An Innovative Water Reaction Turbine of the Ultra Z-Blade Designed for Water Conditions of Low-Head and Ultra-Low Flow

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Article Info

Abstract

In comparison to conventional fossil fuels like coal and gas, hydropower offers many advantages. This is because it does not discharge harmful gases into the atmosphere, which contributes to air pollution. Nevertheless, there will be negative ecological effects in the area around a hydropower energy-producing plant if it is built. Hydropower is significantly less dangerous than pico-hydro systems, which only require a trickle of water to generate electricity through the rotation of a turbine. The reaction-type turbine is the topic of this study because it can be rotated by a relatively small amount of water. Cross pipe turbines (CPTs), split reaction turbines (SRTs), and Z-blade turbines (ZBTs) are all examples of older turbine designs that prioritized pressure above flow. There has been little progress made so far to compensate for the low head and ultra-low flow water segment. In order to tap into low head and ultra-flow water resources, this work attempts to address this by developing an ultra z-blade turbine for pico-hydro producing systems with two types of pipes measuring 0.75 inches and 2.0 inches in diameter. The concepts of mass, momentum, and energy conservation are used to generate the equations. The performance of the newly developed U-ZBT is compared to that of the well-established CPT, SRT, and ZBT via an experimental method. As a result, a 0.75-inch pipe size performed better than a 2.0-inch pipe size at a maximum speed of 130 rpm and a water flow rate of 1.77 L/sec.

1. Introduction

Numerous nations across the globe exhibit a profound preoccupation with the concept of sustainable development, mostly driven by the pressing issues of environmental change and the rapid expansion of urbanization. According to projections, the global population is anticipated to reach 9.7 billion individuals by the year 2050, and it is expected that over 25% of this population will reside in regions experiencing significant water scarcity [1]. In recent years, there has been a substantial surge in the global energy consumption. It is projected

that by 2035, there will be more than 30% rises in global temperatures, although the average temperature would remain constant at or below 2oC. These problems have significantly escalated to become some of the most formidable in relation to environmental sustainability [2]. Therefore, it has been proved that the utilization of renewable energy sources that are based on water improves the environment [3].

Hydroelectric power plants possess the capacity to transform the inherent kinetic energy present in water into electrical energy, which may be utilized for many purposes [4]. In the realm of renewable energy, hydropower emerges as a very cost-effective source, possessing immense potential for utilization in forthcoming electricity generation endeavors. Its significance and viability should not be underestimated. Hydropower has emerged as the most stable, efficient, and dependable renewable energy source, drawing upon a wealth of industrial knowledge spanning over a century [5], [6]. Based on the latest statistical data, there is a notable global expansion in the generation of hydroelectricity, whereby hydroelectric power contributes to around 20% of the whole global electric power production [7].

The need for small-scale hydroelectric systems in developing countries has experienced rapid growth since the onset of the twenty-first century. Despite the fact that large-scale projects can produce enough electricity for industrial areas, they have not been able to meet the country's rural population's energy needs [8]. Communities situated beyond the conventional power grid were compelled to depend on fossil fuel-based generators to meet their domestic electricity needs, leading to a notable surge in carbon emissions. Given that a significant proportion of settlements are situated in close proximity to rivers, it would be prudent to explore areas with a low head (specifically, less than 10 meters) for potential energy sources [9], [10].

Among the many parts that make up a pico hydro system is usually the turbine. Pico-hydro turbines represent a promising solution for decentralized renewable energy generation, particularly in remote or low-power applications [11]. This is because these places have a lower energy demand. These systems are designed to harness the kinetic energy of flowing water to produce electricity, even in conditions where traditional hydroelectric plants may be impractical. The performance classification suggests that pico-hydro power producing devices offer significant benefits and are particularly well-suited for rural areas with less energy demands. This article delves into the nuances of pico-hydro turbines specifically tailored for low-head and ultra-low flow water conditions, which present unique challenges and opportunities [12]. Some experts have established a specific head measurement of water flow, which may be shown in Table 1.

Table 1 *Classification of water head*

Class	Head
Ultra-Low Head	H < 3 meters
Low Head	3 meters < H < 30 meters
Medium Head	30 meters < H < 75 meters
High head	H > 75 meters

Water conditions characterized by low-head (the vertical distance the water falls) and ultra-low flow (minimal water volume) demand specialized turbine designs to optimize performance. Standard turbines, designed for high-head and significant flow, may not be efficient under these constraints. Consequently, pico-hydro systems need to address reduced water flow and low pressure effectively to generate power efficiently.

Typically, pico-hydroelectric power systems have a maximum power output of 5 kW. Due to their predominantly run-of-river nature, these systems control the flow of the river by means of pipelines typically located in isolated regions. This allows them to manage the flow of the river [13]. The ultimate goal of such adaptations is to maximize energy extraction while minimizing material and operational costs. This involves innovative design approaches that enhance the turbine's capability to operate efficiently under these restricted conditions. By focusing on turbine geometry, blade design, and operational strategies tailored to low-head and ultra-low flow conditions, these systems aim to improve reliability and energy output [14].

Understanding the interaction between water flow and turbine mechanics is crucial. The turbine is a composite construction made up of a shaft and nozzle or stator that work together to convert the pressure and momentum in a water flow into rotational mechanical energy. For low-head conditions, turbines often use a horizontal axis, allowing them to harness even small vertical drops. In ultra-low flow scenarios, turbines may incorporate more refined blade designs or innovative materials to capture minimal water energy effectively. Additionally, optimizing the turbine's efficiency involves addressing factors such as cavitation, water velocity, and mechanical losses. In theoretical terms, turbines possess the capacity to be categorized into either impulse or response-type water turbines [15].

