

Performance Analysis of Micro Hydro Power Plants Using a Pelton Turbine with Two Nozzle Variations

Abstract: This research begins with the design, assembly, operation and testing stages of the plant. The type of turbine being tested is a vertical thrust pelton turbine with a variation of 2 nozzles. The purpose of this study was to find the effect of the position of the two angles and the diameter of the nozzle on the water discharge. The steps taken in this test are that the 1st nozzle is placed at an angle position of 0°, and the 2nd nozzle is varied at the angle position of 15°, 30° and 45°, and also with variations in the diameter of the nozzle of 0.5 cm, 0.75 cm, and 0.9 cm to determine the turbine performance. And looking for the value of turbine efficiency, system efficiency and generator efficiency. The results showed that the maximum input power value in this study was 14.40 Watt. The maximum torque value occurs at an angle of 45° with a nozzle diameter of 0.75 cm by 33.78 kg.mm, the maximum turbine power occurs at an angle of 45° with a nozzle diameter of 0.5 cm at 4.52 Watt, the maximum power of the electric generator occurs at an angle of 45° with a nozzle diameter of 0.5 cm of 1.25 Watt. The maximum turbine efficiency occurs at an angle of 45° with a nozzle diameter of 0.75 of 99.98%. The maximum system efficiency occurs at an angle of 45° with a nozzle diameter of 0.9 cm by 15.12%. The maximum efficiency of the electric generator occurs at an angle of 45° with a nozzle diameter of 0.9 cm for 97.99%.

Streszczenie: Badania te rozpoczynają się od etapu projektowania, montażu, eksploatacji i testowania instalacji. Typ testowanej turbiny to turbina Peltona o pionowym ciągu z odmianą 2 dysz. Celem badań było określenie wpływu położenia obu kątów oraz średnicy dyszy na wypływ wody. Kroki podjęte w tym teście polegają na tym, że pierwszą dyszę ustawia się pod kątem 0°, a drugą dyszę zmienia się pod kątem 15°, 30° i 45°, a także ze zmianami średnicy dyszy o 0,5 cm, 0,75 cm i 0,9 cm, aby określić wydajność turbiny. I szukanie wartości sprawności turbiny, sprawności układu i sprawności generatora. Wyniki pokazały, że maksymalna wartość mocy wejściowej w tym badaniu wyniosła 14,40 W. Maksymalna wartość momentu obrotowego występuje przy kącie 45° przy średnicy dyszy 0,75 cm na 33,78 kg.mm, maksymalna moc turbiny występuje przy kącie 45° przy średnicy dyszy 0,5 cm przy 4,52 Wat, maksymalna moc silnika elektrycznego generator występuje pod kątem 45° przy średnicy dyszy 0,5 cm o mocy 1,25 W. Maksymalna sprawność turbiny występuje przy kącie 45° przy średnicy dyszy 0,75 wynoszącej 99,98%. Maksymalna wydajność układu występuje pod kątem 45° przy średnicy dyszy 0,9 cm o 15,12%. Maksymalna wydajność generatora elektrycznego występuje pod kątem 45° przy średnicy dyszy 0,9 cm dla 97,99%. (Analiza wydajności mikro elektrowni wodnych Używanie turbiny Peltona z dwoma wariantami dysz)

Keywords: Pelton Turbine, Two Nozzles, Generator, Micro Hydro, Generator

Słowa kluczowe: Turbina Peltona, Dwie Dysze, Generator, Micro Hydro, Generator

1. Introduction

The need for electricity is increasing yearly due to increased development, especially in the industrial sector, economic growth and population growth in Indonesia. Electricity supply from PLN does not cover all regions of Indonesia, especially areas with geographical locations that are difficult to reach but have good renewable energy potential [1]. One of these energy potentials is water's energy potential, which can be converted into electrical energy using a water turbine connected to a generator [2]. A power plant that uses the possibility of water is a type of Hydroelectric Power Plant [3].

Micro hydro is one of the most suitable and efficient renewable energy sources that has been used for more than a century. Most rural areas in developed and developing countries use hydroelectric power to generate electricity cheaply and efficiently. Micro-hydro is often used as a type of Micro-hydro Power Plant [4].

Micro hydro is a small-scale power plant that utilizes river water flow as power (resources) to drive water turbines by converting the potential energy of water into mechanical work, which will turn water turbines and generators to produce electrical energy. The construction of Micro hydro is simple and can be operated in remote areas and areas around rivers that have not yet received electricity [5].

