The Effects of Blade Height on the Efficiency of Gravitational Water Vortex Turbine

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ABSTRACT: This paper presents the results of a study on the effect of blade height on the efficiency of a free-vortex water turbine. Laboratory experimentation was conducted to find the shaft power generation and the efficiency of the turbine. Water turbines with six blades and four different heights (208 mm, 248 mm, 288 mm, and 320 mm) were built and tested to determine the most appropriate blade height. The turbines were tested in a conical basin with inlet and outlet diameters of 600 mm and 100 mm and a height of 800 mm, at volume flow rates of 0.0088 m³/s, 0.0105 m³/s, and 0.0108 m³/s. The results showed that the turbine with a blade height of 288 mm was the most appropriate, yielding the highest efficiency of 30,46% at a water flow rate of 0.0108 m³/s.

KEYWORDS: Turbine, Vortex, and Efficiency

I. INTRODUCTION

The Gravitational Water Vortex Power Plant (GWVPP) is a power generation system that utilizes artificially created water vortices to rotate a turbine shaft, and then the rotational energy of the turbine shaft is used to drive an electric generator to produce electricity. GWVPP was discovered by the Austrian engineer Frank Zotlöterer [1]. This power generation system does not need a dam like conventional power plants. The GWVPP can operate with a water height as low as 0.7 m. The installation of GWVPP has huge environmental benefit, is safe for fish due to the low turbine speed, and improves water quality by oxygenation. The construction cost of this GWVPP system is relatively low due to its simpler design, which doesn't need dam structures and utilizes locally available materials. Dhakal, et al. [2] conducted a study on a design of the GWVPP system with low head, integrated into three types of existing water infrastructures: irrigation canals, reservoirs, and dams. A 1.6 kW scale system was designed and utilized to harness the energy of water flow within the irrigation canal. This makes it suitable for use in river streams and for rural electrification [3].There are many studies conducted to optimize the performance of GWVPP. GWVPP systems typically used two geometries of circulation basin: cylindrical and conical basin, both with tangential inlets and central outlets. Figure 1 shows these geometries and their main dimensions.
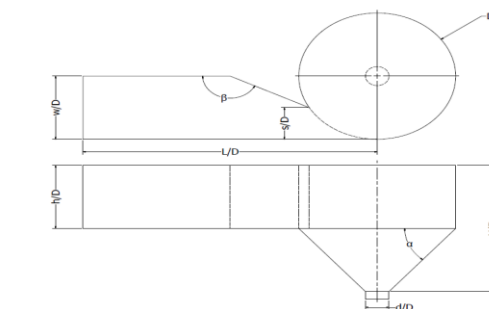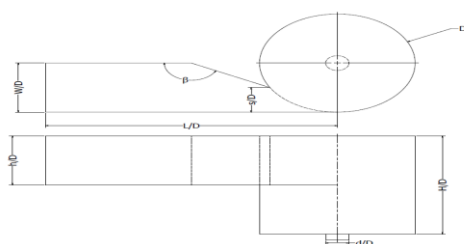

Figure 1. Main Dimensions for: (a) The Cylindrical Basin, and (b) The Conical Basin [4].

Dhakal, et al. [5] studied to compare the Strength of the vortices formed by conical and cylindrical basins. Tests of the same turbine on a conical basin provided a maximum efficiency of 29.63%, which is significantly greater than the values obtained from the tests on a cylindrical basin. Dhakal et al. [6] studied the optimization of three different runner designs with straight, twisted, and curved blade profiles to improve the efficiency of the GWVPP. The CFD analysis using Ansys CFX showed that the curved blade profile was the most efficient, with a peak efficiency of 82%, compared to 46% for the straight blade runner and 63% for the twisted blade profile. The experimental turbine test confirmed that the runner's behavior aligned with the predictions from the CFD analysis and had a peak efficiency of 71% at a head of 0.5 m. Sritram and Suntivarakorn [7] studied the effects of blade number and turbine baffle plates on the efficiency of a free-vortex water turbine. The laboratory experimentation showed that the 5-blade turbine is suitable because it yields the highest torque from the impact of water flow. The testing results also showed that the installation of baffle plates on both the top and bottom blades, with the curve area around the blades comprising 50% of the total, achieved the highest

efficiency of 43.83%, which was 6.59% higher than the efficiency achieved without baffle plates. Dhakal et al. [8] studied the runner position in the basin to generate the maximum output power from GVVP. The maximum output power was found at the runner position of 65–75% of the total height of the basin from the top position for both cylindrical and conical basins. From this information, the objective of this study was to investigate the effect of blade heights on the efficiency of power generation from a free-vortex flow water turbine. The current study is building upon earlier work [9]. The study was based on a laboratory experiment.

