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Research Article

Engineering

A DOUBLE NOZZLE CROSS FLOW TURBINE FLUID FLOW DYNAMICS

雙噴嘴交叉流輪機 流體流動動力學

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Abstract

The dynamics of fluid flow are very important to the process of converting water energy into mechanical energy at the nozzle double runner cross flow turbine blade. Fluid dynamics of a jet of water from a nozzle release energy as the water crosses the cross flow turbine runner. This research aims to improve turbine performance and the effectiveness of fluid flow dynamics that drive cross flow turbine runner blades using double nozzles. The method of research using a cross flow turbine with double nozzle is a combination of vertical and horizontal nozzles. The turbine runner casing and blade are made of transparent acrylic material so that the flow dynamics can be observed directly. The laboratory scale double nozzle cross flow turbine is comprised of 24 blades, 3 mm thick, 40 mm long and 200 mm runner blade diameter. Test the performance of the turbine by measuring rotation, torque, and power, and by photographing the dynamics of the fluid flow that drives the turbine runner blade. The results of the study found that the visualization of the dynamics of fluid flow in turbines with double nozzles is more regular, evenly distributed, focused, and directed, moving the turbine runner blade cross flow so as to be able to increase turbine performance higher. The highest double nozzle cross flow turbine performance is 6.04 Watt power and 81.68% efficiency, at a water discharge of 0.22 liters /s.

Keywords: Fluid Dynamics, Double Nozzle, Turbine

摘要 流體流動的動力學對於在噴嘴雙流道橫流式渦輪葉片處將水能轉換為機械能的過程非常重要。當水穿過橫流式渦輪機流道時，來自噴嘴的水流的流體動力學釋放能量。這項研究旨在提高渦輪機性能和使用雙噴嘴驅動橫流渦輪機轉輪葉片的流體流動動力學的有效性。使用帶有雙噴嘴的錯流式渦輪機的研究方法是垂直噴嘴和水平噴嘴的組合。渦輪葉輪機殼和葉片由透明的丙烯酸材料製成，因此可以直接觀察流動動態。實驗室規模的雙噴嘴錯流渦輪機由 24 個葉片組成，厚 3

mm，長 40 毫米，流道葉片直徑 200 mm。通過測量旋轉，扭矩和功率，並拍攝驅動渦輪葉片的流體流動動力學，來測試渦輪的性能。研究結果發現，雙噴嘴渦輪機中流體流動動力學的可視化更加規則，均匀分佈，集中且定向，從而移動渦輪機葉輪的橫流，從而能夠提高渦輪機性能。最高雙噴嘴錯流渦輪機性能為 6.04 瓦功率，效率為 81.68%，排水量為 0.22 升/秒

关键词: 流體動力學，雙噴嘴，渦輪

I. INTRODUCTION

Cross-flow water turbines are frequently used by companies and communities to utilize the potential energy associated with gravity and water, which is one of the basic forms of energy available in nature that can be converted into mechanical and electrical energy. To improve the daily, quality of life, hydropower is an excellent target to optimize for its technical, economic and environmentally friendly use [1]. Energy intensification and conservation can be accomplished through the development and utilization of hydropower as a turbine driver. Optimizing the utilization of hydropower sources is especially important because it can easily reach remote and poor areas, which can reduce poverty. Hydropower is a green energy has become quite popular internationally due to its ease of use and flexibility [2].

Kinetic energy and potential energy in river and irrigation waterways in rural areas have present an excellent opportunity to drive cross-flow turbines to produce rotational power. The capacity of the power generation system is strongly influenced by the variable head and water flow rate. Thus, it is important to consider the potential energy of the water flow [3]. The advantages of micro-hydropower plants include their efficient and economic characteristics, which can be harnessed to serve rural communities. The power output is relatively simple to adjust, more reliable, inexpensive, and durable, with even small-scale hydropower has environmental impacts. Micro-hydropower plants only utilize free flowing water. A relatively small discharge with a low head is sufficient to operate a cross-flow turbine power plant, and the technology is an inexpensive method of producing power [4].