Micro-hydro has three main parts to produce electrical energy: water as a source of driving power, water turbines and generators. Of these components, which plays an essential role as an energy converter to generate electrical energy, is a water turbine—the water turbine functions to convert the water's kinetic energy into mechanical energy to rotate the generator. Several types of turbines can be applied to Micro-hydro, one of which is the Pelton turbine [6].

The Pelton turbine is an impulse turbine because, in the Pelton turbine, the twist occurs due to the deflection of the water jet in the double runner bowl [7]. Therefore the

Pelton turbine is also called a free jet turbine. The water flowing out of the nozzle is the same pressure as the surrounding atmospheric pressure. The high energy of the place and stress when it enters the Pelton turbine blades will be converted into velocity energy [8].

This water turbine takes advantage of a high head of water even with a slight water discharge [9] The efficiency of a Pelton turbine depends on several design parameters, namely runner diameter, runner length, runner speed, turbine power, blade spacing and number of blades, blade curvature radius, and nozzle direction to the turbine. In Pelton turbines, it is possible to use more than one jet (nozzle).

Previous studies discussed the influence of the angle and diameter of the nozzle on the efficiency of the Pelton turbine on Micro-hydro, which was carried out by [5]. Research [10, 11] discusses increasing the power output of micro hydro by adding the number of nozzles. This study examines the Micro hydro prototype using a Pelton turbine with a vertical shaft. Two nozzles will be used where the first nozzle is installed in a fixed position, and the second nozzle varies the beam angle and uses different nozzle diameters. In addition, in this study, micro hydro was made in the form of a prototype so that it is easy to analyze system performance and also for practicum needs.

2. Research Methods

II.1. Design Stage

The design stage is the process of designing a tool, in other words, making a tool design pattern which is the first step before use. The things that will be done in the design of the Micro hydro Prototype design using a Pelton turbine are the shape and placement of the parts of this tool.

II.2. Assembly Stage

Assembly is a process of arrangement that supports each other so that the desired form of working mechanism

can be realized. The assembly process is divided into several stages:

a. Marking

Marking is the initial pressure in the assembly process on the frame. Some materials need to be measured and marked, such as the turbine housing to support the rotational load of the turbine and then the table as the tool holder.

b. Cutting

After being marked, make the turbine housing frame according to the drawing. Then make blades and disks by cutting. The cuts must be careful so that the shape's size remains symmetrical.

c. Installation

This process is the installation process between the disc and the turbine blade, then installing the large diameter pulley and connecting it to the small diameter pulley in the generator using a V-belt.

Figure 1 shows the micro hydro prototype design used in this study. Figure 2 shows the nozzle installation model on the turbine.

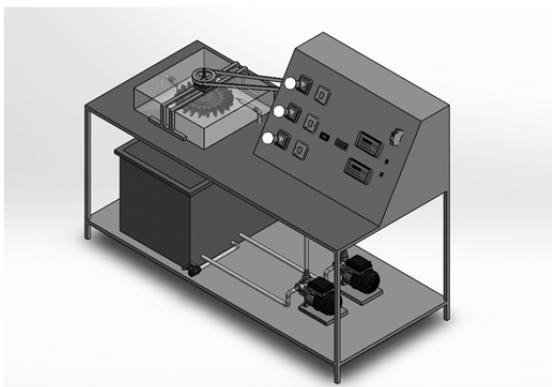


Fig 1. Micro Hydro Prototype Design



Fig 2. Turbine Nozzle Mounting Model

II.3. How the Tool Works

When the water pump is run and the stop valve is opened, the water in the water reservoir will flow to the turbine through the penstock pipe and nozzle, then hit the turbine blade so that the turbine rotates. The water that hits the turbine then falls back into the water reservoir. The rotating turbine will drive the generator pulley. Then the pulley will cause the generator to produce electrical energy.

II.4. Data retrieval

Data collection steps:

1. Prepare the equipment (laptop and plx – daq application).
2. Connect the laptop to Arduino on the circuit panel.
3. Open the plx – daq application and connect the laptop so that the value input can be read automatically.

4. Make sure both nozzles are installed with nozzles with the same nozzle diameter. (for initial data collection, a nozzle with a diameter of 0.5 cm was used).

5. In the first test, the first nozzle is installed at 0° position, and the second nozzle is installed at an angle of 15°.

