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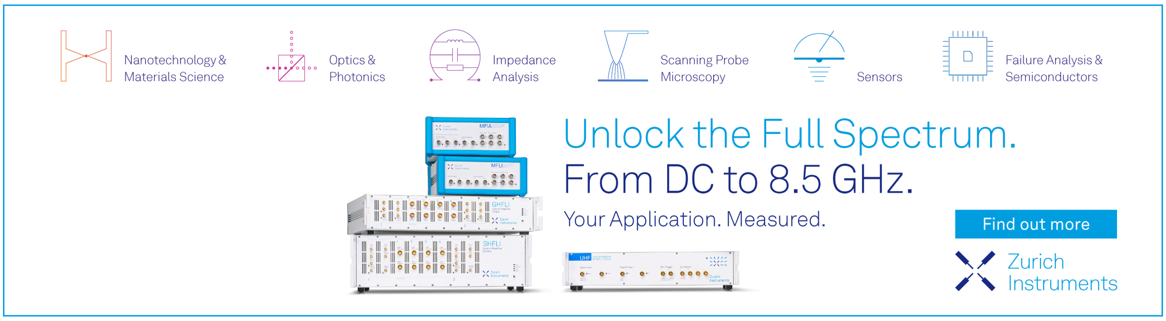

Development of Testing Equipment of Gravitational Water Vortex Turbine

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Abstract. This paper presents the development of a gravitational water vortex turbine model for testing equipment. This testing equipment will be used to support the laboratory work and conduct research by the lecturers and students at the Mechanical Engineering Department, University of Lampung. The design is based on the geometry of the circulation tank, the profile of the blades, and the number of blades. This testing equipment consists of a conical circulation basin with an inlet diameter of 60 cm and an outlet diameter of 10 cm and a turbine with a top diameter of 20 cm and a bottom diameter of 15 cm using curved blades. The tests were carried out for the different numbers of turbine blades by varying the flow rate from 8 l/s to 12 l/s. The test results showed the highest efficiency of 22,04 % using six turbine blades, compared to four or five turbine blades at a flow rate of 10 l/s. Test results of this testing equipment also showed it could provide the performance characteristics of a gravitational water vortex turbine properly to carry out the laboratory work.

INTRODUCTION

The learning process taking place at the Faculty of Engineering, Mechanical Engineering, University of Lampung currently consists of 10 laboratories: CNC Lab, Design Lab, Materials Lab, Manufactured Products Lab, Computer, Industrial Metrology Lab, Structural Mechanics Lab. Thermodynamics Laboratory, Fluid Dynamics Laboratory, and Internal Combustion Engine Laboratory. These laboratories serve as research facilities for teachers and students to carry out laboratory work. Laboratory work is of great importance in engineering education, enabling students to plan and conduct laboratory experiments, analyze and interpret data, effectively communicate technical results through report writing, and basic concepts. It is intended to help develop skills in obtaining and using information and engineering literature, including prerequisite course. Due to limited university funding, currently available test equipment is inadequate to support work in this laboratory. Therefore, it is necessary to have test equipment sufficient to meet the needs of laboratory operations. This paper presents the design and development of a Gravity Water Vortex Turbine (GWVP) turbine model test rig to support the conduct of laboratory work at the Department of Mechanical Engineering, University of Lampung. The developed test rig will also be tested to see if it can properly perform the gravity water vortex turbine.

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Turbine

Turbine is one of the most important components for vortex flow power generation. The turbine is positioned in the center, aligned with the central outlet of the basin. The turbines convert the vortex flow energy of water to mechanical work. turbine is forced by the water power that came from the water vortex and converts to mechanical work. The optimal turbine blade position in a vortex flow power plant for a conical basin is 65-75% of the total height of the basin from the top position because at this position the maximum speed is reached [1].. Three different blades with straight (rectangular blade), angled blade, and curved (curved blade) where the blade profile is rectangular also studied and concluded that the curved blade profile is suitable for vortex flow power generation [2]. The results also show that efficiency decrease with an increase in the number of blades because it causes greater distortion in the vortex. Increasing the turbine blade radius also reduces the efficiency of the turbine, this is caused by friction on the inner surface of the basin [3]. Sritram and Suntivarakorn [4] conducted a study on the effect of the number of blades and baffle plates of a turbine on the efficiency of a free vortex flow turbine. The experiments showed the number of turbine blades with five blades was the most suitable number of blades because it produced the maximum torque when receiving jets of water. Insulation plates are also designed and installed at the top and bottom of the turbine blades. The results showed that the proportion of 50% of the curvature of the area was the most suitable, and the blades installed with the upper and lower insulating plates had the highest efficiency of 43.83%, which was 6.59% higher than without the insulating plates.