Several researchers and practitioners have developed in-depth studies on cross flow turbines, with numerical optimization methods of geometric turbine blades which state that the optimal pitch ratio depends on the number of blades and the turbine radius ratio. The cross flow turbine is very suitable for use in small water discharges and low water fall height. It is simple to construct and easy to manufacture, using local materials in accordance with micro scale power plants in the countryside [5]. Common cross flow turbines so far use only one nozzle, which results in low performance. This research is developing a cross flow turbine with double nozzles. This kind of turbine was also analyzed using the fluid dynamics [6]. In addition to fluid dynamics, the performance of crossflow water turbines is also dependent on the geometric shape of the turbine blade, head, water discharge, and loss of flow energy. The absorption, utilization, and loss of water energy in the turbine blade is influenced by the dynamics of fluid flow, fluid distribution, and the concentration of water energy transfer in the blade runner and conversion to the form of motion energy [7]. In accordance with the various conditions that many researchers have studied, cross flow turbines are more popularly used as prime movers for micro hydro power plants in remote areas. However, in this turbine, it is necessary to pay attention to the water inlet jet through the nozzle, as well as leakage flow in the gap between the turbine casing and runner and excessive water in the penstock pipe [8]. Better turbine performance is influenced by the right turbine blade angle position, which produces higher turbine power and higher turbine efficiency. Furthermore, the effect of nozzle blade position toward the turbine runner shaft is also evaluated on a low turbine head and smaller flow rate. Most of the radial impulse turbines utilized are cross flow, such as a micro hydro plant prime mover in rural areas under low water discharge and low head [9]. Therefore, cross flow turbines are continually striving to improve their performance compared to other traditional turbines [10]. The construction of this type of cross flow impulse turbine is very compact and very simple. It consists of two parallel circular disks that are joined together by a series of curved blades forming a turbine runner.

II. METHODS/MATERIALS

A. Materials

The materials used in this research for making a double jet or nozzle crossflow turbine are a transparent acrylic plate, axle steel for the turbine shaft, a steel frame, and an acrylic double nozzle with vertical and horizontal positions. The cross-flow turbine with a double nozzle consists of a runner with a blade thickness of 3 mm, as shown in Figure 1, in which the working fluid is blue colored water, which is easily observed by the flow dynamics. The double nozzle cross-flow turbines have two nozzles, one in the vertical position and the other in the horizontal position, as shown in the schema model in Figure 1 and Figure 2 as follows:

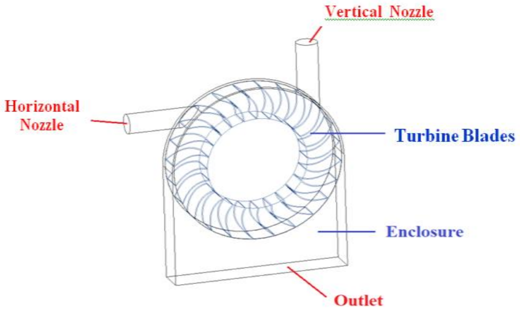

Figure 1. Double nozzle cross-flow turbine [11]

A turbine steel base, U steel profile, bolts, and nuts, glue, insulation tape, plastic pipes, water supply regulator valves, water storage tanks. The installation test uses a double nozzle cross-flow turbine Dengan Pembebanan Konstan Sebesar 3 Newton on 3.5 m head with water discharge varied as needed.

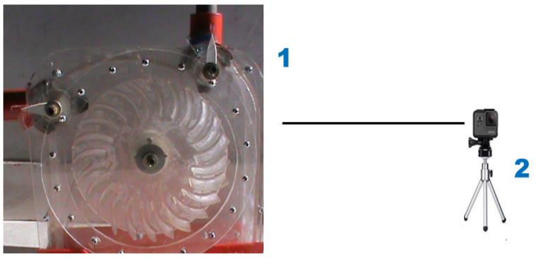

Figure 2. Experimental set-up:
(1) Double nozzle cross-flow turbine,
(2) Camera

The fluid dynamics of the cross-flow impulse turbine occur in the water flow moving across the two-stage runner blades. In the first stage, the water flow from the turbine nozzle passes through the blades, leaves the first stage turbine blade, and passes into the second stage turbine blade by crossing the turbine center. Once the water flow is inside the second stage turbine blade, it produces to the turbine for the second time. Finally, the water flow leaves the second stage turbine blade and then the turbine area [11]. The phenomenon of water flow crossing the runner twice is why this turbine is called a cross-flow turbine: the initial stage converts the radiant energy generated by the nozzle twice, driving the turbine runner [9].

