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Performance Analysis of the Archimedes Double Screw Turbine as a Micro Hydro Power Plant with Varying Flow Rate

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ABSTRACT

Samadua is an area in South Aceh Regency which has a lot of water energy potential to be used as energy to drive water turbines. The potential for water energy, it is necessary to develop renewable energy power technology, namely micro hydro power plants that can be utilized by the community. The type of water turbine that is suitable for application in the area that have water potential with low head and discharge is the Archimedes Double Screw Turbine. The Archimedes double screw turbine is a type of turbine that capable of operating with a low head of 1-15 m in river flows and irrigation and has the advantage of being environmentally friendly. The aim of this research is to design and manufacture an Archimedes Double Screw turbine that is appropriate and in accordance with the real conditions in the stream of Samadua river, -South Aceh, then analyze the influence and determine the torque ratio on the performance of the Archimedes Double Screw Turbine by measuring rotation speed, torque, power and efficiency based on variations in river flow rate. The Archimedes Double Screw turbine is made from 201 stainless steel which has dimensions of N = 2 blades (= 260 mm, = 140 mm) with a pitch of 2Ro, turbine length (L = 2 m), head = 1 m, angle θ = 30^0. The variables measured and observed are turbine rotation, torque, and flow rate. Tests were carried out on 3 variations of flow discharge, namely 0.02 m^3/s, 0.009 m^3/s, and 0.003 m^3/s. The test results showed that the highest turbine rotation and power occurred at a flow rate of 0.02 m^3/s of 292.10 rpm and 122.20 watts and the maximum turbine efficiency was 62%. Thus, the turbine with maximum power is obtained when the flow rate is 0.02 m^3/s, while the turbine with maximum efficiency is obtained when the flow rate is 0.02 m^3/s. For the numerical simulation results, the optimum pressure distribution value is 4.873 kPa and the minimum is 0.1536 kPa, so the comparison of the experimental results with the numerical simulation is that the numerical simulation optimum torque value is 2.50 N/m and the experimental optimum torque value is 2.00 N /m.

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I. Introduction

The Aceh region has many sources of water energy, river flows or irrigation, with an average water fall height of 1-2 meters and a water discharge of around 0.05 m^3/s [1]. Samadua is an area in South Aceh Regency which has quite a lot of water energy potential to be used as energy to drive water turbines. The potential of water energy requires the development of new, renewable energy power generation technology that can be utilized by the community. The type of water turbine that is suitable for application in areas that have water potential with low head and discharge is the Archimedes Screw Turbine. The Archimedes Screw turbine is a type of turbine that can operate at low head and flow. This type of turbine is used for micro-hydro power generation in low-elevation river flows [2]. The Archimedes Screw turbine has several advantages over other types of low head turbines and does not require a special control system because it uses standard equipment and generator units, is easy to construct, easy to install and maintain, environmentally friendly and fish-

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friendly, high turbine efficiency for low head and high discharge operating conditions [3]. The performance of an Archimedes Screw Turbine is influenced by the parameters involved in designing the turbine itself. One of the important parameters in designing an Archimedes Screw Turbine is the dimensions of the thread radius and pitch. Based on research conducted by several previous researchers, it was found that the Archimedes Double Screw Turbine has a very good flow rate [4]. Based on the things explained above, the problem formulation is how to design and manufacture the Archimedes Double Screw Turbine correctly and in accordance with the real conditions in Samadua river - South Aceh, as well as analyzing the influence and knowing the torque ratio on the performance of the Archimedes Turbine Double Screw measures rotational speed *(n)*, torque (*T*), power (*P*) and efficiency (*η*) based on variations in river flow rate.

II. Literature Review

A. Turbine Archimedes Screw

Archimedes Screw is a turbine that is very special because it can operate in areas that have very low heads. In its use, this screw turbine depends on the head condition in the field. The screw turbine works at a low head with the water level falling between 1-15 m. The slope angle for determining the turbine head is between $30^0 – 60^0$ [4].

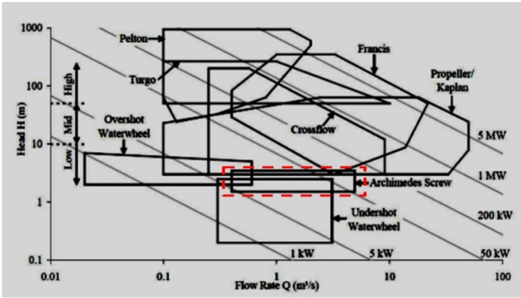

Fig. 1. Classification of Thread Turbine with Head and Output Power

The working principle of this screw turbine where the pressure from the water through the turbine screw blades experiences a pressure drop in line with the decrease in water velocity due to the resistance of the turbine threads, this pressure will rotate the turbine and drive the electric generator after the power of the shaft is transmitted through the gearbox [4].

