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Design and Construction of A Vortex Type Turbine Driving A 100 Watt Generator

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Abstract

This study aims to describe the design and construction of a vortex-type turbine driving a 100-watt generator. The research method used is an experimental method, namely by designing, making, and testing a vortex turbine to determine the system's ability to produce 100 watts of electrical power. Based on the test results, turbines with blade angle variations of 30°, 45° and 60° at the same water discharge of 2,026L/s, it was found that the 60° blade angle produced better performance. This is shown at an angle of 60° obtaining a turbine speed of 714.882 and a hydrostatic pressure of 121,590 Pa, which is higher than an angle of 30° which obtains a turbine speed of 563.786 and a hydrostatic pressure of 121,590 and an angle of 45° which only obtains a turbine speed of 740.1 and a hydrostatic pressure of 95,245. Thus, it can be concluded that the blade angle affects turbine performance, where the 60° angle in this test is able to optimize the conversion of water energy into mechanical and electrical energy more effectively than the 30° and 45° angles.

Keywords: Design, Turbine, Vortex Type, Drive, Generator

INTRODUCTION

Energy is the most important thing in people's lives to carry out daily activities. One of the energy sources that has been widely researched is water currents. The use of various types of turbines is increasingly advanced (Budiman et al., 2022). Indonesia is an agricultural country with the 5th largest potential for water resources in the world. The potential for water resources is very abundant with a total of around 3,200 billion m3 / year (Jonkman et al., 2009). So water turbines are prioritized over wind turbines because the wind in Indonesia is relatively less stable. Overall, water is a necessity for the survival of all creatures on Earth (Pinto et al., 2020).

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The basic principle of hydroelectric power is to convert the energy contained in flowing water in rivers or seas into mechanical energy, which can then be converted into electrical energy (Sørensen et al., 2014). The primary equiment needed to build a waterwheel is a turbine and a generator (Du & Selig, 1988) Hydroelectric power plants aim to generate additional energy from nature and have been developed in many countries on a large scale, requiring significant water demand (Timmer & van Rooij, 2003). This type of hydroelectric power plant is often called microhydro (Saenz-Aguirre et al., 2020).

Microhydro, or picohydro, typically utilizes waterfalls with large falls. Meanwhile, rivers with smaller falls have not been optimally utilized. Yet, Indonesia boasts significant river water potential from 5,590 rivers spread across various islands (*Bladed Wind Turbine Design Software*, 2022). This serves as a reference for utilizing this potential by transforming it into a vortex flow (circulating water flow) (Moon et al., 2023). A vortex turbine is a type of microhydro turbine that uses water vortexes to drive its blades. Vortex turbines operate at low heads of 0.7 m–3 m with a discharge of 50 L/s (Dai et al., 2024).This type of turbine is well-suited for river flow, as most rivers have low heads (Fernandez-Gamiz et al., 2017).

LITERATURE REVIEW

Hydroelectric power plant

A hydroelectric power plant (PLTA) is a power plant that relies on the potential and kinetic energy of water to generate electricity. This generated electrical energy is commonly referred to as hydroelectricity. The primary form of this type of power plant is a generator connected to a turbine driven by the kinetic energy of the water. In a PLTA, the potential energy of the water is converted into electrical energy. First, the potential energy is converted into mechanical energy in a water turbine, which then turns a generator, generating electricity (Wendt & Hingst, 2020).

According to Munandar (Kim et al., 2023) a turbine is a driving machine, where the energy of the working fluid is used directly to rotate the turbine blades. So, unlike what happens in a piston engine, in a turbine there are no machine parts that move translationally. The rotating part of the turbine is called the rotor or turbine blades, while the non-moving part is called the stator or turbine housing. The turbine blades are located inside the turbine housing and the turbine blades rotate the power shaft that drives or rotates the load (propeller, electric generator, pump, compressor, or other machine) (Dwika et al., 2024).

Hydroelectric power generation isn't limited to water from a dam, but also includes power plants that utilize other forms of water power, such as wave power. Hydroelectric power

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has several advantages over other forms of electricity generation, such as its ability to adapt to load demands, environmental friendliness, and non-pollution (Dvorak, 2023).

