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The Design and Evaluation of the Dual-Helix Archimedes Screw Turbine Using Computational Fluid Dynamics and Finite Element Analysis

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Abstract- This study designed and evaluated a dual-helix Archimedes Screw Turbine (AST) for low-head hydropower using Computational Fluid Dynamics (CFD) and Finite Element Analysis (FEA). The research aimed to improve hydraulic performance over conventional single-helix designs. A 3D CAD model was simulated under varying flow rates (0.01–0.02 m³/s), inclination angles (20°–45°), and hydraulic heads (0.5–1.0 m). CFD results showed that performance was highly sensitive to these operational parameters, achieving a maximum power output of 245 W at 0.02 m³/s and a 45° inclination under a 1.0 m head. Comparative analysis revealed that the dual-helix AST produced 65 W under a 0.7 m head, nearly doubling the 33 W output of a conventional single-helix turbine under similar conditions. Structural evaluation using FEA with Stainless Steel 316 properties confirmed the design's reliability, with minimal deformation, a safety factor exceeding 10, and a fatigue life of 1 x 10^7 cycles. The findings demonstrate that the dual-helix AST is a technically feasible and efficient solution for sustainable micro-hydropower generation in rural Philippine communities.

Index Terms- Turbine, Archimedes, Power Generation, Hydropower, Simulation, Dual Helix

I. INTRODUCTION

Hydropower was long recognized as a reliable and renewable source of energy, owing to the continuous availability of flowing water and its capacity for stable power output. However, conventional hydro turbines (e.g., Kaplan and Francis) often required relatively high head and flow conditions, limited their applicability in many low-head sites. ASTs were able to efficiently convert low-head water flow energy into mechanical power, making them suitable for small rivers, irrigation, canals, and rural waterways [1]. In the Philippines, many rural and agricultural zones had watercourses with low hydraulic heads, where ASTs were considered viable solutions for local power generation. However, a lack of optimized designs and rigorous performance simulations tailored to local flow limited adoption. Design guidelines and performance models for ASTs existed, but many were empirical or were based on simplified assumptions. The majority of simulation or experimental studies focused on single-screw or multi-blade single-helix ASTs [4][5][6]. This study aimed to design and simulate a dual-helix Archimedes screw turbine model, evaluating performance metrics such as torque, rotational speed, hydraulic efficiency, and sensitivity to design parameters (pitch, helix geometry, inclination angle, and the like). The simulation modeled a dual-helix AST, performed a simulation-based performance evaluation, and provided design recommendations. The objectives were to design dual helix AST for low head applications, simulate hydraulic performance under varying operational condition, and determine if there is a significant difference between single helix and dual helix by comparison of electricity generated. The design was evaluated through a comparison of the simulated results with related studies under similar parameters and conditions, bridging the research gap in designing, simulating, and analyzing dual-helix ASTs

Literature review

The local development of AST. The Philippines possesses significant low-head hydropower potential due to its irrigation systems, rivers, and agricultural waterways. However, local AST development remains limited compared to international research. A Philippine study developed a double-blade AST for irrigation canal applications and demonstrated that inlet geometry significantly affects turbine filling efficiency and rotational performance [9]. Researchers in Cebu developed an AST prototype intended to provide electricity for off-grid communities, proving that locally sourced materials can be used for sustainable energy generation [10]. A study from Cavite State University developed a stream-type pico-hydropower system using AST technology for rural electrification and emphasized affordability and practical implementation [11]. Another local innovation integrated AST technology with agricultural applications, highlighting its versatility in rural sustainability projects [11].

Global developments of AST. The Archimedes screw was originally developed as a water-lifting mechanism in ancient times and was later adapted for hydropower generation by reversing its operating principle. Instead of lifting water, flowing water rotates the screw rotor to generate mechanical energy. Modern Archimedes Screw Turbines (ASTs) have become increasingly utilized in low-head hydropower applications because conventional turbines such as Kaplan and Francis turbines require higher hydraulic heads for efficient operation. Studies show that ASTs can operate efficiently at heads below 5 meters and commonly achieve efficiencies ranging from 60% to 80%, with some optimized systems reaching up to 90% efficiency [1][4].

