UTILIZING AN OPEN IMPELLER OF A CENTRIFUGAL PUMP IN REVERSE MODE TO GENERATE ELECTRICITY

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Utilizing an Open Impeller of a Centrifugal Pump in Reverse Mode to Generate Electricity

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Abstract**—** The increasing demand for electricity, particularly in remote and off-grid regions, has highlighted the need for cost-effective and environmentally sustainable energy solutions. This study investigates the feasibility of utilizing a centrifugal pump, operated in reverse mode with an open impeller, as a turbine for micro-hydro power generation. Small hydropower (SHP) systems, characterized by their affordability and minimal ecological impact, represent a promising alternative to large-scale energy projects. Experimental tests were conducted to evaluate the operational parameters of the open impeller, focusing on the Best Efficiency Point (BEP), power output, and efficiency at varying discharge rates and inlet heads. Results revealed a peak efficiency of 77% at a power output of 3447 W, a rotational speed of 1990 rpm at a head of 13 m, and a flow rate of 14.58 m³/s. The findings demonstrate that the open impeller effectively functions as a micro-turbine, offering a viable solution for electricity generation in isolated rural communities or standalone urban homes with adequate water resources. This study underscores the potential of centrifugal pumps in reverse mode as a cost-efficient and scalable alternative for micro-hydro power systems, fostering energy accessibility in underserved areas.

Keywords— Centrifugal Pump, Open Impeller, Electricity Generation, Pump as Turbine, Power Output.

I. Introduction

The global demand for sustainable and renewable energy solutions has intensified over the past two decades, with small hydropower systems emerging as significant contributors to electricity generation from renewable sources [1]. The advancement of technology, coupled with the push for industrialization, has created an urgent need for reliable energy sources in both urban and remote areas. This surge in electricity demand has sparked renewed interest in developing small hydroelectric power (SHP) projects, primarily due to their economic viability and lower environmental impact compared to large-scale hydropower projects [2].

Electrical energy is fundamentally linked to improved living conditions, yet many rural areas remain unconnected to the national grid, particularly in developing countries like Nigeria [3]. This lack of access to electricity presents a unique opportunity to explore innovative solutions, such as utilizing centrifugal pump impellers in a reverse operation as turbines for electricity generation in these underserved regions.

Traditional methods of establishing large-scale power generation facilities—be it thermal, nuclear, or conventional hydroelectric sources—are often prohibitive in terms of cost, time, and environmental disruption. In contrast, micro-hydroelectric power generation using centrifugal pumps offers a simpler, cost-effective, and less intrusive approach to providing electricity, especially in remote locations. Several countries, including Belgium and Nepal, have already implemented "pump-as-turbine" technology in their micro-hydro schemes to address local energy needs [4, 5].

For low-capacity hydroelectric plants (less than 100 kW), the potential of employing centrifugal pump impellers as turbines warrants thorough exploration [6]. The reverse operation of centrifugal pumps has surfaced as an innovative solution for power generation. Advances in electrical machinery control technologies that enable variable speed and torque regulation have further facilitated the practicality of utilizing centrifugal pumps in reverse for energy generation [7].

Existing conventional turbines typically feature inlet guide vanes, which are absent in centrifugal pumps used in reverse mode. This distinction leads to variations in discharge characteristics relative to standard turbines. However, centrifugal pumps operating as turbines' inherent simplicity, durability, and efficiency present a compelling alternative [8].

The performance of a centrifugal pump, particularly its impeller design, plays a critical role in its operational efficacy. The dimensions and configurations of the impeller are instrumental in defining the pump's overall performance, influencing its capacity and total dynamic head (TDH). This study focuses on the open impeller type, posited as an effective alternative to traditional turbines for generating electrical power. This research aims to examine the operational parameters of an open impeller centrifugal pump functioning as a turbine for electricity generation. Key objectives include:

- Determining the centrifugal pump's Best Efficiency Point (BEP) in turbine mode.
- Evaluating the operational power of the pump as a turbine (PAT).
- Assessing the pump's performance across varying discharge rates.