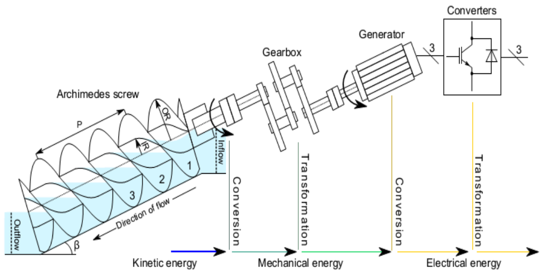

Fig. 2. Turbine Schematic of Archimedes Screw

Some of the advantages of screw turbines compared to other types of water turbines are [5] :

a. It is well developed in areas that have a water source with a fairly large discharge (river) but only has a low head up to 1 (one) meter.
b. Does not require a very complicated control system like other turbines.
c. Can be operated without filters and does not disturb the river ecosystem.
d. Has high efficiency and reliability, with a large variation of discharge and is very good for small water discharge.
e. The age of the turbine is more durable especially if it is operated at low speed and is cheap in its maintenance.
f. It does not require fine nets to prevent the entry of debris into the turbine, which can reduce maintenance costs.

B. Design of Screw Turbine Demensions

The geometry of a turbine or Archimedes screw pump is determined by the external dimensions and dimensions in the turbine [5].

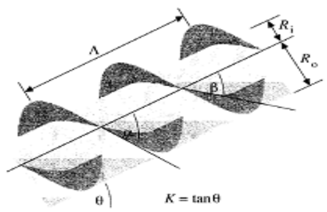

Fig. 3. Profile of Archimedes Screw Turbine

Where :

R_i = Radius in screw blade ($0 < R_i < R_o$).
R_o = Outer radius of turbine blade.
Λ = Turbine blade thread range ($0 \leq \Lambda \leq 2\pi R_o / K$).
K = tan θ.
θ = The tilt angle of the turbine shaft.
α = Screw angle (at Ro position).
N = Number of threads (1,2, ...).

The outer dimensions of the turbine consist of the outer radius of the R_o screw, the screw range Λ, and the axle slope angle θ. The outer dimensions are determined by the location of the screw placement, the screw material to be used and the water discharge. The tilt angle θ turbine is generally between 30° to 60°. While the inner dimensions of the turbine include the radius in R_i, the number of N blades, and the distance between the threads if N > 1. The dimensions in the free turbine are chosen, so that optimization of the screw turbine can be done by changing and varying it. The length of the screw shaft L can be calculated by equation (1) :

$$L = \frac{H}{K} \tag{1}$$

Rorres offers a formulation for determining Archimedes thread dimensions based on calculating the maximization of water volume between threaded ranges, the maximum volume of which is expressed in equation (2).

$$v_T^* = \pi R_o^2 \Lambda^* v^* \tag{2}$$

At the maximum volume, the inner diameter can be obtained from equation (3).

$$R_i = \rho \,.\, R_i \tag{3}$$

Threaded range at maximum volume is expressed by equation (4).

$$\Lambda = \frac{2\pi R_O \lambda}{K} \tag{4}$$

The relationship between the ratio of optimum volume v, optimum radius and optimum range N is shown in Table 1. Then for the volume, radius and thread range equations are defined in equations (5), (6), and (7) below :

$$V = \frac{V_T}{\pi R^2 \Lambda} \tag{5}$$

$$\rho = \frac{Ri}{Ro} \tag{6}$$

$$\lambda = \frac{K\Lambda}{2\pi R_O} \tag{7}$$

The amount of m range required at the screw turbine shaft length L for optimum range length Λ^* can be calculated by equation (8) :

$$m = \frac{L}{\Lambda} \tag{8}$$

Equation (1) and (8) together with Table 1 are used to determine Archimedes threaded turbine design dimensions in this research activity. The maximum screw turbine rotation is n_maks (rpm) and the relationship between dimensions ranges Λ and the outer radius of R_o blade for various turbine slope angles can be expressed in equations (9) and (10) [5].

$$n_{maks} = \frac{50}{2\, R_o^{2/3}} \tag{9}$$

$\Lambda = 2{,}4\, Ro$ untuk $\theta < 30^0$

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$\Lambda = 2{,}0\ Ro$ untuk $\theta = 30^0$ (10)
$\Lambda = 1{,}6\ Ro$ untuk $\theta > 30^0$