6. Run the pump while waiting for the data recording to finish inputting on the laptop. (Data recording is in the form of turbine rotation (Nt), generator rotation (Ng), Discharge at both nozzles (Q1 and Q2), Current (I), and Voltage (V)).

7. After inputting data, stop the pump for a moment and reset the second nozzle inclination to 30°, then rerun the pump (the same goes when changing the nozzle inclination to 45°).

8. After inputting the data with a nozzle size of 0.5, turn off the pump and replace both ends of the nozzle with a diameter of 0.75 cm.

9. Repeat steps 4 – 7 (also for inputting data at a 0.9 cm diameter nozzle).

10. Testing and data collection are complete. Turn off Pump

II.5. Data collection

After the data collection process is carried out, the next step is data collection. Several parameters that need to be recorded include Generator rotation (Ng), Turbine rotation (Nt), Current generated by the generator (I), Voltage generated by the generator (V), and Water discharge at the nozzle (Q).

II.6. Data Processing and Data Analysis

After the data is collected, then data processing is carried out. Data processing is carried out as follows:

1. Calculate the power produced by the turbine (P)
2. Calculating Turbine efficiency (η_t), System Efficiency (η_s) and Generator Efficiency (η_g)
3. Make a graph of power (P) with turbine rotation (Nt)
4. Make a graph of efficiency (η) with turbine rotation (Nt)

II.7. Results of Micro Hydro Design

A micro hydro power plant is a power generation system that utilizes the water discharge around us to be converted into electrical energy. You do this by using the water discharge to drive a turbine which will produce mechanical energy. Furthermore, this mechanical energy drives the generator and produces electricity. The physical form of the micro hydro power plant that has been made is presented in Figure 3.



Fig 3. Micro Hydro prototype

3. Results and Discussion

III.1. Data analysis

Data processing or calculations have been carried out based on the experimental data loaded with a nozzle size of 0.5 and nozzle one at position 0° first data on the attachment page.

Calculation of the Turbine Speed Triangle

Nozzle Cross-sectional Area (A), Mass Flow Rate (\dot{m}), Flow Velocity (V), Input Power (P_{in}).

Calculation of the Turbine Speed Triangle

- Head Value (H)
- Runner Circumference Speed (U_1)
- Beam Speed (V_1)
- Calculation of Relative Speed of Beam (Vr_1)
- Angle Calculation at Entrance (β)
- Calculation of outflow velocity (V_f)
- Absolute speed calculation (V_2)
- Velocity of eddies at exit (Vw_2)
- Calculation of outflow velocity (U_2)

Turbine Performance Calculation

- Tangential Speed (ω)
- Turbine Specific Speed (N_s)
- Turbine Power (P_t)
- Generator Power (P_g)

Torque (T)

- Power Plan
- Torque

Calculation of Micro Hydro Efficiency

- Turbine Efficiency (η_t)
- System Efficiency (η_s)
- Generator Efficiency (η_g)

III.2. Graph

Graph of the relationship between water discharge and generator power with a nozzle size of 0.9 cm and nozzle 1 position 0°

From graph 4, the most significant generator power from each nozzle angle position is located at an angle of 45°. The lowest total discharge of 31.06 l/minute produces a generator power of 0.253 Watts at nozzle position 2 of 15°. The highest complete release was 33.08 l/minute, with a generator power of 0.325 watts and nozzle two at 30°. The most considerable generator power of the nozzle with a diameter of 0.9 cm is 0.361 Watts at the angle of nozzle 2 of 45° with a discharge of 32.49 l/minute. For nozzle two at an angle of 30° with a power of 0.295 Watts, the capacity increased by 4.66% compared to the position of nozzle two at an angle of 15° with an average power of 0.281 Watts. While the position of nozzle 2 is at an angle of 45° with an average power produced of 0.295 watts, which is 15.03% greater than the nozzle two positions of 15°.