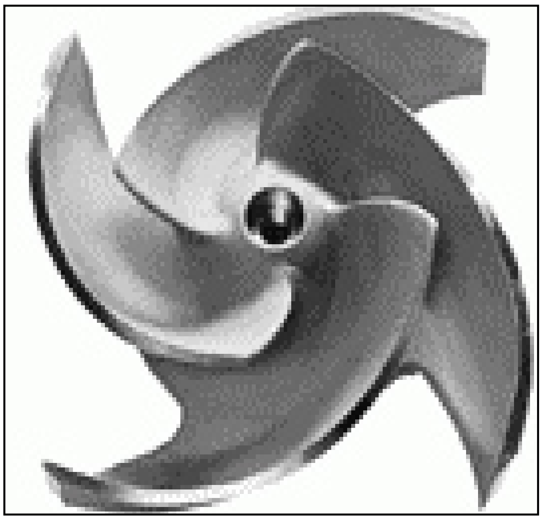

Figure 1. Open Impeller [9]

II. Literature Review

[10] explored the use of an end suction centrifugal pump operating in turbine mode for micro-hydro applications coupled with an induction generator. Their investigation encompassed both experimental and simulation approaches on a single-stage, low-specific-speed pump (<10 kW). Notably, their findings demonstrated that centrifugal pumps could function effectively in turbine mode without mechanical modifications. The study highlighted that achieving the Best Efficiency Point (BEP) required higher flow rates and heads than the pump's rated conditions. Efficiency improvements were linked to geometric modifications of hydraulic characteristics, and coupling the pump with a modified induction motor and electric control systems successfully regulated output voltage and frequency.

[11] evaluated the feasibility of pump-as-turbine (PAT) systems for addressing energy challenges in rural and hilly regions. Using computational fluid dynamics (CFD) simulations, they analyzed a mixed-flow centrifugal pump with a specific speed of 1850 rpm. Their experiments revealed a maximum efficiency of 83.10% at a flow rate of 0.127 m³/s and a head of 12.48 m, operating at 1450 rpm in turbine mode. The numerical and experimental findings showed satisfactory agreement, underscoring the reliability of PAT systems.

[12] focused on PAT systems' mechanical energy generation capabilities. Experimental performance curves for the "Etanorm pump 150-315" demonstrated up to 80% efficiencies under varying flow rates and rotational speeds. For instance, at a small head of 11.5 m and a speed of 760 rpm with a flow rate of 300 m³/head, the PAT system generated 7.5 kW on the impeller shaft. These results underscored the adaptability of PAT systems for diverse operational conditions.

[8] conducted a functional characterization of centrifugal pumps in turbine mode, analyzing the influence of rotational speed on efficiency and operational parameters. Their findings demonstrated that turbine characteristics could be partially predicted from pump characteristics, with water exiting the runner free of swirl flow at BEP. Additionally, they observed lower radial stresses in turbine mode compared to pump operation.

Using an experimental rig, [13] experimentally investigated a centrifugal pump operating as a turbine (PAT). Their results confirmed that centrifugal pumps could operate efficiently in turbine mode without mechanical complications, achieving higher heads and discharge values compared to pump operation. However, the BEP in turbine mode was observed to be lower than in pump mode, aligning with previous research findings.

[14] developed a novel approach for predicting the inverse characteristics of industrial centrifugal pumps using three-dimensional CFD simulations. Their method, validated in pumping mode and compared with experimental data for reverse mode operation, provided insights into the best efficiency point and inverse characteristics. Testing on three pumps with varying specific speeds highlighted the accuracy of their predictive model, demonstrating its utility for PAT applications.