Acharya, et al.[5] conducted a simulation to optimize the shape of the motion of a free vortex power plant using a conical basin. In this study, two parameters of the inlet jet angle and the radius of curvature of the turbine blades on torque, power and turbine efficiency were studied. Both parameters were analyzed analytically and verified using 3-d simulation. The results showed that the maximum torque generated is 0.413 Nm at the angle of the blade inlet of 18^o and a radius of curvature of 285 mm.

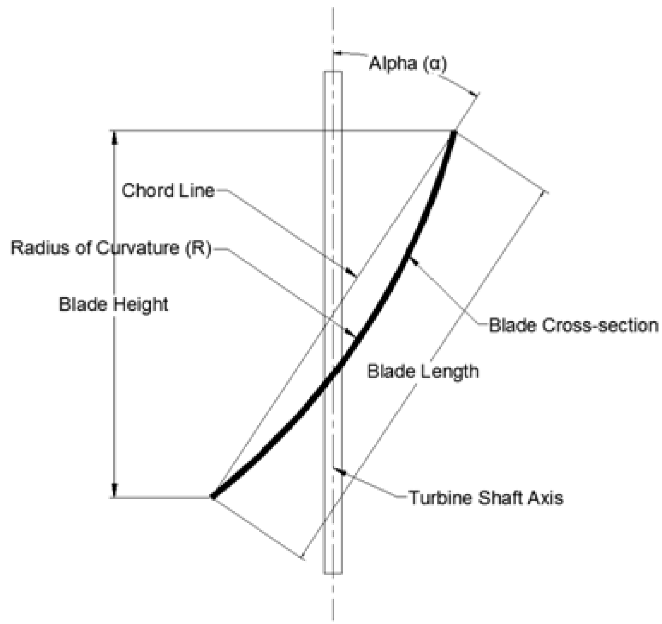


FIGURE 1. Turbine blade parameters [5].

Configuration Inlet and Outlet

The inflow of water discharged into the sewers connected to the basin determines the inflow of the GWVPP. Channels direct water flow tangentially into a basin. The width of the channel between the two ends can be different or the same. Inlet height indicates the height of the channel from the floor of the pool. The inlet and outlet parameters are shown in Figure 2.