As depicted in Fig. 1, a significant proportion of the hydro turbines currently in existence are specifically designed to operate under conditions characterized by high-head and high-flow water [14]. This preference can be attributed to the market dynamics of economies of scale, wherein firms benefit from cost advantages resulting from their size, production, or scale of operation. Additionally, such turbines have gained favor among utilities. Despite the relatively low potential energy available in low-head and low-flow scenarios, it is possible to achieve significant efficiency in harvesting the potential energy with appropriate turbine design. One notable benefit associated with the utilisation of such a turbine is its capacity to sustain uninterrupted operation, even in circumstances where water resources are limited, notably in periods characterised by drought. Significantly, in addition to large-scale water dams, there exist ample natural water resources with water heads of less than 10 m, making them appropriate for pico-hydro turbines [16].
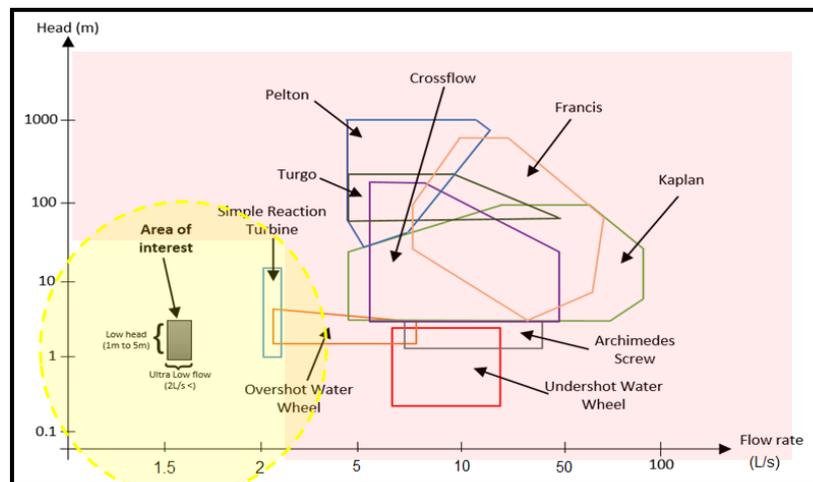

Fig. 1 *Typical turbine application range chart*

Hence, the response type turbine was chosen as a benchmark in turbine design for this study. Furthermore, garden water sprinklers provided inspiration for the turbine's development, which is now known as the Ultra Z-Blade Turbine (U-ZBT). The material that the Ultra Z-Blade Turbine (U-ZBT) is made of has the qualities of simplicity, affordability, and ease of maintenance. In the following sections of this study, the qualities and benefits of the Ultra Z-Blade Turbine (U-ZBT) will be examined in greater depth.

The research yielded the development and testing of a groundbreaking reaction water turbine called the Ultra Z-Blade turbine. This turbine demonstrates remarkable appropriateness for application in micro-hydro systems located in areas with low head and low flow conditions. The article seeks to examine the development of turbine classification and the progress made in creating various response water turbine kinds. These discussions are essential in the preliminary stages of constructing the U-ZBT. A comprehensive analysis is provided, delving into the complexity of the underlying principles, the intricate production processes involved, and the far-reaching repercussions associated with the current water turbine systems. This examination of the turbine also takes into account factors such as the turbine's capacity, cost, and the optimization of the budgeting procedure, among other considerations. Using the governing equations and the concepts of mass conservation, momentum, and energy, parametric analysis was used to investigate the performance characteristics of U-ZBT. Hence, the investigation focused on analyzing key variables, including angular velocity (ω), mass flow rate ($\dot{m}$), and optimal turbine diameter (D_T), across different operational heads.

1.1 Correlation Between CPT, SRT and ZBT

The responsive hydraulic machine type turbine, which can run effectively with low flow and ultra-low head water resources, has not been widely available for purchase until recently. The reaction turbines that most closely resemble the turbine in question are the split reaction turbine (SRT) and the Z-Blade turbine (ZBT). It is crucial to remember, nevertheless, that these turbines work best at hydroelectric sites with ultra-low water flow rates and low head, not at sites with high head and high flow rates. The cross pipe turbine (CPT) was replaced by the SRT in 2009. The SRT was created as a competitive substitute for the CPT [17]. More analysis led to the conclusion that the Crossflow turbine (CPT) exhibited some constraints that rendered it inappropriate for the generation of power at low head hydro sites while simultaneously reaching the needed level of efficiency. This conclusion was reached after more investigation [18]. The SRT and CPT, as illustrated in Fig. 2, were developed by Abhijit Date in 2009. Additionally, the development of the ZBT was influenced by the SRT. The turbine under consideration was