A hydroelectric power plant essentially converts water energy into electrical energy. Water acts as a potential source that can be used to drive a turbine, and the water in the dam then flows down into a hole to turn the turbine. The rotation of the turbine generates mechanical energy, which is converted into electrical energy by a generator. The hydroelectric power plant then transmits the energy to the electrical power supply and connects it with cables (Im & Kim, 2019).

Understanding Water Turbines

According to Arismunandar (Mereu et al., 2019) a water turbine is a prime mover where water rotates the turbine wheel, without translational (back and forth) motion, producing shaft rotation to drive the load (generator). Inside the turbine, the working fluid undergoes an expansion process, namely the process of reducing fluid pressure, and flows continuously. The working fluid can be water, steam, or gas. So in general a water turbine can be interpreted as an energy conversion machine that can produce power by expanding (reducing the pressure) of the fluid in the form of water that flows continuously through the water turbine. According to Djiteng Marsudi (J. Lee et al., 2016)the working principle of the turbine is to convert the potential energy of water into kinetic energy.

Types of Turbines

Based on the working principle of the turbine in converting the potential energy of water into mechanical energy, turbines are divided into two groups, namely impulse turbines and reaction turbines. Based on the direction of flow (Dardabi et al., 2022) turbines are grouped into two groups, namely radial flow turbines and axial flow turbines.

Radial Flow Turbine

A radial flow turbine is a turbine whose flow direction is perpendicular to the direction of rotation of the turbine shaft. Radial flow turbines are used for low flow rates (working fluid flow) and high pressure differences. (Ginanjar & Halimi, 2024a).

Axial Flow Turbine

A turbine that is parallel to the direction of rotation of the turbine shaft. Axial-flow turbines are used for high flow rates and low pressure differences (1 – 40 bar). Axial-flow

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turbines are mostly used in applications involving fluids (Ginanjar & Halimi, 2024b).

Reaction Turbine

Reaction turbines, commonly called overpressure turbines, consist of guide and path blades. In reaction turbines, the water expansion process occurs within both the fixed and moving blades, and both blades are submerged in the water flow. Reaction turbines are used for low- and medium-head applications. Some examples of reaction turbines are the Francis turbine, the Kaplan turbine, and the Vortex turbine (Oktaviani et al., 2020).

Kaplan turbine is a turbine with propeller-shaped blades that can be adjusted to get maximum efficiency according to the size of the flow and water level. According to Subekti, RA, (2015). Kaplan turbine is a propeller-type water turbine that has adjustable blades/fins, in the reaction turbine the water enters the network under pressure and then flows to the blades, with the increase in the capacity of the water entering the turbine, the cross-sectional area of the channel through which the water passes will also increase and in addition the rotational speed can be determined higher the specific speed increases, the curvature of the blades, the number of blades and the bends of the water in the blades are reduced. In fact, the Kaplan turbine is a development of the Francis turbine, its development was carried out in 1913 by an Austrian scientist named Viktor Kaplan (Nurjanah et al., 2021). The Kaplan turbine is also included in the type of reaction turbine. Another specialty, the Kaplan turbine can be applied to low heads (water fall height), therefore, this turbine is suitable for use in river hydroelectric power plants. Advantages of the Kaplan turbine (Subekti, RA, 2015). Adjustable runner turbine blades require only low scale heads and have a very small head count from 3 blades to 8 (Mancò et al., 2021).

Vortex Turbine Working Process

The vortex hydropower system is a new technology that utilizes the energy contained in large whirlpools created by low head differences in rivers (Sunarlik, 2017) . How a vortex turbine works:

1. River water from the riverbank is channeled and carried to a circulation tank. This circulation tank has a circular hole at its base.
2. The low pressure at the bottom of the tank and the water velocity at the inlet of the circulation tank affect the strength of the vortex flow.
3. The potential energy is completely converted into rotational kinetic energy in the core.
4. The vortex is then extracted through a vertical axis turbine.
5. The water then returns to the river through the outlet.

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Vortex Flow

This vortex flow is a turbulent flow. It is called turbulent flow because the flow is irregular and forms a vortex. Vorticity (vortex flow velocity) is very high in the core area around the axis and the pressure dips sharply downwards towards the exhaust port (Adam et al., 2020). Vortex flow is a fluid mass whose particles rotate in the direction of the streamline and form a concentric circle. The swirling movement is caused by a difference in speed between adjacent fluid layers, or it can also be interpreted as the natural movement of the fluid caused by the parameters of pressure and velocity. A rationally rotating vortex where viscosity influences it is the effect of a vortex vortex.