The nozzle is a very important turbine component that directs and shoots bursts of water jets into the turbine runner blade [10]. The turbine runner blade is the main component of the rotor; it captures the water jet and absorbs water energy when crossing the turbine runner blade. The kinetic energy is absorbed by the runner blade surface and then forwarded to the turbine shaft to produce runner rotational motion. The runner blades assembled on the disk are supported by a shaft, and this assemblage is technically known as a turbine runner. The cross-flow turbine runner consists of cylindrical circular blades that are relatively long in the transverse direction, and they are welded to two round discs mounted on the shaft [11]. Until now, cross-flow turbines have had low performance compared to other conventional water turbines. Theoretical studies and observations in the field have found that crossflow turbines with a single jet are still part of the runner untouched by the water dynamics crossing the turbine, thereby causing suboptimal turbine power and efficiency. The research installation uses a water pump to lift water from the reservoir in the reservoir tank, thus guaranteeing constant water flow and constant head. The water pipeline installation, from the water tank to the turbine, was fitted with a water discharge regulator valve and a pressure gauge to measure the turbine inlet water pressure.

B. Methods

This research model is at laboratory scale and uses a double jet crossflow turbine with a horizontal shaft. The turbine wheel runners consist of round discs at the edges where there are a number of blades with equal and symmetrical spacing. Turbine blades are made of curved plates in the form of cylindrical runners with a length of 40 mm.

The turbine runner diameter is 200 mm, there are 24 blades, and the blade thickness is 3 mm. Each side of the turbine casing is made of transparent acrylic material so that it is easy to observe directly the fluid dynamics of the water flow moving across the cross-flow turbine runner blade.

III. TEST SPECIMEN

Figures 3 and 4 show the assembly and testing of impulse crossflow turbines with double nozzles, made and carried out on a laboratory scale as follows:

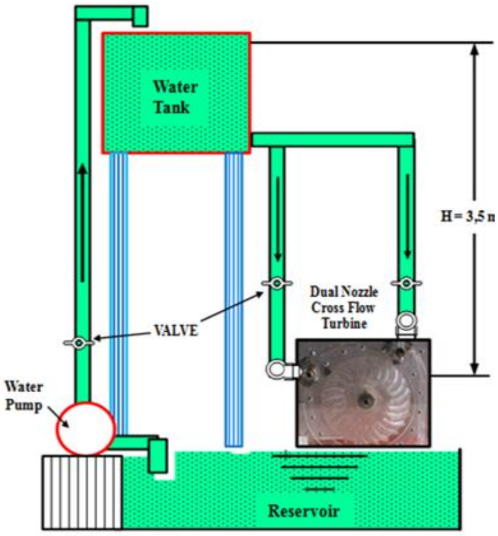

Figure 3. Testing specimen diagram

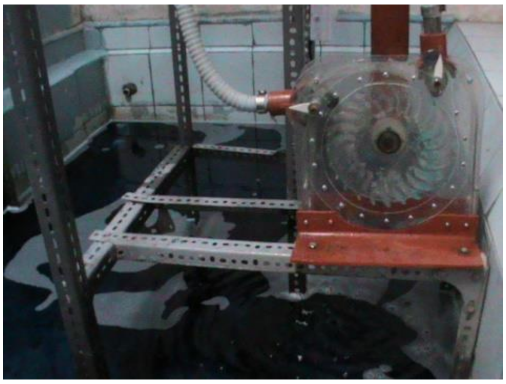

Figure. 4. Experiment set-up: 1. Double nozzle/jet cross-flow turbine [6]

The crossflow water turbine is a prime mover for changing the potential energy of falling water into kinetic energy on the nozzle in the form of a water jet hitting the turbine runner and causing the turbine shaft to produce a rotational motion. The main parts of the crossflow turbine [5] are: (1) a penstock pipe as a conduit that carries water to the nozzle, (2) the nozzle, which directs and emits the water bursts into the turbine runner blade, and (3) the runner wheels, which receive and absorb kinetic energy when crossed, pounded, or hit by the water jet that passes through it.

