International Journal of Advances in Applied Sciences (IJAAS)
Vol. 15, No. 3, September 2026, pp. 1227~1238
ISSN: 2252-8814, DOI: 10.11591/ijaas.v15.i3.pp1227-1238

Test rig development for overshot water wheels under low-head, low-flow conditions in pico-hydropower applications

Izzatie Akmal Zulkarnain[1], Irma Wani Jamaludin[1], Mohd Farriz Basar[1], Kamaruzzaman Sopian[2]
[1]Faculty of Electrical Technology and Engineering, Universiti Teknikal Malaysia Melaka, Melaka, Malaysia
[2]Department of Mechanical Engineering, Faculty of Engineering, Universiti Teknologi PETRONAS, Seri Iskandar, Malaysia

Article Info

Article history:

Received Oct 4, 2025
Revised Jul 3, 2026
Accepted Aug 13, 2026

Keywords:

Low-flow
Low-head
Pico-hydropower
Test rig
Water wheel

ABSTRACT

This study presents the development and validation of a controllable experimental test rig for overshot water wheels operating under low-head and low-flow conditions commonly found in pico-hydropower resources. Many potential pico-hydro sites operate at heads below 1.5 m with minimal flow, where conventional turbines often experience reduced efficiency and suitable laboratory-scale testing facilities remain limited. The developed system consists of two high-density polyethylene (HDPE) water tanks, an adjustable-inclination water channel, a circulation pump, and an overshot water wheel equipped with recyclable polyethylene terephthalate (PET) bottle blades. The test rig operates within hydraulic range of 0.525 - 1.169 m head and 0.01 - 0.02 m³/s flow rate, enabling the simulation of realistic pico-hydropower conditions. Water velocity was regulated using the water trajectory method by varying the channel inclination angle between 10° and 50°, producing velocities ranging from 1.494 m/s to 4.519 m/s. Experimental results show stable and repeatable hydraulic conditions with measurement uncertainty of approximately ± 0.03 m/s. These findings demonstrate that the developed test rig provides a reliable platform for future investigations of overshot water wheel performance parameters, including rotational speed, angular velocity, force, torque, mechanical power, and efficiency in pico-hydropower applications.

Corresponding Author:

Mohd Farriz Basar
Faculty of Electrical Technology and Engineering, Universiti Teknikal Malaysia Melaka
Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia
Email: mfarriz@utem.edu.my

1. INTRODUCTION

Pico-hydropower, defined as hydro-based systems generating below 5 kW, has emerged as a viable renewable energy solution for rural and isolated communities [1]. Its affordability, simplicity, and minimal environmental impact make it a key contributor to the United Nations' sustainable development goal 7 (affordable and clean energy) [2]. However, many potential pico-hydro sites are characterized by low-head (≤ 1.5 m) and low-flow (≤ 0.02 m³/s) conditions [3], [4], which significantly limit the efficiency of conventional turbines.

Overshot water wheels, which operate by utilizing the gravitational potential energy of water flowing over the wheel [5], are among the earliest hydropower devices still considered relevant in modern applications [6]. Their reliability, long lifespan, and ability to work with small discharges make them promise for pico-hydropower contexts. Yet, most traditional overshot designs are better suited for higher heads and flows or higher heads and low-flows [7], resulting in reduced efficiency under constrained hydraulic conditions [8], [9]. For this reason, there is a pressing need for new designs and testing methodologies tailored to extremely low-resource environments.

Existing experimental setups often struggle to replicate realistic pico-hydropower conditions, particularly under low-head and low-flow environments. Many are expensive, technically complex [8], [10], or lack the ability to accurately control head and discharge. In addition, there has been limited advancement in designing test rigs that can both simulate real operating conditions [11] and evaluate innovative water wheel configurations. This limitation restricts systematic assessment of overshot water wheels in low-resource applications, especially for rural electrification, where water supply is limited. Consequently, the full potential of overshot water wheels in pico-hydropower systems remains largely underexplored [5], [12].

This effort aims to develop and assess an effective water test rig for overshot water wheels operating under low-head, low-flow circumstances, tackling the practical issues identified in pico-hydropower applications. The proposed waterwheel test rig is designed to be simple and capable of recreating close to real operational conditions. The performance assessment emphasizes hydraulic and mechanical characteristics, utilizing a water wheel with blades made from recyclable polyethylene terephthalate (PET) bottles, tested at heads ranging from 0.525 m to 1.169 m and flow rates between 0.01 m^3/s and 0.02 m^3/s. The research uses the water trajectory approach to control flow velocity and evaluate its impact on velocity head, water head, and flow rate. Then, the hydraulic rotary approach is applied to assess the rotational speed, angular velocity, torque, force, mechanical power, and efficiency, facilitating a systematic performance analysis. This research illustrates the viability of overshot water wheels as a sustainable approach for rural electrification in contexts where traditional designs are inadequate, providing both a methodological framework and a practical design to enhance pico-hydropower technologies in resource-limited environments [13], [14].