Recent international studies focused on improving AST performance through computational fluid dynamics (CFD), experimental testing, and geometric optimization. Rosly et al. analyzed parameters such as screw diameter, pitch, and blade count and found that increasing blade number improves efficiency up to an optimal point before friction losses increase [5]. Abdullah et al. validated CFD as a reliable tool for predicting velocity distribution, pressure gradients, and torque behavior in AST systems. Their findings confirmed that proper blade geometry significantly affects energy conversion efficiency [2].

Dellinger et al. and Erinofiardi et al. further emphasized the importance of inclination angle and blade count in improving turbine performance. Their studies showed that increasing inclination angles improves rotational speed, but excessive angles may reduce hydraulic efficiency. Multi-blade configurations demonstrated improved water capture but showed diminishing returns when blade count becomes excessive [3][6].

Existing prototypes and parameters used in previous studies. Several international prototypes have demonstrated the practical viability of AST systems in low-head environments. Experimental prototypes commonly use screw lengths ranging from 1 to 3 meters and operate under flow rates between 0.01 m^3/s to 1.22 m^3/s depending on system scale.

One study analyzed an Archimedes screw turbine operating at approximately 1.22 m^3/s, demonstrating how efficiency increases with discharge under optimized operating conditions. The researchers found that AST performance can accommodate volumetric flow rates between 0.1 m^3/s to 0.6 m^3/s while maintaining stable rotational speeds [7].

Another prototype study used geometric parameters consisting of:

- Outer diameter = 43 mm
- Inner diameter = 17 mm
- Pitch = 20–60 mm
- Blade configurations = 1–3 blades
- Inclination angle = 25°

The study found that multi-blade systems improved flow interaction and power output compared to single-blade systems [5].

A local prototype developed in Pampanga, Philippines designed an AST system for footbridge lighting applications. The turbine operated under a 0.07 m head and 0.009379 m^3/s flow rate, generating 33 W mechanical power, 17.96 W electrical power, and achieving 80.88% efficiency, demonstrating the viability of ASTs for rural electrification [8].

Previous studies consistently identified several important parameters that influence AST performance.

Hydraulic Parameters
- Flow rate: 0.01–1.22 m^3/s
- Head: 0.07–5 m
- Water velocity: 0.624–1.5 m/s [7][8]

Geometric Parameters
- Screw length: 1–3 m
- Outer diameter: 0.272–0.334 m

- Inner diameter: 0.146–0.178 m
- Pitch: 0.234–0.476 m
- Blade count: 1–3 blades [5]

Operational Parameters
- Inclination angle: 20°–45°
- Rotational speed: 75–205 RPM
- Torque output
- Mechanical power output
- Hydraulic efficiency [2][6]

This study adopted similar operational ranges by testing flow rates of 0.01, 0.015, and 0.02 m^3/s, head values of 0.5–1.0 m, and inclination angles ranging from 20° to 45°, while introducing a dual-helix configuration for further performance improvement.

II. METHODOLOGY

This study employed a developmental and simulation-based research design. The approach focused on the design and computational evaluation of a dual-helix Archimedes screw turbine intended for hydropower generation. The research process involved the creation of a three-dimensional CAD model and the use of computer simulations to analyze the turbine's hydraulic and mechanical performance.

The parameters were based on standard hydropower design guidelines and prior studies such as those by YoosefDoost and Lubitz (2021), Erinofiardi et al. (2022), and Rosly et al. (2016). The selected parameters ensured that the designed turbine operated efficiently within the hydropower range, under heads of 1–5 meters and moderate flow rates.