Other supporting instruments that will be prepared [5] are (a) a water pump, which is used to fill the reservoir tank with water so that the head and water supply to the turbine is maintained continuously, (b). a pressure gauge to measure water pressure, (c) a stopwatch to measure the duration of the water flow, (d) a tachometer as a rotary gauge on the turbine shaft, (e) a water flow meter to measure water flow into the turbine, and (f) a ruler to measure the component dimensions and turbine installations used at the time of the study.

The study was done experimentally. This included preparing the materials and tools, installing the crossflow water turbine, calibrating and testing the measurement instrument, and collecting and analyzing the data. The manufacture is a component production process and assembly or installation of the double nozzle crossflow turbine test equipment was carried out at Ujung Pandang State Polytechnic using a Computer Numerical Control (CNC) machine. Then, the research was conducted at the Paulus Christian University of Indonesia in the Fluid Machine Laboratory. The research activities began by filling a bathtub with water. At that point, the water was blue so that the flow of water looked clear when it was emitted from the nozzle and crossed the turbine. After all the measuring instruments are properly installed in the correct position, water will start flowing by pumping it into the upper reservoir water tank until it reaches the specified level. By consistently controlling the flow rate of the water entering the turbine through the valve after the water moves the turbine runner blade, it immediately falls into the underwater reservoir. Furthermore, water is continuously pumped into the water tank through the connecting duct pipe so that the water level is maintained at stable flow conditions and it controls the water level in the tank.

The amount of the flow rate into the turbine must be controlled at the water valve located at the end of the turbine inlet. Opening the valve regulates the flow of water from the tank to the nozzle so that it produces a strong jet of water into the turbine blades. After the turbine runner blades begin to move, the water is released into the reservoir tank at the bottom of the turbine to be pumped back to the water tank as the turbine's upper reservoir position. In the cycle testing procedure, the data are collected by first adjusting the position and number of turbine nozzles, then the flow of water entering the turbine is regulated by controlling the turbine inlet flow valve opening and the water level in the tank under stable conditions. The data on the turbine rotation (n) is obtained using a digital tachometer. The turbine torque is used as the braking system and the dynamics of the water that crosses the turbine are visualized using a digital camera. Data obtained from the measurement results on each variation of water discharge or water flow rate are 0.19 liters/s, 0.20 liters s, 0.21 liters/s, 0.22 liters/s, and 0.23 liters/s with a load constant of 3 Newton at a turbine head of 3.5 m.

IV. Results and Discussion

A. Result of Fluid Dynamics in Vertical Nozzle Crossflow Turbines

The vertical nozzle crossflow turbine uses a double nozzle by closing the horizontal nozzle. For the first observation, only the 90° angle, the vertical nozzle is used. The nozzle diameter is about 12 mm, with a turbine head of 3.5 m. First, the crossflow turbine is run until it operates on a stable rotation. After that, the fluid flow dynamic is observed, and photographs of the flow are obtained as far as 15 cm from the crossflow turbine. The turbine casing is made of transparent acrylic plates; the water is colored blue so that the fluid dynamics can be clearly observed directly and recorded with the camera. Figure 5 shows the crossflow turbine with a 90° vertical nozzle, with a 12-mm diameter that can emit and direct the water into the turbine.