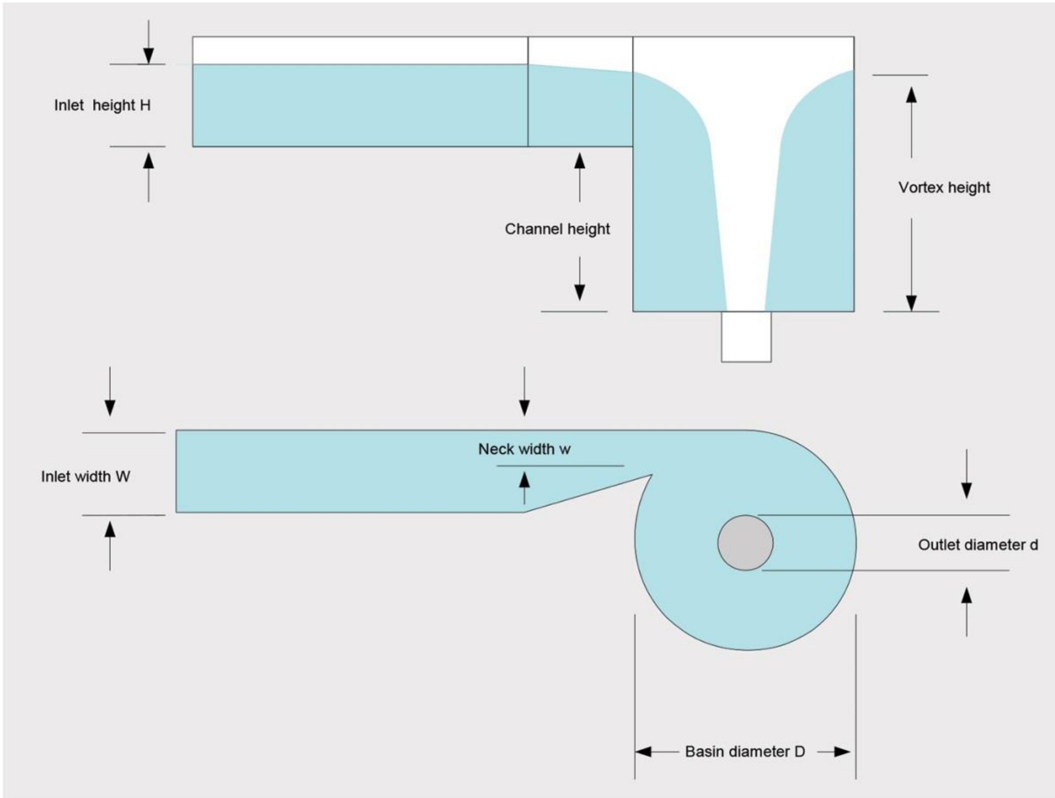


FIGURE 2. Scheme of gravitational water vortex power plant

Figure 2 shows the exit of the basin. Its diameter has a great influence not only on the efficiency of the vortex turbine, but also on the strength of the vortex [6] [7]. Wanchat et al. reported the effect on the efficiency of a vortex turbine for varying the exit diameter from 0.10 m to 0.40 m. investigated both numerically and experimentally. al. [6]. The model used a cylindrical pool with a diameter of 1 m and a height of 1 m. The inlet channel converged at the pool-connected end and the inlet velocity was set to 0.1 m/s. A five-blade vertical axis turbine was used to generate electricity. A suitable exit diameter was found to be in the range of 0.20 m to 0.3 m. The overall system efficiency was 30%. Shabala et al. al. [7] performed simulation and experimental studies on GWVPP. For this model, we used a cylindrical washbasin with a height of 100 cm, a diameter of 100 cm, and an outlet diameter of 20 cm. Simulation results showed that the exit velocity is inversely proportional to the exit diameter. The exit velocity is highest when H$inle$t is maximum, which is consistent with the experimental results. power etc. [8] also found that inlet flow rate has a significant effect on efficiency. The efficiency of the vortex turbine was directly proportional to the inlet flow rate and the optimum inlet height was 35% of the reservoir height.