III. Materials

A. Materials Used for the Experiment of the Open Impeller for the Turbine Test

The following are the materials and instruments used for the experiment:

Table 1. List of Materials and Instrument used for both Pump and Turbine Test

S/N	Material/Instruments	Pump Descriptions	Turbine Descriptions
1	Centrifugal Pump	3.8 hp	3.8 hp
2	Gauge Valve	51 mm	79 mm
3	Intake Pipe	Diameter 51 mm	Diameter 79 mm
4	Out Pipe	Diameter 65 mm	Diameter 68
5	Ground Tank	As Adequate	As Adequate
6	Tachometer	Cyber Tech. (NUSPSC 25174406)	Cyber Tech. (NUSPSC 25174406)
7	Manometer	Canstock (csp 14719981)	Canstock (csp 14719981)
8	Stop Watch	Digital	Digital
9	Impeller	Open Type	Pelton Type

IV. Methods

A. Performance Test on the Centrifugal Pump Using an Open Impeller as a Turbine

The performance testing of the centrifugal pump operated in turbine mode utilized the methodology proposed by [15]. The experimental setup, depicted in Figure 2, comprised a PVC pipe connected from the bottom of an overhead tank to the turbine. A manometer and gauge valve were installed along the pipe to facilitate accurate measurement of flow rates.

An underground tank was incorporated into the system to regulate the discharge from the turbine tailrace. A second gauge valve was situated on the pipeline discharging water from the turbine's tailrace to the underground tank, allowing for enhanced control of water flow between the turbine tailrace and the underground reservoir.

The water discharged from the turbine's tailrace flows into an underground tank, which is equipped with a gauge valve on the discharge pipe. This setup facilitates enhanced control over the water flow between the turbine's tailrace and the underground tank.

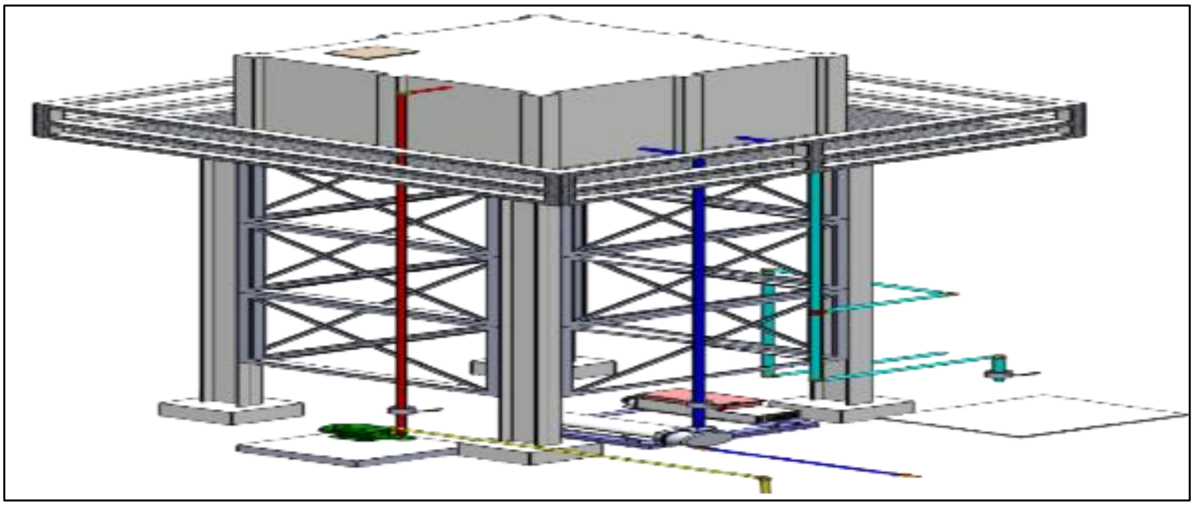

Fig. 2. Turbine Test Schematic Diagram

To ensure a continuous supply of water to the turbine, the water exiting the turbine is recycled back to the overhead tank using an auxiliary pump. A second gauge valve is installed between the underground tank and the auxiliary pump to optimize the control of water flow in this section of the system. Figure 3 illustrates the side view of the schematic diagram representing the turbine test setup.

