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Experimental study of a breastshot waterwheel with the degree of inclination of the nozzle spray against the tip speed ratio

Muhammad Helmi Kurniawan[1], Khusnul Khotimah Ayuningtiyas[2], Ridho Dwi Syahrial[3]

[1]Department of Mechanical Engineering, Universitas Brawijaya, Indonesia

[2]Department of Environmental Engineering, Universitas Pembangunan Nasional "Veteran" Jawa Timur, Indonesia

[3]Department of Mechanical Engineering, Politeknik Negeri Pontianak, Indonesia

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ABSTRACT

The energy crisis is a severe problem facing the world, including Indonesia. Along with the times, innovation is needed to implement sustainable energy. Non-fossil energy sources have not been widely used, and efforts are still needed to utilize these energy sources. The waterwheel was the first device used in water production. One of the innovations for the sustainability of non-fossil energy is to make a waterwheel. There are still several waterwheels in Indonesia, but an investigation is needed to determine their condition. So in this study, investigating the breastshot water wheel uses a nozzle-based construction with variations in the degree of inclination of the spray against the TSR value. The results showed that the greater the inclination of the nozzle angle, the higher the velocity of the water flow when it enters the wheel. Adding water speed to this wheel will increase the momentum and tangential force. An increase in the tangential force will increase the wheel's torque so that the wheel strength will increase. This increase in power will, of course, result in greater efficiency, thereby increasing the tip speed ratio (TSR).

Corresponding Author:

Muhammad Helmi Kurniawan,
Department of Mechanical Engineering,
Universitas Brawijaya,
Jl. Veteran, Malang, Jawa Timur 65145, Indonesia.
Email: mr.helmi.kurniawan@gmail.com

1. INTRODUCTION

One of the world's most severe problems today is the energy crisis [1][2]. The energy source that most people use is fossil energy. The use of fossil energy by industrial companies in various countries has worsened the situation of fossil energy [3]. The energy crisis and global warming arising from fossil energy have directed attention to seeking new and renewable energy sources as sources of energy production that are efficient and sustainable [4][5]. Population growth, technology and industrial development of a country will increase energy consumption, so efforts must be made to increase the energy supply [6]. Development and economic development to achieve a decent standard of living will increase energy demand in the future [7]. This condition can turn energy into a profitable commodity that is very promising. This opportunity encourages various parties to make efforts to provide and manage efficient energy by utilizing new and renewable energy sources such as water energy [8]. Water energy is a renewable energy that can come from nature directly. Indonesia has a very large source of water energy, which can be used as a source of electrical energy [9]. The provision of sufficient, easy, inexpensive, environmentally friendly and sustainable electricity is indispensable for the future development of the Indonesian economy. Indonesia's electrification rates can be seen in Figure 1 below.

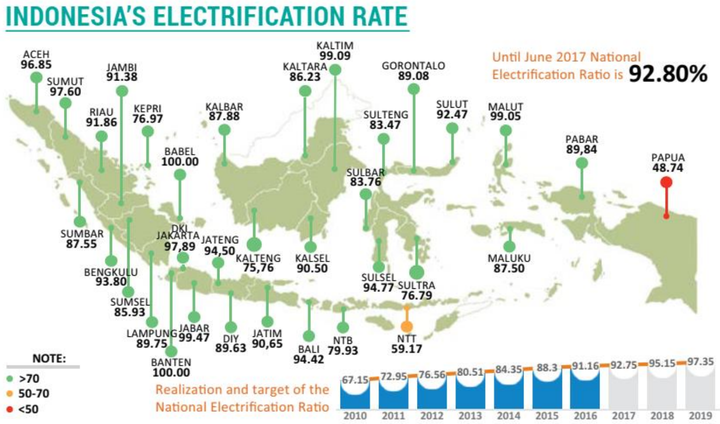

Figure 1. Indonesia's electrification rate
Source: [10]

They decreased physical energy. However, fossil fuels and energy can be offset for decades. Consequently, many countries have developed alternative energy strategies to achieve sustainability [11]. Indonesia is the biggest archipelago country in the world. Indonesia has 18,306 islands and a sea area of 3,544,743.9 km². Due to this maritime location, Indonesia's air pollution is very high. Moreover, Indonesia has highlands with different heights when viewed from the sea. Geographically, Indonesia has enormous wind potential. The utilization of hydropower or installed hydropower capacity in 2013 only reached 7,572 MW of the total hydropower capacity of 75,000 MW, an increase of 80% from 2008 of 4,200 MW. Meanwhile, the installed capacity of geothermal power plants in 2013 reached 1,343.5 MW, an increase of 13% compared to 2008 of 1,189 MW, or an average annual growth of 2.6% for the last five years [12][13]. Meanwhile, alternative non-fossil/renewable energy sources are still underutilized, as shown in Table 1. Other non-fossil energy sources have yet to be widely utilized, and efforts are still required to utilize these energy resources, which have so far been used to provide non-fossil energy sources. Fossil energy. Fossil energy in the national energy mix [14][15]. Indonesia's new renewable energy (EBT) target can be seen in Figure 2 below.