METHOD

This research was conducted during a specific period and at a predetermined location, in accordance with the data collection and experimental requirements (Oktaviani et al., 2020).

The design period began with the ratification of the design title by the Head of the Mechanical Engineering Study Program, Faculty of Engineering and Management of Water Resources Management, HKBP Nommensen University, Pematangsiantar, and was carried out for approximately 4 months, from January 2026 to April 2026. The design location for "DESIGN AND CONSTRUCTION OF A VORTEX TYPE TURBINE TO DRIVE A GENERATOR" is on Jalan Akasia Raya, Perumnas BT 6, Simalungun Regency, Siantar City, North Sumatra 21151.

The research method used is the experimental method, namely by designing, making, and testing a vortex turbine to determine the system's ability to produce 100 watts of electrical power. Electrical energy is a primary need in various community activities (Troldborg et al., 2015). However, not all areas have adequate access to electricity, especially in remote areas far from the main electricity grid. Therefore, it is necessary to utilize alternative energy sources available in the surrounding environment, one of which is water energy. Small-scale hydroelectric power plants or microhydro can be a solution to generate electrical energy by utilizing water flows that have a small discharge and low water fall height . One technology that can be used is a vortex turbine, a turbine that works by utilizing water eddies formed in a pool or basin. Although vortex turbine technology has several advantages such as simple construction, environmentally friendly, and can work at low heads, there are still several problems in its application. These problems incl(Gao et al., 2015)ude suboptimal turbine design, low energy conversion efficiency, and less than maximum electrical power generated by the generator. Based on these problems, research is needed on the design and manufacture of vortex turbines that are capable of driving generators so that they can produce electrical power

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of around 100 watts. This research is expected to provide solutions for the effective and efficient use of small-scale water energy (Alhassan et al., 2025).

A literature review is the stage of examining various scientific sources such as journals, books, and previous research related to vortex turbines. The purpose of this literature review is to obtain a theoretical basis, understand the development of vortex turbine technology, and identify previous research findings that can be used as references in future research. Based on the various studies conducted, it can be concluded that vortex turbine performance is influenced by several key factors, namely:

Large Blade Count (6–8 blades): Provides a larger surface area for the water vortex to push against. As a result, the turbine rotates more easily when the water first flows (high initial torque). Small Blade Count (3–4 blades): Requires a higher vortex speed to start rotating because the gaps between the blades are too wide (H. M. Lee & Kwon, 2019). Rotational Speed (RPM) Fewer Blades: Tends to have a higher RPM because the blade material has less drag on the water. This is suitable if you are using a generator that requires fast rotation (Moon et al., 2023).

Many Blades: RPM tends to be lower and more stable (Krsimantoro et al., 2023). However, if they are too close together, water will be trapped in the runner and cause choking, which will actually decrease the rotational speed (Lin, 2020). Flow Interference: If the blades are too many and close together, the water flow between the blades will be disturbed by the turbulence from the blade in front.

RESULTS

Design results



Figure 1. Internal View of the Vortex Type Turbine Driving the Generator

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Figure 2. External view of the vortex type turbine driving the generator

Calculation method

1. Calculate water discharge

Q= $A\ x\ v$

Q = 0.002065m ^{2}x 1m/s

Q = 0.002026 m^3/s

Q = 2.026L/s

Where :

Q=Water A= Cross-sectional area

v= flow velocity

$Q_{1=}$(Av cos 30 °)I +(Av sin30 °)=(0.00785 m^2)(1m/s)cos 30 °+ °)=(0.00785 m^2)(1m/s)sin 30°

$Q_{2=}$(Av

2. Calculating turbine torque

T =$\frac{P}{w}$

T =$\frac{0,176}{12}$

T = 0.014 Nm

Where :

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P = Power (Watts)
w = Angular velocity of the blade (rad/s)

3. Calculate the angular velocity of the blade

$w = \frac{v}{r}$
$w = \frac{1m/s}{8{,}5x10-^{2}}$
w = 0.12x 10^2rad/s
w = 12 rad/s

4. Calculate the water speed

$v = \frac{(2\pi r)(500rpm)}{60}$
$v = \frac{(2\pi)(8{,}5x10-^{2}m((500rpm)}{60}$
$v = \frac{(2\pi)(8{,}5)}{60}$
$v = \frac{53{,}38}{60}$
v=0.89m/s