Key parameters to be defined include:
- Outer and inner screw diameters: These determined the turbine's physical scale and flow capacity.
- Pitch length (S): This referred to the axial distance between successive turns of the screw, influencing torque and discharge.
- Inclination angle (θ): This represented the angle of installation relative to the horizontal, typically between 20° to 45°, which affected head utilization and flow filling.
- Helix spacing: This referred to the distance between the two screw axes in the dual configuration to minimized interference and enhanced flow uniformity.
- Flow rate (Q) and hydraulic head (H): These were derived from low-head hydropower conditions.
- Material selection: AISI 316 stainless steel for the screw and casing due to its corrosion resistance and mechanical strength.
- Fluid properties: water, assumed to be an incompressible Newtonian fluid ($\rho = 998.2$ kg/m^3, $\mu = 0.001003$ Pa·s).

The following equations were used (Nuramal et al., 2017):

$$P_h = \rho g Q H \quad (1)$$

Hydraulic Power—the theoretical energy input from the flowing water.

$$P_m = T\omega$$

Mechanical Power Output—power derived from the rotational torque of the turbine shaft.

$$\eta = \frac{P_m}{P_h} \text{ x } 100\%$$

Hydraulic Efficiency—ratio of mechanical output to hydraulic input.

$$T = \frac{P_m}{\omega}$$

Torque—derived from the mechanical power output and angular velocity. (Simmons et al., 2021)

The results of these computations were used to determine initial performance expectations and to validate the accuracy of the subsequent simulation outputs.

The following equations are used for design parameter identification:
- maximum volume of water in one cycle rotation of the screw (Vu) in terms of the outer radius and pitch of the screw.

$$V_u = \pi R_o^2 p \quad (1)$$

Where Vu = volume per revolution; R0 is the screw radius; and p is the pitch length.

- The volume of one chute is expressed by (VC) as shown in Eq. (2).

$$V_c = \frac{(\pi(R_o^2 - R_i^2)L)}{N}$$

- A bucket is the maximum connected region occupied by the trapped water within any one chute and is expressed as shown in Eq. (3).

$$V_b = \frac{V_u}{N} \qquad (3)$$

- The gap width between the screw turbine and the diameter of the screw enclosure Eqs. (4) and (5) respectively.

$$G_w = 0.0045\sqrt{D_o}\ \text{m} \qquad (4)$$

$$D_e = D_o + 2G_w \qquad (5)$$

where, G_w = gap width between the screw turbine and D_e = diameter of the screw

- To calculate the water debit, we can use Eq. (6) (Charisiadis, 2015).

$$Q = AV \qquad (6)$$

where Q = flow rate, A = area, and V = velocity.

- The hydraulic power is determined from Eq. (8) (Nuramal et al., 2017).

$$P_h = \rho gQH \qquad (7)$$

where P = hydraulic power(Watt), ρ = (kg/m^3),
Q = (m3/s) or height of water drop (m), and g = gravitaty(m/s2).

- The speed of the screw using Eq. (8) (Charisiadis, 2015).

$$n = \frac{60Q}{V_u} \qquad (8)$$

where n = speed of the screw and V_u = volume of the screw in one revolution.

- The recommended rotational speed within the limits, as shown in Eq. (9).

$$n \leq \frac{50}{D_o^{\frac{2}{3}}} \qquad (9)$$

- The mechanical power available at the turbine shaft can be determined by measuring the torque (T) at a corresponding angular speed (ω) as shown in Eq. (10).

$$P_m = T\omega \qquad (10)$$

- The mechanical efficiency of the shown in Eq. (11).

$$\eta_m = \frac{P_m}{P} \qquad (11)$$

where nm = mechanical efficiency; P_m = mechanical power; and P = power.

The design of external parameters of the screw turbine was based on the small rivers' and irrigation canals' water flow rates and heads (Williamson et al., 2019; YoosefDoost & Lubitz, 2020).

Table 1. The screw geometry external parameters are at L = 1 m, Q = 0.01 m3/s, and an inclination angle of 40°.