II. MATERIAL AND METHODS

2.1. Testing Equipment

This study was conducted on shaft power generation using a free-vortex water turbine in the laboratory of the Department of Mechanical Engineering at the University of Lampung. Figure 2 shows the scheme of the testing equipment for the free vortex turbine system. The system comprises an upper storage tank measuring $1\times1\times1$ m, connected to a channel and a conical basin with an inlet diameter of 600 mm and a height of 800 mm. At the bottom of the conical basin, there is a water outlet hole with a diameter of 100 mm, and a water pump with a capacity of 1,000 liters/minute is employed. In Figure 2, water is pumped from a storage tank below through a pipe. The water flows into the upper tank, then through a pipe before reaching the vortex basin. In the vortex basin, a turbine is installed with its shaft to harness the energy from the centrifugal force of the vortex in the conical basin. Subsequently, the water flows centrifugally to the lower water storage tank, where it is continuously pumped back for use in the experiment. This device transforms kinetic energy derived from low head water flow to turn a turbine and produce mechanical energy that can be used to generate electricity.
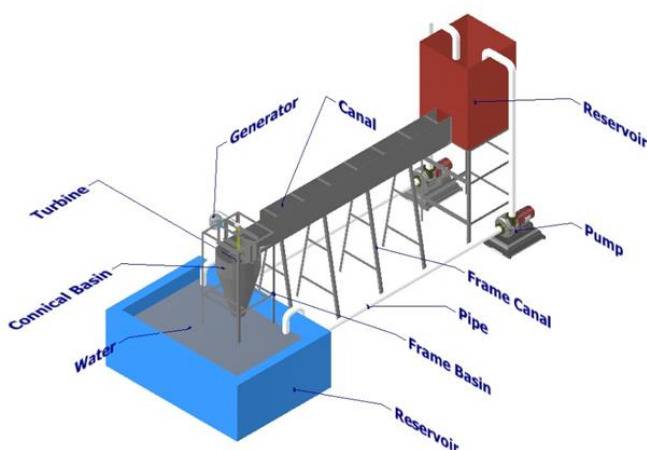

Figure 2. Schematic of Testing Equipment

2.2. Turbine

The schematic model of the turbine to be used in the testing equipment is shown in Figure 3. The parameters of the turbine are the height of the turbine (H), the top and bottom diameters of the turbine (D_1 and D_2), the shape of the blade,

the number of blades (n), and the blade angle of inclination (α). The heights of the test turbines were 208 mm, 248 mm, 288 mm, and 288 mm, and each had six blades. The top and bottom diameter values for each turbine height can be seen in Table 1. The blades were made of iron and were curved in the shape shown in Figure 2. The inclination of the turbine blades mounted on the turbine shaft is 19°.

Table 1. Top and Bottom Diameter Values

No	Turbin height (mm)	Bottom diameter (mm)	Top diameter (mm)
1	208	200	336
2	248	200	355
3	288	200	380
4	320	200	400

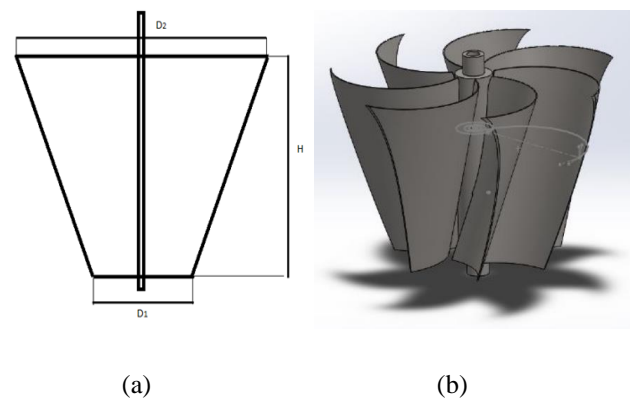(a)   (b)

Figure 3. (a) Turbine Parameters. (b). 3 Drawing of Turbine Model.