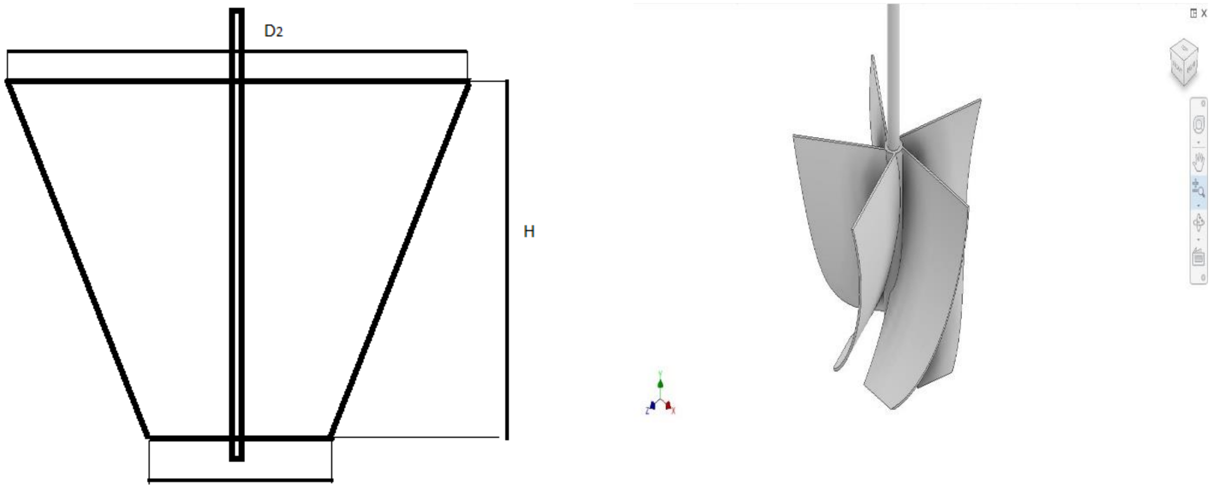
Basin Configurations

There are different eddy profiles depending on the GWVPP watershed design. Wanchat and Suntivarakorn [9] performed simulations to study the parameters affecting the velocity vector flow field using his three proposed designs: inlet guide. We found that cylindrical cymbals with inlet guides were the most suitable cymbals as they provided better and more consistent velocity than other cymbals. Dakar et al. Al. [10] The study was conducted using a conical pelvis instead of a conventional cylindrical pelvis. Vortex velocities were measured for various pool diameters, notch angles, notch inlet widths Win, cone angles and channel heights Hc$hannel$. Win, cone angle, and Hc$hannel$ were found to have the greatest effect on vortex velocity. To maximize performance, the value of Win should be as small as possible, and the cone angle and Hc$hannel$ should be as high as possible. It is also recommended to keep the notch length (air intake duct length) as long as possible to avoid unnecessary losses.

MATERIAL AND METHODS

Turbine Parameters Determining

The model of designed turbine to be used in the testing equipment is shown in Figure 2. The parameters of turbine to be determined: height of turbine H, diameter of turbine D_1 and D_2, shape of blade, number of blades n, and blade angle of inclination α.



(a) (b)

FIGURE 3. (a) Turbine parameters. (b). 3 d drawing of turbine model.

Determining the dimensions of the testing equipment system and the parameters of the turbine should consider the space conditions of the Fluid Mechanics Laboratory and the available measurement instruments. 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.

Fabrication of Testing Equipment

The scheme of the testing equipment design can be seen in Figure 4. This device transforms kinetic energy derived from low head water flow to turn a turbine and produce mechanical energy that can be used to drive an electricity generator.

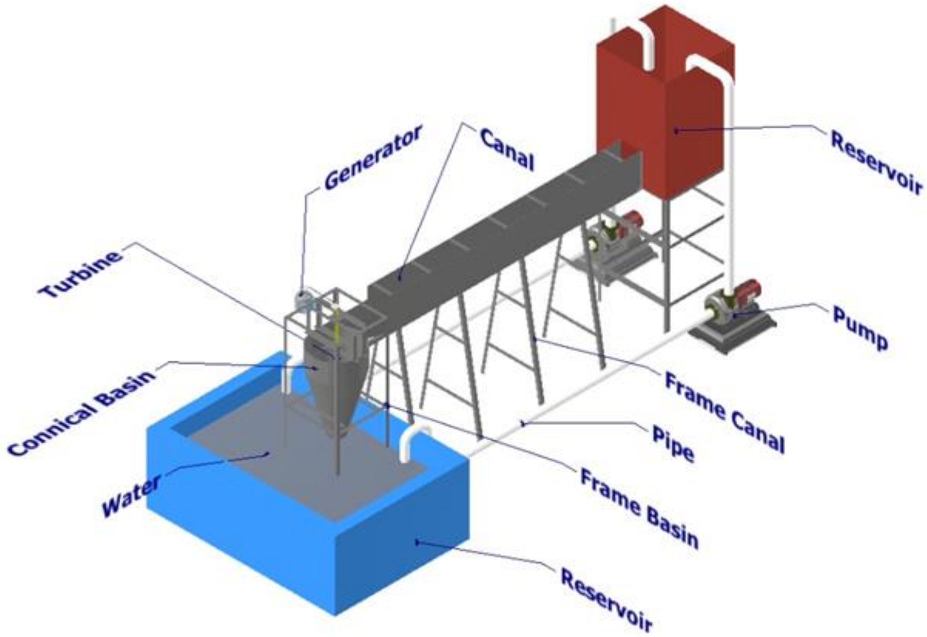


FIGURE 5. Schematic of testing equipment

The efficiency η_t of turbine model can be calculated using the equation:

$$\eta_{sys} = \frac{P_t}{\rho \cdot g \cdot \mathrm{Q.\,H}} \tag{1}$$

where P_t is turbine shaft power (W), ρ is water density (kg/m^3), Q is volume flow rate, and H is vortex height. The power of a turbine is calculated using the equation:

$$P_t = T\omega \tag{2}$$

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

RESULTS AND DISCUSSION

According to the conditions of space in our Fluid Mechanics Laboratory, the volume of the reservoir and the long and cross-sectional area of the channel were determined to be 1 m^3 and 4 m and 25 cm x 40 cm, respectively. Notch angle and notch inlet width are 18^o [11] and 10 cm. To carry out the test, the available head of flow is 1 m. The volume flow rate in the channel was measured by a propeller flow meter, which varied from 1.37 m/s to 1.56 m/s.