Number of Blades (N)	Outer diameter (Do) mm	Inner diameter (Di) mm	Pitch (p) mm	Rotational speed (N) rpm
1	334	178	339	150
2	288	154	423	167
3	272	146	476	173

A parametric analysis was conducted to evaluate how the inclination angles, varying from 20° to 45°, influences the rotational speed of the screw turbine. All other design parameters, including discharge (Q =

0.01 m³/s), screw length (L = 1 m), and diameters, were kept constant.

Table 2. Rotational Speed of Screw Turbine (3 Blades) at Different Inclination Angles.

Inclination Angle (°)	Rotational Speed (rpm)
20°	75 rpm
25°	96 rpm
30°	119 rpm
35°	144 rpm
40°	173 rpm
45°	205 rpm

The hydraulic power can be calculated using the flowing water at different flow rates and water heads, as shown in Table 3. The minimum hydraulic power at the minimum flow rate and head can be calculated as P = ρgQH = 1000 x 9.8 x 0.01 x 0.5 = 49.05 watts.

Table 3. The hydraulic power of flowing water is ranged by flow rates and heads.

Water flow rate (m^3/s)	Net head (m)	Hydraulic power of water (watt)
0.01	0.5	49.05
	0.6	58.86
	0.7	68.67
	0.8	78.48
	0.9	88.29
	1	98.1
0.015	0.5	73.575
	0.6	88.29
	0.7	103.005
	0.8	117.72
	0.9	132.435
	1	147.15
0.02	0.5	98.1
	0.6	117.72
	0.7	137.34
	0.8	156.96
	0.9	176.58
	1	196.2

The three-dimensional modeling phase will involve creating a digital representation of the proposed dual-helix Archimedes screw turbine, which will later serve as the basis for computational simulations and analysis. The modeling process was carried out using ANSYS Fluent, which was selected for its precision, parametric control, and compatibility with fluid analysis environments.

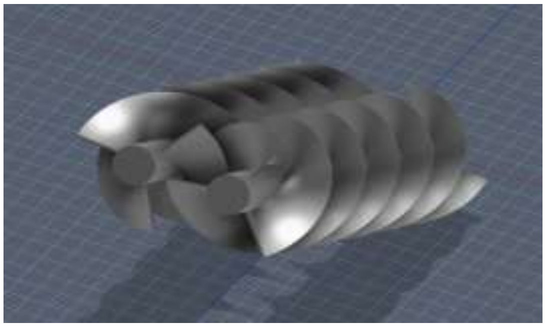


Figure 1: Dual-helix Archimedes Screw 3D layout, (a) Turbine Enclosure, (b) turbine inlet and outlet

The key components to be represented in the 3D model will include:

- The dual helical blades (main rotating elements)
- The central shaft for torque transmission
- The casing or trough that guides water flow
- The inlet and outlet regions define the flow boundaries

The performance of the proposed dual-helix Archimedes screw turbine was evaluated through computational simulations using ANSYS Fluent and ANSYS Mechanical. A three-dimensional turbine model was developed and tested under low-head pico-hydropower conditions to analyze fluid flow behavior, torque generation, power output, and structural integrity.

For the Computational Fluid Dynamics (CFD) analysis, water was defined as an incompressible

Newtonian fluid with a density of 998.2 kg/m³ and viscosity of 0.001003 Pa·s. The turbine material was assigned as AISI 316 stainless steel. Boundary conditions included a velocity inlet based on the required flow rate and an atmospheric pressure outlet. The screw turbine was placed within a rotating region to simulate operational motion. Inclination angles ranging from 20° to 45° and flow rates of 0.01, 0.015, and 0.02 m³/s were tested to evaluate performance under varying operating conditions. A fine computational mesh was applied, particularly near blade surfaces, and mesh independence testing was conducted to ensure simulation accuracy. The SST k-ω turbulence model was used, and simulations were iterated until convergence was achieved.

Simulation outputs such as velocity distribution, pressure contours, streamline behavior, torque generation, and rotational performance were extracted and analyzed. Mechanical power and hydraulic power were calculated using standard engineering equations. The performance of the dual-helix model was then compared with existing single-helix studies to determine improvements in efficiency and power generation.