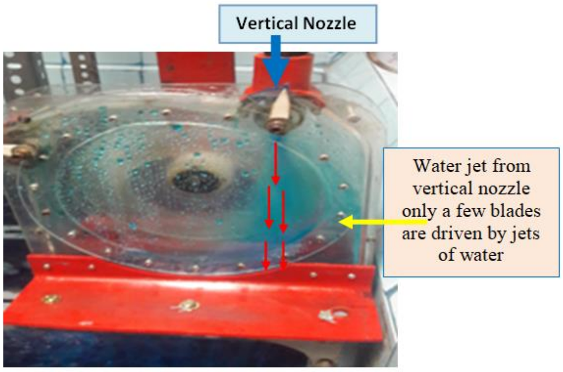

Figure 5. Fluid flow dynamics in a vertical nozzle and nozzle horizontal close

The fluid dynamics of the water on the crossflow turbine with a vertical nozzle can be seen (Figure 5). In terms of the working fluid flow dynamics in the vertical nozzle crossflow turbine, water only sprays vertically and only a small portion of the turbine blade is hit or pushed (Figure 5). The water jet does not cross the middle of the turbine; instead, it moves the blade at the first stage so that the turbine blade can only absorb the water-energy as the energy of motion from the water jet once [8]. The water jet entering the turbine only crashes or hits a small portion of the turbine blades, which results in the loss of a portion of the water jet's hydraulic energy and decreases the turbine's performance [8], [13].

B. Result of fluid dynamics in horizontal nozzle crossflow turbines

When the nozzle crossflow turbine with 0° angle and a diameter of 12 mm are in the horizontal position, it regulates and sprays water into the turbine runner blades. As seen in the photo in figure 6, the fluid flow dynamics demonstrate how the water flow passes through the horizontal nozzle crossflow turbine. Based on the visualization result, the water flow is more stable throughout the turbine runner blades. The horizontal nozzle sprays water to pound the turbine blades that are driven [13]. The photograph also shows in Figure 6 that there is a reflected water jet. The water jet collision from the turbine casing causes a backflow, resulting in loss of water power. This condition would greatly reduce water power as a water turbine drive. Just a small amount of water entering the turbine crossing area. From the observation results, it is seen, that the water power produced by the horizontal nozzle with a small water jet, could only convert a small power to the turbine [10].

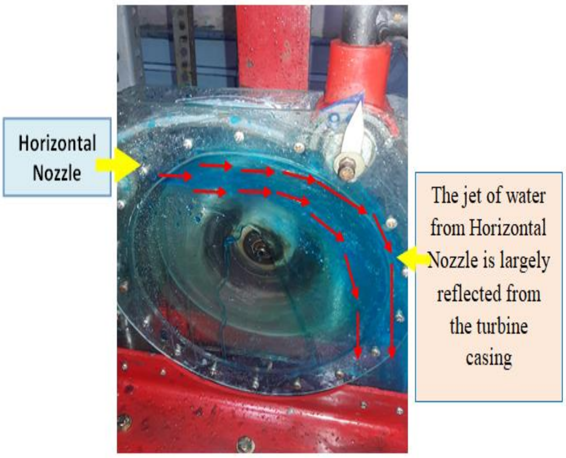

Figure 6. Fluid flow dynamics with a horizontal nozzle and nozzle vertical close

In accordance with the fluid flow dynamics shown in Figure 6 about the dynamics of the working fluid flow when the turbine crossflow using a single horizontal position of nozzle, shows that the working fluid sprayed by nozzle moves crossflow turbine blade, then crashes the shaft and flow through the turbine blades, moves to the turbine space, resulting in loss of water jet hydraulic energy and changes jet of water when entering the second stage blade chamber, and such conditions greatly affect the turbine efficiency [14], [15].

C.Result of Fluid Dynamics in a Double Nozzle Crossflow Turbine

Crossflow turbines with double nozzles are using a combination of vertical and horizontal nozzles. Water jets enter the turbine in the vertical and horizontal position of the nozzle. This system causes more blades to be crossed by the water jet from the nozzle. Then water spray flows into the runner of turbine blades, occurs from the first or top level of the blade to the second stage bottom level. From the observed result, it could be seen clearly, that the fluid flow dynamic produced by water jets from the nozzle occurs a crossing flow pattern as it resulting in a driving force in the water turbine blade [16]. Even the jets of water from the horizontal nozzle are directed by the jets of water from the vertical nozzle so that a higher water-energy is absorbed by the turbine blades causing the turbine power and turbine efficiency to be increased [17].