Despite increasing interest in pico-hydropower technologies, limited research has developed experimental systems capable of accurately simulating extremely low-head and low-flow hydraulic conditions while remaining simple and affordable for practical applications. Therefore, the novelty of this study lies in the development of a low-cost water test rig designed to reproduce realistic pico-hydropower conditions for overshot water wheel evaluation. The system integrates a water trajectory approach to regulate hydraulic parameters and a hydraulic rotary approach to analyze mechanical performance, enabling systematic evaluation of velocity head, torque, rotational speed, and power output. In addition, the use of recyclable PET bottle blades demonstrates a sustainable and locally accessible design, supporting practical engineering applications of pico-hydropower systems for rural electrification in ultra-low hydraulic resource environments.

Compared with many existing experimental setups that are often costly, technically complex, or unable to precisely control hydraulic parameters under low-head conditions, the proposed test rig provides a simpler and more controllable experimental system. The combination of an adjustable water channel, continuous water circulation, and integrated hydraulic rotary analysis enables systematic and repeatable evaluation of overshot water wheel performance under realistic pico-hydropower conditions. This experimental water test rig may also support future integration with computational modelling (e.g., computational fluid dynamics), internet of things (IoT)-based monitoring systems, smart grid environments, enabling data-driven optimization, real-time monitoring, and improved energy management for small-scale renewable energy systems.

2. RESEARCH METHOD

Figure 1 illustrates the research methodology, which is based on empirical studies, overshot water wheel design, and systematic testing. The water test rig serves as the central experimental platform, providing a practical setup for the water trajectory and hydraulic rotary systems. These systems are capable of measuring 14 output parameters, including area of channel (A), vertical fall of water (x), horizontal displacement (y), inclination angle (θ), flow velocity (V_{wt}), water head (H), velocity head (h_v), flow rate (Q), rotational speed (r_s), angular velocity (ω), force (F), torque (τ), mechanical power (P_m), and efficiency (η).

2.1. Test rig development and experimental setup

This research has made a substantial contribution by developing an improved experimental setup that is easy to build and closely matches the near-real situation of pico-hydropower plants. The water test rig, as depicted in Figure 2, harnesses the gravitational potential energy of the water tank. Performance tests were conducted using this water test rig, with water head ranging from 0.525 m to 1.169 m and flow rates 0.01 m^3/s to 0.02 m^3/s. The design of the overshot water wheel test rig allows for better control of water conditions, ensuring more stable performance across different flow rates.