To evaluate structural reliability, Finite Element Analysis (FEA) was conducted using ANSYS Mechanical. The torque values obtained from CFD simulations were applied as loading conditions to the turbine shaft and blades. Fixed supports were assigned to simulate bearing constraints. Structural performance was assessed based on total deformation, equivalent stress distribution, factor of safety, and fatigue life.

Finally, simulation results were post-processed through graphical plots, pressure maps, velocity streamlines, and stress distributions. The generated results were validated through comparison with existing AST studies to determine the feasibility and performance advantages of the proposed dual-helix configuration for low-head hydropower applications

III. RESULTS

CFD Simulation Parameters and Quality. The computational domain was discretized into a high-density mesh comprising approximately 1.77 million cells and 6.25 million nodes. Surface refinement was strategically applied to the turbine blade regions to capture localized pressure gradients. The orthogonal Quality is 0.1096 (Minimum) and Aspect Ratio of 79.14 (Maximum). Iterations were terminated after 500 cycles. While turbulence quantities (k and ω) slightly exceeded strict thresholds, the continuity residual reached 2.27x10-4and velocity residuals dropped to 10-5 Torque and moment plots for both helices exhibited asymptotic stability, confirming numerical reliability.

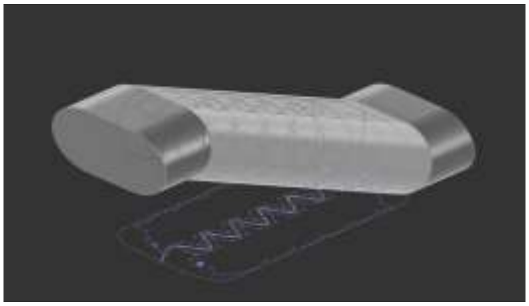


Figure 2. Screw Enclosure A

CFD simulations using the SST (k–ω) model revealed distinct flow pattern; fluid acceleration was observed within the helical channels, with peak velocities occurring near the blade tips and downstream sections, high-pressure zones were localized on the upstream-facing surfaces, while low-pressure zones appeared on the downstream sides, creating the necessary differential for torque generation. A slight asymmetry in the velocity field was noted between the left and right helices.

Table 4. Fluid properties and boundary conditions that define the flow field behavior

Parameter	Value/Setting	Unit
Inlet Velocity	1.5	m/s
Fluid Material	Water Liquid	—
Fluid Density	998.2	kg/m^3
Dynamic Viscosity	0.001003	kg/m^3
Operating Pressure	0 (Gauge)	Pa
Turbulent Intensity	5	%

Before applying the screw geometry optimization process, triple-blade screw geometry has been created to evaluate the reference power output and to analyze the effects of working parameters on the power output. As shown in figure below, there is an area of high-speed flow in the inlet section of the turbine, and as the fluid exits the turbine, the flow becomes highly turbulent, forming a spiral wake flow

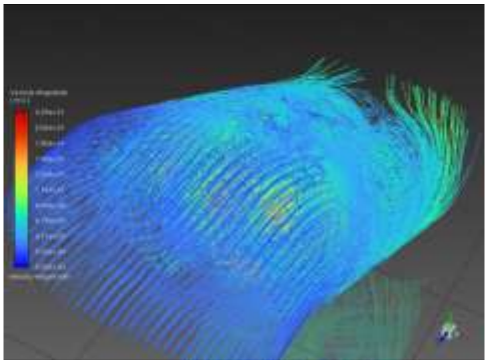


Figure 3: ANSYS CFD modeling of triple-blade turbine streamline of the flow

Power Generated. The CFD simulations showed that turbine power output was significantly influenced by the combined effects of flow rate, head, and inclination angle. Power output was determined using the torque generated by the turbine and its angular velocity.

