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The Effect of Laying Nozzle Distance Position on Operational Results Renewable Power Plant Pico-Hydro

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Abstract: New and renewable energy sources today and in the future are human needs that need to be sought and explored from all existing nature, especially in countries with many sources of application, such as Indonesia. Indonesia is an archipelago country that has a vast nature with abundant alternative energy sources such as river flow, irrigation which can be used as a source of energy for pico-hydro power plant. The purpose of this study was to determine the performance of pico-hydro with a test model for the position of nozzle position mounted on the pico-hydro using screw Archimedes turbine. The research method is carried out by direct experimentation from a tool that has been made using water fluid that is circulated continuously as if in actual operating conditions. The results of this research show that the positioning of the nozzle distance as the water output to drive the turbine blades affect operational results obtained. The farther distance from nozzle position to thread, the power and rotation also decrease, on the other hand, if nozzle is too close, the water sprayed by nozzle causes a back force of water so that the results are not optimal. In this research, the greatest power is generated at a nozzle distance of 4 cm, which is 230 Watt at a flow rate of 24 m^3/h, and the lowest power is obtained at 44 Watt at flow rate of 2 m^3/h where this position is ideal for pico-hydro installation. The best turbine shaft rotation in this study was produced at a nozzle distance of 4 cm which is 195 rpm, in this condition the spray of water flowing out of the tip of the nozzle towards the screw blade of the first part of the turbine which hits the sidelines of the screw occurs without resistance.

Keywords: Pico-hydro, water discharge, nozzle, renewable energy

1. Introduction

At this time all countries in the world through the unity of nations are busy looking for renewable energy sources as a substitute for conventional energy which will soon run out. This condition is experienced not only for developed countries, but also developing countries such as Indonesia. Indonesia has a lot of energy potential, both non-renewable energy and renewable energy. Currently, the potential energy used in Indonesia still uses conventional energy in the

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form of fossil fuels (coal, natural gas and petroleum) [1]. Therefore, it has become a shared obligation and responsibility as individuals or groups of Indonesian society to seek new and renewable alternative energy. One of the new and renewable energies that can be utilized is a pico-hydro power plant with main components, namely water flow, stock pipes, nozzle, turbine, generator [2], [3]. This generator system model with low water discharge can produce electrical power at 1 kW which can turn on lights and electricity needs on a scale of 3 residents' houses. However, large-scale sizes are becoming smaller and modifications have been made to make the generating unit more compatible with different site characteristics [4]. Most parts of Indonesia have the right structure and geography for small-scale pico-hydro manufacture. In general, rural areas still have good natural resources, one of which is water. Water resources are often found such as river flows and rice field irrigation channels, but there are still many that have not been utilized optimally from the rivers and rice fields irrigation channels, so it becomes natural if innovation continues to be a source of power generation [1], [5].

Although pico-hydro technology for low head application has only been drawing attention from researchers and policymakers in the recent past, it is not a new technology but rather a mature technology parallel to other hydro scale [6], [7]. In many parts of the world, various types of pico-hydro technology have been in use. The environmental impacts of large pico-hydro schemes are substantial and well documented [8], including modifying flow regimes, hindering or preventing the movement of aquatic biota, and causing damage and mortality to fish through direct contact with the turbines or indirectly by cavitation [9], [10]. In theory, a pico-hydro power plant is a power generation system that utilizes a very small-scale hydro power source with a capacity of less than 5 kW which can be applied to rivers in rural areas, agricultural irrigation flow, sewers [11], [12], [13]. The type of pico-hydro power plant to be built must meet several criteria such as good enough river water flow and adequate place for the construction of systems that will work as the main driver of pico-hydro [14], [15]. Research conducted by Budiarso stated that the main part of the guide in the form of a nozzle has an impact on the performance of the shaft for this type of turgo turbine [16], So the nozzle model must be designed according to the conditions of its application in the field or its reliability position [17], [18].

In fact, to improve the performance of hydro power in the form of a hydro power system, the nozzle is an important component that must be considered for its use, where the nozzle is an important part of a water energy conversion system as a component that interact directly with water in driving the turbine thread. Screw type water turbine are divided into two type, namely: steel strough and type closed compact installation. Steel trough screw turbine is a type of turbine that has an open blade or blade, so that the water flowing into the turbine blade is only as wide as the bucket [19], [20]. As for the screw turbine, the closed compact installation type is a turbine type that has the entire installation closed. In this type of turbine, it allows the water flowing into the turbine blades to almost fill the part that covers the turbine installation [21], [22].

This research was carried out by installing a complete screw turbine and the focus of the test model was the distance from the position of the nozzle to the screw. This nozzle as the main component of pico-hydro has an important role as a regulator of pressure and speed in the water that will rotate the screw turbine blades. Therefore, it is necessary to design and position the right placement in positioning its location, so that it can push the position of the perfect blade placement distance. In this study, a test will be carried out on the nozzle with variations in the position of the placement of the nozzle distance and the optimum water flow rate to determine the best performance produced by pico-hydro.