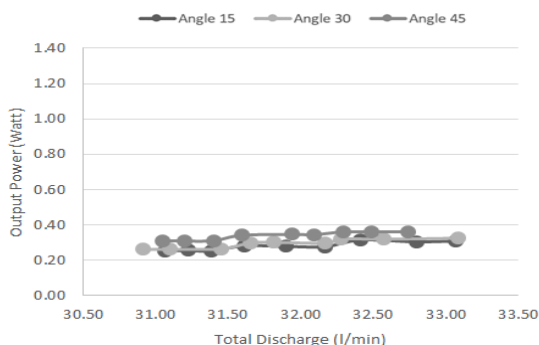


Fig 4. Graph of the Relationship of Water Discharge (Q) to Generator Power (P_g) at a 0.9 cm Diameter Nozzle

At a nozzle angle of 0° and 15°, a nozzle with a diameter of 0.5 cm produces an average power of 0.84 Watts and then experiences an increase of 80.98% compared to a nozzle with a diameter of 0.75 cm. The average power generated by a nozzle with a diameter of 0.75 cm is 0.159 watts. While the ratio between the nozzle

with a diameter of 0.5 cm to a nozzle with a diameter of 0.9 cm also experienced an increase of 66.45% of the power generated, equal to 0.253 watts.

At a nozzle angle of 0° and 30°, a 0.5 cm diameter nozzle produces an average power of 1.01 Watts, increasing by 67.1% compared to a 0.75 cm diameter nozzle. The average power generated by a nozzle with a diameter of 0.75 cm is 0.332 watts. While the ratio between the nozzle with a diameter of 0.5 cm to the nozzle with a diameter of 0.9 cm also experienced an increase of 70.81% of the power generated, equal to 0.295 watts.

At a nozzle angle of 0° and 45°, a 0.5 cm diameter nozzle produces an average power of 1.124 watts, increasing by 56.97% compared to a 0.75 cm diameter nozzle. The average power generated by a nozzle with a diameter of 0.75 cm is 0.484 watts. While the ratio between the nozzle with a diameter of 0.5 cm to the nozzle with a diameter of 0.9 cm also experienced an increase of 69.88% of the power generated, equal to 0.339 watts.

Graph of the relationship between water discharge and turbine power with a nozzle size of 0.5 cm and nozzle 1 at position 0°

From graph 3, the most excellent turbine power from each nozzle angle position is located at an angle of 45°. The lowest total discharge of 24.25 l/minute produces a turbine power of 3.43 Watts at nozzle position 2 of 15°. The highest complete release is 26.76 l/minute, making a turbine power of 3.34 Watts, also at nozzle two positions of 15°. The most significant turbine power of the nozzle with a diameter of 0.5 cm is 4.66 Watts at the angle of nozzle 2 of 45° with a discharge of 24.44 l/minute. For nozzle two at an angle of 30° with a power of 3.44 Watt, the capacity increased by 0.78% compared to the position of nozzle two at an angle of 15° with an average power of 3.41 Watt. At the same time, the position of nozzle two at an angle of 45° with an average power produced of 4.60 Watts is 25.84% greater than nozzle two positions of 15°..

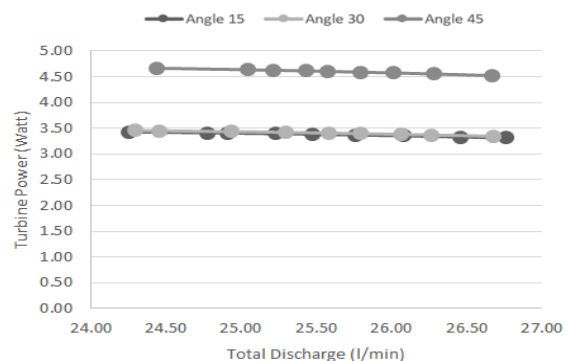


Fig 5. Graph of the Relationship of Water Discharge (Q) to Turbine Power (P_t) at a 0.5 cm Diameter Nozzle

Figure 5 at a nozzle angle of 0° and 15°, a 0.5 cm diameter nozzle produces an average power of 3.41 Watts and then experiences a not-too-significant increase of 0.96% compared to a 0.75 cm diameter nozzle. The average power generated by a nozzle with a diameter of 0.75 cm is 3.38 watts. At the same time, the comparison between the nozzle with a diameter of 0.5 cm to a nozzle with a diameter of 0.9 cm experienced a significant increase of 67.5% of the power generated, equal to 1.11 Watts.

At a nozzle angle of 0° and 30°, a 0.5 cm diameter nozzle produces an average power of 3.44 Watts and then experiences a not-too-significant increase of 0.89% compared to a 0.75 cm diameter nozzle. The average power generated by a nozzle with a diameter of 0.75 cm is 3.41 watts. At the same time, the comparison between the

nozzle with a diameter of 0.5 cm to a nozzle with a diameter of 0.9 cm experienced a significant increase of 67.45% of the power generated, which is equal to 1.12 Watts.