Table 5. Summary of Total Dynamic Head vs. Angle of Inclination difference for 0.01 m³/s

Angle of Inclination (degree)	Total Dynamic Head (TDH)					
	0.5m	0.6m	0.7m	0.8m	0.9m	1m
20°	17.5W	14W	10.5W	12W	19W	21
25°	26W	17.5W	17.5W	23W	37W	44
30°	54W	63W	44W	40W	40W	37
35°	53W	44W	65W	67W	37W	33
40°	9W	35W	42W	39W	70W	72
45°	12W	7W	5W	2W	23W	14

At a flow rate of 0.01 m³/s, the highest power output recorded was 72 W at a 40° inclination angle with a 1.0 m head, while the lowest output was 2 W at a 45° angle with a 0.8 m head. Results indicated that moderate inclination angles of 30° to 40° performed more efficiently under low-flow conditions, while steeper angles caused overflow leakage and reduced energy transfer.

Table 6. Summary of Total Dynamic Head vs. Angle of Inclination difference for 0.015 m³/s

Angle of Inclination (degree)	Total Dynamic Head (TDH)					
	0.5m	0.6m	0.7m	0.8m	0.9m	1m
20°	70W	75W	82W	89W	86W	93W
25°	74W	77W	86W	131W	133W	105W
30°	79W	98W	84W	56W	86W	107W
35°	77W	75W	98W	145W	51W	70W
40°	58W	86W	91W	56W	150W	163W
45°	75W	82W	105W	89W	58W	84W

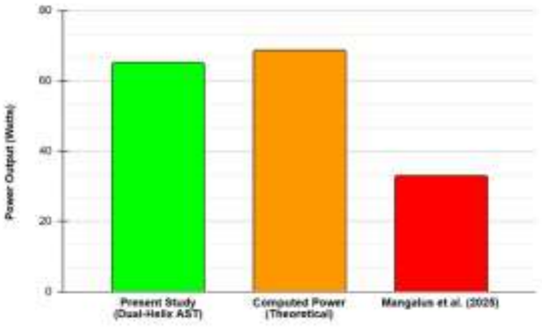
At a flow rate of 0.015 m³/s, the highest power output increased to 163 W, recorded at a 40° inclination angle and 1.0 m head. Strong performance was also observed at 25°, 35°, and 40°, showing that the optimal operating range expanded as flow rate increased. Lower-performing configurations produced outputs as low as 51 W, indicating sensitivity to improper head-angle combinations.

Table 7. Summary of Total Dynamic Head vs. Angle of Inclination difference for 0.02 m³/s.

Angle of Inclination (degree)	Total Dynamic Head (TDH)					
	0.5m	0.6m	0.7m	0.8m	0.9m	1m
20°	51W	123W	138W	105W	124W	140W
25°	70W	130W	142W	149W	159W	193W
30°	105W	137W	145W	147W	208W	228W
35°	49W	105W	144W	102W	110W	201W
40°	18W	72W	105W	145W	149W	210W
45°	23W	88W	13W	117W	158W	245W

At the highest flow rate of 0.02 m³/s, the turbine achieved its maximum recorded power output of 245 W at a 45° inclination angle with a 1.0 m head. Other high-performing configurations included 228 W at 30° and 210 W at 40° under the same head condition. The lowest outputs at this flow rate ranged from 18 W to 70 W, primarily occurring at lower heads of 0.5 m.

Comparison Of Dual Helix To Past Studies. The performance of the developed dual-helix Archimedes screw turbine was compared with the conventional single-helix AST developed by Mangalus et al. (2025) under the same 0.7 m head condition. While the previous study operated at a flow rate of 0.009379 m³/s, the present study was evaluated at 0.01 m³/s.



Results showed that the proposed dual-helix turbine generated 65 W of power output, which was significantly higher than the 33 W produced by the single-helix design. Despite operating under a lower flow rate, the dual-helix configuration produced nearly twice the power output, indicating improved energy extraction efficiency.

The theoretical power output of the developed system was calculated at 68.67 W, while the CFD simulation produced 65 W, resulting in a 5.34% deviation. This small difference confirms the reliability of the simulation results.