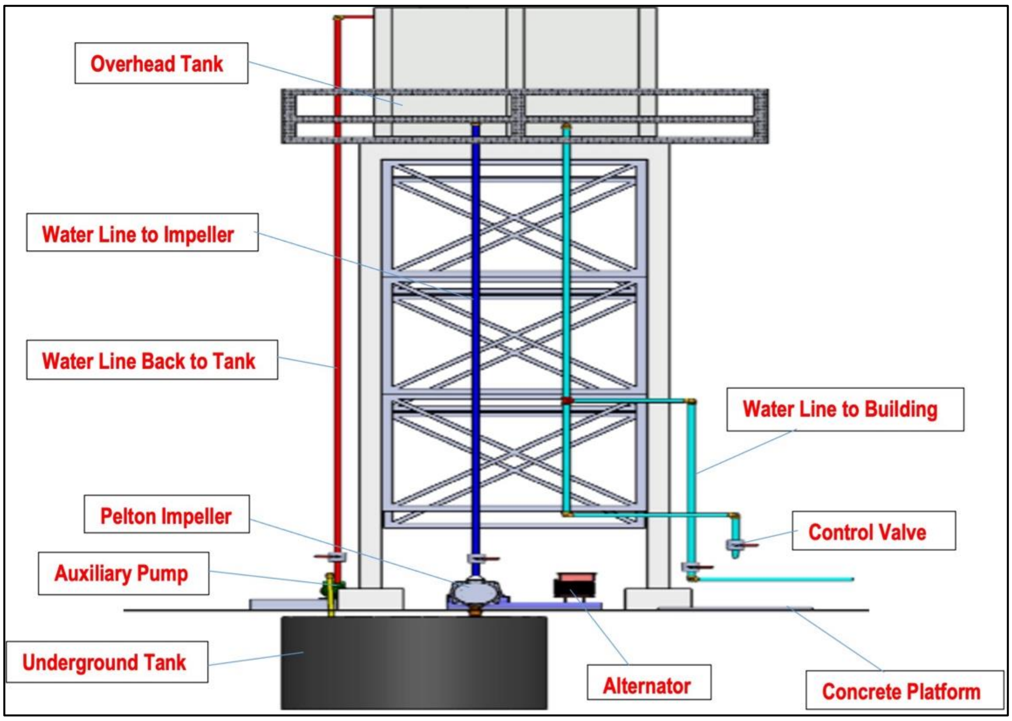

Fig. 3. Turbine Test Schematic Diagram Side View

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The experimental procedure was conducted at five distinct heads using an open impeller type centrifugal pump, allowing for the free gravitational flow of water from the overhead tank to the turbine impeller. The impeller speed was monitored using a tachometer placed in close proximity to it. The five test heads used in the experiment were 7.60 m, 9.10 m, 10.70 m, 12.20 m, and 13.70 m, as detailed by [16]. The centrifugal pump was thoroughly primed prior to testing, and all valves were opened to prevent any choking in the system during low flow conditions. This was managed by carefully adjusting the bypass valve as needed. The desired turbine head was accurately achieved through height measurements, followed by the necessary adjustments to the positioning and setup of the entire centrifugal pump system for each specific head.

Once the centrifugal pump system was fixed and readjusted at the desired head the valves and the by-pass valves were reopened for water to flow so as to take the next set of readings at different flow rates. At each step, the water was allowed to flow with the valves constantly adjusted so as to maintain accurate measurements of the readings. This procedure was repeated for all the experiments.

B. Data Collection and Analysis

1. *Measurement of Flow Rates:* Flow rates were recorded using the installed manometer and gauge valve and collected over various operational conditions.
2. *Evaluation of Power Output:* The operational power of the pump as turbine (PAT) was calculated based on the measured flow rates and head developed by the pumping system.
3. *Performance Metrics:* Key performance metrics, including the efficiency, flow characteristic curves, and operational limits of the centrifugal pump, were derived through empirical testing and analysis.

This methodology provides a robust framework for assessing the feasibility of centrifugal pump impellers as viable alternatives to traditional turbine methodologies in micro-hydroelectric power generation.