The measurement instruments used to conduct this laboratory experiment are a torque meter to measure the turbine shaft torque, a tacho meter to measure the turbine rotation speed (rpm), and a propeller flow meter to measure the velocity of flow (m/s).
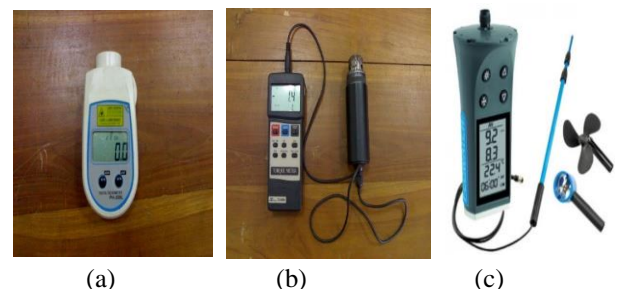

(a)   (b)   (c)

Figure 4. Photograph of Measurement Instruments: (a) Tacho Meter; (b) Torque Meter; and (c) Propeller Flow Meter.

2.3. Experimental method

To determine the suitable height of the turbine blades, the efficiency of the turbine operation was tested using turbines with heights of 208 mm, 248 mm, 288 mm, and 320 mm. This laboratory test aimed to find shaft power generation from a free-vortex water turbine. The water flow rate was set at

0.0088 m³/s, 0.0105 m³/s, dan 0.0108 m³/s, and measurements were taken for water head, turbine torque and turbine speed. The results were used to calculate efficiency values.

The efficiency ηt of turbine can be calculated using the equation [10]:

$$\eta_t = \frac{P_t}{\rho \cdot g \cdot Q.H} \qquad (1)$$

where Pt is turbine shaft power (W), ρ is water density (kg/m3), Q is volume flow rate, and H is vortex height. The power of a turbine is calculated using the equation:

$$P_t = T\omega \qquad (2)$$

where T is turbine torque (N.m), and ω is rotational speed of turbine (rad/s).

III. RESULT AND DISSCUSSION

A photo of the fabricated experimental setup is shown in Figure 5, with the turbine shown in Figure 6. The channel is 4 m long with a cross-sectional area of 250 mm x 400 mm. Notch angle and notch inlet width are 18º [11] and 100 mm. The fabricated conical basin is shown in Figure 7.

Figure 5. Fabricated testing Equipment System.

Figure 6. Turbines Used in the Experiment

Figure 7. Fabricated Conical Basin.

Figure 8, 9, 10 and 11 show the relationship between turbine shaft power and speed for turbine heights of 208 mm, 248 mm, 288 mm, and 320 mm, respectively. Each turbine was tested with volume flow rates of 0.0088 m³/s, 0.0105 m³/s, dan 0.0108 m³/s. Figure 8, 9, 10, and 11 show that the power initially increases until it reaches its peak power and then decreases as speed increases. This is due to the torque produced to overcome the load on the turbine shaft, which decreases linearly as the turbine speed increases. The peak power occurs at different speeds for all flow rates. In Figure 8, the turbine with a height of 208 mm yields the maximum turbine power of 15,97 W at a flow rate of 0.0108 m3/s, in Figure 9, the turbine with a height of 248 mm yields the maximum turbine power of 12,22 W at the flow rate of 0,0108 m³/s, in Figure 10, the turbine with a height of 288 mm yields the maximum turbine power of 25,82 W at the flow rate of 0,0108 m³/s, and in Figure 11, the turbine with a height of 320 mm yields the maximum turbine power of 19,58 W at the flow rate of 0,0108 m³/s. These test results show that the turbine with a height of 288 mm yields the maximum power at the same volume flow rate compared to turbines with heights of 208 mm, 248 mm, and 320 mm. It was found that when the height of the turbine blades was increased to 288 mm, the surface area also increased to receive the impact from the centrifugal flow of water, resulting in higher torque. But when the height of the blades reached 320 mm, the blades were too high, causing the water flow through the hole to develop resistance against the movement of the blades, resulting in a reduction in the torque produced by the turbine.
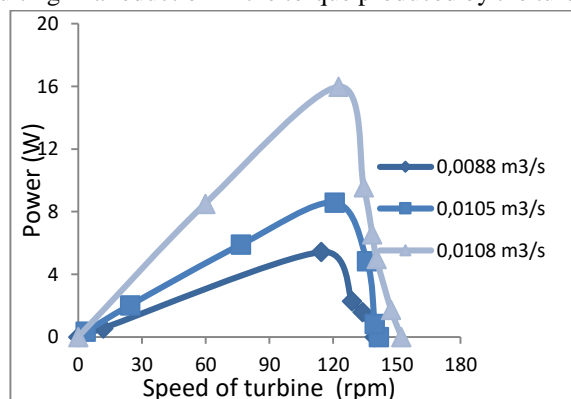