5. Calculate turbine power (P out)/

Pout = T x w
Pout = 0.014 x 12
Pout = 0.168 watts
Where :
T = Torque
w = Angular velocity of the blade (rad/s)

6. Calculate turbine power (P in)

Pin =ρ · g · Q · H
Pin = 1000 x 9.81 x 4 x 0.2
Pin = 7.8

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Where :
ρ = density of water (±1000 kg/m³)
g = 9.81 m/s²
Q = water discharge (m³/s)
H = height of fall (m)

7. Calculating turbine efficiency

$n = \frac{Poutput}{Pinput}$x 100%
$n = \frac{0,168}{7,8}$x 100%
$n = 45\%$

8. Calculating generator power

Pg = VI
Pg = 10.10
Pg = 100 watt
Where:
V = Electric voltage (V) I = Electric current (A)

9. Calculating the axis planning

a. Torsional moment
$T = 9,47 \times 10^5 \frac{pd}{n^1}$
$T = 9,47 \times 10^5 \frac{0,1}{1500}$
$T = \frac{947}{100} \times 100000 \frac{0,1}{1500}$
T =947 x 1000$\frac{0,1}{1500}$
T = 947 x$\frac{100}{1500}$
T =$\frac{94700}{1500}$
T = 63.13 kg/m

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Where :

$T = Torsi(kg/m)$

$Pd = Daya\ motor\ (kw)$

$N = Putaran$

Finding the shaft diameter:

$$ds\ poros = [\frac{5,1}{ta} kt \times cb \times t]\frac{1}{3}$$

$$ds\ poros = [\frac{5,1}{120} \times 2 \times 2 \times 500,557]\frac{1}{3}$$

$$ds\ poros = [0,0425 \times 2 \times 2 \times 500,557]\frac{1}{3}$$

$$ds\ poros = \ 85,09469\frac{1}{3}$$

$$ds\ poros = (\frac{8509469}{100000})\frac{1}{3}$$

$$ds\ poros = 3\sqrt{\frac{8509469}{10\sqrt[3]{10^2}}}$$

$$ds\ poros = \sqrt[3]{\frac{85094690}{100}}$$

$$ds\ poros = 276,74\ \div 10\ mm$$

$$ds\ poros = 27,674\ mm$$

$Dimana$:

$Ta\ = Tegangan\ geser\ izin\ (kg.mm)$

$ds = Diameter\ poros\ (mm)$

$kt = Faktor\ koreksi\ = 2,0$

$cb = faktor\ akhir\ lenturan = 2,0$

$T = torsi\ (kg.mm)$

10. Pulley planning

Pulley 1:

$$Dp = \frac{n_1 \times dp}{n_2}$$

$$Dp = \frac{1500 \times 100}{408}$$

$$Dp = 367,64\ mm$$

Pulley 2:

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$$dp = \frac{n_2 \times DP}{n_1}$$
$$dp = \frac{408 \times 400}{1500}$$
$$dp = \frac{163.200}{1500}$$
$$dp = 108{,}8\ mm$$

Calculating the Driven Pulley Rotation

$$n_2 = \frac{1500 \times 117}{400}$$
$$n_2 = \frac{175.500}{400}$$
$$n_2 = 438{,}75$$

11. V-belt planning

Linear velocity of the belt:

$$V = \frac{dp \times n^1}{60 \times 1000}\frac{m}{s}$$
$$V = \frac{3{,}14 \times 100 \times 1500}{60000}$$
$$V = \frac{471.000}{60000}$$
$$V = 7{,}85\ m/s$$

$Dimana$:

$Dp = Diameter\ pulley\ penggerak$

n_1= Generator rotation (rpm)

12. Bearing calculation

Fr =$\frac{m.v^2}{R}$

Fr =$\frac{(m)(1m/s)^2}{8{,}5x10^{-2}m}$

Fr =$\frac{(189kg)(1m^2/s)}{8{,}5x10^{-2}m}$

Fr =$\frac{189}{8{,}5x10^2}$

Fr = 22.23 x 1 0^2kg,m/s^2

Fr = 2223 N

Fa = m. w^2.R

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Fa =(189kg)(12 rad/s)^2(8.5x1 0$-^2$m)
Fa = (189kg)(144rad/s)(8.5x10 $-^2$m)
Fa = 27.216x8.5x10 $-^2$
Fa = 231336x10 $-^2$
Fa = 2313.36N
Then:
Ft = Fr + Fa
Ft = 2223N + 2313.36N
Ft = 4.536N