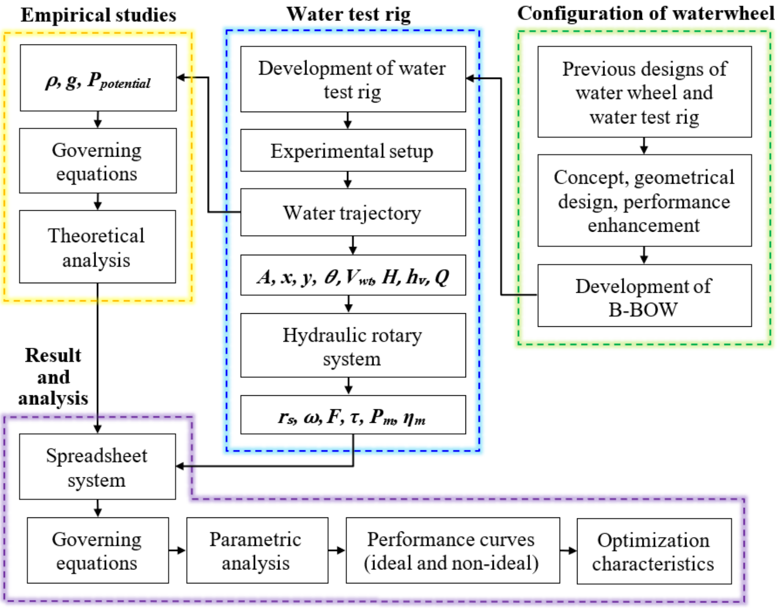


Figure 1. Framework of experimental work for overshot water wheel

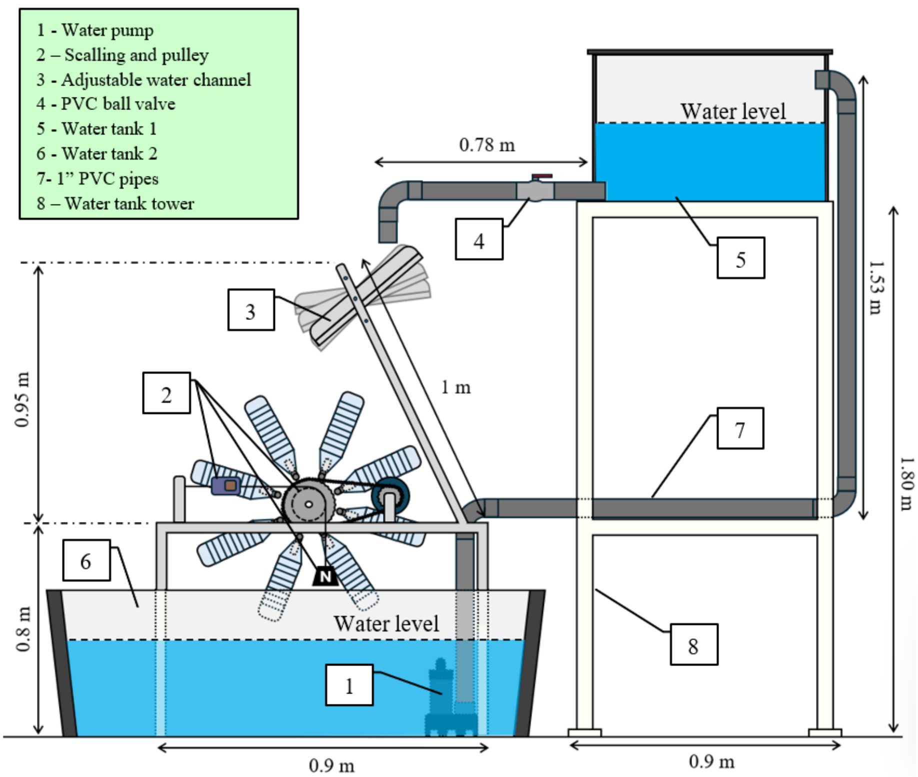


Figure 2. Schematic of water test rig

The test rig consists of the B-BOW turbine, mechanical system, water tank, and water pump. The water flows from water tank 1 to the adjustable water channel and simultaneously strikes the water wheel blades. Then, a water pump is used to raise the water from water tank 2 to water tank 1 through 1-inch polyvinyl chloride (PVC) pipes. After that, once the water strikes the PET bottle's blades, the water wheel starts to rotate at certain speeds depending on the velocity of the water. The rotation of the water wheel drives the shaft of the generators, generating mechanical power that is converted into electrical power simultaneously [15], [16]. Additionally, this process ensures continuous water circulation.

Water tank 1 (model: Kossan N50RA) has a nominal capacity of up to 365 L of water, with an effective capacity of 225 L, while water tank 2 (model: Roto CT 150/200) has a nominal capacity of 758 L with an effective capacity of 568 L. Both tanks are made of high-density polyethylene (HDPE), a durable and corrosion-resistant material that ensures longevity and prevents contamination. Meanwhile, the water pump (model: Gemini SU 200) used is an aquarium pump type with a maximum flow rate of 90 L/min. During actual river operation, water tank 1 collects river water, which is recirculated through the system before being redirected back to the river, represented by water tank 2. In addition, the electric generator employed is a golden motor 902-36V-24R-902 with a capacity of 250 W.

In this study, the test rig operates within a controlled hydraulic range of water head between 0.525 m and 1.169 m and flow rates from 0.01 m^3/s to 0.02 m^3/s, which serve as performance benchmarks for evaluating overshot water wheel behavior under realistic pico-hydropower conditions. The PET bottle blades were selected due to their lightweight structure, corrosion resistance, and wide availability [16], making them suitable for low-cost and sustainable turbine prototyping. The naturally curved geometry of PET bottles provides a simple blade profile capable of effectively capturing water flow and transferring momentum to the water wheel under low-head hydraulic conditions. Furthermore, the adjustable channel inclination and modular rig configuration allow the system to be adapted for different water wheel sizes and blade configurations, enabling scalability for future pico-hydropower development.

In addition, the hydraulic rotary analysis evaluates key performance indicators, including rotational speed, torque, mechanical power, and efficiency, which serve as systematic performance benchmarks for assessing the water wheel's energy conversion performance under varying hydraulic conditions. These parameters enable structured evaluation of efficiency behavior and torque vs flow rate conditions, while the integration of a generator allows preliminary validation of the system's mechanical-to-electrical energy conversion capability. The developed test rig was designed to replicate key characteristics of real pico-hydropower environments by incorporating controlled hydraulic conditions, continuous water circulation, and an adjustable water channel. These features enable the system to simulate low-head river conditions and provide a scalable experimental platform for evaluating overshot water wheel performance prior to deployment in actual river sites.

2.2. Water velocity by the trajectory method

In a hydro-based energy system, the water trajectory method plays a crucial role in determining water velocity and flow characteristics [17], [18]. This method is adapted from Latt *et al.* [19], which involves analyzing the x and y, to determine V_{wt} using gravitational acceleration (g), as stated in (1).

$$V_{wt} = \frac{x}{\sqrt{\frac{2y}{g}}} \tag{1}$$

In the context of the overshot water wheel setup, the water trajectory method is applied to regulate the water flow from the water tank 1 to the bottle blades, resulting in different generations of water velocities. Therefore, this adjustment is essential to set H from 0.525 m to 1.169 m and Q between 0.01 m^3/s and 0.02 m^3/s, since both H and Q depend on the velocity. The V_{wt} upon impact directly influences rs, F, τ, and overall energy conversion efficiency in the B-BOW system. Furthermore, Figure 3 shows the experimental measurement setup used to calculate V_{wt} based on horizontal and vertical displacement.