Figure 8. Rotational Speed vs Turbine Power Using a Turbine Height of 208 mm
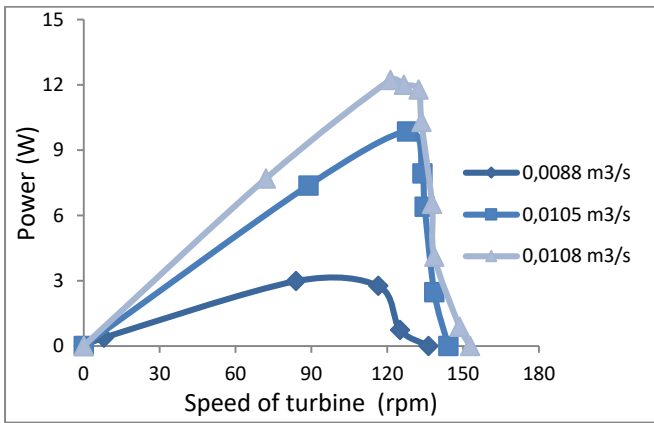
Figure 9. Rotational Speed vs Turbine Power Using a Turbine Height of 248 mm.
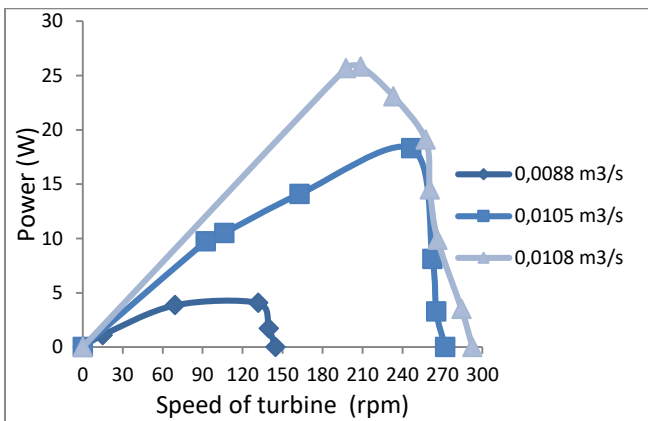

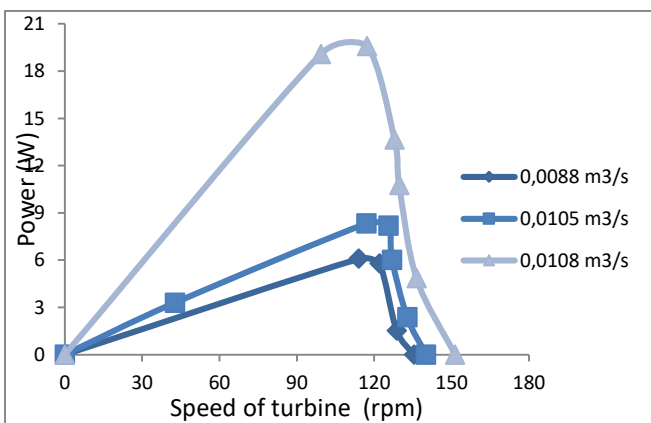**Figure 10. Rotational Speed vs Turbine Power Using a Turbine Height of 288 mm.**

Figure 11. Rotational Speed vs Turbine Power Using a Turbine Height of 320 mm

The test results of the turbine's efficiency against speed are shown in Figure 12, 13, 14, and 15. These figures show the same trend where the curves initially increase until it reaches its peak efficiency and then decrease as speed increases for all volume flow rates. In Figure 12, the turbine with a height of 208 mm yields the maximum efficiency of 18,97 % at a flow rate of 0,01 m^3/s, in Figure 13, the turbine with a height of 248 mm yields the maximum efficiency of 19,01 % at a flow rate of 0,01 m^3/s, in Figure 14, the turbine with a height of 288 mm yields the maximum efficiency of 30,46 % at

flow rate of 0,01 m^3/s, and in Figure 15, the turbine with a height of 320 mm yields the maximum efficiency of 28,96 % at flow rate of 0,01 m^3/s. This is because operating the turbine with a blade height of 288 mm produced the maximum power when it received water jets, in contrast to the turbines with blade heights of 208 mm, 248 mm, and 320 mm.
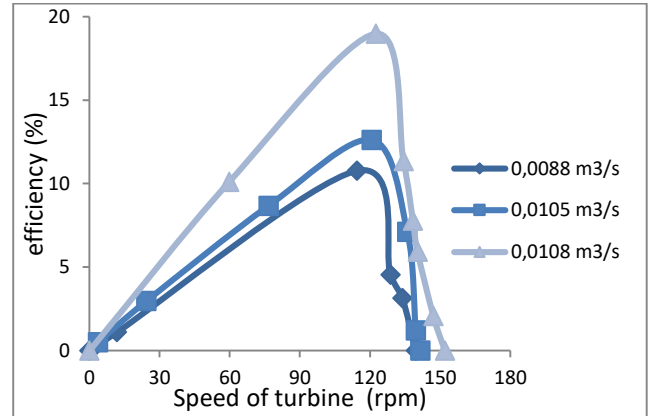