C. Determination of Flow Rate

Using the process adopted by [17, 3], the flow rate Q was calculated from equation (1).

$$Q = 1 \cdot 73\sqrt{\Delta h}\ l/s \quad (1)$$

D. Determination of Power Output

The process used by [18] was adopted in calculating the power output (P_{out}) of the turbine, which is Bernoulli's Equation. (2 – 6)

$$P_{out} = w_s \times \dot{m} \quad (2)$$

where,

$$Work\ Shaft\ (w_s) = \left(gh - \frac{V^2}{2}\right) \quad (3)$$

$$\dot{m} = \rho AV \quad (4)$$

$$Velocity\ (V) = \frac{\pi DN}{60} \quad (5)$$

$$Cross\ Sectional\ Area\ (A) = \frac{\pi}{4}D^2 \quad (6)$$

E. Determination of Power Input

The process by [19] was adopted to calculate the power input of the Pelton type impeller. According to equation (7) The power input is the power giver to turn the impeller blade.

$$P_{in} = \frac{\rho QH}{75 \times \eta} \quad (7)$$

where, η is the manufacture's pump efficiency (0.55) that is 55%.

F. Determination of Efficiency

The process used by [18] was adopted to calculate the pump efficiency (η). See equation (8).

$$\eta = \frac{P_{out}}{P_{in}} \times 100\% \quad (8)$$

G. Determination of Specific Speed of Turbine

The Process adopted by [20] was used to calculate the Specific Speed of the turbine. According to equation (9).

$$N_{ST} = \frac{N\sqrt{P_{out}}}{H^{5/4}} \quad (9)$$

$where,\ N =$ kinematic speed in rpm.

V. Result and Discussion

A. Experimental Findings

The results of the experiments conducted on the centrifugal pump performance in turbine mode using an open impeller are detailed in standard units compliant with micro hydropower standards. Measurements were taken across five different inlet heads, providing a comprehensive dataset for analysis. The polynomial correlation equation derived from regression analysis serves as the model for generating predictions in this study.

B. Effect of Power Output on Efficiency

The relationship between power output and efficiency was observed to be curvilinear. As power output increased, efficiency correspondingly improved until reaching a peak, after which efficiency declined across all five inlet heads (Figure 4). The maximum efficiency achieved was measured at a specific power output, aligning with the findings of [15, 14]. However, it was noted that the efficiencies reported by these studies were generally lower. The coefficients of variation for efficiency concerning power output ranged from 73% to 98%, indicating that the models reliably forecast the efficiency trends across different power outputs.

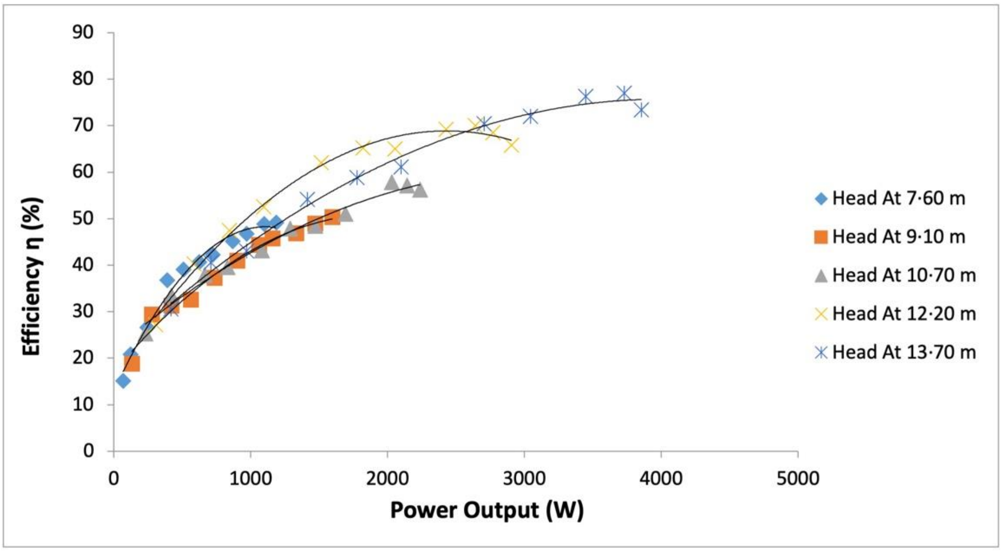

Fig. 4. Effect of Power Output on the Efficiency of the Turbine for Open Impeller

C. Effect of Power Input on Efficiency

Similarly, the data demonstrated a strong correlation between power input and efficiency, revealing a consistent curvilinear trend. Efficiency increased with power input, peaked, and subsequently fell, a pattern consistently observed across all tested heads (Figure 5). This behavior suggests that exceeding the best efficiency point (BEP) leads to reduced efficiency, aligning with previous studies by [14, 1], with the latter reporting lower maximum input power and efficiency ratings 4·17kW and 58%, respectively. The variation coefficients for this relationship ranged from 76% to 98%, further supporting the model's fit across the observed trends.