In Figure 3, the measurement parameters used to determine the V_{wt}. The setup consists of two points, A and B. Point A represents the initial position of the falling water, while Point B marks where the water first contacts the B-BOW's blades, to initiate rotation and energy conversion. Additionally, this setup determines three crucial parameters for analyzing V_{wt}, which are x, y, and displacement distance, AB. With these parameters, the velocity head, h_v, can be theoretically calculated by applying Bernoulli's principle [20], as stated in (2). After that, the total head, H, is determined by adding h_v and y, as presented in (3). Next, the flow rate, Q, is the product of V_{wt} and A, as in (4). Then, the potential power is assessed upon obtaining values for H and Q using (5).

$$h_v = \frac{v^2}{2g} \tag{2}$$

$$H = y + h_v = y + \frac{x^2}{4y} \tag{3}$$

$$Q = V_{wt} A \tag{4}$$

$$P_{potential} = \rho Q g H \tag{5}$$

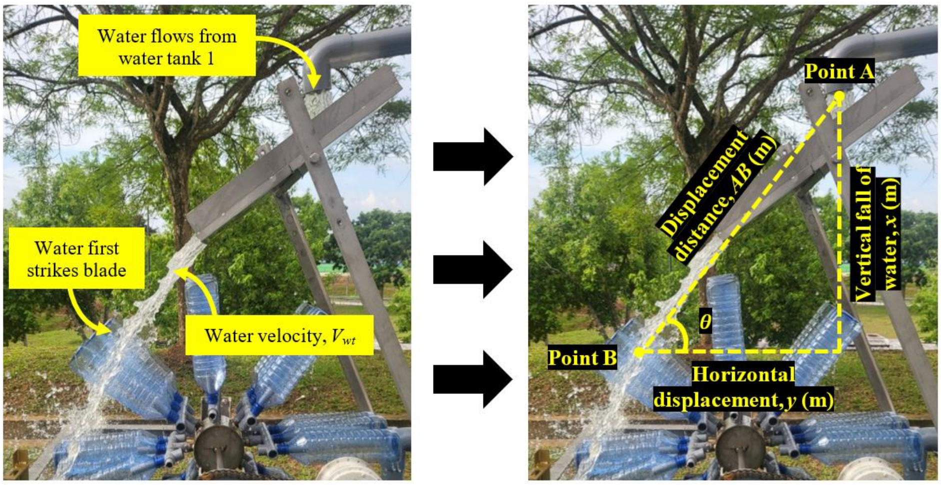


Figure 3. Water trajectory method

Moreover, the angle of inclination, θ, of the water channel significantly influences the values of x, y, and AB. The value of θ is measured manually using an angle protractor, while x and AB are obtained using a measuring tape, where the measurement steps of θ, x, and AB are taken. In this experiment, θ is set at 10°, 15°, 20°, 30°, 40°, 45°, and 50°. As water flows through the inclined water channel, the point where water first strikes the bottle blade surface determines the value of x. Subsequently, y is derived using trigonometric functions, particularly by applying the cosine function, as in (6).

$$\cos, \theta \ (°) = \frac{Horizontal\ displacement, y\ (m)}{Displacement\ distance, AB\ (m)} \tag{6}$$

2.3. Hydraulic rotary system

A hydraulic rotary system in hydropower is a mechanism that converts the kinetic and potential energy of flowing or falling water into mechanical rotation through a turbine [21]. In the overshot water wheel, this system plays a crucial role in transforming the potential energy generated by the gravitational force of falling water into rotational motion [16], [22]. It consists of several components, including the water wheel, central shaft, bearings and supports, and a torque transmission system (gear and pulley) [20]. Each of these components contributes to the overall efficiency of the energy conversion process, as illustrated in Figure 4.

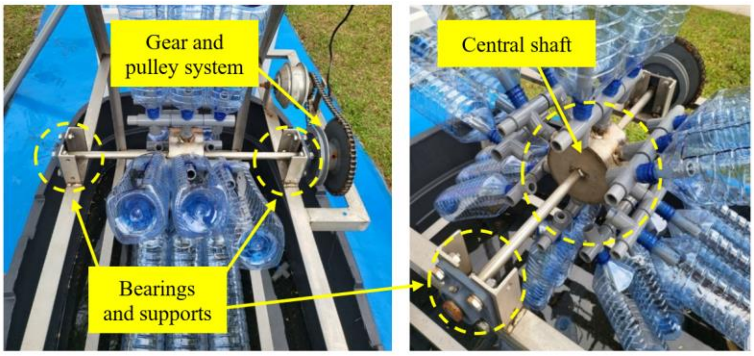


Figure 4. Components in the hydraulic rotary system on the B-BOW turbine

Meanwhile, Figure 5 highlights the integration of a chain-driven torque transmission system, which regulates rotational motion between the driving sprocket, namely gear A and the driven sprocket, namely gear B. The system utilizes gears combined with a chain drive to transfer torque and speed over longer distances. These gears consist of 48 teeth on the driven sprocket and 19 teeth on the driving sprocket, resulting in a gear ratio of 1:2.5. This means that the driving sprocket (gear B) must rotate 2.5 times for the driven sprocket (gear A) to complete one full rotation. Additionally, two units of pillow block bearings (UCF 312) are installed to support the central shaft, minimizing friction and facilitating smooth rotation.