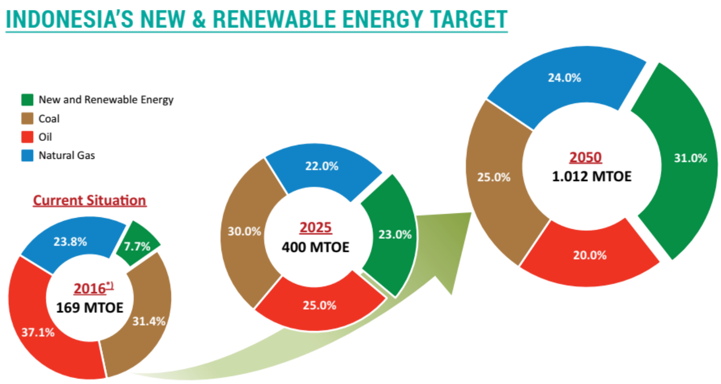

Figure 2. Indonesia's new and renewable energy targets

A hydraulic motor is a machine that converts mechanical energy into active fluid energy (potential energy and kinetic energy) or vice versa. Hydroelectric equipment is generally divided into two main categories: 1. Work equipment Is a hydraulic tool that converts mechanical energy into hydraulic energy. For example, pumps, compressors, blowers, fan valves, etc. 2. Engine power Is a hydraulic motor that converts water energy into mechanical energy on the shaft, for example, water heaters, water treatment plants, gas turbines, waterwheels, and others. The waterwheel was the first device used in water production. The main difference between a waterwheel and a hydraulic system is that the waterwheel rotates—flow velocity when the flow changes direction and velocity [16][17]. The wheel can be defined as a mechanical device that works in the shape of a wheel, with a bucket (cover or column) on an arc, positioned at an angle to the horizontal; the water wheel is a mechanism for transmitting hydrodynamic energy mechanically in the form of torque in the axle. The water cycle takes advantage of the natural contrast of a small stream surface. The water going in and out of the cycle has no excess pressure, only atmospheric pressure. The water reaches the wheel arches, which are most directly connected to the engine [18].

However, even so, the use of waterwheels still exists today because it also has advantages over water turbines, namely their simple and inexpensive construction and easy and inexpensive maintenance [19]. Although it has many disadvantages compared to water turbines, this straightforward technology is suitable for use in remote villages as long as the potential for hydropower sources is sufficiently guaranteed. Historical data show that the principle of converting hydropower into mechanical energy has been known for over 2,500 years by using a simple wooden waterwheel as a generator. The use of waterwheels started in India, then spread to Mercer, and then continued to Europe and America. The systematic design of waterwheels began in the 18th century when much research was carried out to improve the waterwheels' performance. Eventually, the turbine construction was brought to the water. The theoretically designed waterwheel, built on a poncelet, was widely used in England in the early 19th century [20].

In the previous study [21], which focused on sediment analysis from river events of 0.09708 d3/x and a head of 0.26 x, the nipple waterwheel can be used as an independent power plant in remote areas. Technical test results are available. 112.6 W maximum mechanical power with 45.5% efficiency at par.77.9 Nm at 13.8 rpm. Moreover, research results show that the dam. This is exacerbated by water waste (domestic waste) [22]. Methods with greater inclination (in this case, 20° to 25°) can cause loss or leakage of the space between the holes. Moreover, the waterway dramatically affects the efficiency of the waterwheel. Adequate Maximum (ηmax) depending on tilt angle, 10°, 15°, and 20° 55% and 61% from 1.15 to 1.58.

In addition, the waterwheel design is solid and easy to build, work on and repair construction structures that generate operating costs and less maintenance. Figure 3 shows the specifications of the different waterwheels.

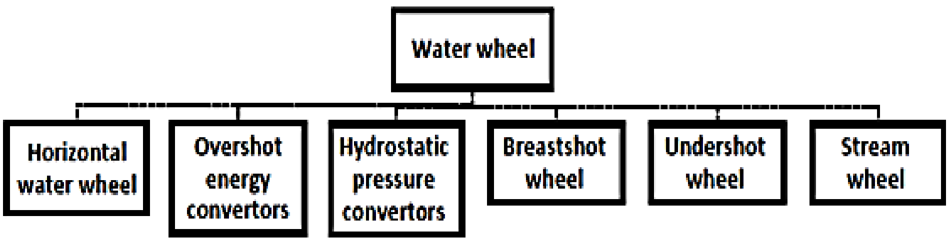

Figure 3. Classification of waterwheels.
Source:[23]

According to the method of applying water to the wheel's blades against the wheel axle, which is often applied In the current river flow, waterwheels are classified as undershot, overshot, and breastshot (middle shot) waterwheels [19][24][25]. The water flowing into and out of the wheel has no excess pressure, only atmospheric pressure. The speed of the water flowing into the wheel must be large because if the speed is large, the impetus on the blades of the water wheel will be greater. The research that will be carried out is an experimental study of the breastshot waterwheel using a construction-based nozzle with a variation of blade angle to the tip speed ratio (TSR) value and analyzing the performance and performance of the breastshot waterwheel using a system (nozzle tilt angle) to improve the performance of the waterwheel [26].

2. RESEARCH METHOD

The conceptual study describes the relationship between theoretical concepts for research purposes [27]. So the relationship between theory and problem, Either the idea of solving the problem at hand or the idea of a solution [28]. No concept It must be based on the theoretical framework concept. This study is an application and application of knowledge in the field of hydraulics that can be used as a solution and manufacturing project planning. Reference in analyzing industrial equipment failure and predicting system operational limitations so that it becomes a safety standard for the operation of industrial machines in the field of energy conversion. In this research, an experimental analysis of the breastshot water wheel will be carried out using a variation of the slope of the nozzle angle, namely with a double nozzle [(25°), (15°)] & [(20°), (10°)] to the Tip Speed Ratio (TSR) value.) to improve the performance of the waterwheel. The waterwheel blades have 12 curved blades and use a nozzle as a flow cross-section [29]. The blade used is a curved type and includes three main parts, namely a shaft with a diameter of 1.5 cm, a diameter of 48 cm made of acrylic material and a blade totalling 12 blades which has a thickness of 2 mm made of transparent acrylic material which is mounted around the disc. The planned dimensions of the water wheel are shown in Figure 4 below.