produced in the year 2018, utilizing the same material as SRT, namely grey PVC pipe fittings. However, it exhibits a more intricate design in comparison to ZBT [19].
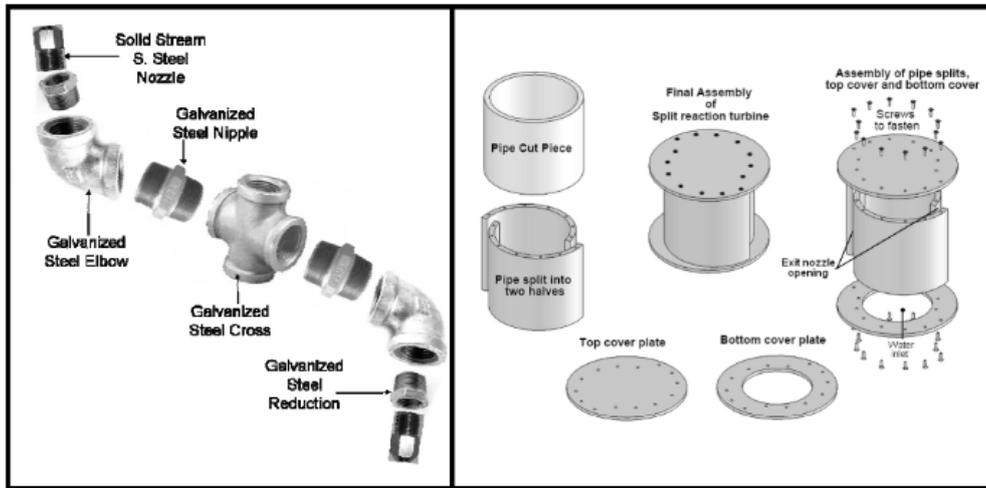

Fig. 2 *Cross pipe turbine and split reaction turbine*

The preset dimensions of common galvanised steel pipe fittings, particularly those related to turbine diameter and nozzle exit area, have an impact on CPT limitations [20]. Another drawback associated with the CPT idea is its limited ability to maneuver effectively and efficiently under conditions of low head water levels, especially in the case of larger turbines [21]. In a similar vein, the V-ring lip seal's design is primarily to blame for the CPT's considerable power loss during use. Due to a variety of limitations, the production of CPT has been discontinued, leading to the introduction of SRT as its replacement [22]. When examining the complexity of manufacturing, it can be observed that the SRT exhibited a higher level of intricacy in comparison to the CPT. The fabrication process requires a minimum of 6 hours, but the CPT process can be completed in approximately 4 hours. Table 1 illustrates the notable distinctions between SRT and CPT in terms of the materials employed and the production procedures utilized. Another form of turbine that requires a relatively shorter duration for fabrication is the ZBT turbine, which typically takes approximately three hours to develop [20].

Table 1 *Contrast of simple reaction turbines*

Simple reaction turbine	Material	Critical part / process	Fabrication difficulty	Inspired by
CPT	Galvanised steel pipe	V-ring lip seal	Moderate (a minimum 4 of hours)	Lawn sprinkler
SRT	Grey PVC pipe	V-ring lip seal and process of attachment of the split pipe with bottom cover plate	High (a minimum of 6 hours)	Savonius wind rotor
ZBT	Grey PVC pipe	Turbine coupling	Low (a minimum of 3 hours)	Lawn sprinkler
U-ZBT	Grey PVC pipe	Turbine coupling	Low (a minimum of 2.5 hours)	Lawn Sprinkle

2. Design of Hydraulic Water Turbines

In this particular section, the emphasis was placed on the design process that has been methodically applied in order to accomplish the goals. The method used to look into the performance parameters of an Ultra Z-blade reaction type water turbine (U-ZBT) both theoretically and empirically.

The turbine that Hero and Baker's mill created was a major contributor to the creation of simple reaction turbines, as has been widely acknowledged for a number of decades [23]. A subset of the wide variety of turbine designs that have developed as variations of the aforementioned turbines are represented by the CPT, Whitlaw's mill, Quek's turbine, and Pupil's turbine [24]. But as time passed, it became clear that the results of its functioning were now far from favourable and that they shouldn't be used in certain circumstances or near bodies of water. Additionally, it was determined that these outcomes were not suitable for usage in general. Despite the fact that this type of turbine has been criticized in the past for being inefficient and difficult to control, it is nevertheless widely used today. This resulted in the development of the SRT and U-ZBT, which led to the introduction of a fresh and distinctive insight on the future prospects of simple reaction turbines. This potential had previously been underestimated and underutilised, but this issue was fixed with the installation of these two turbines.

One of the notable changes implemented in relation to the CPT involves substituting the conventional galvanised iron (GI) pipe with grey PVC pipe Class D, offering more adaptability. The U-ZBT was developed using ordinary PVC pipe fittings with a nominal diameter of Ø0.75" (Type I) and Ø2.0" (Type IV), as depicted in Fig. 3. and Fig. 4.

Table 2 *Illustration of U-ZBT*

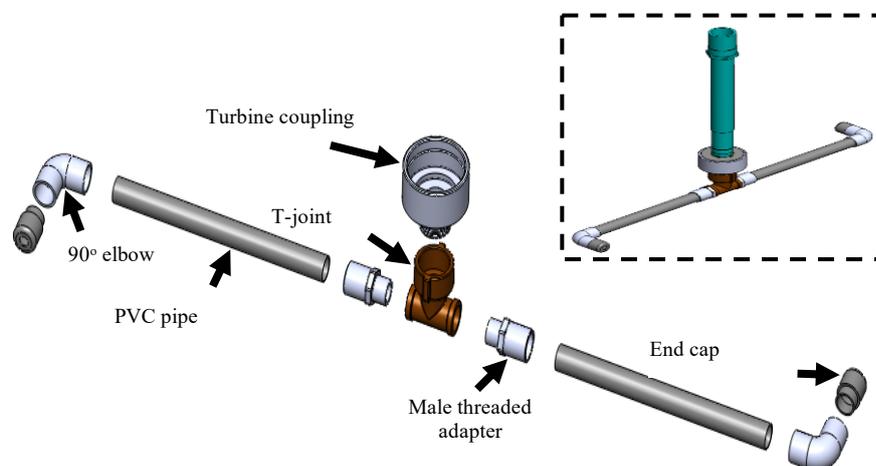| Item	Description
Prototype Criteria	Turbines are made up of four major components:
	a) one unit of T-joint pipe at the centre
	b) two units of arms made of PVC male
	threaded adapter fittings and PVC pipes of various lengths
	c) two units of 90° PVC elbow
	d) two units of PVC end cap
Material	Grey PVC pipe
Assembly difficulty	Low (a minimum of 2.5 hours)
Preservation	Easy
Consistency	Anti-corrosion and low-friction properties
Inspired by	Lawn sprinkle