13.Calculation of turbine speed with angle$30°, 45° dan\ 60°$

$V_1 = \frac{(2\pi r)(rpm)}{60} cos30°i + \frac{(2\pi r)(rpm)}{60} sin\ 30\ °j$
$V_2 = \frac{(2\pi r)(rpm)}{60} cos45°i + \frac{(2\pi r)(rpm)}{60} sin\ 45\ °j$
$V_3 = \frac{(2\pi r)(rpm)}{60} cos60°i + \frac{(2\pi r)(rpm)}{60} sin\ 60\ °j$
$V_1 = \frac{(2\pi r)(rpm)}{60} cos30°i + \frac{(2\pi r)(rpm)}{60} sin\ 30\ °j$
$V_1 = \frac{(2.3,14.10cm)(500)}{60} \frac{1}{3}\sqrt{3}i + \frac{(2.3,14.10cm)(500)}{60} \frac{1}{2}j$
$V_1 = 523,33.\frac{1}{3}\sqrt{3}i + 523.33\ \frac{1}{2}j$
$V_1 = 174,43\sqrt{3}i + 523.23\ \frac{1}{2}j$
$V_1 = 302,121i + 261,665j$
$V_1 = 563,786$
So the angular speed of the turbine at 30 °is 563.786
$V_2 = \frac{(2\pi r)(rpm)}{60} cos45°i + \frac{(2\pi r)(rpm)}{60} sin\ 45\ °j$
$V_2 = \frac{(2.3,14.10cm)(500)}{60} \frac{1}{2}\sqrt{2}i + \frac{(2\pi r)(rpm)}{60} \frac{1}{2}\sqrt{2}\,j$
$V_2 = 523,33.\frac{1}{2}\sqrt{2}i + \frac{1}{2}\sqrt{2}j$
$V_2 = 370,05i + 370,05j$
$V_2 = 740,1$
So the turbine speed at an angle of 45 °is 740.1
$V_3 = \frac{(2\pi r)(rpm)}{60} cos60°i + \frac{(2\pi r)(rpm)}{60} sin\ 60\ °j$
$V_3 = \frac{(2.3,14.10cm)(500)}{60} . \frac{1}{2} i + \frac{(2\pi r)(rpm)}{60} \frac{1}{2}\sqrt{3}j$

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$V_3 = 523{,}33.\ \frac{1}{2}i + 523.33.\ \frac{1}{2}\sqrt{3}j$

$V_3 = 261{,}665i + 453{,}217j$

$V_3 = 714{,}882$

So the speed of the 60 angle turbine °is 714.882

14.Calculation of hydrostatic pressure

$P_{1=}\frac{F}{A}Cos\ 30°i + \frac{F}{A}Sin\ 30°j$

$P_{2=}\frac{F}{A}Cos\ 45°i + \frac{F}{A}Sin\ 45°j$

$P_{3=}\frac{F}{A}Cos\ 60°i + \frac{F}{A}Sin\ 60°j$

$P_{1=}$(0.84atm)($\frac{1}{2}\sqrt{3}$)i+(0.84atm)($\frac{1}{2}$)j=(0.42 $\sqrt{3}$)i+(0.42)j

$P_{2=}$(0.84atm)($\frac{1}{2}\sqrt{2}$) i+(0.84atm)($\frac{1}{2}\sqrt{2}$)j=(0.42 $\sqrt{2}$) i+(0.42$\sqrt{2}$)j

$P_{3=}(0{,}84atm)\left(\frac{1}{2}\right)i + (0{,}84atm))$($\frac{1}{2}\sqrt{2}$)j=0.42i+(0.72$\sqrt{2}$)j

$P_{total=}P_{1+}P_{2+}P_{3=}$0.73i+0.72h+0.62i+0.3h+0.72i+0.73h

$P_{total=}1{,}75i + 1{,}75j$

$P_{total=}\sqrt{(1{,}75)^2 + (1{,}75)^2}$

$P_{total=}\sqrt{3{,}0625 + 3{,}0625}$

$P_{total=}\sqrt{6{,}125}$

$P_{total=}$2.5 atm

$P_{total=}$250000Pa

Q

Test results tables and graphs

This test was carried out three times with different blade angles, namely 30 °,45 °and 60. °This aims to get better results (Dai et al., 2024). Before continuing the test with different blade angles, it would be better if we first look for the water discharge produced at the height and diameter of the channel, as in the following table and graph (Yang et al., 2020).