2. Methodology

The research method used is an applied experimental method on a prototype basis before being tested industrially feasible to be applied to the actual system conditions, then at the end of the study makes a correlation with the results of previous research, especially those that are close to the basic theory and its relation to standards suitable for use or suitable for application with optimal performance. The research equipment for testing the pico-hydro system in this research can be seen in figure 1 while figure 2 is a research test model. The working of this tool are that first the water contained in reservoir or box is sucked in using the pump contained in the box, then water is flowed into the pipe to top Archimedes screw turbine blade with a nozzle spray output. Water from the nozzle tip flows into space between the blade screw ranges and exits from bottom end. This causes gravity of the water and the hydrostatic pressure difference in blade screw chamber so that it pushes the blade screw along the turbine shaft and rotates the turbine shaft on its axis. Then pulley located at the top end of turbine shaft rotates the electric generator which is connected to pulley on the generator.

The test design model used in the form of variation distance position the nozzle to the thread of the first part that is exposed to water spray is 2 cm, 4 cm and 6 cm. The position of the placement distance from nozzle to the thread is what basically becomes a reference for whether the pico-hydro that has been made can be applied or should be through further development research. In general, the main stages in research are preparation stage, implementation stage, analysis and completion.

1. Preparation phase: At this stage, prepare all matters relating to what stages will be carried out, for example the preparation of materials and tools to make experimental tools that will be applied to the pico-hydro power plant with the material to be used for the screw taken from materials that are around the research site with materials that are easily available. Preparations were also made for other materials including elbows, water pumps, generators,

elbow iron, reservoir tank, PVC pipes etc. While the measuring instruments to be installed include a water flow meter, pressure sensor, tachometer, manometer and load cell, all of which will be installed until they are ready for testing and calibration so that they meet the requirements for data collection.

2. Implementation phase: This stage is carried out after the preparation stage is complete and is really ready to be tested. In this part of the implementation, it is actually the process of taking test data, with operational conditions that have been set as planned, for example data on variations in the position of the nozzle distance, determining the screw Archimedes angle, torque, stress and flow rate visualization on the flow meter, so that from This data will obtain information on the performance of the Archimedes screw turbine which is applied to pico-hydro.
3. Data Analysis and Completion phase: The data analysis stage is by analyzing the data obtained and making discussions, putting it into graphs, tables according to the right graph phenomenon, so that pico-hydro performance data will be obtained with model of the position nozzle spacing, minimum information related to its use is it suitable to be applied to pico-hydro plants based on actual technical standard.

In actual condition to complete and facilitate the specifics of this research work, it is presented in the detailed specifications of the research tools in table 1, and the test parameters are in the form of table 2. The operational conditions are tested to obtain data that is in accordance with research standards. Before testing the research equipment, calibration is carried out based on the applicable measurement rules.

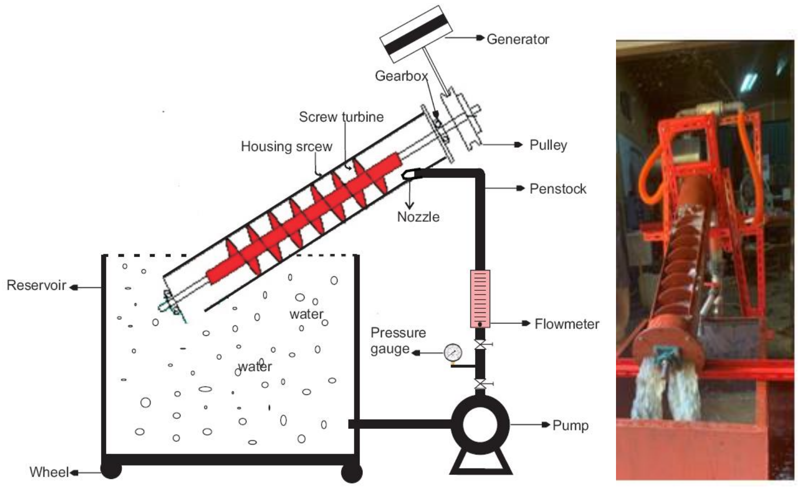
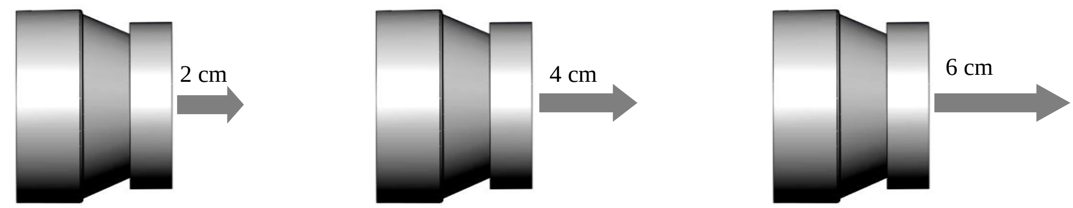