FIGURE 6. Channel of testing equipment.

Turbine Model

The turbine blade has a rectangular blade profile. According to the results, it is concluded that the curved blade profile is suitable for vortex flow power plants [5]. The turbine is positioned in the center, parallel to the outflow at the center of the circulation tank. The optimal turbine blade position in a vortex flow power plant is 65–75% of the overall height of the tank measured from the top of the channel. In this test, the position of the turbine is 320 mm from the bottom of the tank. The shape of the turbine follows the shape of the cylindrical basin with a turbine height of 288 mm and top and bottom turbine diameters of 380 mm and 200 mm, respectively. The inclination of the turbine blades mounted on the turbine shaft is 18° [5]. Tests were carried out to determine the performance of turbines with 4, 5, and 6 blades.

FIGURE 7. Turbine model

Basin Design

The cylindrical basin with an inlet guide was used according to the recommendation of Dhakal et al. [1]. The conical basin's inlet diameter is 600 mm. The orifice diameter was calculated to be 100 mm. Optimum vortex strength occurs within the range of orifice diameter to tank diameter ratios (d/D) of 14%–18% for low and high head sites, respectively [3]. For an orifice diameter of 100 mm, the ratio is 16%, which is reasonably close to the value at which the optimum vortex strength occurs.

FIGURE 8. Conical basin

Test Results and Disscussion

Figure 10, 11, and 12 show the relation between turbine shaft power and speed for 4 blades, 5 blades, and 6 blades, respectively. Each turbine was tested with volume flow rates of 0,008 m^3/s, 0,01 m^3/s, and 012 m^3/s. The variation of turbine shaft power with speed is seen to be parabolic in all turbines tested. Figure 10, 11, and 12 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 10, the turbine with 4 blades yields the maximum turbine power of 17,08 W at the flow rate of 0,012 m^3/s; in Figure 11, the turbine with 5 blades yields the maximum turbine power of 14,71 W at the flow rate of 0,012 m^3/s; and in Figure 12, the turbine with 6 blades yields the maximum turbine power of 17,01 W at the flow rate of 0,010 m^3/s. These test results show the turbine with six blades yields the most power at the same volume flow rates compared to turbines with four and five blades. It is due to the surface area turbine with 6 blades contacting with water was greater, resulting in higher torque due to impact from the centrifugal flow of water. These results are different from those found by Sritram and Suntivarakorn [4] and are in agreement with the experimental investigations in [12]. This indicates that it may increase the number of blades to increase the power of the turbine produced for future work.