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Table 1. Measurement results for finding the water discharge produced with a channel height of 5 cm, a water height of 15 cm and a channel diameter of 4 cm and a channel diameter of 50 cm.

No	Channel height	Water level	Channel diameter	The water discharge produced
1	5 m	15 cm	5 cm	2,026L/s
2	5 m	15 cm	5 cm	2,026L/s

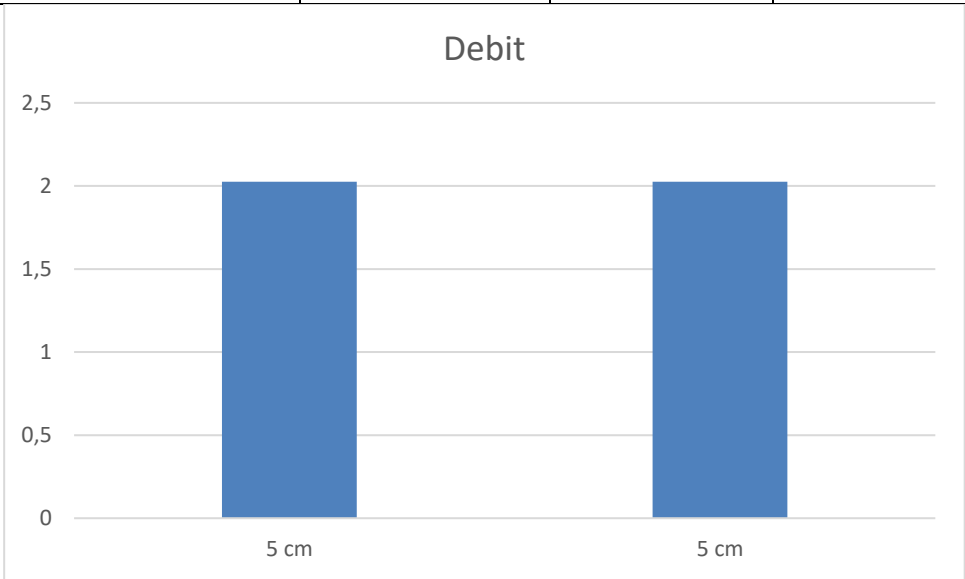


Figure 1. Graph of the resulting water discharge test

From the test results at a channel height of 5 cm, a channel diameter of 5 cm and a water height of 15 cm, it produces a water discharge of 2,026L/s (Baldacchino et al., 2018). The water discharge remains constant and does not change. After knowing the incoming water discharge, we continue testing the rpm at blade angles of 30 °, 45 °and 60. °We can see the test results in table 4.2 and Figure 4.2 as follows (Velte et al., 2008).

Table 2. Results of turbine speed tests with blade angles of 30 °, 45 °and 60°

No	Angle of the spoon	Turbine speed
1	30°	563,786
2	45°	740.1
3	60°	714,882

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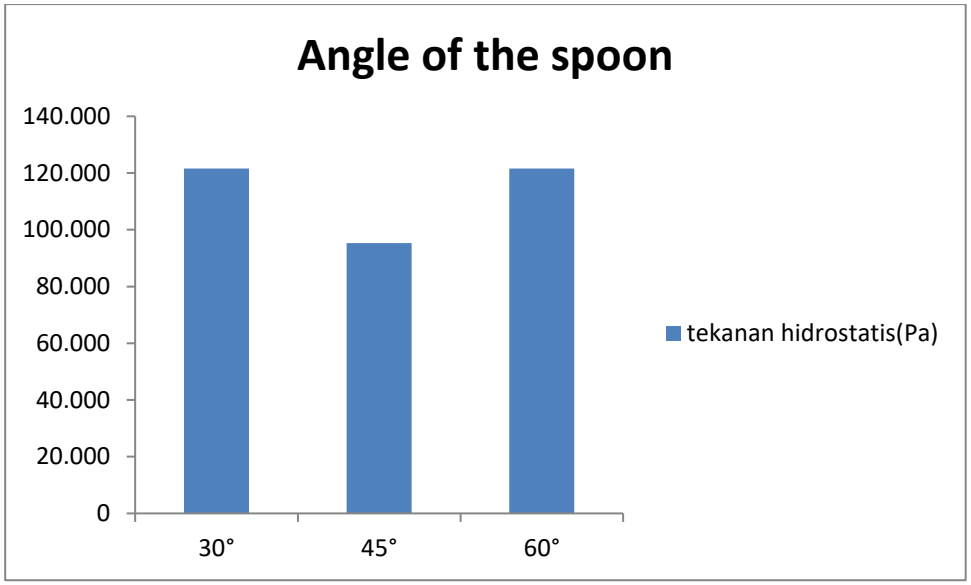