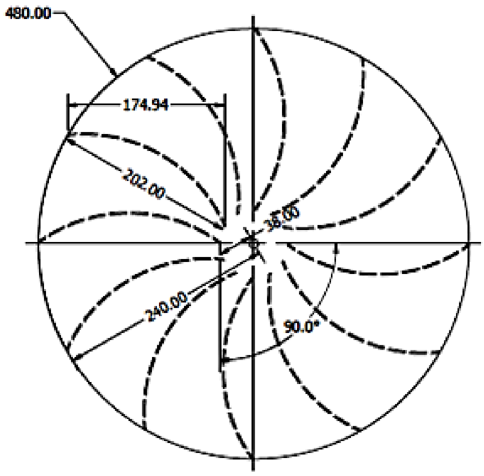

Figure 4. The image of the waterwheel blade has 12 blades [30]

The water that comes out of the overflow channel of the upper water tank will flow into the water channel; it is in this part of the water channel that all tests are carried out, starting from testing the water discharge, testing the depth of immersion, and other tests [31]. After this drain, the water will flow back into the bottom of the water tank. The water channel in this study has a length of 300 cm and a width of 25 cm and uses an acrylic plate material. The schematic picture of the waterwheel installation research process can be observed in Figure 5 below.

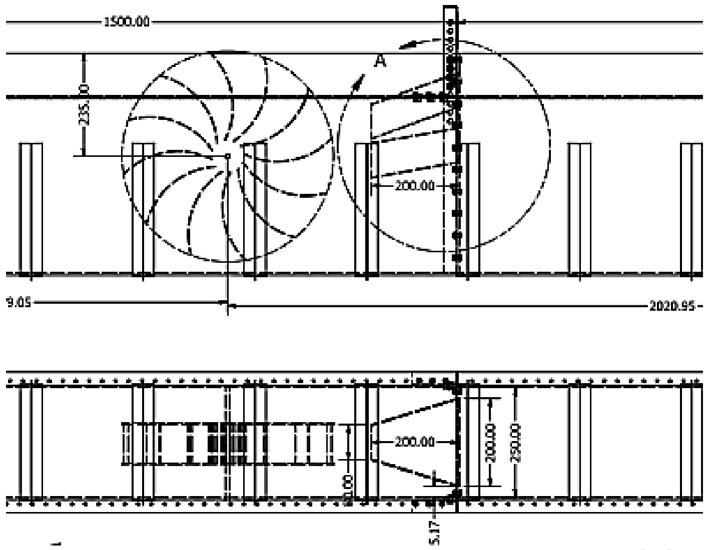

Figure 5. Waterwheel Channel Installation With Double Nozzles [32]

This study uses acrylic and filament materials in the manufacture of nozzles with a manufacturing process with 3D printing where the filament materials are combined under computer control to create 3D (visual real) and to be further analyzed through experimentation [33][34]. Calculation of the water flow rate, the water wheel coefficient, and the number of nozzles to be used so that this research can be studied scientifically. A nozzle is often a pipe or square of varying cross-sectional area and can be used to direct or modify the flow of a fluid (liquid or gas). Nozzles are often used to control the flow rate, velocity, direction, mass, shape, and pressure of the emergent stream. The nozzle has a different diameter at both ends, which aims to determine the flow velocity that will exit the nozzle, namely a large diameter at the inlet and a small diameter at the outlet, resulting in a change in the velocity of the fluid flowing through the nozzle. The nozzle velocity of the fluid increases according to the pressure energy. The main principle of using a nozzle for water or incompressible fluids uses the principle of the law of continuity, namely the conservation of mass.

3. RESULTS AND DISCUSSIONS

3.1 Test data.

The overall data from the waterwheel test results with variations in the degree of nozzle tilt, water flow rate, and waterwheel shaft rotation can be seen in the table below: waterwheel test results data. The following is shown in the data table taken at each water wheel test with variations in the degree of inclination of each nozzle.

Table 1. Waterwheel Test Data with Double Nozzle Variation of Degrees of Nozzle Tilt (25°-15°) at a discharge of 15 litres/second.

Information	Spin Speed [RPM]	Fb [N]	Debit [m3/s]	Pm (Watt)	Efisiensi (%)	Torsi (N.m)
	102	0.02	0.015	0.022858228	0.05461437	0.00214
	102	0.02	0.015	0.022858228	0.05461437	0.00214
	102	0.01	0.015	0.011429114	0.02730718	0.00107
ater flow rate (v) =. m/s	102	0.01	0.015	0.011429114	0.02730718	0.00107
RPM = n (rpm)	100	0.01	0.015	0.011205014	0.02677175	0.00107
Pm = Mechanical Power	99	1.57	0.015	1.741595295	4.16113279	0.16799
Fb = Braking Force	99	1.59	0.015	1.763781222	4.21414085	0.17013
	99	1.57	0.015	1.741595295	4.16113279	0.16799
	97	1.57	0.015	1.706411551	4.0770695	0.16799
	...	...	...	...	...	...

The discussion of this sub shows the effect of discharge and rotation on the power produced by the windmill at each variation of the angle of the nozzle inclination. From the Waterwheel Efficiency equation, the efficiency value is the amount of mechanical power (Pm) divided by the water power (Pa). In other words, the relationship from the mechanical power equation is that if the wheel's power increases for the same water power conditions, the efficiency of the wheel also increases. Therefore the discussion in this sub-chapter will be based on the graphic relationship between wheel rotation (rpm) and efficiency (η). Thus to fully understand the efficiency of the mill in the operation of the mill in this study, the following graph shows the relationship between water rotation (rpm) and efficiency (η) for each variation of the angle of the nozzle inclination.

