was 4 mm and 1 mm, respectively. The generated voltage and current for 0.5 m, 1.0 m, and 1.5 m heads were analyzed, and the output power was compared with various shaft rotations based on the variation of the head. At the same head, voltage and current were obtained much more for MS-made ASHT. At 1.5m, higher voltage and current were investigated; the voltage and current were 10.2V and 0.57A for MS-made. MS-made ASHT exhibited 52.20% and 23.90% more voltage and current, respectively than PVC-made ASHT at 1.5m head. The maximum power was observed for MS-made ASHT, which was 5.82W at 502 rpm. This paper underscores the importance of balancing design parameters, blade material, and operating conditions to optimize ASHT for sustainable hydropower generation.

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1. INTRODUCTION

The ASHT is an innovative method for hydroelectric power generation, especially applicable in locations with low water heads [1]. The ASHT effectively utilizes resources by adapting the principles of the Archimedes screw to turbine design [2, 3]. The system's simplicity, scalability, and responsiveness to low-flow conditions provide it with an innovative approach to renewable energy generation [4]. Renewable energy, sourced from perpetually replenished natural resources such as solar, wind, geothermal, hydropower, and biomass, provides a sustainable alternative to limited fossil fuels [5-7]. Numerous studies have emphasized the advantages of employing Archimedes screw turbines, and it is clear that these turbines operate most effectively under low head and low flow rate circumstances. However, it would be highly significant to analyze the combined effects of all the parameters on the performance of the ASHT [8]. The potential for harnessing hydropower is frequently limited in rivers characterized by low head and high discharge, highlighting the necessity for innovative solutions such as the ASHT [9]. The ASHT provides a novel and efficient solution for hydroelectric power generation by applying Archimedes screw principles to renewable energy applications.

The researchers have determined that shaft slope, pitch distance, and water discharge are the characteristics that have a discernible impact on

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the performance mechanics of the screw turbine [10]. The operational efficiency of an Archimedes screw turbine is impacted by many significant variables, such as the internal and external dimensions of the screw, the screw's pitch, the conditions at the intake and outlet, the slope of the system, the head, and the rate of water flow [11-15]. The aforementioned characteristics play a crucial role in determining the operational efficiency of the turbine. Moreover, they play a crucial role in the computation of essential performance indicators, including torque, power output, and efficiency of the Archimedes screw turbine [16, 17]. To validate and support the paper results, laboratory experiments were carried out on the Archimedes screw turbine. The experiments conducted aimed to substantiate the theoretical predictions and evaluate the practical functionality of the turbine across different scenarios [18].

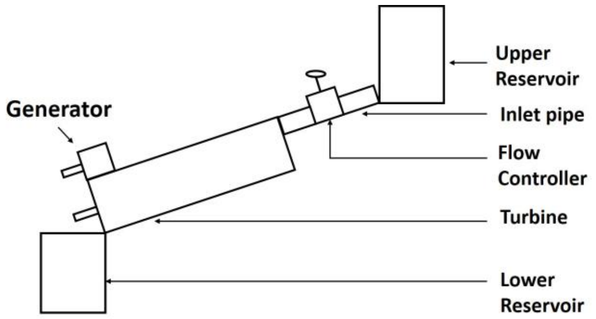
Bouvant et al. [19] evaluated the efficiency of AST by analyzing its coefficient of power. The investigation analyzed the performance of AST considering different variables, including inner and outer diameter, blade inclination angle, and axle length. The team utilized CFD simulations to investigate the interaction between the specified parameters and their impact on turbine performance. Lee et al. [20] developed a study grounded in a conceptual design derived from the findings of a literature review. The investigation constructed and evaluated the AST within the experimental laboratory to evaluate the performance of turbines. The performance of an Archimedes screw turbine is significantly influenced by several design parameters, particularly the thread diameter and pitch, which are essential in its development [21]. The design considerations improve the turbine's efficiency while also connecting with the principles of contemporary sustainable development. Focusing on economic growth, social progress, and environmental preservation, sustainable development highlights the importance of creating solutions such as optimized screw turbines that serve both present and future generations while promoting the responsible use of natural resources [22]. The performance improvement methods for the Archimedes screw are now able to be investigated to enhance efficiency [23]. Recent studies have investigated the performance of Archimedes screw turbines using CFD simulations, laboratory experiments, and design optimizations. These studies highlight essential parameters to improve efficiency and sustainable processes.