Moreover, the rotational speed of the water wheel, rs, is one of the parameters in the hydraulic rotary system, and it directly influences angular velocity and mechanical power, Pmech. Therefore, to measure rs, a digital tachometer is used to detect the speed of the rotating turbine blades in revolutions per minute (rpm). The tachometer (model: Onosokki HT-4200) functions by emitting a laser beam toward a reflective strip attached to the spur gears, as shown in Figure 5. As the beam reflects to the sensor, the device calculates speed based on the frequency of reflected pulses. Once the rs is obtained, it is converted into angular velocity, ω using (7). For this hydraulic rotary analysis, there are two separates r_s measurements that will be taken: rs(A) for gear A and rs(B) for gear B.

$$\omega = \frac{2\pi \cdot r_s}{60} \tag{7}$$

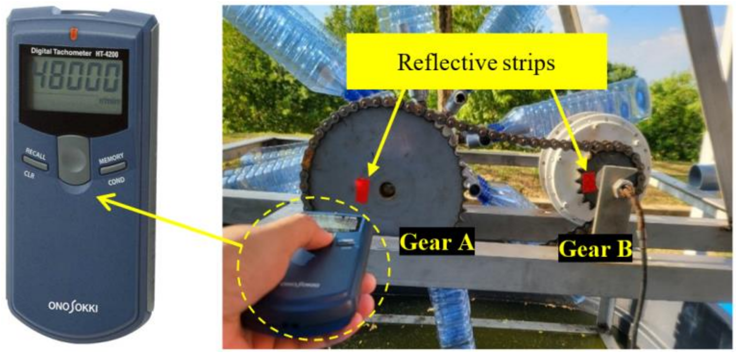


Figure 5. HT 4200 used to measure rs on gear A and gear B

The r_s measured at gear A represents the speed of the water wheel, as this gear is directly connected to the main shaft of the water wheel. Meanwhile, gear B corresponds to the speed at the generator (model: golden motor, 902-36V-24R-902). Due to the 1:2.5 gear ratio, gear B rotates approximately 150% faster than gear A, enabling a higher rs input to the generator and enhancing electrical output performance. Next, the τ is calculated using (8), where R refer to the radius of the water wheel, once the F is obtained. Lastly, the P_m can be calculated since it is the product of the τ and ω of the water wheel, as stated in (9).

$$\tau = FR \tag{8}$$

$$P_m = \tau\omega \tag{9}$$

Furthermore, the water wheel's hydraulic rotary system is further optimized through a parametric analysis where variable parameters such as number of bottles (B_c), blade opening angles (θ_b), and number of blades (B), are adjusted to maximize efficiency, as listed in Table 1.

Table 1. Different configurations of the B-BOW turbine

Number of blades	Number of bottles	Blade opening angles
4	3	0°, 60°, 120°, 180°
	4	0°, 60°, 120°, 180°
	5	0°, 60°, 120°, 180°
8	3	0°, 60°, 120°, 180°
	4	0°, 60°, 120°, 180°
	5	0°, 60°, 120°, 180°

3. RESULTS AND DISCUSSION

Table 2 shows the result of water velocity and water head calculation while varying different angles of inclination, θ of the water channel. As the angle of inclination increased, the value of H, which is the sum of h_v and y, varied accordingly. The highest V_{wt} was recorded at the lowest inclination angle of 10° with a value of 4.519 m/s, whereas lower velocities were observed at higher angles, indicating the impact of inclination on water flow dynamics. This trend suggests that lower angles reduce y, leading to lower velocities and affecting energy transfer efficiency in the B-BOW turbine.

Table 2. Calculated value of V_{wt} and H while varying θ

Steps	Methods	Value						
1: θ (°)	Angle protractor	10	15	20	30	40	45	50
2: AB (m)	Measuring tape	0.74	0.64	0.59	0.6	0.64	0.63	0.87
3: x (m)	Measuring tape	0.13	0.17	0.2	0.3	0.41	0.45	0.67
4: y (m)	$\cos\theta = \frac{y}{AB}$	0.73	0.62	0.55	0.52	0.49	0.45	0.56
5: V_{wt} (m/s)	$V_{wt} = \frac{x}{\sqrt{\frac{2y}{g}}}$	4.519	3.38	2.71	2.103	1.693	1.494	1.512
6: h_v (m)	$h_v = \frac{v^2}{2g}$	1.041	0.582	0.374	0.225	0.146	0.114	0.117
7: H (m)	$H = y + h_v$	1.169	0.747	0.576	0.525	0.557	0.559	0.783

According to Table 2, the first step is setting the θ using an angle protractor before allowing the water to flow. Then, followed by steps 2 and 3, x and AB are measured using a measuring tape. Next, step 4 involves calculating y using the sine function. In step 5, the V_{wt} is determined based on the measured values of x and y. Finally, steps 6 and 7 are used to compute the h_v and H, respectively. Figure 6 shows the graph derived based on the relationship between the inclination angle, water velocity, and water head.