At a nozzle angle of 0° and 45°, a 0.5 cm diameter nozzle produces an average power of 4.6 watts, increasing by 25.05% compared to a 0.75 cm diameter nozzle. The average power generated by a nozzle with a diameter of 0.75 cm is 3.45 watts. While the ratio between the nozzle with a diameter of 0.5 cm to the nozzle with a diameter of 0.9 cm also experienced an increase of 75.55% of the power generated, equal to 1.12 Watts.

Graph of the relationship between water discharge and torque with a nozzle size of 0.5 cm and nozzle 1 at position 0°

At a nozzle angle of 0° and 15°, a 0.5 cm diameter nozzle produces an average torque of 21.93 kg. mm, then experiences an increase of 51.46% at a 0.75 cm diameter nozzle. The average torque produced by a nozzle with a diameter of 0.75 cm is 32.21 kg.mm. At the same time, the ratio between the nozzle with a diameter of 0.5 cm to the nozzle with a diameter of 0.9 cm experienced a decrease of 1.57% of the resulting torque, which was 21.58 kg.mm.

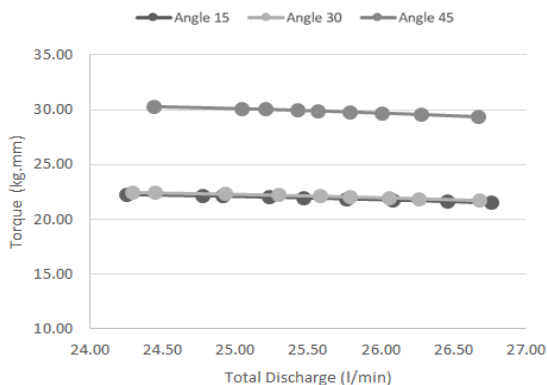


Fig 6. Graph of the Relationship of Water Discharge (Q) to Torque (T) at a 0.5 cm Diameter Nozzle

Figure 6 at the nozzle angles of 0° and 30°, the nozzle with a diameter of 0.5 cm produces an average torque of 22.12 kg.mm then experiences an increase of 50.16% at the nozzle with a diameter of 0.75 cm. The average torque produced by a nozzle with a diameter of 0.75 cm is 33.47 kg.mm. At the same time, the ratio between the nozzle with a diameter of 0.5 cm to the nozzle with a diameter of 0.9 cm experienced a decrease of 1.42% of the resulting torque, which was 21.80 kg.mm.

At a nozzle angle of 0° and 45°, a 0.5 cm diameter nozzle produces an average torque of 22.12 kg.mm then experiences an increase of 50.16% at a 0.75 cm diameter nozzle. The average torque produced by a nozzle with a diameter of 0.75 cm is 33.47 kg.mm. At the same time, the ratio between the nozzle with a diameter of 0.5 cm to the nozzle with a diameter of 0.9 cm experienced a decrease of 1.42% of the resulting torque, which was 21.80 kg.mm.

Graph of the relationship of water discharge to Turbine Efficiency with a nozzle size of 0.5 cm and nozzle 1 position 0°

From graph 7, the most excellent turbine efficiency of each nozzle angle position is located at an angle of 45°. The lowest total discharge of 24.25 l/minute produces a turbine efficiency of 32.01% at nozzle position 2 of 15°. The highest final release was 26.76 l/min resulting in a turbine efficiency of 23.01% and a nozzle two position of 15°. The efficiency of the largest turbine nozzle with a diameter of 0.5

cm is 42.53% at the nozzle angle 2 of 45° with a flow rate of 24.44 l/minute.

At a nozzle angle of 0° and 15°, a nozzle with a diameter of 0.5 cm produces an average efficiency of 27.22% and then an increase of 65.93% compared to a nozzle with a diameter of 0.75 cm. Meanwhile, the ratio between nozzles with a diameter of 0.5 cm to nozzles with a diameter of 0.9 cm also experienced an increase of 20.39%.

At a nozzle angle of 0° and 30°, a nozzle with a diameter of 0.5 cm produces an average efficiency of 27.23% and then an increase of 66.88% compared to a nozzle with a diameter of 0.75 cm. Meanwhile, the ratio between nozzles with a diameter of 0.5 cm to nozzles with a diameter of 0.9 cm also experienced an increase of 21.17%.