Table 1. Screw Turbine Parameters

Number Of Blades N (1)	Optimal Radius Ratio ρ^* (2)	Optimal Pitch Ratio λ^* (3)	Optimal Volume Pertum Ratio $\lambda^* v (N, \rho^*, \lambda^*)$ (4)	Optimal Volume Ratio $v (N, \rho^*, \lambda^*)$ (5)
1	**0.5358**	**0.1285**	**0.0361**	**0.2811**
2	**0.5369**	**0.1863**	**0.0512**	**0.2747**
3	0.5357	0.2217	0.0598	0.2697
4	0.5353	0.2456	0.0655	0.2667
5	0.5352	0.2630	0.0696	0.2647
6	0.5353	0.2763	0.0727	0.2631
7	0.5354	0.2869	0.0752	0.2619
9	0.5356	0.3029	0.0788	0.2601
10	0.5356	0.3092	0.0802	0.2592
11	0.5358	0.3145	0.0813	0.2586
12	0.5360	0.3193	0.0824	0.2580
13	0.5360	0.3234	0.0833	0.2574
14	0.5360	0.3270	0.0841	0.2571
15	0.5364	0.3303	0.0848	0.2567
16	0.5362	0.3333	0.0854	0.2562
17	0.5362	0.3364	0.0860	0.2556
18	0.5368	0.3380	0.0865	0.2559
19	0.5364	0.3404	0.0870	0.2555
∞	0.5394	0.3953	0.0977	0.2471

The power produced by a turbine with certain efficiency can be determined by equation (11) :

$$P_{th} = \rho \,.\, g \,.\, Q \,.\, H \,.\, \eta \quad (11)$$

Where :
P_{th} = Turbine Power (Watts)
ρ = Mass type of water (kg /m^3)
Q = Debit (m^3/s)
g = Gravity acceleration (m /s^2)
H = "net head" / effective height.
η = Turbine efficiency.

So to get turbine discharge can be searched using equation (12).

$$P_{th} = \rho \ g \ Q \ H \ \eta$$

$$Q = \frac{P}{\rho \eta H g} \quad (12)$$

The efficiency of a turbine is affected by power. Archimedes screw turbine efficiency is a comparison between turbine power and fluid power. The efficiency of can be determined by equation (13) as follows :

$$\eta = \frac{P\ Output}{P\ Input} \times 100\% \quad (13)$$

Determination of turbine efficiency depends on the type of turbine used, where in the design the load is taken at maximum conditions, namely full load or 100% as in Figure 4.

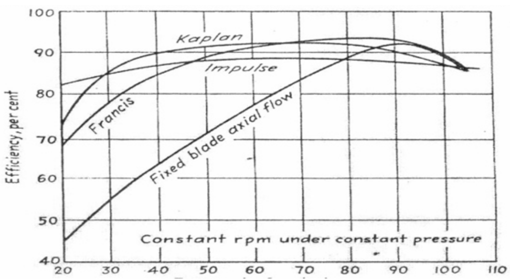


Fig. 4. Profile of Archimedes Screw Turbine

At certain power, channel efficiency can be increased by increasing the size of the pipe, but this means an increase in costs. For certain channels, efficiency will increase when the power is reduced. Therefore, for certain channels can be determined the maximum power that can be produced, and for certain power the best diameter can be determined.

C. Debit Calculation

In determining the shape of the discharge turbine, it is very necessary to know the cross-sectional area of the water channel that enters the turbine, where the cross-sectional area of the water channel that enters the turbine depends on the flow of water. This is in accordance with the continuity equation $Q = A.V$ The flow of fluid flowing will have a certain flow velocity, the relationship of flow velocity with discharge and cross-sectional area can be written in equation 14 below.

$$Q = A \times V \tag{14}$$

Where :

Q = Water discharge (m^3/s)
V = Water speed (m/s)
A = Cross-sectional area (m^2)

D. Computational Fluid Dynamic (CFD)

CFD or Computational Fluid Dynamics consists of two words which have the following meanings [7] [8] :

1. Computational is everything related to mathematics and numerical or computational methods.
2. Fluid Dynamics is the dynamics of everything flowing from one place to another.

From the meaning of each word in CFD, it can be concluded that the meaning of CFD is a branch of science that studies how to predict the shape of fluid flow, heat transfer, chemical reactions and other phenomena that can be modeled with CFD.