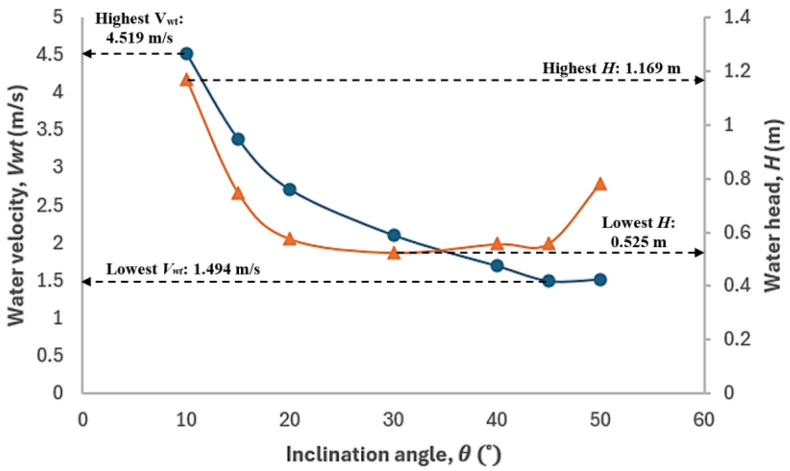
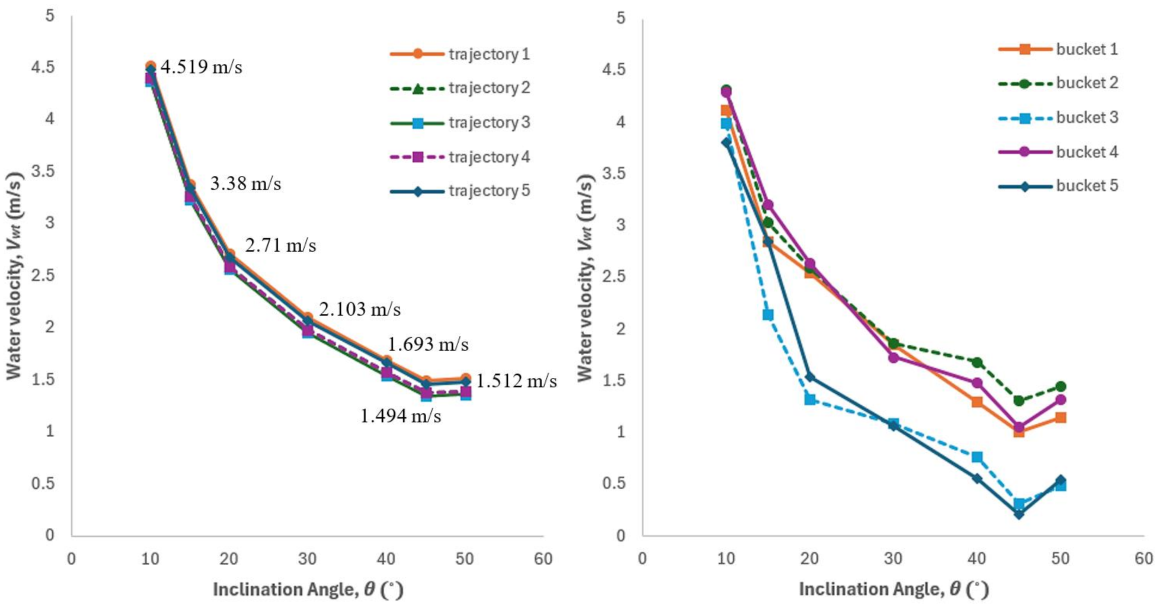


Figure 6. Relationship between inclination angle, water velocity, and water head

The graph in Figure 6 indicates that at lower θ, particularly at 10°, the V_{wt} reaches its maximum value of 4.519 m/s, corresponding to the highest water head, 1.169 m. As θ increases, a sharp decline in velocity is observed, stabilizing around 1.494 m/s at 45° of inclination angle. Conversely, the water head shows an opposite trend, with the maximum H of 1.169 m occurring at low angles before decreasing to its minimum value of 0.525 m. This inverse relationship suggests that increasing the inclination angle reduces both the kinetic and hydraulic potential available for energy capture, primarily due to reduced vertical displacement. Furthermore, one of the primary advantages of the water trajectory method is its simplicity and accuracy in estimating water velocity without requiring complex instrumentation. Figure 7 compares water velocity measurements obtained using the water trajectory and conventional bucket methods at different inclination angles. Both methods show a decreasing velocity trend with increasing inclination angle. Figure 7(a) presents the trajectory method results, while Figure 7(b) shows the bucket method results.



(a) (b)

Figure 7. Comparison of water velocity across different inclination angles using (a) the water trajectory and (b) the bucket method

Referring to Figure 7, the water trajectory-based approach consistently produced water velocity values that were in close agreement with direct measurements, demonstrating strong repeatability across five trials. In contrast, the bucket method tended to underestimate velocity, largely due to measurement uncertainties and the influence of human error. Factors such as inconsistent timing during water collection, incomplete filling of the bucket, and spillage during handling introduced variability that reduced the accuracy of this method [23]. This comparison highlights that the water trajectory method not only minimizes operator-dependent errors but also provides a more reliable representation of the actual hydraulic conditions acting on the water wheel.

Table 3 summarizes the results of the uncertainty analysis for both methods of water velocity determination across different inclination angles. Uncertainty analysis is a systematic approach used to quantify the reliability and variability of experimental measurements by evaluating the range of possible errors in the data. The water trajectory method relies on geometrical measurements of displacement and channel angle [24], while the bucket method depends on the operator's ability to collect and measure discharged water, which is more prone to human error. Based on the table, the water trajectory method consistently produces low standard deviations between 0.059 to 0.066 m/s, yielding uncertainties of about ± 0.03 m/s. In contrast, the bucket method exhibited much higher standard deviations up to 0.64 m/s and uncertainties exceeding ± 0.287 m/s at certain angles.