At a nozzle angle of 0° and 45°, a nozzle with a diameter of 0.5 cm produces an average efficiency of 27.40% and then an increase of 66.71% compared to a nozzle with a diameter of 0.75 cm. Meanwhile, the ratio between nozzles with a diameter of 0.5 cm to nozzles with a diameter of 0.9 cm also experienced an increase of 20.56%.

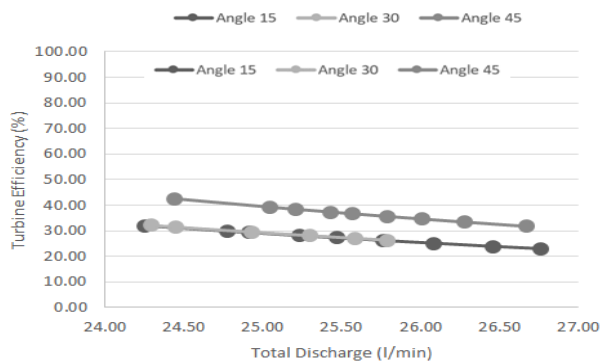


Fig 7. Graph of Relationship of Water Discharge (Q) to Turbine Power Efficiency (η_t) at 0.5 cm Diameter Nozzle

Graph of the relationship between water discharge and system efficiency with a nozzle size of 0.5 cm and nozzle 1 position 0°

From the graph above, the most excellent system efficiency from each position of the nozzle angle is located at a tip of 45°. The lowest total discharge of 24.25 l/minute produces a system efficiency of 7.19% at the nozzle two positions of 15°. The highest final release was 26.76 l/minute resulting in system efficiency of 6.17%, also at the nozzle two positions of 15°. The efficiency of the most extensive nozzle system with a diameter of 0.5 cm is 9.37% at the angle of nozzle 2 of 45° with a flow rate of 24.44 l/minute.

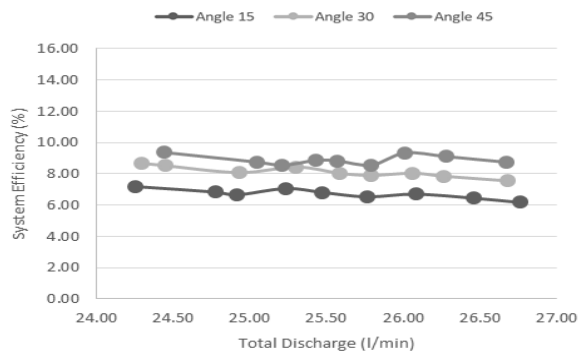


Fig 8. Graph of Relationship of Water Discharge (Q) to System Efficiency (η_s) at 0.5 cm Diameter Nozzle

In Figure 8, at nozzle angles of 0° and 15°, a nozzle with a diameter of 0.5 cm produces an average efficiency of 6.71%, then an increase of 2.44% compared to a nozzle with a diameter of 0.75 cm. Meanwhile, the ratio between nozzles with a diameter of 0.5 cm to nozzles with a diameter of 0.9 cm also experienced an increase of 5.29%.

At a nozzle angle of 0° and 30°, a nozzle with a diameter of 0.5 cm produces an average efficiency of 6.88%, then an increase of 3.57% compared to a nozzle with a diameter of 0.75 cm. Meanwhile, the ratio between nozzles with a diameter of 0.5 cm to nozzles with a diameter of 0.9 cm also increased by 5.79%.

At a nozzle angle of 0° and 45°, a nozzle with a diameter of 0.5 cm produces an average efficiency of 7.06%, then an increase of 5.84% compared to a nozzle with a diameter of 0.75 cm. Meanwhile, the ratio between nozzles with a diameter of 0.5 cm to nozzles with a diameter of 0.9 cm also increased by 7.34%.

4. Conclusion

Based on the test results and data calculations regarding the Micro Hydro Power Plant using a Pelton turbine with two nozzle variations, it can be concluded the results of the Pelton turbine test that has been carried out, the performance of nozzle one at position 0° and nozzle two at position 45° at nozzle diameter 0, 5 cm, 0.75 cm and 0.9 cm are the most effective for generating electricity. Based on the results of the Pelton turbine test that has been carried out, the best system efficiency is obtained for a nozzle with a nozzle diameter of 0.9 cm at nozzle 2 of 45°.

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