Table. 2. Waterwheel Test Data with Double Nozzle Variation of Degrees of Nozzle Tilt (20°-10°) at 15 litres/second discharge.

Information	Spin Speed [RPM]	Fb [N]	Debit [m3/s]	Pm (Watt)	Efisiensi (%)	Torsi (N.m)
	102	0.02	0.015	0.010756813	0.02753666	0.00107
	102	0.02	0.015	0.010756813	0.02753666	0.00107
Water flow rate (v)	102	0.01	0.015	0.021513626	0.05507331	0.00214
=. m/s	102	0.01	0.015	0.010756813	0.02753666	0.00107
RPM = n (rpm)	100	0.01	0.015	0.010308613	0.02638929	0.00107
Pm = Mechanical	99	1.57	0.015	0.278332543	0.71251095	0.02889
Power	99	1.59	0.015	0.494813409	1.26668613	0.05136
Fb = Braking Force	99	1.57	0.015	0.484504797	1.24029684	0.05029
	97	1.57	0.015	0.474196184	1.21390754	0.04922
	...	...	...	...	...	...

3.2 Data processing (waterwheel efficiency).

This discussion shows the effect of discharge and rotation on the power produced by the windmill at each variation of the angle of the nozzle tilt. It is known that besides power and torque, efficiency is also one of the parameters of the wheel's performance. Thus to fully understand the efficiency of the mill in the operation of the mill in this study, the following graph shows the relationship between water rotation (rpm) and efficiency (η) for each variation of the angle of inclination of the nozzle in the figure below In figure 6 it can be seen that the phenomenon of the relationship between rotation and efficiency at each angle of the nozzle tested and for each variation of the angle of the nozzle inclination where the load decreases or in other words the rotation value increases, the turbine efficiency increases [35][36]. In other words, the research results show that the greater the angle of inclination of the nozzle, the more water flow will increase the rotational speed when it enters the waterwheel blades, so the efficiency of the wheel will also increase. With the use of a nozzle, the water flow into the wheel will be concentrated. The concentration of this water will reduce the wastage of water out of the water wheel. By increasing the slope of the nozzle angle, there will be an increase in the speed of the water flow when it enters the wheel, resulting in higher efficiency. This happens because of an increase in the speed of the waterwheel so that the power of the waterwheel also increases. This is due to the fact that the kinetic energy of the water flow can be used more in a water wheel with a tilt angle of the water wheel with the potential power of the available water. Therefore, the higher efficiency of the waterwheel with a greater variation of the nozzle inclination angle can be understood because, in the previous section, higher mill power was also obtained in the waterwheel with a greater variation of the nozzle inclination angle.

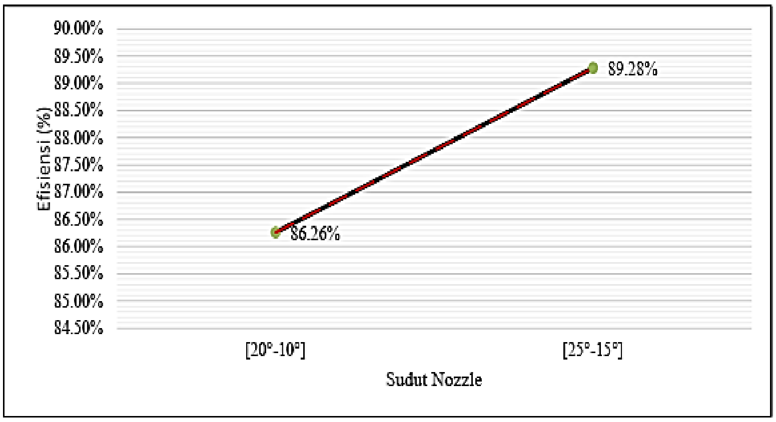

Figure 6. The relationship between the nozzle angle and maximum efficiency with variations in the double nozzle angle [(25°-15°)] & [(20°-15°)] at a water discharge of 15 litres/second.

The graph in the picture above shows the relationship between rotation (rpm) and efficiency above with variations in the angle of the double nozzle [(25°-15°)] & [(20°-15°)] at a water discharge of 15 litres/second, showing the conditions The most excellent efficiency for the waterwheel operation angle (25°-15°) is at 63 rpm, which is 89.28%. The lowest efficiency is at 16 rpm, which is 35.49%. The most excellent efficiency for angle (20°-10°) is found at 44 rpm, 86.26%, and the lowest efficiency is at 20 rpm, which is equal to 42.72%. The relationship between the nozzle angle and the efficiency of the wheel shows a different pattern for each water wheel with variations in the angle of the nozzle. This phenomenon occurs because the flow conditions are in open channels where the increasing steepness or slope of the water nozzle used causes the area and flow velocity to increase. The behaviour of the flow and the blades of the waterwheel was recorded in the form of video recordings to determine the phenomena that occurred. The video recording results will be displayed in the form of a series of images that represent each movement of the water wheel. From these pictures, it can be observed the movement of the blade and the flow hitting the blade. For better observations, several videos were taken at the highest momentum received by the blade, where the maximum waterwheel conditions will provide maximum thrust on the waterwheel blades, as shown in Figure 6. In addition, observations were also made on the worst conditions of the wheel performance to understand the phenomenon flow under these conditions.