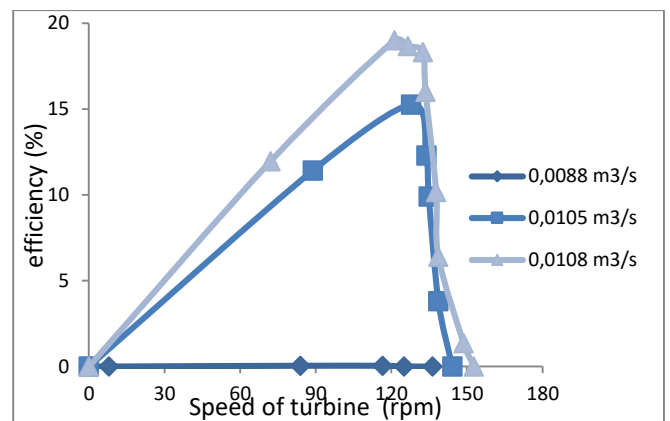**Figure 12. Rotational Speed vs Efficiency Using a Turbine Height of 208 mm**

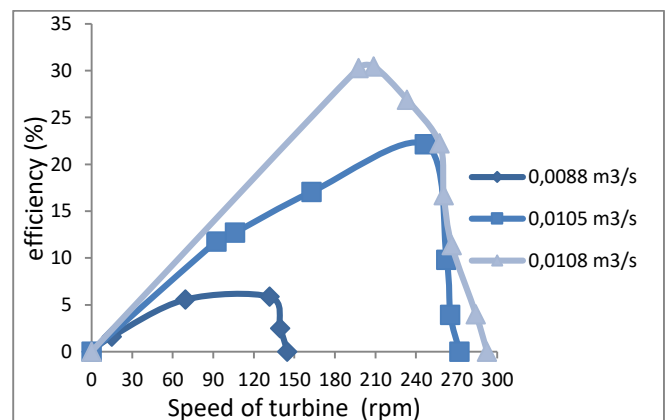**Figure 13. Rotational Speed vs Efficiency Using a Turbine Height of 248 mm**

Figure 14. Rotational Speed vs Efficiency Using a Turbine Height of 288 mm
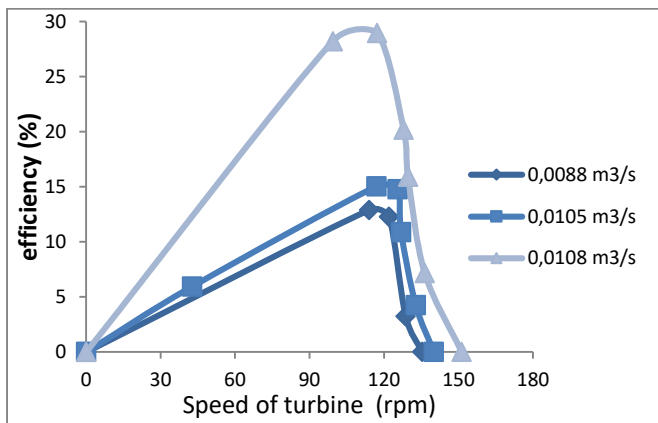
Figure 15. Rotational Speed vs Efficiency Using a Turbine Height of 320 mm

CONCLUSIONS

The study showed that the height of turbine blades affect the efficiency of the free vortex turbine. The water turbines with six curved blades and heights of 208 mm, 248 mm, 288 mm, and 320 mm were tested in a conical basin with an inlet diameter of 600 mm, an outlet diameter of 100 mm, and a height of 800 mm The water flow rate was set at 0,0088 m3/s, 0,0105 m³/s, and 0,0108 m³/s. It was found that the turbine with a blade height of 288 mm, or a height ratio (blade height/basin height) of 3, was the most appropriate for use. It yielded the highest power and efficiency because the surface of the blades was effective at receiving the impact from the centrifugal flow of water. The test results showed that the turbine with a height of 288 mm provided a maximum efficiency of 30.46% at a water flow rate of 0.0108 m³/s, which was higher than the values obtained in all the other turbine tests.

ACKNOWLEDGMENT

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