Fig. 3 *Ultra Z-blade turbine*
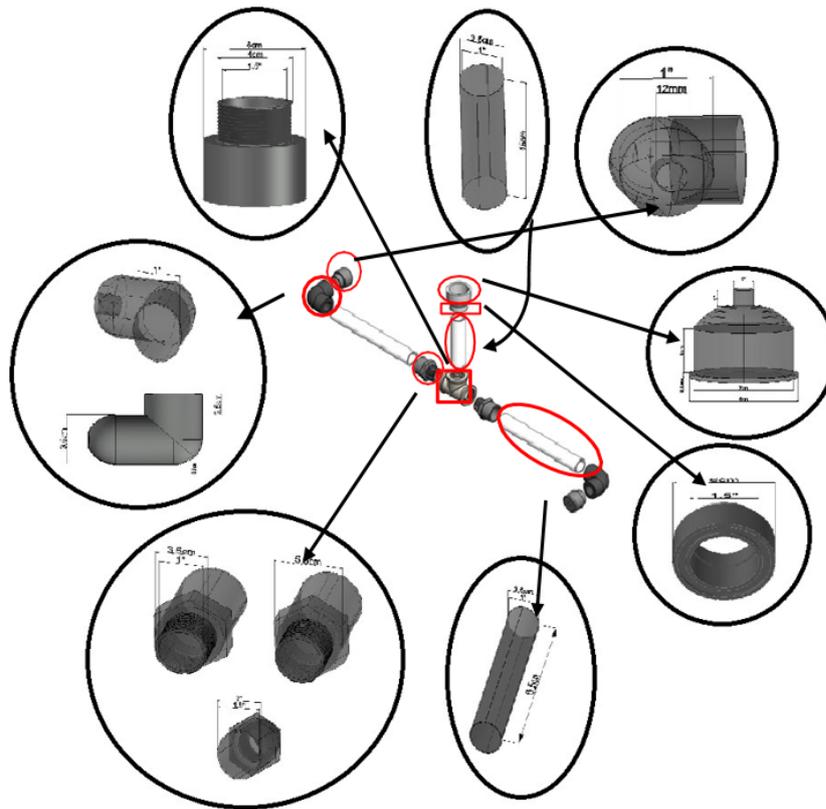
Fig. 4 *Exploded drawing of U-ZBT*

The turbine connection, depicted in Figure 5, plays a crucial role in the Ultra Z-blade turbine as it represents the junction of two pipelines. One of these pipelines is a fixed segment, while the other is a revolving section. Ideally, the coupling of the turbine should effectively prevent any leakage of the supplied water, so ensuring the preservation of the given potential energy and the avoidance of energy dissipation. The rotating section comprises several components, namely the coupling housing, radial shaft seal, bearing, 70 mm C-clip, and T-joint pipe. In contrast, the fixed component is comprised solely of the inflow pipe and a C-clip measuring 30 mm in diameter.

In response to the limitations posed by the SRT and the CPT, a novel turbine, referred to as the U-ZBT, was developed. Table 2 presents a comprehensive description of the components and construction composition of U-ZBT.
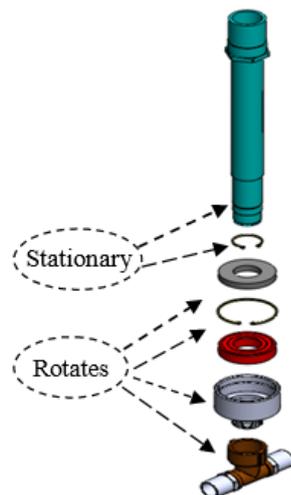

Fig. 5 *Ultra Z-blade turbine coupling*

The cost of PVC pipe is comparatively lower than that of galvanised steel pipe. Moreover, PVC pipe is easily available at nearby hardware stores and may be rapidly modified or customised to suit a much smaller turbine diameter in comparison to galvanised steel pipe. The process of assembly is characterised by its simplicity, as it does not require extensive technical expertise, the employment of skilled professionals, or the utilisation of advanced manufacturing machinery.