There are several stages to carrying out numerical simulations, including the following:

1. *Mesh*
   The mesh process is carried out after the process of creating the geometry to be analyzed is carried out. The mesh process is carried out to divide parts of the geometry into small parts or is often called meshing. The size of the mesh will greatly influence the accuracy of the CFD analysis results. The smaller the mesh size in the geometry, the more accurate the results obtained will be or will be closer to the actual value. However, this will affect computing power, the smaller the mesh size, the longer the time required for the meshing process compared to a larger mesh size [8].
2. Boundary Conditions
   Boundary conditions are conditions within the limits of a predetermined volume control. In boundary conditions there are two methods used to analyze fluid flow patterns, namely:
   a. The differential analysis method is to look for detailed flow patterns (x, y, z) at each point.
   b. The integral analysis or control volume method is to find a balance between incoming and outgoing flows and determine things that influence the flow.
3. Turbulence Model k - ε (k – Epsilon)
   In the turbulence modeling for this case, the most suitable model is the k – ε model where the turbulent flow is characterized by fluctuating velocities. Turbulence can occur because of the very high speed of the fluid and the particles in the fluid do not move normally, causing an irregular effect. Some mixed fluctuations are transferred in the form of momentum, energy and concentration species which cause a number of fluctuations to move. Fluctuations can occur on a small scale at fairly high frequencies so that calculations are relatively more difficult to simulate in practical engineering calculations. And can instantly adjust the equations to be time averaged, ensemble averaged or manipulated to remove small scales so that the equations of the modified set are easier to calculate. In the k – ε model, two transport equations based on k and ε are added. The equation for variable k can be expressed in the following equation:

$$\frac{Dk}{Dt} = \frac{\partial}{\partial x_i}\left[\left(\mu + \frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_i}\right] + G_k + G_b - \rho\epsilon - Y_M \tag{15}$$

The variable equation ε can be stated as follows:

$$\rho \frac{D\epsilon}{Dt} = \frac{\partial}{\partial x_i}\left[\left(\mu + \frac{\mu_t}{\sigma_\epsilon}\right)\frac{\partial \epsilon}{\partial x_i}\right] + C_{1\epsilon}\frac{\epsilon}{k}(G_k + C_{3\epsilon}P_b) - C_{2\epsilon}\rho\frac{\epsilon^2}{k} + S_\epsilon \quad (16)$$

The average fluid velocity, Gb depicts the turbulent kinetic energy derivative which is influenced by the fluid's buoyant force, Y_m shows compressible turbulent fluctuations. C_{1E}, C_{2E} and C_{3E} are constants, σ_k and σ_ϵ are Prandtl Numbers. The variable k – ε has several model variations, but in this case, we will use the RNG k – ε and realizable k – ε models. The RNG k – ε model uses careful statics (renormalization) which is similar to the standard model, but there are several advantages, including the following:

a. The RNG model has additions in the ε equation that can significantly increase the precision in fast current tension.
b. The effect of vortices in turbulence on the RNG will increase the accuracy of the vortex flow.
c. The RNG model provides analytical formulas in the form of Prandtl numbers, whereas the standard model uses constant specific numbers.
d. The standard model uses a high Reynolds number model, while the RNG provides an analysis that derives a differential formula for effective viscosity that takes into account the low Reynolds number.

The realizable model has several advantages compared to the standard model, including the following:

a. The realizable model contains a new formula for analyzing turbulent viscous.
b. The new equation for the dissipation rate ε is derived from the actual equation for the mean-square fluctuating vorticity transport.

III. Method

In analyzing the performance of Turbine Archimedes Double Screw, there are several methods that are carried out including the following:

1. Conducting a survey of potential water energy sources in Samadua, South Aceh including measuring water flow and head, determining the angle of turbine placement and collecting survey data.
2. Designing the dimensions of the Archimedes Double Screw Turbine, including calculating turbine dimensions (blade, pitch, frame and turbine angle), calculating and determining the type of material for making the Archimedes Double Screw Turbine.
3. Carrying out the fabrication of the Archimedes Double Screw Turbine in accordance with the design drawings, including providing tools and materials for the manufacturing process, carrying out the manufacturing and assembly process of the Archimedes Double Screw Turbine.
4. Carrying out the process of setting and calibrating the Archimedes Double Screw Turbine.
5. Carrying out tests to determine the performance of the Archimedes Double Screw Turbine, including measuring the rotation speed (n), torque (T), power (P) and optimum efficiency (η).
6. Analyzing data from measurements of rotational speed (n), torque (T), power (P) and optimum efficiency (η), as well as analyzing data from torque comparison results with numerical simulations based on variations in flow rate discharge.
7. Preparing reports by writing reports and preparing output targets requires making a research journal.