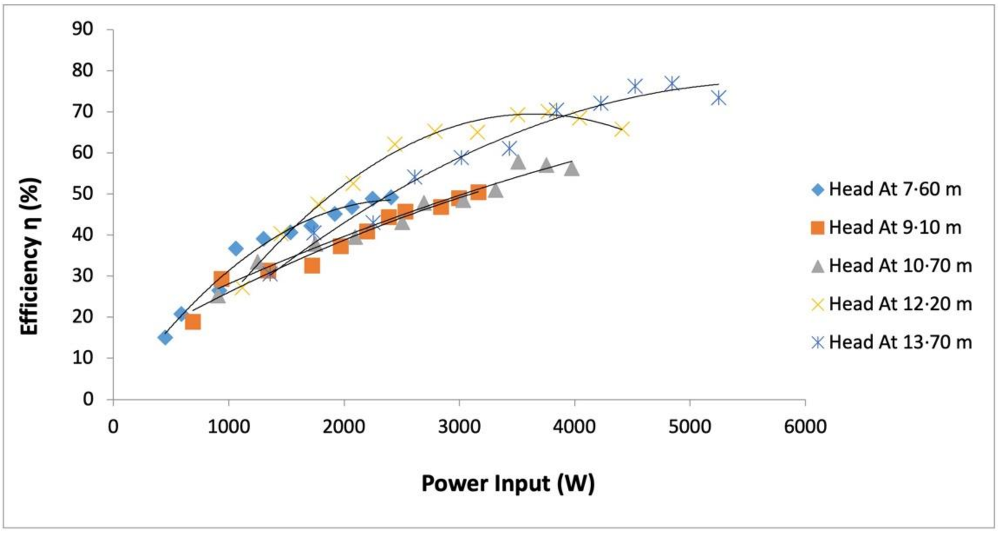

Fig. 5. Effect of Power Input on the Efficiency of the Turbine for Open Impeller

D. Effect of Flow Rate on Efficiency

The flow rate was also examined for its influence on efficiency, revealing a curvilinear relationship where increased flow rates resulted in higher efficiencies until a peak was reached, after which efficiency declined. (Figure 6). The highest efficiency recorded for the open impeller occurred at 76·28%, whereas the best efficiency point of the flow rate occurred at 13·61 m^3⁄s. This finding corroborates the results from [21, 22], with a notable observation that [22] reported a shift toward higher flow rates for maximum efficiency. The coefficients of variation for this relationship ranged from 75% to 99%, showcasing the model's validity in depicting the efficiency trends.