Fig. 1 - Apparatus research tools used



(a) Nozzle distance to screw (b) Nozzle distance to screw (c) Nozzle distance to screw

Fig. 2 - Test design position nozzle distance to screw turbine (a) 2 cm; (b) 4 cm; (c) 6 cm

3. Results and Discussion

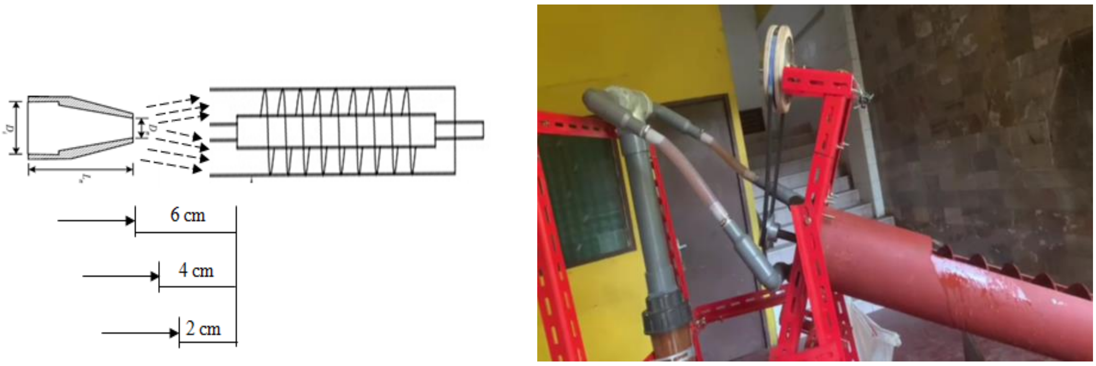
The discussion consists of several stages of work, starting from making the body or frame of the tool and turbine holder, piping installation, installing measuring instruments, making a test model for the distance placement of nozzle position on screw turbine, to conducting structured data collection experiments. The Taguchi optimization method has been carried out in predicting the best data processing results, namely several parameters that can be produced such as turbine shaft rotation, air pressure, turbine power. The results of the analysis using Taguchi are presented in a structured discussion on the analysis of the following data processing results. This research was conducted by experiment using equipment that has been designed in such a way according to the rules of engineering science. Figure 3 is the realization of the results of making experimental models and tools with various placements of components of measuring tools and apparatus in detecting the flow system that occurs in the pico-hydro generator model. In figure 3 it appears that the research team is making observations in taking experimental samples to obtain the desired data according to the predetermined model or design. In this study, the model in question is to observe various conditions of the nozzle distance position to turbine thread section, meaning that by varying position of the nozzle spacing as water spray pressure model, the right nozzle position distance model will be obtained in moving screw blades on the turbine shaft automatically uniform and continuous from one thread to another. In the data collection process, the nozzle distance position has been determined, namely starting from the largest at distance of 6 cm, then 4 cm and 2 cm, all of which are measured from starting point of the output front nozzle diameter. The measurement process in data collection is carried out alternately by entering the water flow discharge from lowest number, which in this study was chosen starting from 2 m^3/h to 24 m^3/h, each increase being taken from an even number with a difference of 2 per each sample given flow rate, which is 2 then 4, 6, 8, 10 ...up to 24 m^3/h.

Table 1 - Specifications of measuring instruments used in this study

Measuring tools and equipment	Units	Specifications
Frame material (steel box)	mm	20 x 40 x 6
Nozzle Thickness	mm	1.5
Service pump	HP	Induction motor 2.0
Storage tank	m	1.2 x 1.2 x 0.75
Laser digital tachometer	rpm	Measuring range 2.5-99.999
Generator low	Watt	Magnet neyodimium N52
Pressure gauge	kg/cm^2	1 until 6 maks

Table 2 - The test parameters used in this study

Test parameters	Units	Research Range
Head maks (h)	meter	8
Water discharge (Q)	m^3/h	1 until 24
Nozzle distance	cm	2, 4 and 6
Nozzle angle (α)	Degree	60
Load (m)	kg	0.2-1.2



(a) (b)

Fig. 3 - Experimental conditions (a) complete condition nozzle to screw distance; (b) side view of nozzle position on pico-hydro test equipment