IV. Results and Discussion

Based on the method that has been prepared, there are several stages carried out to obtain research results, as follows.

A. Preparation Phase

In this preparation stage, a river flow location survey will be carried out and data will be collected, namely head, river width, river depth (edges and middle of the river), flow speed and water discharge at the location that will be determined for the installation of the Archimedes Double Screw Turbine. Based on the data that has been surveyed, it will be used to design the Archimedes Double Screw Turbine. The materials and tools used during the survey of the screw turbine installation location were Garmin Map 60SX brand GPS, tape measure, cork and camera. As for the location of the river flow, collection of flow measurement data and the location of the Archimedes Double Screw Turbine can be seen in Figure 5.

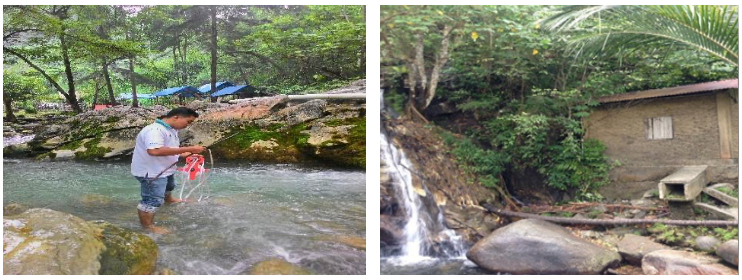


Fig. 5. Location of River Flow and Location of the Archimedes Double Screw Turbine

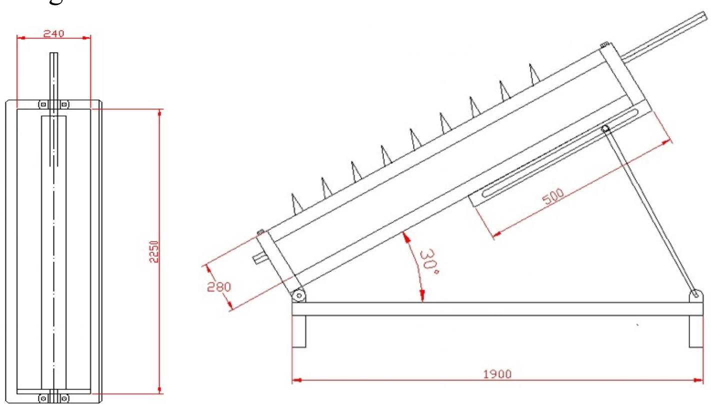
B. Design Phase Results

At this design stage, in accordance with existing survey data, theoretical calculations will be carried out based on the Rorer's formulation, including calculating the length of the turbine, calculate the outer radius of the turbine thread (R_o) and the inner radius of the turbine thread (R_i) determine the turbine thread pitch distance, then design the Archimedes Double Screw Turbine, determine the Archimedes Double Screw Turbine model, determine the number of turbine blades, determine the tilt angle of the turbine placement. The materials and tools used are a PC/Laptop, Auto CAD 2007 Application Software. Below are several data parameters used for turbine design which can be seen in Table 2.

Table 2. Design Data Parameters (N = 2 Blade, Head = 1 m, Radius θ = 30^0 and Q = 0,05 m^3/s

Parameter	Nilai	Satuan
Turbine Lenght (L)	2	m
Outer Shaft Diameter	110	mm
Inner Shaft Diameter	25,4	mm
Outer radius of 2 blade threads (R_o)	260	mm
Inner eadius of 2 *blade threads* (R_i)	140	mm
Pitch 2 *blade* (Λ)	260	mm
Number of threads 2 *blade* (N)	16	Unit
Turbine Casing Lenght	2250	mm
Turbine Casing Width	240	mm
Length of Turbine Mount	1900	mm

Based on the data parameters from the results of calculating the dimensions of the Archimedes Double Screw Turbine, the engineering drawing design results are designed to have a slope angle of 30^0 and can be seen in Figure 6.