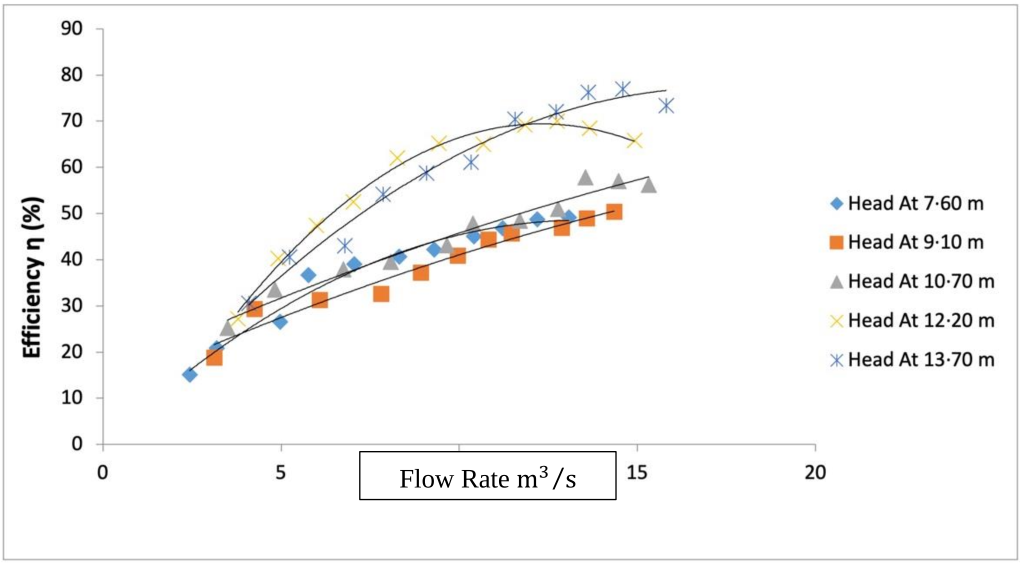

Fig. 6. Effect of Flow Rate on the Efficiency of the Turbine for Open Impeller

E. Effect of Impeller Speed on Flow Rate

Additional observations indicated that impeller speed increased with flow rate. Specifically, for higher inlet heads, impeller speed showed pronounced increases, particularly at elevated head levels due to the gravitational forces acting on the water. The trends observed were consistent with previous studies by [23, 13, 24], illustrating commonalities in hydraulic performance insights across the literature. The coefficients of variation concerning the effects of flow rate on speed ranged from 96% to 99% (Figure 7), affirming the model's applicability in these findings.

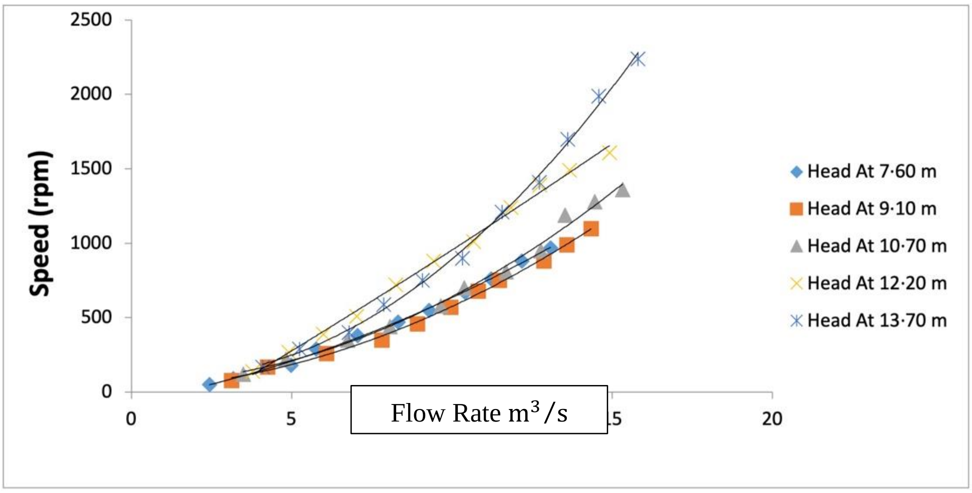

Fig. 7. Effect of Flow Rate on the Speed of Open Impeller

VI. Conclusion

The primary objective of this study was to investigate the operational parameters of a centrifugal pump utilizing an open impeller in turbine mode for micro-hydro power generation. The findings suggest that the open impeller configuration effectively harnesses energy from water resources, making it suitable for applications in isolated rural areas or standalone urban homes, provided there is adequate access to water reservoirs year-round.

Key conclusions drawn from the experimental results include:

- The open impeller reached its best efficiency point at 77%, indicating optimal performance at specific operating conditions.
- The operational power output derived from the centrifugal pump was established, affirming the potential of the open impeller to produce commendable power outputs of 3447W under varying conditions.
- The correlation of speed variations with flow rate across different heads was successfully characterized, highlighting the influence of gravitational forces on performance efficiency.

These findings contribute valuable insights into the design and implementation of micro-hydropower systems, emphasizing the viability of centrifugal pumps as turbines in renewable energy applications. Future research may extend these findings by exploring longer-term operational efficiency and integrating environmental considerations for sustainable energy solutions.

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