Figure 2. Graph of test results with blade angles of 30 °, 45 °,and 60°

From the test results with an angle of 30 °producing 563.786 turbine speeds, an angle of 45 °producing 740.1 turbine speeds and an angle of 60 °producing 714.882 (Kim et al., 2023).

Table 2. Results of hydrostatic pressure testing with blade angles of 30 °, 45 °,and 60°

No	Angle of the spoon	Hydrostatic pressure (Pa)
1	30°	121,590
2	45°	95,245
3	60°	121,590

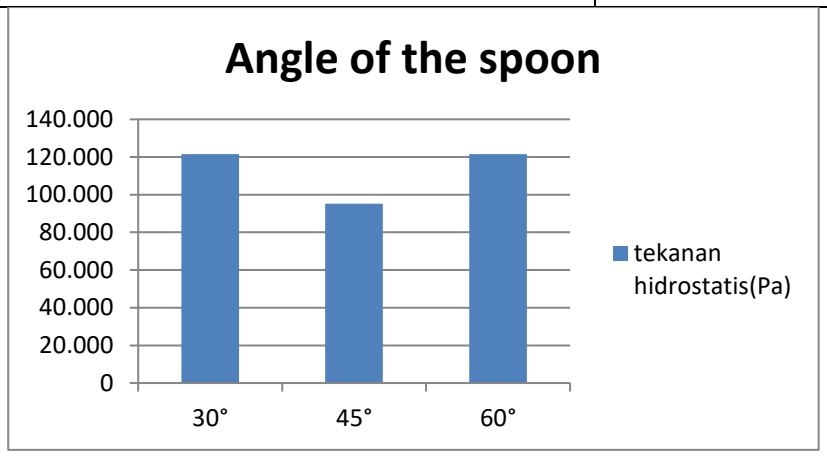


Figure 3. Graph of the hydrostatic pressure produced with blade angles of 30 °, 45 °,and 60°

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In this test, the blade angle 3 0°produces a hydrostatic pressure of 121,590Pa, the blade angle 45 °produces a hydrostatic pressure of 95,245Pa and the blade angle 60 °produces a hydrostatic pressure of 121,590Pa (Fouatih et al., 2022).

CONCLUSION

Based on the test results, turbines with blade angle variations of 30°, 45° and 60° at the same water discharge of 2.026L/s, it was found that the 60° blade angle produced better performance. This is shown at an angle of 60° obtaining a turbine speed of 714.882 and a hydrostatic pressure of 121,590 Pa, which is higher than the 30° angle which obtained a turbine speed of 563.786 and a hydrostatic pressure of 121,590 and an angle of 45° which only obtained a turbine speed of 740.1 and a hydrostatic pressure of 95,245. Thus, it can be concluded that the blade angle affects the performance of the turbine, where the 60° angle in this test is able to optimize the conversion of water energy into mechanical and electrical energy more effectively than the 30° and 45° angles.

Suggestion

Based on the results of the tests that have been carried out, there are several suggestions that can be given, namely:

1. It is recommended to use a 60° blade angle because it provides more optimal turbine performance results at the same discharge conditions.
2. Further research is needed with a wider variety of blade angles to obtain a more accurate optimal angle.
3. It is recommended to measure other parameters such as turbine power and efficiency for a more complete performance analysis.
4. Testing should be done repeatedly to increase data accuracy.
5. It is necessary to pay attention to the stability of the water discharge and the condition of the equipment such as the shaft and bearings to minimize measurement errors.

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