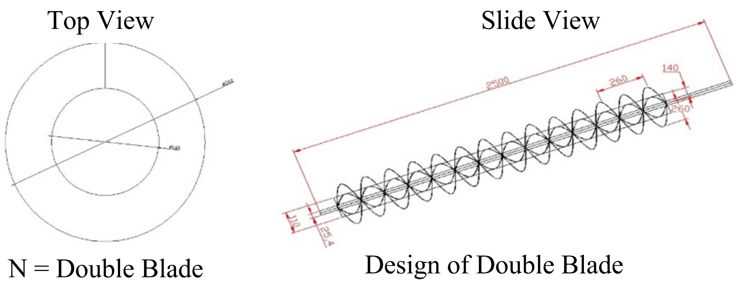


Fig. 6. Design Archimedes Double Screw Turbine

C. Stages of Making an Archimedes Double Screw Turbine

The manufacturing stage of the Archimedes Double Screw Turbine is carried out based on the design drawing of the Archimedes Double Screw Turbine which has been designed according to its main dimensions. The mechanical components of the Archimedes Double Screw Turbine consist of turbine threads, shaft, turbine bearing, turbine housing (U-shaped threaded casing) and turbine mounting frame.

Fig. 7. Manufacture Archimedes Double Screw Turbine

D. Testing and Measurement Stage

The testing and measurement phase of the Archimedes Double Screw Turbine with a 2 blade turbine screw model which will be carried out in this research is by paying attention to several parameters such as the tilt angle of the turbine which is 30^0, variations in flow rate (Q), rotation speed (n) and torque (T) on the screw turbine shaft as well as the optimum power (P) and optimum efficiency (η) produced by the 2 blade Archimedes Double Screw Turbine. The tools and materials used are Arduino ATMEGA 2560 + display, Parallax Microcontroller Data Acquisition For Excel (PLX-DAQ) application, proximity, load cell + module, power cable, USB printer cable, PC/laptop, inverter, tachometer, multimeter and tool kits. The experimental process for the 2 blade Archimedes Double Screw Turbine was carried out in Samadua river - South Aceh.

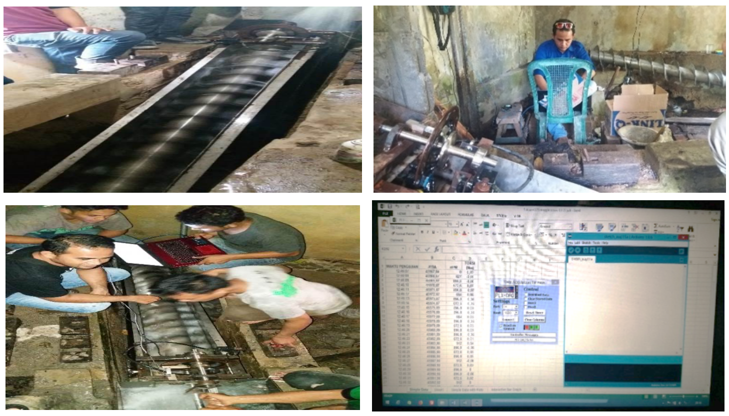


Figure 8. Activities for Testing and Collecting Performance Data Archimedes Double Screw

E. *Analysis of the Effect of Flow Rate Variations (Q) on the Angle Slope of the Archimedes Double Screw Turbine*

V-Notch is used to measure the flow of water, the *V-Notch* specification in the research location has a length of = 2 m, width of 0.5 m and height = 0.32 m, from the measurement of water level to produce H = 0.18 m used for measurement of water discharge in Q1, H = 0.13 m is used to measure water discharge in Q_2, and H = 0.08 m is used for measuring water discharge in Q_3. Determination of water flow discharge is measured actually by knowing the height of falling water from the *V-Notch* tip. The results of measuring flowrate using Weir Discharge Table 90^0 Degree *V-Notch*, the experimental results in measuring water flow discharge (Q) can be seen in Table 3.

Table 3. Experimental Results of Water Flow Discharge

$Q_1 (m^3/s)$	$Q_2 (m^3/s)$	$Q_3 (m^3/s)$
0,02	**0,009**	**0,003**

In Table 3. shows the results of measurements of water discharge obtained including the highest water discharge is 0.02 m^3/s and the lowest water discharge is 0.003 m^3 /s.