Table 3. Uncertainty analysis for water trajectory vs bucket methods

Inclination angle, θ	Water trajectory method			Bucket method		
	Mean (m/s)	Standard deviation (m/s)	Uncertainty ± (m/s)	Mean (m/s)	Standard deviation (m/s)	Uncertainty ± (m/s)
10	4.437	0.064	0.029	4.105	0.212	0.095
15	3.302	0.062	0.028	2.815	0.406	0.182
20	2.630	0.063	0.028	2.127	0.642	0.287
30	2.025	0.062	0.028	1.521	0.407	0.182
40	1.61	0.066	0.029	1.156	0.480	0.215
45	1.416	0.059	0.026	0.782	0.487	0.218
50	1.429	0.064	0.029	0.99	0.447	0.2

The uncertainty analysis confirms that the developed test rig is capable of generating reliable and reproducible velocity measurements under low-head, low-flow conditions. The consistently narrow uncertainty margins of the water trajectory method demonstrate its robustness and suitability as the preferred measurement approach, whereas the larger deviations associated with the bucket method highlight the influence of human error on experimental accuracy. These findings indicate that the trajectory method provides a statistically more reliable estimation of water velocity under low-head and low-flow conditions, thereby improving the robustness of performance evaluation for pico-hydropower systems. Figure 8 presents the uncertainty analysis results that highlight the robustness of trajectory method compared to bucket method.

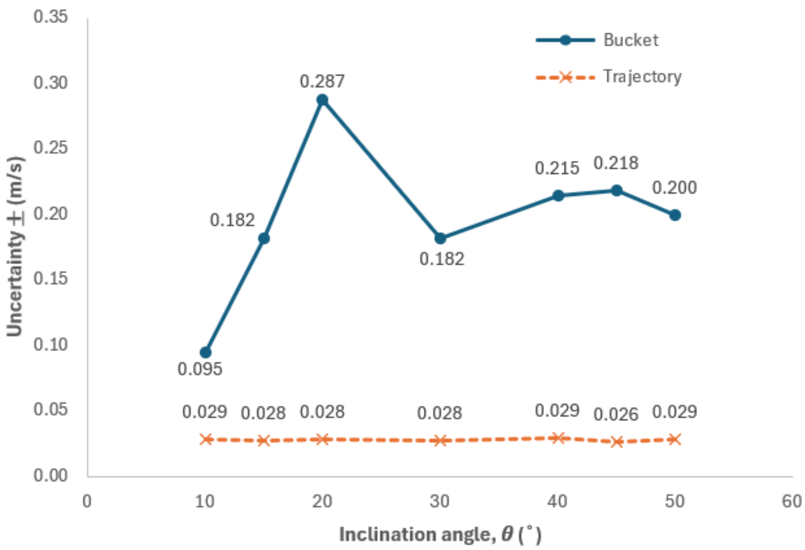


Figure 8. Measurement uncertainty of water velocity for the trajectory method and bucket method across different inclination angles

Across all inclination angles, the trajectory method consistently produced very narrow uncertainty margins (± 0.026 - 0.032 m/s), confirming its high repeatability and resistance to operator-dependent errors. In contrast, the bucket method demonstrated much larger uncertainty values, ranging from ± 0.09 m/s at low angles to a peak of ± 0.287 m/s at 20°, reflecting the influence of human handling factors such as spillage, timing errors, and incomplete water collection. This disparity reinforces that while both methods capture the general velocity trends, the trajectory method provides a more precise and statistically reliable measurement, thereby strengthening the credibility of the test rig results under low-head and low-flow conditions. Overall, the statistical evaluation based on standard deviation and measurement uncertainty provides quantitative evidence of the repeatability and reliability of the experimental measurements, supporting the robustness of the developed test rig under low-head and low-flow conditions. These statistical indicators also strengthen the reliability of the derived performance parameters, including velocity and efficiency. In addition, the use of recyclable PET bottle blades demonstrates the potential of low-cost and environmentally sustainable materials for small-scale hydropower development, particularly in rural or resource-limited environments.

Compared with other pico-hydropower turbines, such as crossflow, Kaplan, and propeller turbines, which generally operate more efficiently under moderate to high hydraulic heads [25], the overshot water wheel offers a practical alternative for low-head and low-flow environments. In such conditions, conventional turbines often experience reduced efficiency or require more complex hydraulic control systems, whereas the overshot water wheel can operate effectively using simple gravitational water inflow [26]. This characteristic highlight the relevance of the developed test rig for evaluating water wheel performance in rural pico-hydropower applications where hydraulic resources are limited.

From a long-term sustainability perspective, the use of recyclable PET bottle blades provides an environmentally friendly and low-cost material option for small-scale hydropower systems. In addition, the simple mechanical configuration of the overshot water wheel reduces maintenance complexity compared with more sophisticated turbine technologies. The low-head and low-flow operating characteristics also minimize disturbance to natural river flow, making the system suitable for environmentally sensitive rural pico-hydropower applications.