The nozzle water jet determines the number of blades that can be driven by a water spray, the greater the path seen in the runner, the more blades is pounded by the water jet from the turbine nozzle. From the results of the visualization of fluid dynamics, it is seen that the wider the cross-sectional area of the water jet the more blades are affected by water spray on the double crossflow turbine [18]. Increasing energy absorbed by each blade, the higher the turbine power and turbine efficiency.

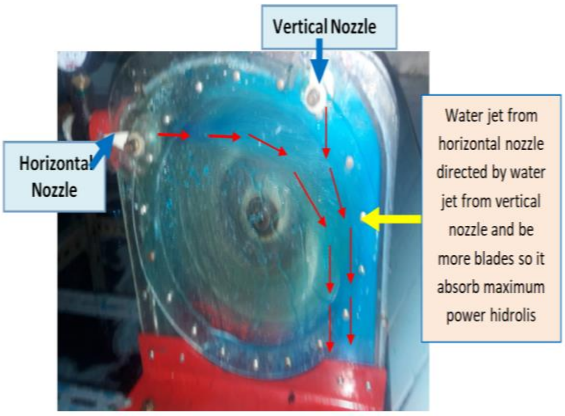

Figure 7. The double nozzle (vertical and horizontal nozzle) turbine water fluid flow dynamics

In a double nozzle cross-flow turbine operation, a water jet passes twice over the cylindrical runner blades. It is seen clearly that the water jet hit the blade on the first stage towards the turbine center and provide most of their kinetic energy. Then on the second stage, the water flow hit the blade and providing another additional energy before leaving the turbine runner blades. The water jet from the nozzle passes the runner twice, causing an increase in turbine efficiency [19]. When water leaves the runner, it also helps clean the runner from small particle impurities. The double nozzle cross-flow turbine has an interference effect between jets causing an increase in turbine efficiency. The advantage of this kind of turbine is that the turbine has a higher rotational speed with a smaller runner [13], [16].

D. Result of the fluid dynamic influence on the double nozzle cross flow turbines performance

The fluid dynamics influence associated with the double nozzle cross turbine performance is very large as shown in Table 1 as follows :

Table 1.
The power of cross-flow turbine

Flow Rate	**Power of cross-flow turbine**		
	Vertical nozzle	**Horizontal nozzle**	**Double nozzle**
0.19 ltr/s	1.67Watt	2.10Watt	2.59Watt
0,20 ltr/s	3.04Watt	3.59Watt	4.11Watt
0,21 lts/s	4.01Watt	4.60Watt	5.35Watt
0,22 ltr/s	4.67Watt	5.34Watt	6.04Watt
0,23 ltr/s	4.60Watt	5.30Watt	6.02Watt

The fluid dynamic on the cross-flow turbine is most effective in transferring water energy to the turbine blade. It can be clearly seen in Table 1 above and figure 7 which is talking about the relationship between the turbine power and the water flow rate. Overall the turbine power increases with the flow rate increase [10]. The maximum turbine power on a crossflow turbine with a vertical nozzle is about 4.67 Watt at a flow rate of 0.22 liters / s, which is lower compared with the turbine using a horizontal nozzle. This is caused by water spray from the nozzle does not make a transverse flow, the energy absorption was just occurring in the first stage and only a few blades were driven by the water spray. Crossflow turbine power with horizontal nozzle starts to increase by 5.34 Watt with a flow rate of 0.22 liters / s. While the crossflow turbine with a double nozzle increases the turbine power vary significantly and the highest power is 6.04 Watt at a flow rate of 0.22 liters / s. Crossflow double nozzle turbine is able to produce a higher turbine power because the fluid flow dynamics are more precise and effective in the water spray direction entering runner blade of turbine [20]. A higher energy of water is received by the turbine blade to produce a greater turbine shaft power as illustrated in Figure 9.