3.1 Analysis of Research Data Processing Results

Figure 4 is the data for the flow of water, the rotation of the screw turbine shaft for variations in the position nozzle placement distance to the first thread and other threads on the archimedes screw. The graph in figure 4 is the relationship between what if given various variations of water flow discharge from the lowest to the largest, whether there is an effect on the results of the shaft rotation, if any, to what extent the conditions are for each position of each nozzle distance. The implementation of figure 4 shows consistent data and graph trends but there are causes and effects that are not in the same order of graph trends, as at the nozzle distance position of 6 cm (the farthest position) the turbine shaft rotation produced is smaller than the distance position of 2 cm and 4 cm. The graph also shows that the initial input water flow rate of 2 m^3/h with the nozzle distance of 6 cm produces a shaft rotation of 110 rpm which is the lowest rotation in this position, however, the increase in rotation with the addition of water discharge is not always the same between the first, second, third discharges and so on, as for example, in the water flow rate of 2 m^3/h to 4 m^3/h the increase is only recorded in 6 digit, namely from 110 rpm to 116 rpm, after increasing 6 m^3/h the result is 120 rpm or an increase of 4 digit as is the case with 8 m^3/h discharge, the rotation obtained is 128 m^3/h, an increase of 8 digit from the previous position. This phenomenon generally occurs in all additions to the given water discharge, but difference in the increase is different. As can be sorted in the position of laying the nozzle distance of 6 cm, the maximum rotation obtained is 183 m^3/h at a flow rate of 24 m^3/h where this position is furthest distance when compared to other position to the screw. The next position that can be explained is the condition where the nozzle is placed 4 cm apart, which is the furthest position to the two spray nozzles. If you look at figure 4, the blue line graph (4 cm distance position) shows the largest rotation of the other nozzle distance positions, namely the maximum rotation at 24 m^3/h discharge of 195 rpm while the lowest shaft rotation is obtained at 2 m^3/h discharge of 135 rpm, while the increase in rotation for each additional input of water flow discharge the value is different, this is probably caused by the driving force of water towards the turbine screw blades there is a back force so that thrust can be not linearly in line with each rotation of the shaft.

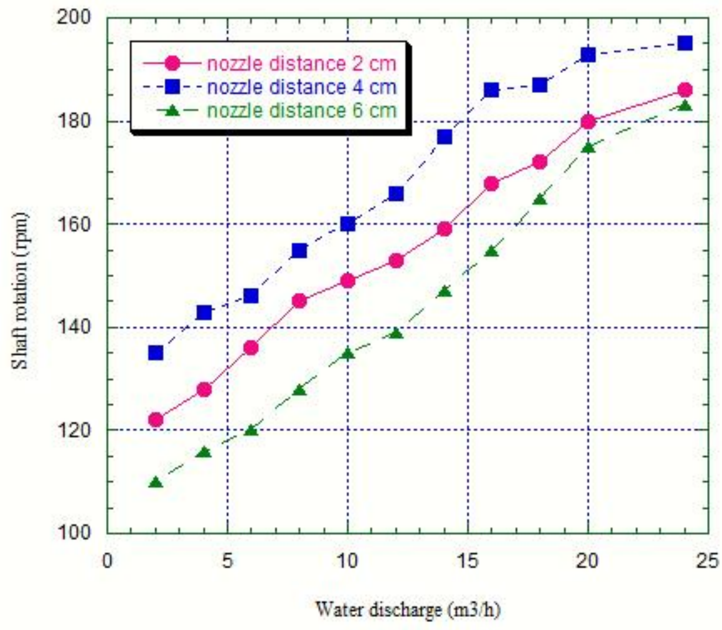


Fig. 4 - Graph of discharge relationship with shaft rotation

As in the position of the nozzle distance of 4 cm and 6 cm, it also occurs at a distance of 2 cm the resulting increase in rotation is not linear the resulting trend, however, as seen in figure 4, the red line is actually higher than the dark green line which incidentally is a nozzle position distance 6 cm. at a nozzle distance of 2 cm the lowest rotation is obtained at 122 rpm at a flow rate of 2 m^3/h while the maximum rotation is obtained at 186 rpm with an input flow of 24 m^3/h, the result of this maximum rotation is 3 points higher than the nozzle distance of 6 cm or lower 9 points from highest, nozzle distance is 4 cm. Analysis the effect flow of water given at each position the nozzle distance illustrates that it still need to be reviewed further related to the results of the figures produced, which is also seen in the graph with the order of forging positions, the nozzle distance is precisely middle position, namely the distance of 4 cm rotation information is generated higher. This condition if examined further logically can be justified because at the position of the nozzle distance of 2 cm this is too close to the water spray coming out of the nozzle, as a result there is a thrust force that hits the screw blades, some of the water turns back or there is a feedback force so that the thrust is pushed between the blades screw not optimal which causes the rotation results are also not optimal. Almost the same condition also occurs at the nozzle position distance of 6 cm, which is the farthest position, where in this situation water coming out of nozzle spray towards the screw blades comes longer, because its position or distance is far from first screw blade so that the resulting rotation becomes slow and in this result is the lowest. The highest result with the most maximum rotation is obtained at nozzle distance of 4 cm, this condition look more stable and the lines are consistent because at that distance position is neither too close nor too far away, so that the spray of water flows out of the nozzle tip towards the blade. The first part of the turbine thread that strikes between the threads is perfect, which is then also supported by the push of water or thrust to be free to push water from one blade to another until it reaches the final thread output. This condition causes rotation of the shaft at nozzle distance of 4 cm to be higher when compared to laying a distance of 2 cm and 6 cm to the turbine thread.