This paper is mainly focused on investigating and evaluating the effect of blade material on Archimedes Spiral Hydro Turbines, providing them as an innovative and sustainable solution for small-scale hydropower generation. The evaluation offers an in-depth analysis of their effectiveness, design benefits, and performance parameters in low-flow conditions.

2. MATERIALS AND METHODS

The research methodology consisted of the following steps: conceptual design, prototype, testing, and optimization. The research was conducted at the Fluid Mechanics Laboratory, Bangladesh Army University of Science and Technology, Saidpur, Bangladesh. The 3D model of all turbine components was carried out before the machining process using SolidWorks 2018. Based on the 3D model, a prototype was fabricated and tested to assess its performance and efficiency. Subsequently, the design was refined and enhanced using the findings obtained from the testing process. The optimization procedure was iterated until the required level of performance and efficiency was attained. The ASHT prototype was constructed using a variety of components and installation diagrams, as shown in Fig. 1. The essential components of the ASHT system included the screw rotor, blade, inner shaft, frame, trough, trough cover, and reservoir. The mentioned components were collected and processed using the machining process. The 3D model of all turbine components was carried out before the machining process using SolidWorks 2018.

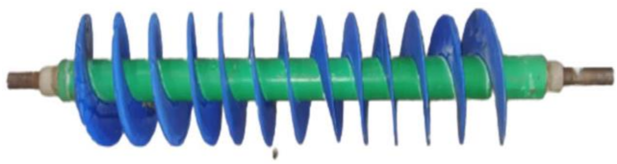
(a)



(b)

Fig. 1. (a) Constructed ASHT prototype, (b) Installation block diagram

The turbine screw in this specific configuration consisted of two screws, as shown in Fig. 2, one fabricated from PVC with a thickness of 4 mm, and another constructed from MS sheet with a thickness of 1 mm. The screws possess a total external diameter of 140 mm, while their internal diameter is 48 mm. The length and diameter of the inner shaft were measured to be 1000 mm and 20 mm, respectively. The selection of a 20 mm diameter for the turbine resulted from carefully considering the trade-off between strength and weight. Additionally, the length of the turbine is determined depending on the particular criteria that need to be satisfied. The blades play a vital role in the screw turbine system as they are responsible for the conversion of kinetic energy from the flowing water into rotational mechanical power. This design incorporated a screw with a total length of 1000 mm and was equipped with 11 blades, allowing the effective processing of a substantial quantity of water during a single revolution. The diameter of the ASHT's trough was 160 mm, while its thickness was 5 mm. The overall length of the trough was 1000 mm. The use of a 160 mm diameter allowed for enough clearance for the rotational movement of the screw blades inside the trough, hence optimizing the efficiency of the turbine.



(a)

(b)

Fig. 2. Fabricated shaft: (a) from PVC, and (b) from MS

The hydro turbine was equipped with two essentials through caps, each having a diameter of 170 mm and a thickness of 5 mm. These caps served as a sturdy base for both the bearing hub and the shaft clamping mechanism. The frame was fabricated from 25.4 mm angle iron, with dimensions of 1000 mm in height and 200 mm in width. This design choice was made to provide a sturdy and secure foundation for the whole turbine equipment. Two reservoirs were used. The top reservoir has a remarkable capacity of 220 l and a height of 1000 mm, offering substantial storage capacity for the necessary water supply to generate power through the turbine. To improve control, a 50.8 mm ball valve is installed at the upper reservoir's water input, enabling accurate water flow adjustment into the turbine. On the other hand, the lower reservoir presents a condensed but effective alternative, with a capacity of 110 l and standing at a height of 500 mm.