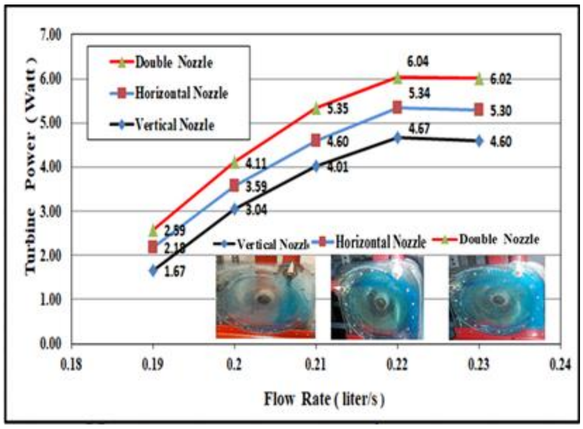

Figure.8. Turbine power *vs* flow rate

In Figure 8, it could be seen that double nozzle of the crossflow turbine produces a higher power because it is able to produce fluid dynamics very regular, uniform and many runner blades are pounded by jet of water. Crossflow turbine with double nozzle could absorb a higher energy of water to drive runner. The power of a crossflow turbine that uses horizontal nozzles is lower because the fluid dynamics of the spray nozzle water only move a portion of the runner area that is crossed by the flow on the turbine blades [20]. Furthermore, the power from crossflow turbines with vertical nozzles is the smallest because the water jet from the nozzle were just driving a few runner blades and the crossing flow does not occur. Then the increase in the capacity of water that crosses the turbine greatly affects the power of the turbine produced because the greater the mass of water entering the turbine, the higher the turbine output power [21].

Based on Table 2 and figure 8 it is seen that the nozzle position and nozzle number in the cross-flow turbine will determine the water jet quality and the water flow movement entering the turbine blade.

Table 2.
The efficiency of the cross-flow turbine

Flow Rate	The efficiency of the cross-flow turbine		
	Vertical nozzle	**Horizontal nozzle**	**Double nozzle**
0.19 ltr/s	25.13%	30.02%	36.25
0,20 ltr/s	42.68%	48.90%	58.75
0,21 lts/s	55.37%	62.67%	74.28
0,22 ltr/s	60.94%	68.17%	81.68
0,23 ltr/s	57.54%	64.44%	76.68

In Table 2 above and Figure 9 it can be clearly seen that the crossflow turbines vertical nozzles produce lower efficiency at 60.94% and the turbine with a horizontal nozzle is slightly higher about 68.17%. But for crossflow turbines with dual nozzles is to use a nozzle to combine in a vertical and horizontal position, which has a fluid flow dynamics that emits the spray water from the nozzle into the crossflow turbine are more directional and able to cross two stages of runner blade. So that it gives a twice power push on the turbine runner. This causes the double nozzle crossflow turbine to produce more power in driving the turbine shaft so that the turbine efficiency would be higher is 81.68%. The double nozzle crossflow turbine is very good because it is able to produce force and water momentum which causes the turbine blade to get power from the water movement dynamics, transverse at the turbine runner, and can increase the turbine efficiency [21].