The majority of the U-ZBT components were made using polyvinyl chloride (PVC), as shown graphically in Figure 6. U-ZBT is fabricated through the amalgamation of components including T-joint pipe, male connected adapter, PVC pipes of diverse lengths, 90-degree PVC elbow, and PVC end cap, utilizing a PVC pipe and fittings system. By employing a specific adhesive, such as PVC cement, the process of connecting the PVC pipe components to construct the turbine blades for the turbine becomes straightforward. In addition, the PVC pipe has a symmetrical construction, which makes it easy to maintain and requires just the barest minimum of adjusting. A male connector fitting, PVC pipe, a 90-degree PVC elbow, and an end cap are some of the widely available parts that may be acquired from a neighborhood hardware store at a price that is not prohibitively expensive. There is minimal customisation required and inexpensive production costs because the rotor coupler (inlet rotary seal) is the only part that needs to be changed.
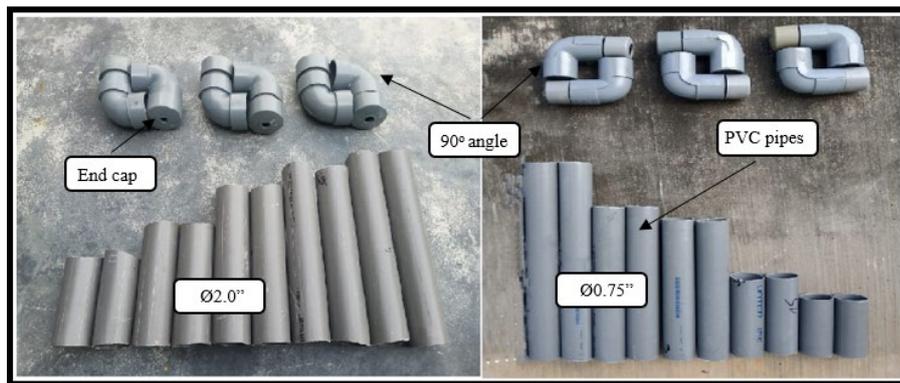

Fig. 6 *Type I and type IV of U-ZBT*

2.1 Correlation Between CPT, SRT and ZBT

Several assumptions were made in the disregard of losses associated with water flow from a water tank or storage and pipework [3], [22], [25]. Similarly, we established assumptions on the automated damages, such as windage losses caused by the rotation of the turbine and frictional losses in the pipe coupling, which were also disregarded [3], [25], [26]. Nevertheless, it is imperative to consider the power loss associated with the water flow through the turbine. Therefore, it was postulated that the force of gravity and the density of water remained consistent during the duration of the trials. Figure 7 illustrates the stationary reference frame of the rotor, highlighting the parameters relevant to the investigation of ideal conditions.
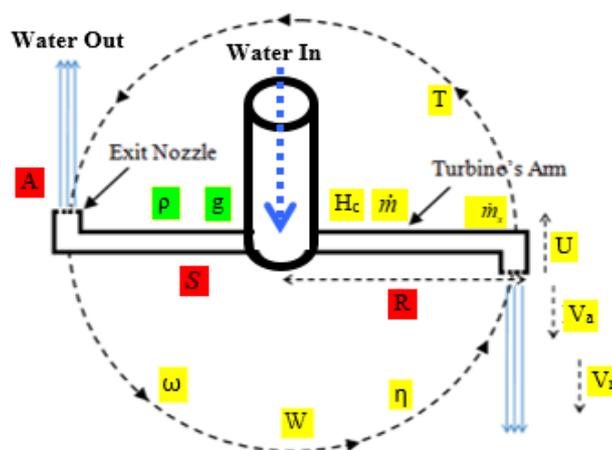

Fig. 7 *Parameters involved in the analysis*

The design of this study incorporates several parameters, namely mass, motion, and vitality. The primary approach and mathematical framework have been revisited, organised, and thoroughly discussed by the researchers [27]. The derived model is utilised to analyse the performance of the Z-Blade reaction water turbine in the context of incompressible water conditions. In the hypothetical scenario when frictional losses are absent, there exist mathematically appropriate arrangements as outlined below.

$$U = R\omega \tag{1}$$

$$V_a = V_r - U \tag{2}$$

$$V_a = V_r - R\omega \tag{3}$$

In the case of rotational turbine, $\omega \neq 0$; the centrifugal head, H_C as below:

$$H_c = \frac{U^2}{2g} = \frac{R^2\omega^2}{2g} \tag{4}$$

$$V_r = \sqrt{2gH + R^2\omega^2} \tag{5}$$

The mass flow rate, $\dot{m}$ can be expressed as:

$$\dot{m} = \rho A \sqrt{2gH + R^2\omega^2} \tag{6}$$

The angular speed of the rotor can be calculated by rewriting Equation (6)

$$\omega = \sqrt{\frac{\left(\frac{\dot{m}}{\rho A}\right)^2 - 2gH}{R^2}} \tag{7}$$

After re-examining the mathematical order, we can get the torque, T, as below:

$$T = \dot{m} V_a R \tag{8}$$

The mechanical output power, $\dot{W}$ produced by the turbine:

$$\dot{W} = T\omega \tag{9}$$

The efficacy of the arrangement in converting potential energy into mechanical work can be expressed as:

$$\eta = \frac{\dot{W}}{\dot{m}gH} \tag{10}$$

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3. Experimental Result Observations

In this section, the findings of the investigation will be discussed in the evaluation of the U-ZBT presentation. When taking into consideration the kinetic energy losses and fluid frictional losses, it was anticipated that the theoretical recitals would make their appearances utilising the principle of mathematical order. Throughout the inquiry, it

was discovered that the overall achievement findings produced from a large number of various experimental investigations that were repeatedly carried out were determined to be highly consistent.