The next phenomenon and illustration of the results tells of figure 5, which is a graph of the relationship between the flow of water given or injected to the torque results for various variations in the distance of the nozzle position in order to act as place for the output of water velocity to drive the turbine blades. Based on the results of the experiment and data processing which is then poured or illustrated in a graph as shown in figure 5, it can be seen that at the position of the nozzle spacing of 2 cm which is shown in figure 5, the red line, when given a flow rate of 2 m^3/h, produces a torque of 0.08 kg.m and continues to increase as the water discharge injection increases which is added to the delivery pipe to the nozzle. If we look at a glance, at the water discharge position of 14 m^3/h to 16 m^3/h, there is a significant increase in the trend when compared to the other lines where the figure ranges from 0.2 kg.m up to 0.27 kg.m and after that there is a constant increase. The result of the increase in torque at each additional discharge is not too high where if average difference not more than 0.3 kg.m, this condition is caused by part the flow that enters first blade of turbine thread imperfectly because return flow as result the position of the nozzle distance being placed too close to the blades and turbine shaft so that the driving force of the flow of water coming out of the nozzle and hitting the turbine blades, some of the water is pushed in and most of it also bounces out, so the torque obtained is also small. In figure 5 it can be seen that the maximum torque at a discharge of 24 m^3/h with the position of placing the nozzle distance of 2 cm is 0.35 kg.m, this result is certainly greater than that obtained in the model of laying the nozzle distance of 6 cm which only produces a maximum torque of 0.28 kg. m and the minimum torque result is 0.07 kg.m as shown in the black line of the graph. Meanwhile, the increase in torque produced is generally not far from that obtained from the previous 2 cm nozzle position, which is the average increase below 0.3 kg.m. In figure 5, it is very clear that the 4 cm nozzle position provides highest torque information compared to the others, the blue line shows the minimum torque at 2 m^3/h water flow of 0.09 kg.m and the maximum torque at water discharge 24 m^3/h that is 0.45 kg.m. The next discussion is related to the relationship between water flow discharge and water pressure in figure 6.

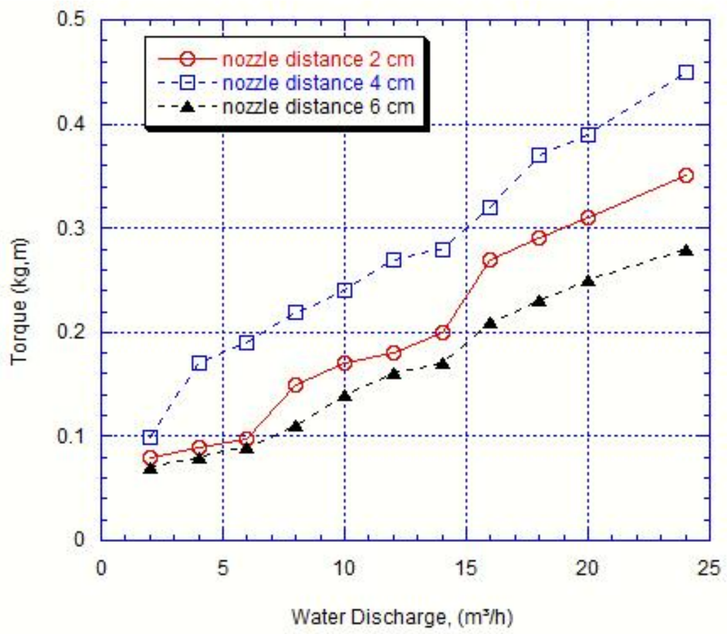


Fig. 5 - The graph of relationship between water discharge and torque at various nozzle positions

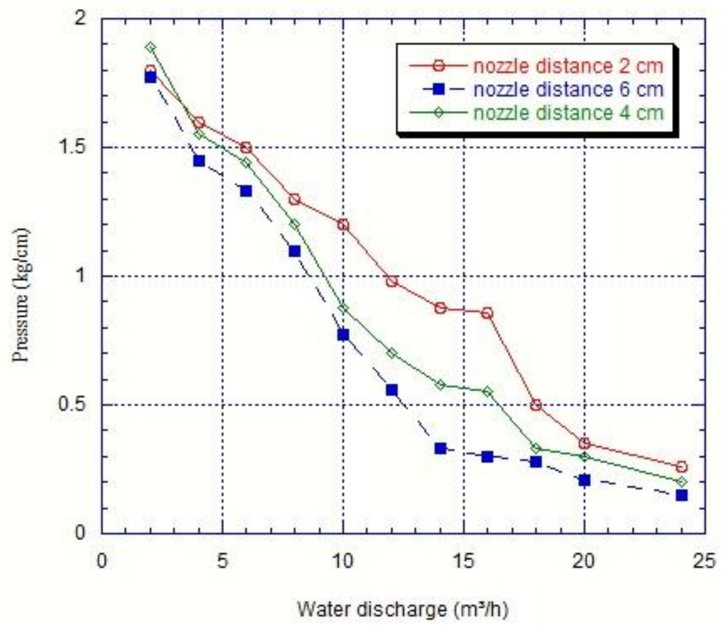


Fig. 6 - The graph of relationship between water discharge and pressure at various nozzle positions