Future research may further improve the developed test rig by applying computational fluid dynamics modelling to analyze the detailed water flow behavior around the water wheel blades. In addition, IoT-based monitoring systems could be introduced to enable real-time performance monitoring and data collection for pico-hydropower installations [27]. The proposed system may also be explored as part of hybrid renewable energy systems, such as integration with solar photovoltaic systems or rural microgrids, to improve energy reliability in remote communities [28].

The developed test rig represents a practical engineering contribution to pico-hydropower research by providing a low-cost, simple, and replicable experimental setup for evaluating overshot water wheel performance under low-head and low-flow conditions, positioning this work within applied renewable energy engineering and experimental hydropower research. The system uses adjustable hydraulic parameters, continuous water circulation, and hydraulic rotary analysis to evaluate turbine performance under conditions similar to rural pico-hydropower environments. This design allows researchers to study small-scale hydropower technologies using a practical and accessible experimental system. From an applied sciences and information technology (IT) perspective, the experimental setup also offers potential for integration with digital monitoring and smart energy systems. For example, the test rig could be equipped with IoT sensors and cloud-based monitoring platforms to enable real-time data collection and performance analysis. This capability can support data-driven optimization, remote monitoring, and better management of small-scale renewable energy systems.

4. CONCLUSION

This study developed and validated a reliable water test rig for overshot water wheels operating under low-head and low-flow conditions, addressing an important gap in pico-hydropower research. The proposed system integrates an adjustable water channel and the water trajectory method to regulate hydraulic parameters and simulate near-real pico-hydropower environments. The test rig operated within a hydraulic range of 0.525 - 1.169 m head and 0.01 - 0.02 m^3/s flow rate, demonstrating stable and controllable experimental conditions. The results indicate that channel inclination significantly influences water velocity and energy transfer, which are important factors in waterwheel performance evaluation. In addition, uncertainty analysis confirmed the reliability of the trajectory method, producing low standard deviations (0.059 - 0.066 m/s) and measurement uncertainty of approximately ± 0.03 m/s, compared with larger variability observed in the bucket method. Overall, the developed B-BOW test rig provides a practical and dependable experimental platform for evaluating overshot water wheel performance under low hydraulic resources, supporting the development and future optimization of sustainable pico-hydropower technologies for rural electrification.

ACKNOWLEDGMENTS

The authors gratefully acknowledge Universiti Teknikal Malaysia Melaka (UTeM) for providing the facilities and support that enabled this study.

FUNDING INFORMATION

This study is funded by Ministry of Higher Education of Malaysia through the Fundamental Research Grant Scheme, No: FRGS/1/2024/TK08/UTEM/02/6.

AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
Izzatie Akmal Zulkarnain	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓				
Irma Wani Jamaludin	✓	✓	✓		✓	✓	✓	✓	✓		✓		✓	
Mohd Farriz Basar	✓	✓		✓		✓	✓		✓	✓	✓	✓	✓	✓
Kamaruzzaman Sopian		✓		✓		✓		✓		✓		✓		✓

C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

DATA AVAILABILITY

The data that support the findings of this study are available from the corresponding author, [MFB], upon reasonable request. The data, which contain information that could compromise the privacy of research participants, are not publicly available due to certain restrictions.

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BIOGRAPHIES OF AUTHORS

Izzatie Akmal Zulkarnain is currently a Ph.D. student in Electrical Engineering at the Faculty of Electrical Technology and Engineering, Universiti Teknikal Malaysia Melaka, Malaysia. She obtained a master's degree in 2009 and a bachelor's degree in 2001, both from Universiti Teknikal Malaysia Melaka. Her areas of research focus on small hydropower. She can be contacted at email: izzatieakmalzul@gmail.com.

Irma Wani Jamaludin is a senior lecturer at the Faculty of Electrical Technology and Engineering, Universiti Teknikal Malaysia Melaka, Malaysia. She obtained a master's degree in 2006 and a bachelor's degree in 2004, both from Universiti Teknologi Malaysia. She specializes in research on mathematical modeling for small hydropower systems. She can be contacted at email: irma@utem.edu.my.

Mohd Farriz Basar is an associate professor at the Faculty of Electrical Technology and Engineering, Universiti Teknikal Malaysia Melaka, Malaysia. He has a Ph.D. degree in Renewable Energy from Universiti Kebangsaan Malaysia, Malaysia (2017), a master's degree from Universiti Teknologi Malaysia (2009), and a bachelor's degree from Universiti Teknologi Malaysia (2001). His areas of research focus on small hydropower and wind turbine systems. He can be contacted at email: mfarriz@utem.edu.my.

Kamaruzzaman Sopian holds the position of professor of Mechanical Engineering at the Universiti Teknologi PETRONAS. His main contributions are in solar radiation modeling and resource assessment, advanced solar photovoltaic systems (grid-connected photovoltaic, solar powered regenerative fuel cell, solar hydrogen production, and thin film silicon solar cell), and advanced solar thermal systems (solar cooling, solar heat pump, solar assisted drying, and combined photovoltaic thermal or hybrid collector). He can be contacted at email: ksopian@utp.edu.my.