FIGURE 9. Testing equipment

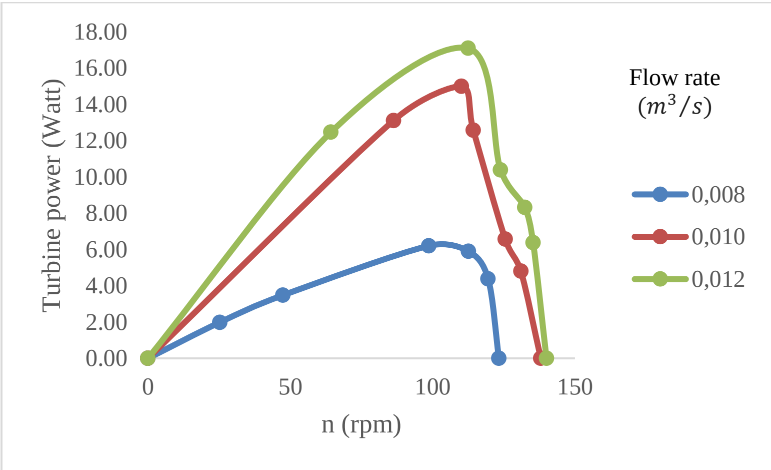


FIGURE 10. Rotational speed vs turbine power using 4 blades

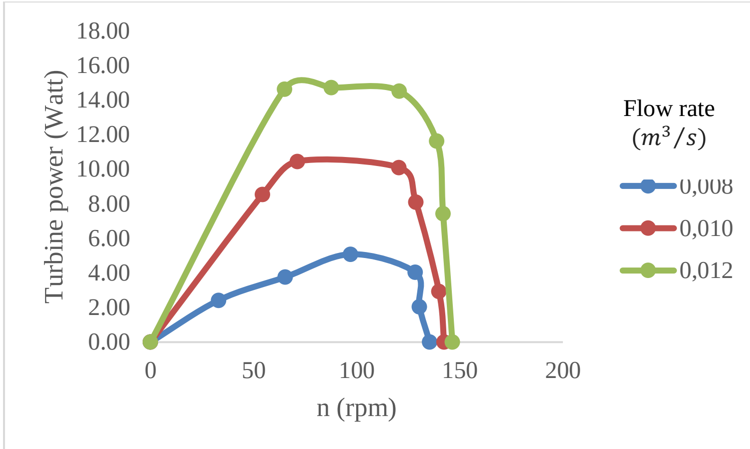


FIGURE 11. Rotational speed vs turbine power using 5 blades

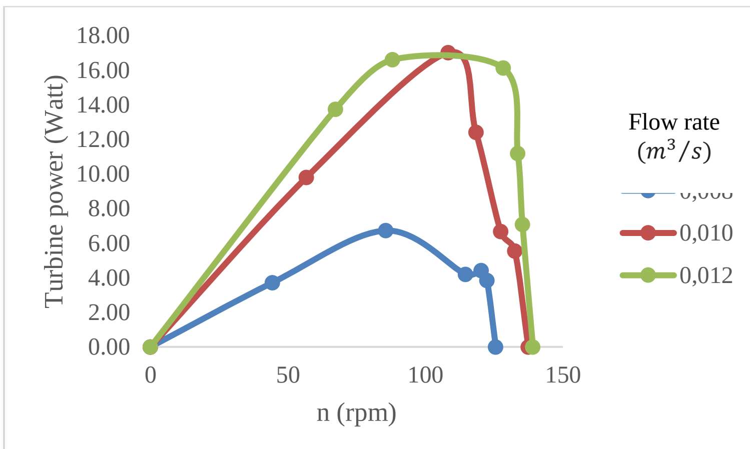


FIGURE 12. Rotational speed vs turbine power using 6 blades

The test results of the efficiency against speed of the turbine are shown in Figure 13, 14, and 15. It can be seen that the trend of the curve initially increases until it reaches its peak efficiency and then decreases as speed increases for all flow rates. In Figure 13, the turbine with 4 blades yields the maximum efficiency of 19,66 % at flow rate of 0,01 m^3/s, in Figure 14, the turbine with 5 blades yields the maximum efficiency of 15,21 at flow rate of 0,012 m^3/s, and in Figure 15, the turbine with 6 blades yields the maximum efficiency of 22.04 % at flow rate of 0,01 m^3/s. This is due to the operation of turbine using 6 blades was the most suitable number of blades because it produced maximum torque when receiving jets of water compared to the turbine with 4 and 5 blades.