3.1 The Performance by U-ZBT

This section presents a comprehensive account of the evaluation and analysis conducted to assess the performance of the U-ZBT. This work offers a thorough examination of the Ultra Z-Blade reaction water turbine's operating curves using both actual and theoretical data. The PVC pipe utilized in the study had nominal diameters of Ø0.019 m (equivalent to 0.75 inches) and Ø0.05 m (equivalent to 2 inches), with the specific diameter chosen based on the length of the pipe. The findings are showcased across a range of water elevations, with a specific focus on the water heads of 4 m and 5 m.

In general, it has been observed that hydro sites with a water head of less than 10 m tend to have the greatest potential for utilization in pico-hydro turbines. The presence of numerous river branches, streams, waterfalls, and irrigation systems within natural landscapes accounts for this phenomenon [28].

Figure 9 illustrates four distinct types of turbines utilized in the context of a simple reaction water turbine. Each turbine is specifically designed to operate under optimal output conditions. When the water head is kept at 4 metres and there is a minimum water flow rate of 20 L/s, the Split Reaction Turbine (SRT) operates at its best [29]. In the case of the Cross Pipe Turbine (CPT), optimal operating conditions are achieved when the water head is at 8 m and the water flowrate is 5.2 L/s [22]. The optimal operating parameters for the Z-Blade Turbine (ZBT) are achieved when the water head is 5 meters and the water flow rate is 2 L/s [30]. In contrast, the Ultra Z-Blade Turbine (U-ZBT) exhibits a water head equivalent to that of the ZBT, measuring 5 meters under optimal conditions. However, the U-ZBT distinguishes itself by offering a significantly lower water flowrate of 1.77 L/s in comparison to alternative turbines.

Although the Submerged Reverse Turbine (SRT) has a relatively lower water head pressure need compared to the Up-Zone Backwash Turbine (U-ZBT), it nevertheless necessitates a considerable water flow rate of at least 1.77 L/s for optimal operation. When the water head is kept at 4 metres and there is a minimum water flow rate of 20 L/s, the Split Reaction Turbine (SRT) operates at its best. It is worth noting that while the U-ZBT shares the same water pressure as the ZBT, it necessitates the lowest flow rate when compared to other alternatives.
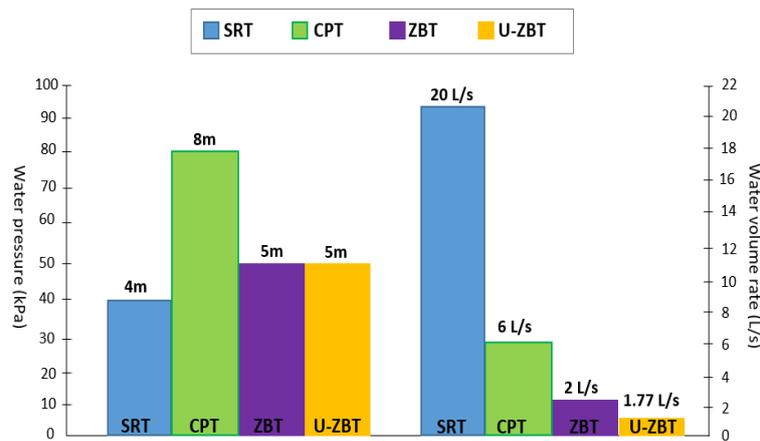

Fig. 8 *Optimum water pressure and water volume rate*

3.2 Nomogram

The primary objective of utilising a nomogram is to visually represent the relationship between several factors that impact the efficiency of a U-ZBT (Underwater Zero-Blade Turbine) operating within a water head range of 4 m to 5 m. Previous scholars, the topic at hand has been extensively examined and analysed [31], The expeditious acquisition of the system's performance characteristics can be achieved by applying the nomogram technique, which involves utilising a minimum of one parameter. Additionally, the nomogram illustrated in Figure 8 was developed with the purpose of estimating the overall turbine system using a single variable.

Figure 9 displays the performance curves of U-ZBT for Type I and Type IV applications. This image exhibits significant implications in various aspects. The most significant finding is the existence of a solitary turbine diameter, which serves as a critical juncture where other variables exhibit significant fluctuations in their size. This observation elucidates the behaviour of each parameter. Under ideal circumstances, the Type I blade with a diameter of Ø0.75 inch demonstrated optimal performance when paired with a rotor diameter of 0.6 m and subjected to a water head of 5 m. When the turbine attains its highest rotational velocity due to the

static head and the pressure generated by the centrifugal pumping effect, it is referred to as operating at its maximum rotational speed.
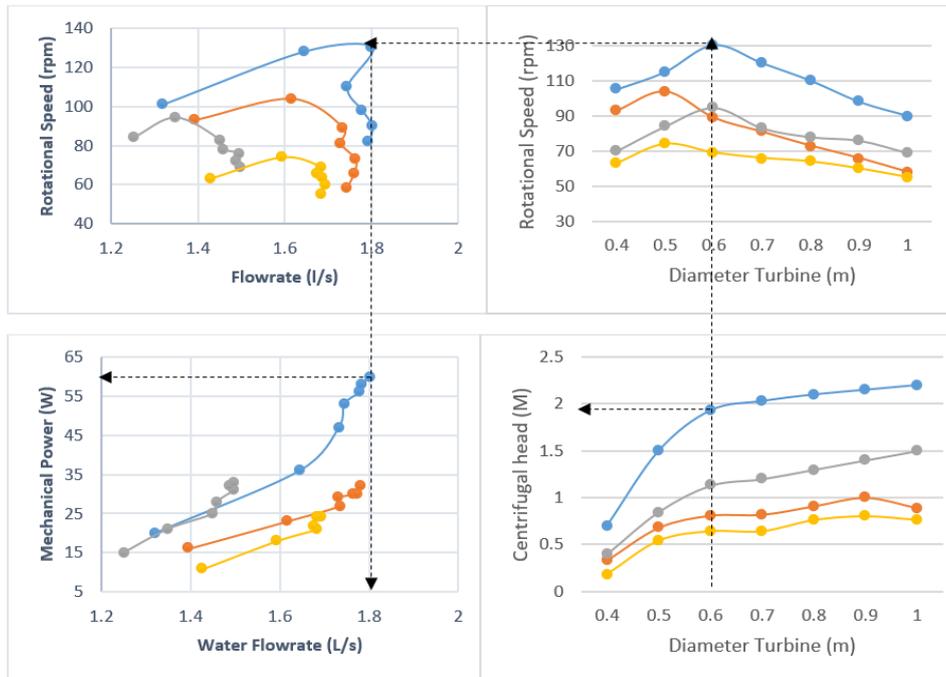