The graph showing the water pressure can be seen in figure 6, where in general it can be said that there is a decrease along with the addition of the flow rate that is inserted into the pipe to be flowed as a working fluid that will push the screw blades. In this case, the higher discharge has an impact on water pressure, namely a decrease in pressure, as is clearly seen in the trend of the line at each position of the nozzle distance in figure 5. At the position of laying the nozzle to the screw 2 cm distance, a pressure of 1.8 kg/cm^2 is obtained at the flow rate. 2 m^3/h and the maximum pressure obtained at the intake water discharge of 24 m^3/h that is 0.26 kg/cm^2. This condition looks the highest compared to other graph lines. Another result is that by placing the nozzle position at a distance of 4 cm, the maximum pressure at a flow rate of 24 m^3/h that is 0.2 kg.cm, which is not too far away from the result of the 2 cm nozzle distance position. Furthermore, for the position of the 6 cm distance, the minimum pressure is 1.77 kg/cm^2 and the maximum pressure is 0.15 kg/cm^2 which is the smallest condition obtained compared to the conditions of the two previous trend lines. When viewed from the downward trend of the line in figure 6, it can actually be confirmed that farther the distance from nozzle position to turbine screw blade, the more impact it will have on the occurrence of pressure drops in every operational condition, because theoretically it can be understood that farther the nozzle spray distance, the higher the pressure will be. will decrease and this condition will be different if the conditions are closer to the spray distance of the water flow from the nozzle.

The analysis of the results is then outlined in figure 7, which is a graph of the relationship between flow rate and power, the power is measured to obtain the output of this experiment as an integral part of the process of accurate data results, as a recommendation for the development of further research. Figure 7 shows the red line, which is position of nozzle placement with a distance of 2 cm to the screw blade, where there is an increase in the power generated by 30 W for intake of 2 m^3/h water flow while the 24 m^3/h discharge generates 197 m^3/h of power. If when viewed from the trend line graph, it appears that each addition of average water discharge is below 30 W and highest difference is seen at the flow rate of 20 m^3/h to 24 m^3/h. The analysis at the position of the nozzle distance of 4 cm to the turbine thread based on the results of the data and graphic illustration shows that this condition has the highest power generated. If sorted on the graph line, it can be seen that the input of 2 m^3/h water flow is obtained by 44 W of power, this situation will continue to increase along with the addition of flow rate, such as 4 m^3/h discharge, 50 W power is obtained, 6 m^3/h is 65 W and so on until the maximum discharge condition of 24 m^3/h produces a power of 230 W which is the highest power in this research. At the condition of position nozzle distance 6 cm which is the furthest distance, minimum power 20 W has been obtained at a water flow rate of 2 m^3/h, this result continues to increase but is not too significant compared to other distances. The maximum power seen is 170 W at a flow rate of 24 m^3/h which is a less than ideal condition for the position of the nozzle distance, this indicates that farther the distance from water as an energy source, the driving media for screw turbine blades, results are also not optimal because of the passage of water slow and long will affect the power generated.