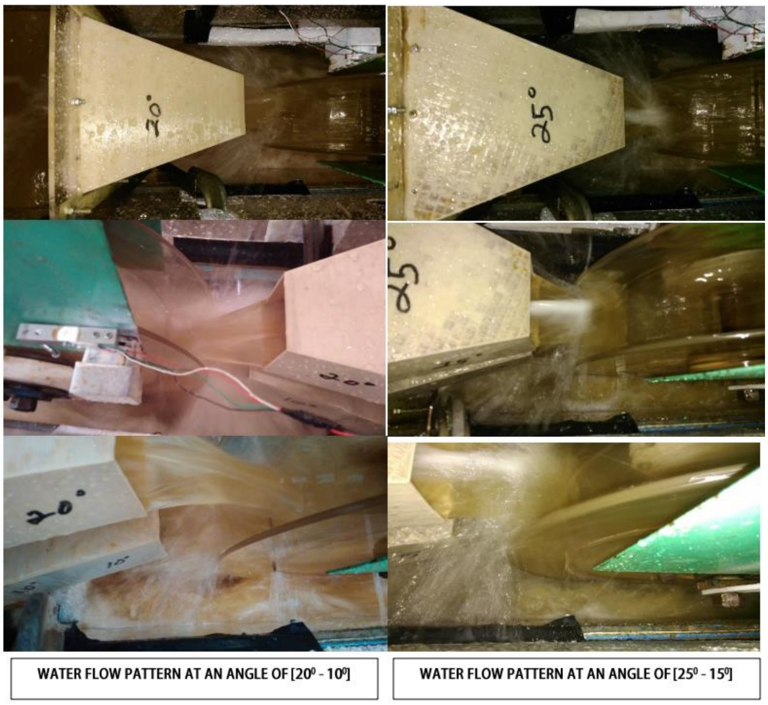

Figure 7. The water flow behaviour at the inlet side of the double nozzle.

Figure 7 above shows that changes in flow behaviour at the inlet side of the water wheel can be due to differences in loading on the shaft. The greater the loading, the greater the water turbulence, and the most significant water oscillation is at the corner nozzles (20°-10°). By increasing the angle of the nozzle, there will be an increase in the speed of the water flow when it enters the wheel. This condition also explains that the greater the inclination of the nozzle angle, the efficiency of the water wheel will increase so that the torque generated will also increase, and the shaft power will increase. If the shaft power increases, the efficiency will also increase because the shaft power is directly proportional to the efficiency [36]. The performance of the waterwheel can also be observed based on the head and capacity of the water flow towards the generator shaft and the efficiency of the wheel. The performance of the turbine can also be seen from the speed, the ratio of the flow rate, and the specific rotation of the turbine or waterwheel operations. Collisions that result in hydraulic losses from the water jets and changes in the direction of the water jets when they enter the waterwheel blades and conditions like that can be predicted to reduce the work efficiency of the waterwheel. The pattern of jets of water flowing in the flow waterwheel is influenced by the number of active blades that are hit by water from the waterwheel nozzle. The number of active blades is determined by how large the nozzle angle is; the more significant the nozzle angle, the more active blades [37][38]. Changes in flow behaviour at the inlet side of the water wheel are caused by differences in the loading on the shaft. The greater the loading, the greater the water circulation, the largest water circulation is at the nozzle angle (25°-15°), and the smallest is at the nozzle angle (20°-10°). This causes a backflow that opposes the absolute speed of the water flow and a large enough pool of water that gives a force load that is opposite to the direction of torque on the blade. This condition also explains that the higher the rotation, the more optimal the wheel power tends to be.

3.3 Tip speed ratio (TSR).

Tip Speed Ratio (TSR) is the ratio between the tangential velocity at the blade's tip and the fluid's actual velocity.

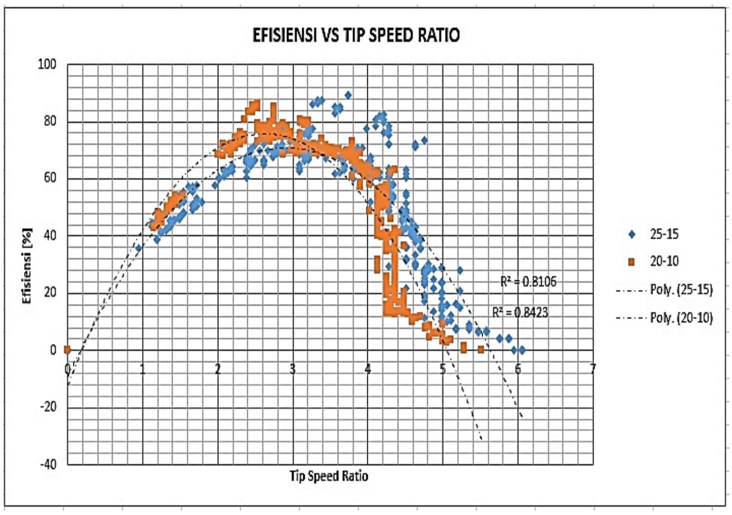

Figure 8. Relationship between tip speed ratio (TSR) and efficiency with double nozzle angle variations [(25°-15°)] & [(20°-15°)].

Maximum efficiency occurs when using a double nozzle variation with an angle (of 25°-15°). In other words, the results of the study show that the greater the angle of the nozzle, the greater the velocity of the water flow when it enters the wheel. The addition of water velocity into this wheel will increase the momentum and will increase the tangential force. The increase in this tangential force will increase the torque of the wheel so that the power of the wheel will increase. This increase in power will, of course, result in greater efficiency resulting in an increased tip speed ratio (TSR). While the value of the tip speed ratio (TSR) and the value of the efficiency produced by the water wheel will increase if the value of the tip speed ratio (TSR) is lower due to the influence of the additional load on the water wheel rotation, then after reaching the highest limit (peak) then the value of the efficiency of the wheel water produced will gradually decrease. Figure 8 above shows the relationship between the tip speed ratio (TSR) and the waterwheel's efficiency. The efficiency produced by using the slope of the nozzle angle will increase as the tip speed ratio (TSR) increases, and each graph shows trendlines that differ from one another [26].