Fig. 9 *Nomogram I on the performance of U-ZBT*

According to the findings of the trial, it is noteworthy that the U-ZBT equipped with Type I demonstrated a remarkable rotational speed of 130 revolutions per minute (rpm). Moreover, it achieved an impressive efficiency of 66%, resulting in the generation of 60 Watts of mechanical power. It is worth mentioning that these outcomes were obtained under the condition of a relatively low flow rate of 1.77 litres per second. Nevertheless, the maximum mechanical power output achieved by employing a Type IV (Ø2 inch) blade, along with an ideal rotor diameter of 0.5 m and a water head of 5 m, was determined to be 33 W. Currently, the Type IV exhibits a water flow rate of 1.7 litres per second and is capable of attaining a rotational speed of 104 rpm.

It was previously noted that as the mass flow rate increased from a small turbine diameter to a medium turbine diameter, the rate of growth of the centrifugal head and rotational speed showed a notable acceleration. This acceleration occurred concurrently with an increase in the mass flow rate. Additional investigation reveals that the rate at which the water flowrate rises decreases as the turbine gets closer to its maximum speed, producing a growth pattern that is almost horizontal. Upon attaining the optimal rotor diameter, the gradient of the graph commences a decline.

3.3 The Impact of Pipe Sizes on Turbine Performance

Figures 10 and 11 depict the empirical values of U-ZBT obtained from the conducted laboratory experiments. These values exhibit a pattern that closely resembles the theoretical analysis, albeit with a notable reduction in magnitude. It was observed that the overall performance of the blade with a diameter of 0.75 inches was superior to that of the blade with a diameter of 2.0 inches for one particular reason, despite the fact that the outcome of the measured performance curves for both pipe diameters was seen to be comparable.

The Ø0.75-inch blade exhibited a higher relative velocity, V_r and tangential velocity, denoted as U, compared to the Ø2-inch blade. Consequently, it is evident that the mass flow rate of the Ø0.75-inch blade surpassed that of the Ø2-inch blade. It is worth noting that the mass flow rate for short turbine diameters was not significantly affected by the size (nominal diameter) of the PVC pipe, as long as the entire nozzle exit area and water head remained constant. This observation indicates that there is no statistically significant difference in the water flow rate values between a 0.75-inch blade and a 2-inch blade when the blades are of short length and positioned at a distance of 5 metres.