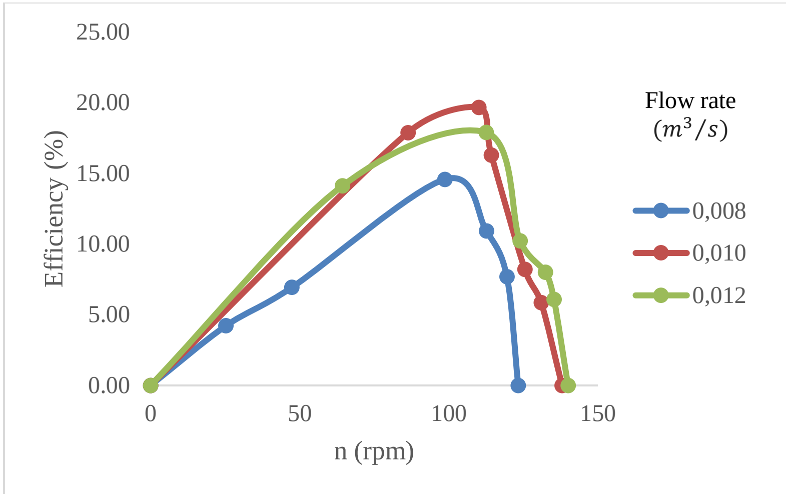


FIGURE 13. Rotational speed vs efficiency using 4 blades

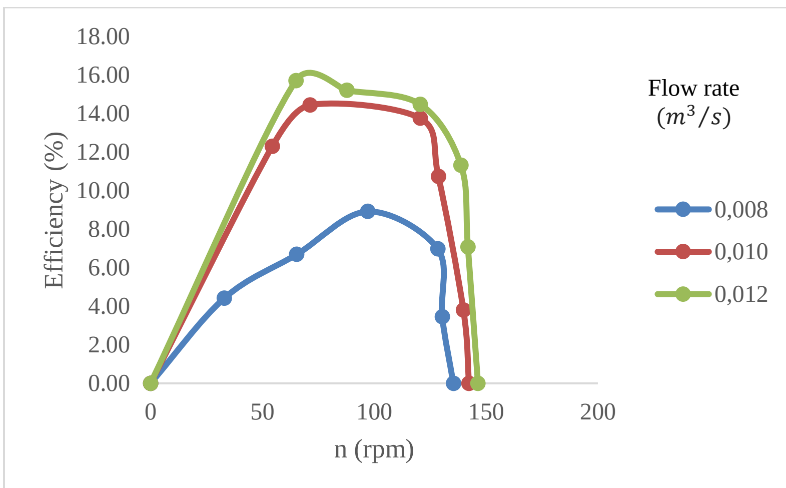


FIGURE 14. Rotational speed vs efficiency using 5 blades

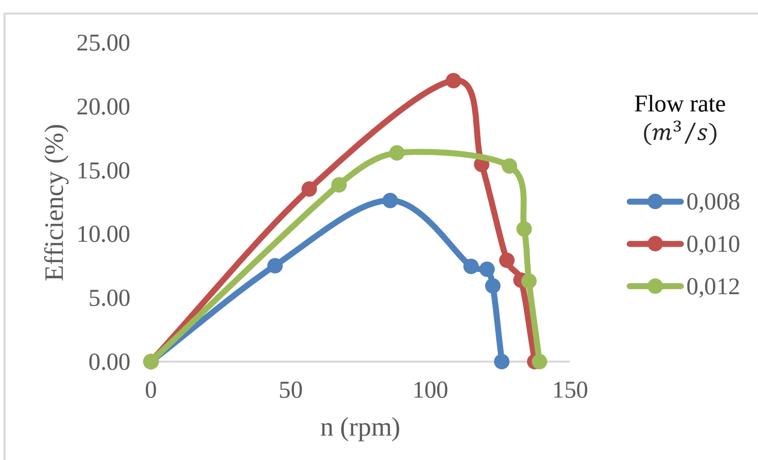


FIGURE 15. Rotational speed vs efficiency using 6 blades

This developed testing equipment can provide properly the test results of the performance of the vortex turbine, so this equipment can be used to support the implementation of laboratory work in Mechanical Engineering to help the students to understand how the vortex turbine converts vortex flow energy of water into mechanical energy, and how the blade numbers and flow rates influence the performance characteristics of vortex turbine. This testing equipment will also help the students who are interested to study to improve the performance of this turbine when it is applied to the system of hydroelectric power generation.

CONCLUSIONS

The development of vortex turbine model test equipment to support the laboratory work of mechanical engineering department is introduced. The components of this test facility are: 4 m long, 25 cm x 40 cm cross section, 18° angle, 10 cm wide notch, 60 mm inlet diameter, 10 cm outlet diameter, 288 mm height, 380 mm top diameter, 3 turbines with a lower diameter of 200 cm. Each turbine has blade numbers 4, 5, and 6. The test results show that this vortex turbine test rig can adequately perform the characteristics of low-head vortex turbines that harness the flow energy of the flow. The test facility consists of a conical basin with a length of 4 m, a cross section of 25 cm x 40 cm, an angle of 18°, a notch width of 10 cm, and an inlet diameter. Three turbines with a diameter of 60 mm, an exit diameter of 10 cm, a height of 288 mm, an upper diameter of 380 mm and a lower diameter of 200 cm. Each turbine has 4, 5, and 6 blade numbers. The test results show that this vortex turbine test rig can adequately perform the characteristics of low-head vortex turbines that harness the flow energy of the flow. The test results show that the number of blades and the flow rate affect the performance of the vortex turbine, with the 6-blade turbine showing the highest maximum turbine efficiency of 22.04%, and the maximum efficiency of 4 and 5 blades being 19.66%. and .15.21%. The trends in the curve of the test results are similar to those found in previous studies by researchers. It concludes that this test instrument can be used to support laboratory work, giving students the opportunity to develop their abilities in designing and conducting experiments, analyzing and interpreting data.Acknowledgments. This work was supported by Penelitian Produk Terapan Grant 2021. The authors would like to acknowledge the financial support from LPPM, University of Lampung.

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