When creating the design of the screw, it was important to examine the existing resources and the precise specifications properly. The process entailed the evaluation of the suitable dimensions, materials, and operational parameters of the screw mechanism, taking into account the flow rate, head, and other physical characteristics of the hydro resource under consideration. In Table 1, all the theoretical parameters of the screw turbine model are enlisted.

Table 1. Parameters of screw turbine model (Theoretical)

Parameters	Value
The outer radius of the turbine (R_O)	70 mm
The inner radius of the diameter (R_i)	24 mm
The total length of the screw shaft (L)	1000 mm
Diameter of the Shaft (D_s)	20 mm
The radius ratio (ρ)	0.34
The total pitch of the screw turbine (λ)	761 mm
Pitch of one blade (p)	69.25 mm
Number of blades (N)	11
The tilt angle of the turbine shaft (ϑ)	30°
Flow rate (Q)	0.0062 m^3/s
Shaft rotation speed (n_s)	704 rpm
Torque of the turbine (T)	1.03 Nm
Casing diameter (D_c)	152 mm

The investigation and analysis of the screw's performance and efficiency may be conducted using the establishment of a controlled experimental setup, where the power output of the screw is measured across different operational parameters. The data obtained from these tests is used to evaluate the effectiveness of the screw and identify potential areas for improvement. The findings from the conducted tests indicate that there is potential for enhancing the performance and efficiency of the screw by optimizing its design.

3. RESULTS AND DISCUSSIONS

3.1 Data Collection and Experimental Analysis

The output from the DC motor generator was measured to obtain the experimental data using two separate multimeters. A tachometer was used to measure the rotation of the shaft; a measuring scale was used to measure the head.

In the case of MS and PVC blades, the generated voltage was different for the same head, as represented in Fig. 3. The generated voltage for MS blades is almost proportionally increased concerning the head. Increasing the head, the generated voltage was increased for both PVC and MS blades. In both cases, maximum voltage was obtained for 1.5 m. This observation implies that an increase in head results in enhanced hydro turbine efficiency. In the case of MS blades, more voltage was generated having the same head. After 1.0 m head, the generated voltage line for PVC blades is relatively lower.

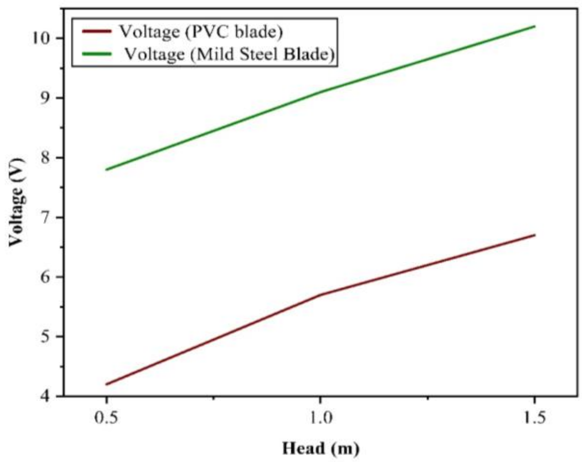


Fig. 3. Comparison of generated voltage between MS and PVC blade against different head

Fig. 4 shows that increased head leads to higher energy production and current output. For the MS blade, the current gradually increased with the increase in the head. For the PVC blade, more current was produced when the head was 1.5 m, indicating the current production suffered when the PVC blade was used. It is observed that when the head is low, the current production is nearly equal for both types of blade material, but there is more difference in the value of current found when the head is more. Table 2 indicates the voltage and current produced by the ASHT across different heads, utilizing both MS and PVC blades.