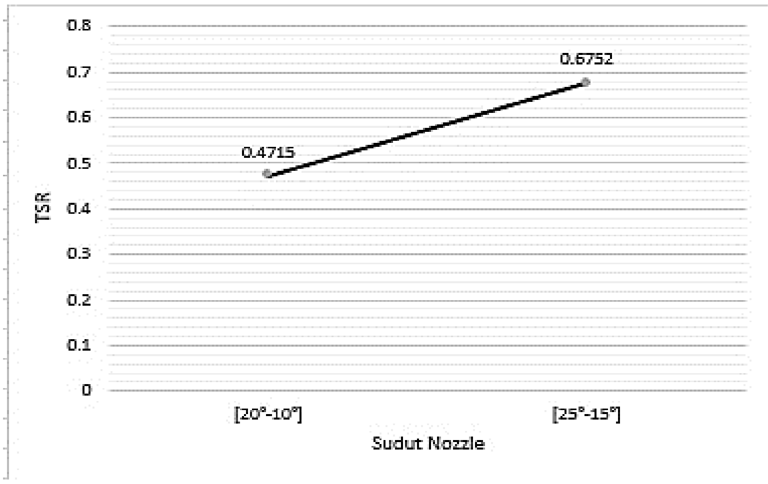

Figure 9. The relationship between the nozzle angle and the optimum tip speed ratio (TSR), namely the tip speed ratio (TSR) with the highest efficiency

Figure 9 above shows that the optimum tip speed ratio (TSR), namely the tip speed ratio (TSR) with the highest efficiency, reaches the highest value at the tip speed ratio (λ) = 0.6752, which is 89.28% with an angle [25°-15 °]. The increase in the efficiency of the water wheel is caused by an increase in the rotation and torque of the water wheel, which causes the output power to increase while the input power from the water flow will remain the same. The tip speed ratio (TSR) is influenced by the magnitude of the quotient of the measurement of the tangential speed of the water wheel with the incoming water flow rate (λ= U/V) [39]. This best performance is due to the kinetic energy of the water flowing through the water wheel rotor. The angle of the nozzle and the blades that are tightly arranged causes a large thrust against the surface of the blade so that the water wheel can increase the number of revolutions (rpm). A waterwheel with a steep nozzle angle has the highest efficiency value so that it is able to carry out optimal energy transfer so that the resulting thrust is greater. The large thrust force results in optimal waterwheel efficiency and performance. The greater the angle of the nozzle used will increase the efficiency of the waterwheel [40][41].

4. CONCLUSION

Maximum efficiency occurs when using a double nozzle variation with an angle (of 25°-15°). In other words, research results show that the greater the angle of the nozzle, the greater the velocity of the water flow when it enters the wheel. The addition of water velocity into this wheel will increase the momentum and will increase the tangential force. The increase in this tangential force will increase the wheel's torque so that the wheel's power will increase. This increase in power will, of course, result in greater efficiency and an increased tip-speed ratio (TSR). While the value of the tip speed ratio (TSR) and the value of the efficiency produced by the water wheel will increase if the value of the tip speed ratio (TSR) is lower due to the influence of the additional load on the water wheel rotation, then after reaching the highest limit (peak) the value of the efficiency of the wheel water produced will gradually decrease. As for the graph of the relationship between efficiency and tip speed ratio above with variations in the double nozzle angle, it shows the operating conditions of the water wheel, the most significant tip speed ratio for the double nozzle angle (25°-15) with a tip speed ratio of 0.6752 is equal to 89.28% and the lowest efficiency is the tip speed ratio of 0.1714 which is 35.49%. While the highest efficiency is at the tip speed ratio of 0.4715, which is 86.26% with an angle (of 20°-10°), and the lowest efficiency is at the tip speed ratio of 0.2143, which is 42.72%. In other words, the study results show that the greater the angle of inclination of the nozzle, the more efficiency of the wheel will also increase.

REFERENCES

[1] L. Pietrosemoli and C. Rodríguez-Monroy, "The Venezuelan energy crisis: Renewable energies in the transition towards sustainability," *Renew. Sustain. Energy Rev.*, vol. 105, no. 1, pp. 415–426, 2019, doi: https://doi.org/10.1016/j.rser.2019.02.014.

[2] M. T. Masood and F. Shah, "Dilemma of third world countries-problems facing pakistan energy crisis a case-in-point," *Int. J. Bus. Manag.*, vol. 7, no. 5, pp. 231–246, 2012, doi: http://dx.doi.org/10.5539/ijbm.v7n5p231.

[3] K. K. Perry, "For politics, people, or the planet? The political economy of fossil fuel reform, energy dependence and climate policy in Haiti," *Energy Res. Soc. Sci.*, vol. 63, no. 1, p. 101397, 2020, doi: https://doi.org/10.1016/j.erss.2019.101397.

[4] K. Solaun and E. Cerda, "Climate change impacts on renewable energy generation. A review of quantitative projections," *Renew. Sustain. Energy Rev.*, vol. 116, no. 1049415, pp. 1–16, 2019, doi: 10.1016/j.rser.2019.109415.

[5] A. K. Gerlak, J. Weston, B. McMahan, R. L. Murray, and M. Mills-Novoa, "Climate risk management and the electricity sector," *Clim. Risk Manag.*, vol. 19, no. December 2017, pp. 12–22, 2018, doi: 10.1016/j.crm.2017.12.003.