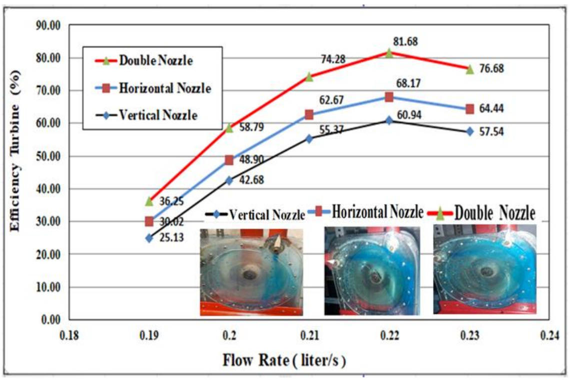

Figure 9. Turbine efficiency *vs* water flow rate

In Figure 9 the double nozzle crossflow turbine efficiency increases with increasing water flow to compare turbines with vertical, horizontal and double nozzles. The double nozzle crossflow turbine optimum efficiency is about 81.68% at a flow rate of 0.22 liters / s. The double nozzle cross nozzle turbine has the highest efficiency because more turbine blades was hit by the water jet. More surface area of the blades is traversed and driven by water jet [17], [19]. The effective head can move the crossflow runner optimally and the crossflow turbine efficiency is greatly influenced by the perfect double nozzle design. The results confirmed that turbine efficiency was greatly influenced by the water jet interaction with the turbine blades. This condition can be demonstrated through the water flow dynamic visualization. The highest efficiency was reached by the double nozzle of cross-flow turbine. Fluid dynamics that cross the turbine blades crossflow has a positive impact in improving performance of crossflow turbine. The turbine blade interaction with water jet released from nozzle must be taken into account in its precise position by automating the turbine blade design so that it matches the water low entering the blade [4], [15]. The fluid flow dynamic pattern in Figures 5, 6 and 7 above, illustrates the fluid flow dynamics that at a low water flow rate, the turbine performance would be lower. Because the flow dynamics still have to fill space between the turbine blades and flow in crossflow. However, when the working fluid flow from the nozzle is strong and fast, the working fluid does not have time to flow into the blade space, no crossflow occurs again from the first or top level of the blade to the bottom second blade level. By observing directly to the picture of the fluid flow dynamics produced by water jet from multiple nozzles, it can be stated that many blades can be reached by the fluid flow to drive the turbine blades and causes a turbine rotation and produces a higher turbine power and higher turbine efficiency [4], [22]. This shows that as the fluid flow velocity increases, the water flow between the turbine blades will tend to be turbulent. Turbulent flow is the movement of irregular fluid flow dynamic, so that water energy is not effectively absorbed by the turbine blade. But if the fluid flow velocity decreases more, the flow will tend to be laminar.

The performance of the crossflow turbine is also influenced by the characteristics of the working fluid dynamics inside the turbine blade at the time of testing. From the test data that has been processed to find flow rate and velocity, it can be seen that the greater the valve opening, the greater the resulting discharge. In other words, the greater the valve opening, the higher the fluid volume per unit time [19]. Figures 5 and 6 illustrate that, with crossflow turbines that use a vertical and horizontal single nozzle, the efficiency starts to increase along with an increase in load. The single vertical nozzle crossflow turbine has a lower efficiency, which is 61.93%, while the turbine with the horizontal nozzle reaches a higher efficiency of 70.95%. Crossflow turbines that use horizontal nozzles have a higher efficiency because of the velocity at the blade’s outer end where the flow dynamics occur in a circle, causing an angular momentum that increases the turbine output power [12], [16]. Transverse water flow velocity, or crossflow capable of passing through the runner blade, has a greater effect on the turbine, resulting in higher efficiency. The turbine crossflow with a double nozzle, where the water jets from the nozzle is more and evenly push or move the blades and could absorb the water-energy twice. The double nozzle at the crossflow turbine would hit more blades and a bigger blade area, directly increasing the crossflow turbine performance due to the more effective flow dynamic factor. The study of crossflow turbines using a double nozzle, with the aim that the turbine blade can absorb more energy from the water flow, aims to increase the turbine power and turbine maximum efficiency [10], [23]. The turbine efficiency is strongly influenced by the large number of turbine blades that can receive and absorb the water energy and the amount of arc entering the crossflow turbine nozzle. The water flow through the blade and runner space visualization could also help the crossflow turbine observation to support the experimental result [8], [13]. Crossflow turbines with double nozzles are turbines that have twice the process of conversion and kinetic water transfer on the turbine runner blade. These turbines are very well applied to optimally utilize the water-energy source as the initial driving force of a power plant [24].

V. CONCLUSION

Fluid dynamics in a double nozzle crossflow turbine can improve performance because the spray of water produced by the nozzle can pass through the crossflow. More turbine blades are driven by water jet to the runner in two-stages and move the turbine blade from two sides: from the horizontal nozzle and the vertical nozzle. The maximum turbine performance was achieved with a turbine efficiency of 81.68% and a turbine power of 6.02 watts at a 0.22 liter/s water flow rate. Crossflow turbines with a single nozzle have a dynamic fluid flow that is not effective in moving the turbine blade, which causes lower turbine efficiency and power generation.

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