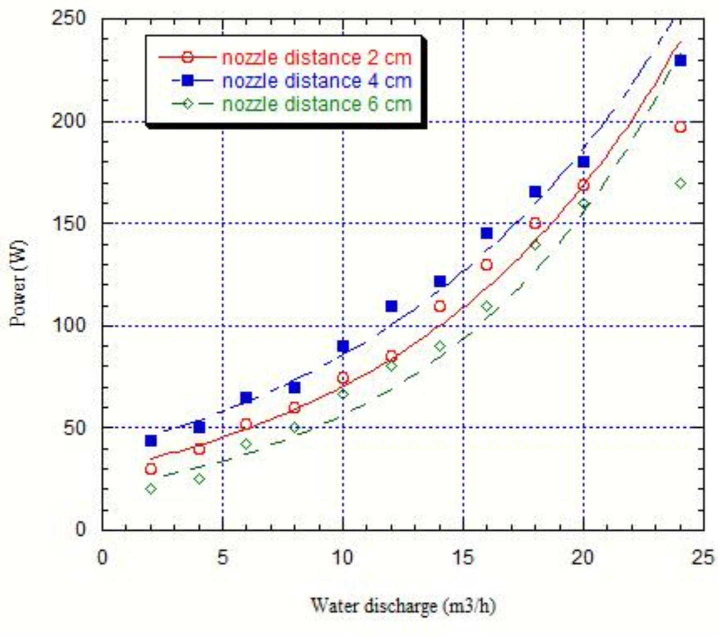
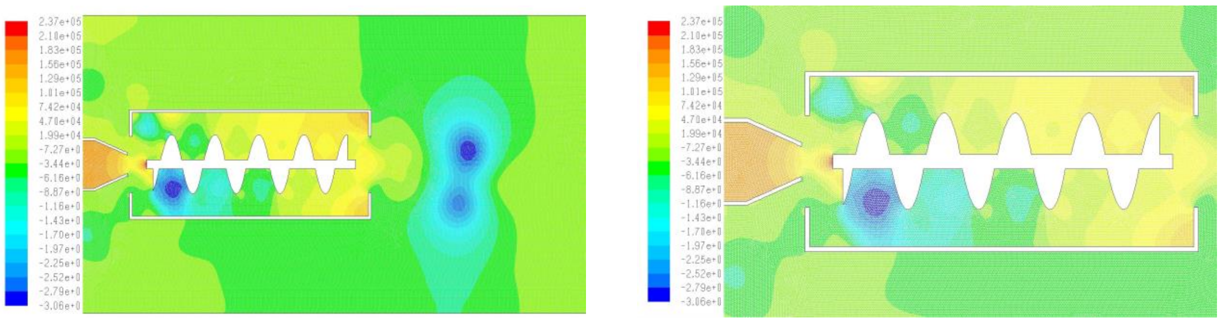


Fig. 7 - The graph of relationship between water discharge and turbine power at various nozzle positions

3.2 Modeling Illustration in Fluid Flow Simulation

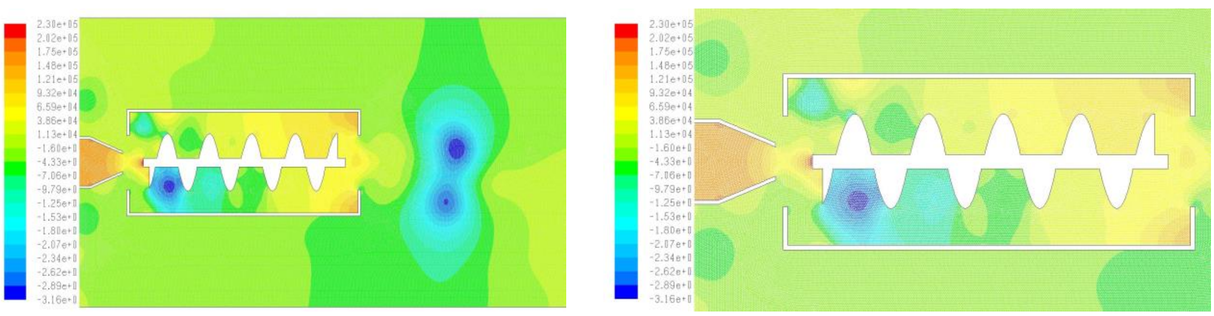
Technological developments make it easy to get a close-to-real picture in this case, which can be done by numerical simulation modeling using ansys. In figure 8, part (a) shows the simulation results of fluid flow at the position of the nozzle placement distance of 2 cm and operating pressure of 0.26 kg/cm^2. If we look at it clearly, we can see that when the water fluid is injected into the nozzle chamber, the pressure begins to form as shown in the brownish color on the nozzle chamber, after the fluid comes out of the nozzle mouth, the pressure starts to form and shows the spread of the fluid after the water hits the end of the shaft, which is then forwarded to the front of the turbine thread which was first exposed to the jet of water. The flow of water coming out of the nozzle has seen the real pressure shown by the yellow color and there is a round brownish dot when it hits the turbine shaft. The blue round circle that was previously flanked by navy blue is a condition where on the sidelines of the screw there is a turbulent flow, this situation is the effect of the flow and pressure of the water that does not flow freely because of the gaps that must be passed through it vertically. Gradually turning and pushing from the point of the first screw to the last screw. The pressure becomes more consistent and continuous and shows stability after passing through the fourth screw blades, as seen in the color forming a regular yellow color. Furthermore, it is still at the same nozzle distance position but the pressure applied is different, namely 1.8 kg/cm^2, as shown in figure 8 part (b) the flow phenomenon is more easily recognized and quickly formed. This condition is caused because the nominal pressure entered is greater, so that it appears that the yellow color significantly dominates and is larger in size compared to figure 8 (a).