[6] M. Mohsin, Q. Abbas, J. Zhang, M. Ikram, and N. Iqbal, "Integrated effect of energy consumption, economic development, and population growth on CO 2 based environmental degradation: a case of transport sector," *Environ. Sci. Pollut. Res.*, vol. 26, no. November, pp. 32824–32835, 2019, doi: https://doi.org/10.1007/s11356-019-06372-8.

[7] H. Schandl *et al.*, "Decoupling global environmental pressure and economic growth: scenarios for energy use, materials use and carbon emissions," *J. Clean. Prod.*, vol. 132, no. 20, pp. 45–56, 2016, doi: https://doi.org/10.1016/j.jclepro.2015.06.100.

[8] A. M. Omer, "Energy, environment and sustainable development," *Renew. Sustain. energy Rev.*, vol. 12, no. 9, pp. 2265–2300, 2008, doi: https://doi.org/10.1016/j.rser.2007.05.001.
[9] O. Ellabban, H. Abu-Rub, and F. Blaabjerg, "Renewable energy resources: Current status, future prospects and their enabling technology," *Renew. Sustain. energy Rev.*, vol. 39, no. 1, pp. 748–764, 2014, doi: https://doi.org/10.1016/j.rser.2014.07.113.
[10] R. E. F. I. 2017, "Renewable Energy: Keystone for Universal Electrification_and Energy Security," *The 3rd International Conference and Exhibition on Geothermal, Hydro, Solar, Wind, Ocean Wave, and Bio Energies., 2017*, 2017. https://www.there4i.org/.
[11] B. A. Nasir, "Design of High Efficiency Cross-Flow Turbine for Hydro-Power Plant," *Int. J. Eng. Adv. Technol.*, vol. 2, no. 3, pp. 2249–8958, 2013.
[12] K. E. dan S. D. M. (ESDM), "Pemerintah Buka Ruang Libatkan Milenial Kembangkan EBT," *Kementerian Energi dan Sumber Daya Mineral (ESDM)*, 2020. http://ebtke.esdm.go.id/post/2020/09/26/2635/pemerintah.buka.ruang.libatkan.milenial.kembangkan.ebt.
[13] M. O. E. and M. Resources and R. of Indonesia, *Handbook of Energy & Economic Statistics of Indonesia*, 1st ed., vol. 1, no. 1. Jakarata, 2017.
[14] J. A. Razak, Y. Ali, M. A. Alghoul, M. Said Zainol, A. Zaharim, and K. Sopian, "Application of Crossflow Turbine in Off-Grid Pico Hydro Renewable Energy System," *Proceeding Am. -Math*, vol. 1, no. 1, pp. 519–526, 2010.
[15] R. E. P. IRENA, *Renewable Energy Prospects: Indonesia, a REmap analysis,*. Abu Dhabi: International Renewable Energy Agency (IRENA), 2017.
[16] T. Pujol and L. Montoro, "High hydraulic performance in horizontal waterwheels," *Renew. Energy*, vol. 35, no. 11, pp. 2543–2551, 2010, doi: https://doi.org/10.1016/j.renene.2010.03.025.
[17] M. Asim *et al.*, "Design and Parametric Optimization of the High-Speed Pico Waterwheel for Rural Electrification of Pakistan," *Sustainability*, vol. 14, no. 11, p. 6930, 2022, doi: https://doi.org/10.3390/su14116930.
[18] A. M. Makarieva and V. G. Gorshkov, "Biotic pump of atmospheric moisture as driver of the hydrological cycle on land," *Hydrol. earth Syst. Sci.*, vol. 11, no. 2, pp. 1013–1033, 2007, doi: https://doi.org/10.5194/hess-11-1013-2007.
[19] S. Baur, L. Geß, A.-K. Seppälä, and J. Eisner, "Low-Tech Waterwheel-Concept for a Simple and Small Hydro Power System for Remote Areas in Nepal," in *5th International Conference on the Developments in Renewable Energy Technology (ICDRET'18)*, 2018, pp. 1–4, [Online]. Available: https://mediatum.ub.tum.de/1446887.
[20] Kaprawi, "Pengaruh Geometri Sudu Dari Turbin Air Darrieus Terhadap Kinerjanya," in *Prosiding Seminar Nasional AVoER ke-3*, 2011, pp. 1–8, [Online]. Available: http://repository.unsri.ac.id/7407/1/PROSIDING_AVOER_2011kafrawi.pdf.
[21] Budiarso, Helmizar, Warjito, A. Nuramal, W. Ramadhanu, and D. Adanta, "Performance of breastshot waterwheel in run of river conditions," in *AIP Conference Proceedings 6 May 2020; 2227 (1): 020014*, 2020, vol. 2227, no. 020014, pp. 1–7, doi: 10.1063/5.0000940.
[22] D. Adanta, Budiarso, and Warjito, "The effect of channel slope angle on breastshot waterwheel turbine performance by numerical method," *Energy Reports*, vol. 6, no. 2, pp. 606–610, 2020, doi: 10.1016/j.egyr.2019.11.126.
[23] M. Al-Dabbagh, "Investigation the Performance of Stream Water Wheel Turbines using CFD Techniques," in *International Conference on Research in Education and Science (ICRES)*, 2018, vol. 2, pp. 354–360, [Online]. Available: http://www.epstem.net/en/download/article-file/528352.
[24] E. Quaranta, "Investigation and optimization of the performance of gravity water wheels," Politecnico di Torino, 2017.
[25] A. Bachan, N. Ghimire, J. Eisner, S. Chitrakar, and H. P. Neopane, "Numerical analysis of low-tech overshot water wheel for off grid purpose," in *Journal of Physics: Conference Series*, 2019, vol. 1266, no. 1, p. 12001, doi: 10.1088/1742-6596/1266/1/012001.
[26] M. H. Kurniawan, R. Soenoko, Winarto, and A. Sunarso, "Studi Eksperimental Performance Kincir Air Breastshot Dengan Menggunakan Nozzle," *Rekayasa Mesin*, vol. 12, no. 3, pp. 633 – 642, 2021, doi: https://doi.org/10.21776/ub.jrm.2021.012.03.13.
[27] L. Varpio, E. Paradis, S. Uijtdehaage, and M. Young, "The distinctions between theory, theoretical framework, and conceptual framework," *Acad. Med.*, vol. 95, no. 7, pp. 989–994, 2020, doi: https://doi.org/10.1097/ACM.0000000000003075.
[28] Y. Stern, "What is cognitive reserve? Theory and research application of the reserve concept," *J. Int.*