The improved performance of the dual-helix design may be attributed to increased blade-water interaction, more continuous fluid engagement, and better flow distribution, which reduced hydraulic losses. These findings demonstrate that the dual-helix configuration offers better performance than conventional single-helix turbines, particularly for low-flow hydropower applications.

Finite Element Analysis Results. Finite Element Analysis (FEA) was conducted using ANSYS Mechanical to evaluate the structural reliability of the proposed dual-helix Archimedes screw turbine under operational loading conditions. A torque load of 175 N·m obtained from CFD simulation was applied to the turbine, using Stainless Steel 316 as the material.

showed Results that the turbine experienced a maximum deformation of 5.23×10^{-5} m, indicating very minimal structural displacement and confirming that the turbine can maintain its geometric stability during operation.

The maximum equivalent (von Mises) stress recorded was 6.40 MPa, which is significantly lower than the material yield strength of 252 MPa, indicating that the turbine operates safely within allowable stress limits and is not expected to experience structural failure.

Safety factor analysis showed a minimum factor of safety greater than 10, with values reaching approximately 15, demonstrating that the design can withstand loads much higher than the applied operating conditions.

Fatigue analysis further showed a minimum fatigue life of approximately 1×10^7 cycles, indicating that the turbine can endure long-term cyclic loading and continuous operation without significant risk of failure.

Overall, the FEA results confirmed that the proposed dual-helix Archimedes screw turbine is structurally stable, mechanically reliable, and feasible for low-head hydropower applications

IV. GET PEER REVIEWED

The manuscript entitled "The Design and Evaluation of Dual-Helix Archimedes Screw Turbine Using Computational Fluid Dynamics and Finite Element Analysis" underwent peer review by faculty members and subject-matter experts in the field of mechanical engineering and renewable energy systems. The reviewers evaluated the manuscript in terms of technical accuracy, research methodology, data analysis, organization, clarity of presentation, and compliance with publication standards.

The reviewers provided comments and recommendations regarding the improvement of the literature review, clarification of the CFD and FEA procedures, consistency of technical terms, presentation of results, and strengthening of the conclusions. These comments served as the basis for revising and improving the quality of the manuscript prior to submission for publication.

V. IMPROVEMENT AS PER REVIEWER COMMENTS

Following the peer-review process, the manuscript was revised in accordance with the reviewers' recommendations. The improvements made include:

1. Refinement of the Introduction and Review of Related Literature to better establish the research gap and justify the development of the dual-helix Archimedes screw turbine.
2. Clarification of the research methodology, including the CFD and FEA simulation procedures, boundary conditions, material properties, and design parameters used in the study.
3. Enhancement of figures, tables, and captions to improve readability and facilitate interpretation of the simulation results.
4. Revision of technical descriptions and terminology to ensure consistency throughout the manuscript.
5. Strengthening of the Results and Discussion section by providing clearer explanations of power output, pressure distribution, structural performance, and comparison with existing single-helix turbine studies.
6. Revision of the Conclusion and Recommendations section to better align with the study objectives and findings.
7. Correction of grammatical, typographical, formatting, and citation-related issues identified during the review process.

These revisions improved the overall quality, technical accuracy, and publication readiness of the manuscript.

VI. CONCLUSION

Conclusion. This study successfully designed and evaluated a dual-helix Archimedes screw turbine for low-head hydropower applications. CFD results showed that power output increased with higher flow rates and head conditions, with the maximum output reaching 245 W at 0.02 m^3/s, 1 m head, and 45° inclination. The findings also identified that optimal inclination angles vary depending on operating conditions, highlighting the importance of balancing flow velocity and hydraulic efficiency.

Comparative analysis showed that the dual-helix configuration generated higher power output than conventional single-helix turbines due to improved blade-water interaction and reduced hydraulic losses. FEA results further confirmed that the design is structurally reliable, showing minimal deformation, low stress levels, high safety factors, and long fatigue life. Overall, the proposed dual-helix turbine is a feasible and efficient alternative for low-head hydropower generation.

VII. ACKNOWLEDGMENT

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