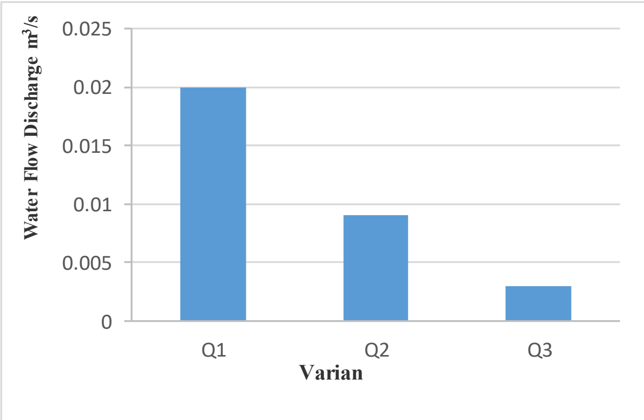


Figure 8. Experimental Results of Water Flow Discharge

F. *Analysis of Test Results on the Archimedes Double Screw Turbine*

The experimental results of the Archimedes Double Screw Turbine were obtained from measurements of rotation (*n*), and torque (*T*), power *(P)* and efficiency based on variations in flow rate (*Q*) in the Archimedes Double Screw Turbine (2 blades) with a turbine tilt angle of $\theta = 30^0$. Measurements were carried out using a computing device using an Arduino ATMEGA 2560. Data obtained from experimental results on the Archimedes Double Screw Turbine (2 blades), the experimental results can be seen in Table 4.

Table 4. Experimental Data From Measurement of Turn (n), Torque (T), Power (P) and Efficiency (η) in Double Screw Turbine

Debit variation (Q)	Rotation (rpm)	Torsion (Nm)	Power (Watt)	Efficiency (%)
Q_1 0,02 m^3/s	292,10	2,00	61,15	31
	274,20	3,00	86,10	44
	243,60	4,00	101,99	52
	233,50	5,00	122,20	62
Q_2 0,009 m^3/s	240,40	2,00	50,32	57
	212,80	3,00	66,82	76
	180,80	4,00	75,69	86
	167,10	5,00	87,45	99

Debit variation (Q)	Rotation (rpm)	Torsion (Nm)	Power (Watt)	Efficiency (%)
Q_3 0,003 m^3/s	174,20	2,00	36,47	124
	133,10	3,00	41,79	142
	118,30	4,00	49,53	168
	55,40	5,00	28,99	99

Table 4 above shows experimental data from measurements of rotation (*n*), torque (*T*), power (*P*), and efficiency (η). From this table it can be explained that when the optimum Q_1water flow rate is 0.02 m^3/s with a turbine angle of 30^0, it produces an optimum rotation (*n*) of 292.10 rpm, the optimum torque (*T*) value is the same as the condition at the water flow rate Q_2 and Q_3 is equal to 5.00 Nm, optimum power (*P*) of 122.20 watts at $Q_1$and optimum efficiency $(\eta)$of 168% in the water flow rate at Q_3. Meanwhile, the minimum water flow rate of Q_3 0.003 m^3/s produces a minimum rotation *(n)* of 55.40 rpm, the minimum torque (*T*) value is the same as the condition at the water flow rate Q_2 and Q_3 is 2.00 Nm, the minimum power (*P*) is 36, 47 Watts and a minimum efficiency (η) of 31% is found in the water flow rate at Q_1.

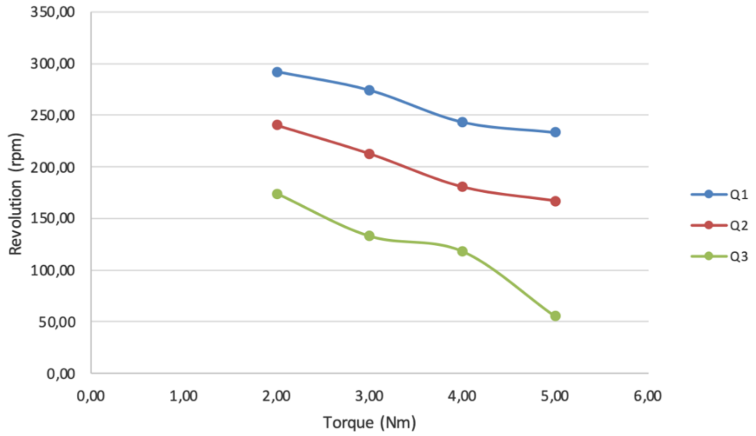


Fig. 9. Relationship Chart of Torque Measurement Results (*T*) with Rounds (*n*) Based on Flow Debit Variations (*Q*)

The graph in Figure 9 explains the relationship between the measurement results between torque (*T*) and rotation *(n)* in all conditions of variation in flow rate (*Q*) with a turbine angle of 30^0. So the graph shows that the highest rotation speed (*n*) occurs at water flow rate Q_1 namely 292.10 rpm, followed by a rotation at Q_2 water discharge of 240.40 rpm and the lowest occurred at Q_3 discharge, namely 174.20 rpm.