Neuropsychol. Soc., vol. 8, no. 3, pp. 448–460, 2002, doi: https://doi.org/10.1017/S1355617702813248.
[29] O. Cleynen, E. Kerikous, S. Hoerner, and D. Thévenin, "Characterization of the performance of a free-stream water wheel using computational fluid dynamics," *Energy*, vol. 165, no. 2, pp. 1392–1400, 2018, doi: https://doi.org/10.1016/j.energy.2018.10.003.
[30] D. P. Sari *et al.*, "Performance of undershot waterwheel in pico scale with difference in the blades number," *J. Brazilian Soc. Mech. Sci. Eng.*, vol. 44, no. 3, p. 107, 2022, doi: https://doi.org/10.1007/s40430-022-03430-0.
[31] P. K. Talukdar, V. Kulkarni, and U. K. Saha, "Field-testing of model helical-bladed hydrokinetic turbines for small-scale power generation," *Renew. Energy*, vol. 127, no. November, pp. 158–167, 2018, doi: https://doi.org/10.1016/j.renene.2018.04.052.
[32] B. Wahyudi, A. Faizin, and S. Soeparman, "Increasing efficiency of overshot waterwheel with overflow keeper double nozzle (OKDN) by using hydraulic ram system," in *Applied mechanics and materials*, 2013, vol. 330, pp. 209–213, [Online]. Available: https://www.scientific.net/AMM.330.209.
[33] S. Soni and M. Taufik, "Design and assembly of fused filament fabrication (FFF) 3D printers," *Mater. Today Proc.*, vol. 46, no. 11, pp. 5233–5241, 2021, doi: https://doi.org/10.1016/j.matpr.2020.08.627.
[34] T. D. Ngo, A. Kashani, G. Imbalzano, K. T. Q. Nguyen, and D. Hui, "Additive manufacturing (3D printing): A review of materials, methods, applications and challenges," *Compos. Part B Eng.*, vol. 143, no. June, pp. 172–196, 2018, doi: https://doi.org/10.1016/j.compositesb.2018.02.012.
[35] M. H. Kurniawan, D. Iswanda, and A. K. Garside, "Perancangan dan Analisis Potensi Pembangkit Listrik Tenaga Mikro Hidro Di Aliran Sungai Brantas Sengkaling Kabupaten Malang Dalam Rangka Mencapai Target Energy Mix 23 % Pada Tahun 2025," *J. Appl. Mech. Eng. Renew. Energy*, vol. 1, no. 2, pp. 46–52, 2021, doi: https://doi.org/10.52158/jamere.v1i2.235.
[36] J. A. Hameed, A. T. Saeed, and M. H. Rajab, "Design and analysis of hydroelectric generation using waterwheel," in *2018 9th International Renewable Energy Congress, IREC 2018*, 2018, vol. 17788781, no. May, pp. 1–6, doi: 10.1109/IREC.2018.8362443.
[37] Y. Jin *et al.*, "Defect-related luminescent bur-like hydroxyapatite microspheres induced apoptosis of MC3T3-E1 cells by lysosomal and mitochondrial pathways," *Sci. China Life Sci.*, vol. 61, no. Maret, pp. 464–475, 2018, doi: https://doi.org/10.1007/s11427-017-9258-3.
[38] Syafriyudin, B. Fajar, S. H. Winoto, and M. Facta, "Early Analysis of Jumping Water Effect on Breastshot Waterwheel for Microhydro Power Plant," in *Journal of Physics: Conference Series*, 2018, vol. 953, no. 1, p. 012039, doi: 10.1088/1742-6596/953/1/012039.
[39] C. Stout *et al.*, "Efficiency Improvement of Vertical Axis Wind Turbines with an Upstream Deflector," *Energy Procedia*, vol. 118, no. 1, pp. 141–148, 2017, doi: https://doi.org/10.1016/j.egypro.2017.07.032.
[40] R. Boli, A. Makhsud, and M. Tahir, "Analisis Daya Output dan Efisiensi Kincir Air Sudu Miring yang Bekerja pada Saluran Horizontal," *Gorontalo J. Infrastruct. Sci. Eng.*, vol. 1, no. 2, pp. 1–7, 2018, doi: https://doi.org/10.32662/gojise.v1i2.423.
[41] A. H. Elbatran, O. B. Yaakob, Y. M. Ahmed, and H. M. Shabara, "Operation, performance and economic analysis of low head micro-hydropower turbines for rural and remote areas: A review," *Renew. Sustain. Energy Rev.*, vol. 43, no. 1, pp. 40–50, 2015, doi: https://doi.org/10.1016/j.rser.2014.11.045.