Moreover, it was observed that the size of the pipe had a significant influence on the rate of rotation, particularly when considering moderate pipe lengths and the ideal turbine diameter. Nevertheless, the effect on shorter lengths was rather minor, while the influence on bigger turbine diameters was more significant.
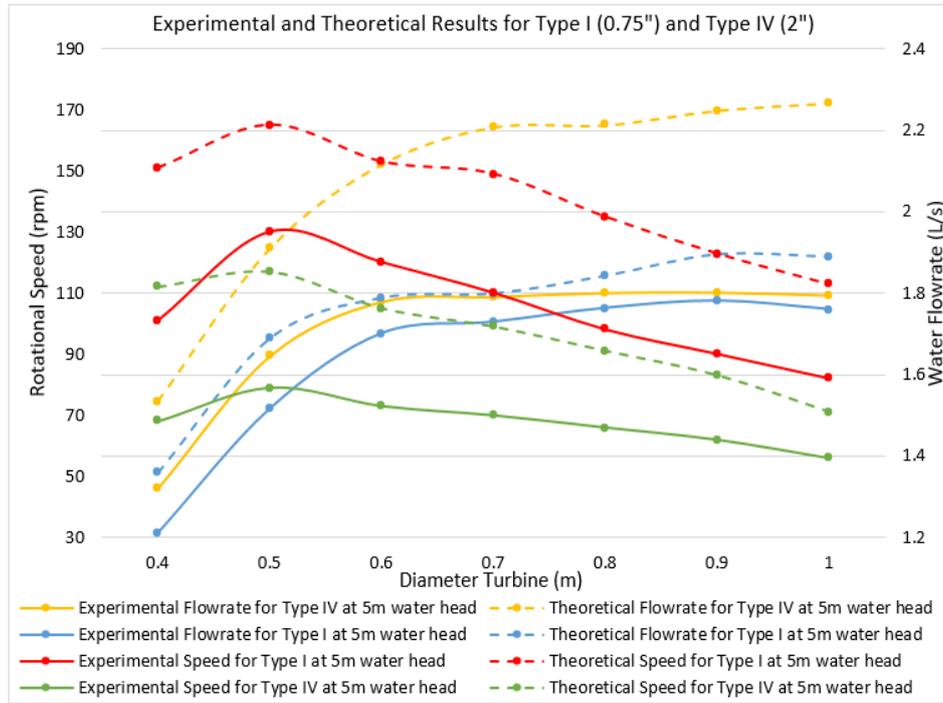
Fig. 10 *Experimental and theoretical results for various pipe sizes at 5 m water head*
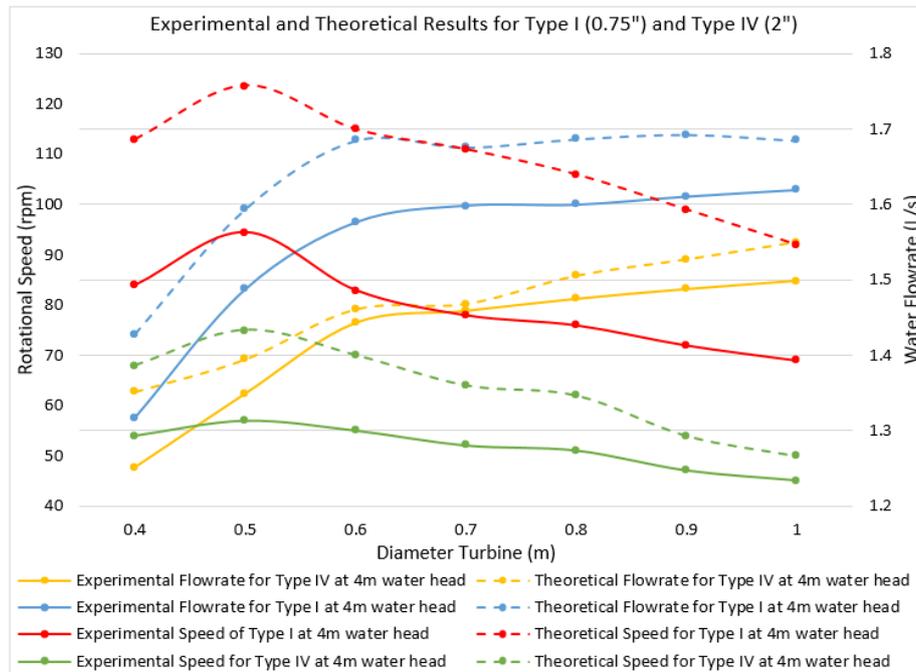

Fig. 11 *Experimental and theoretical results for various pipe sizes at 4 m water head*

Table 3 presents the data obtained from the turbine with the optimal diameter for Type I and Type IV, considering water heads of 5 m and 4 m, respectively. The results indicate that, when subjected to a water head of 5 m, the Ø0.75-inch (Type I) blade exhibits a water flow rate and rotating speed that are approximately 2.9% and 25% more, respectively, than those observed for the Ø2-inch (Type IV) blade. Based on the findings presented, it can be shown that when considering a water head of 4 metres, the water flow rate and rotational speed

associated with a Ø0.75-inch (Type I) blade exhibit an increase of approximately 8.3% and 28.3% respectively, in comparison to the values obtained for a Ø2-inch (Type IV) blade.

Table 3 *Data recorded for type I and type IV at different water head*

Head (m)	Type	Rotational Speed (rpm)		Mass Flow Rate (L/sec)	
		Ideal	Exp.	Ideal	Exp.
5	I	165	130	1.81	1.77
	IV	117	79	2.1	1.8
3	I	123	95	1.68	1.57
	IV	75	57	1.46	1.41

In relation to the impact of pipe sizes on turbine performance, it is observed that Type I exhibits superior performance despite having a smaller pipe size compared to Type IV. This discrepancy can be attributed to the increase in relative velocity resulting from the turbine's high rotational speed. According to the equation governing relative velocity, $V_r = \sqrt{2gh + R^2 w_k{}^2}$ this increase subsequently leads to a higher water flow rate (represented by $m = \rho A V_r$). Partially as a consequence, the performance of Type I, characterized by a blade diameter of 0.75 inches, showed superiority over that of Type IV, distinguished by a blade diameter of 2 inches.

4. Conclusions

The U-ZBT pico-hydro system has been shown through theoretical research and experimental findings to be capable of functioning effectively in conditions of low operational water head and water flow. The study additionally demonstrated that, upon comparison of the two types of U-ZBT systems, Type I of the U-ZBT system displays the most superior performance. The experimental findings indicate that the system is capable of attaining significant rotational velocities, reaching up to 130 revolutions per minute (rpm), while operating with minimal mass flow rates of roughly 1.77 (L/s). Furthermore, the mechanical output power of the system is estimated to be around 60 watts when operating at low head water conditions of 5 m. Furthermore, an important finding of this study suggests that the performance of the Ø0.019 m (0.75-inch) blade surpasses that of the Ø0.05 m (2.0-inch) blade. Additionally, it was observed that the performance of both pipe diameters exhibited improvement as the operational water head was elevated. Additionally, it was observed that the performance curves recorded for both pipe sizes exhibit a striking resemblance, suggesting that the pipe was engineered with a unified objective. When examining this system, it can be observed that the total value of water flowrate exhibits a positive correlation with the value of pipe size, however the total value of rotation speed demonstrates a negative correlation with the value of pipe size.

Acknowledgment

Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of the paper.

Author Contribution

The authors are responsible for the study conception, research design, data collection, data analysis, result interpretation and manuscript drafting.

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