In another part, namely figure 9 is the positioning of the nozzle distance of 4 cm, obtained part (a) minimum pressure of 0.2 kg/cm^2, this result provides information that flow of water flowing in the turbine screw occurs irregularly at beginning of turbine housing entry and hits the shaft, but then the flow will become regular after entering the middle of the turbine shaft or more precisely half way the water flow is driven by turbine screw blades continuously and continuously. This phenomenon continues to run evenly throughout all parts of the turbine and the pressure will be greater or stronger when it is inserted 1.89 kg/cm^2, where the situation becomes more visible the pressure of the flowing water as shown in figure 9 (b) in yellow until it reaches the output or output, also shows that there is still enlargement. In this analysis, it means that the position of nozzle placement distance of 4 cm to the first turbine thread has a greater pressure when compared to the position of nozzle distance of 2 cm. Along with these conditions, experimental data of the 4 cm nozzle distance position dominates the highest increase, these results conditions make it more ideal in terms of performance, as analyzed in figures 4 to 7 graphs are aligned and in line with the numerical simulation results both in terms of pressure and speed and power produced by a power plant pico-hydro.



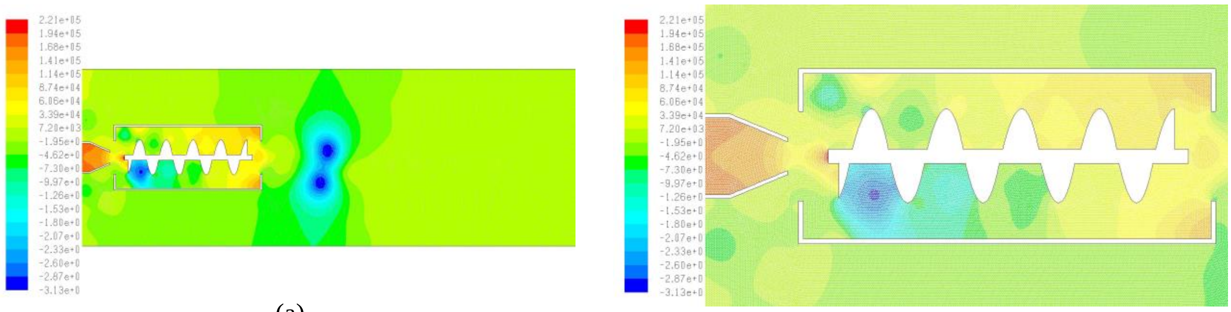
(a) (b)

Fig. 8 - Fluid flow at a nozzle distance of 2 cm (a) pressure 0.26 kg/cm^2; (b) pressure 1.8 kg/cm^2



(a) (b)

Fig. 9 - Fluid flow at a nozzle distance of 4 cm (a) pressure 0.2 kg/cm^2; (b) pressure 1.89 kg/cm^2



(a) (b)

Fig. 10 - Fluid flow at a nozzle distance of 6 cm (a) pressure 0.15 kg/cm^2; (b) pressure 1.77 kg/cm^2

The next indication in the simulation model is shown in fig.10, namely the nozzle distance is 6 cm, the applied pressure is 0.15 kg/cm^2 and the maximum pressure is 1.77 kg/cm^2. The treatment system to get the simulation results of the operational conditions entered same as in figure (a) and figure (b). From the series of illustration results shown in this simulation, at a distance of 6 cm from the nozzle to screw, the result is actually smaller than shown in the color indication in each flow pot. Another explanation is that we can see from the starting point of the water spray output to the turbine, which looks like a reddish color which indicates the flow is starting to indicate the direction of flow formation, but when compared to the 2 cm and 4 cm nozzle distance conditions we can see the dimensions of the largest nozzle position distance. This is precisely where the movement of the water flow is slow. This model can be seen from the color fig. 10 there is still a green color that is evenly distributed to the top or at first on the part of the turbine blades that are sprayed, as well as the bottom part between the green threads to the middle of the shaft which is still slowing down flow movement. The flow increases when it passes distance of more than 50% of the total length turbine shaft. The effect of nozzle distance on the generated power has been obtained experimentally, while the power results using CFD software were not obtained because the CFD simulation was carried out using 2-dimensional flow. In order to obtain power, it will be developed in subsequent research using CFD 3D flow simulation model software. Data processing has been carried out experimentally and numerical simulations using computational fluid dynamics (CFD) while mathematical formulations will be developed in future research

4. Conclusion

This research has been carried out and the results of data collection have been obtained, from the results of data processing and contained in discussion informing that at certain operational and discharge conditions from 2 m^3/h to 24 m^3/h can drive a screw turbine, however, the results obtained are certainly different so that development research is needed to perfect them. The performance in this study is stated in the result that the power generated reaches 230 W at a flow rate of 24 m^3/h with the position of placing the nozzle distance of 4 cm to the turbine thread. This condition is the best result compared to other nozzle positions, namely 2 cm or 6 cm. Farther the nozzle distance results in the slow arrival of water that pushes the turbine blades, and vice versa, the closer the nozzle position, there will be feedback or a back force due to hitting the front turbine blades. This flow phenomenon has been confirmed experimentally and by simulation modeling as evidenced by the color of the contour image at each position of the nozzle distance.

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