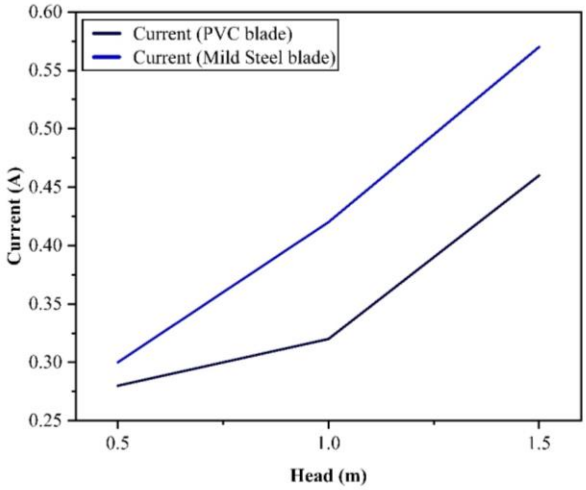


Fig. 4. The comparison of current between MS and PVC blade against different head

Table 2. The generated voltage and current against different heads for MS and PVC blades

Head (m)	Voltage (V)		Current (A)	
	PVC-Blade	MS-Blade	PVC-Blade	MS-Blade
0.5	4.2	7.8	0.28	0.30
1.0	5.7	9.1	0.32	0.42
1.5	6.7	10.2	0.46	0.57

Research conducted by Muzaka et al. [24] for a slope angle of 30° indicates that the obtained values have a voltage of 8.19 V and a current of 4.03 A. In this study, a voltage of 10.2 V was achieved for the MS-blade at 1.5 m head, although the current observed was lower than the values reported by Muzaka et al.

Fig. 5 shows that the curve for the PVC blade tends to have more power change with a change in shaft rotation, but for the MS blade, the change in power was less. The MS-made blade ASHT generated more power and the maximum power was 5.82 W for 502 rpm. For PVC blades, the maximum power was 3.08 W for 480 rpm. In both cases, maximum power was obtained for 1.5 m head. The maximum power was obtained for the MS blade due to the lower blade thickness. The power generation or performance is affected by the blade thickness of the hydro turbine. For a turbine angle of 30°, a power output of 6.65 W was reported by Weking et al. [25] In this study, the maximum power for the MS-blade was determined to be 5.82 W.

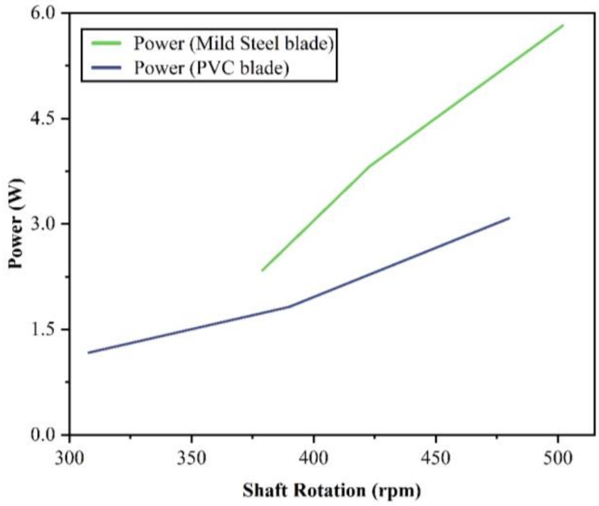


Fig. 5. Mild steel blade and PVC blade power compared to different shaft rotations based on variation of head

4. CONCLUSION

The paper provides a comprehensive evaluation of the ASHT, mainly focusing on comparing blades made of MS and PVC under different operating conditions. The research demonstrates that both the screw design and the material used for the blades significantly influence the turbine's efficiency, power output, and overall performance. The key findings of this paper are:

- The MS blades consistently generate more voltage and current than PVC blades at the same head levels, especially beyond 1.0 m head.
- The MS blades show higher power output at lower shaft rotations than the PVC blades, achieving a maximum of 5.82 W at 502 rpm.
- Blade thickness and blade materials affect the ASHT's performance.
- ASHT can effectively harness energy from low-flow water sources.

The paper highlights the importance of balancing design parameters, blade material, and operating conditions to optimize ASHT for renewable energy generation. The torque and efficiency of the ASHT can be investigated for both MS-made and PVC-made ASHT and can also study advanced materials to improve efficiency and optimization of blade geometry to enhance the sustainability of ASHT.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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