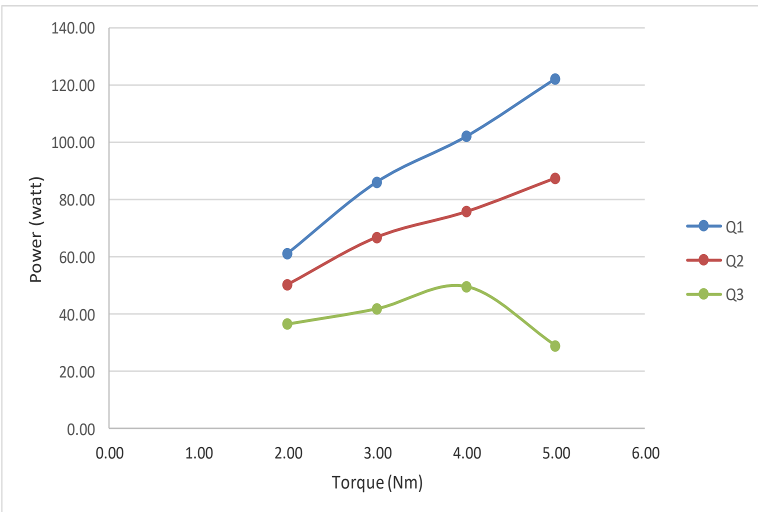


Fig. 10. Graph Relationship of Torque Measurement Results (*T*) with Power (*P*) Based on Flow Discharge Variation (*Q*) Against the Turbine Angle

The graph in Figure 10 explains the relationship between the measurement results between torque (*T*) and power (*P*) in all conditions of variations in flow rate (*Q*) with a turbine angle of 30^0. So the graph shows that the highest power (*P*) occurs at water flow rate Q_1, namely amounting to 122.20 Watts, followed by the power at the Q_2 water discharge of 87.45 Watts and the lowest power occurred at the Q_3 water discharge, namely 49.53 Watts.

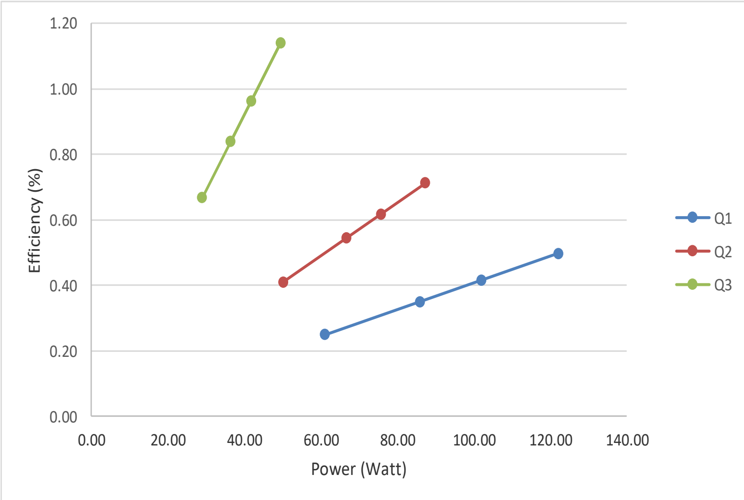


Fig. 11. Graphs of Relationship between Results of Measurement of Power (*P*) with Efficiency (*η*) Based on Flow Rate Variation (*Q*).

The graph in Figure 11 explains the relationship between the measurement results between power (*P*) and efficiency (η) in all conditions of varying water discharge (*Q*) with a turbine angle of 30^0. So the graph shows that the highest efficiency (η) occurs at water discharge Q_3, namely 168 %, followed by efficiency in Q_2 water discharge of 99% and the lowest occurred in Q_1 water discharge, namely 62%.

G. Comparative Analysis of Test Results with Numerical Simulation on Archimedes Double Screw Turbines

In this analytical study, what is carried out is to compare torque values as a reference for carrying out simulations. Table 5 shows the results of experimental comparison of torque (*T*) with numerical simulations on the Archimedes Double Screw Turbine based on variations in flow rate (*Q*).

Table 5. Comparison Results of Experimental Torque (*T)* Measurements with Numerical Simulations on Archimedes Double Screw Turbines

Treatment	**Flow Rate (m^3/s)**	**Experimental Torque (N/m)**	**Simulated Torque (N/m)**
Full Open	0,02 m^3/s	2,00	2,50
Open 2/3	0,009 m^3/s	2,00	2,20
Open 1/3	0,003 m^3/s	2,00	2,09

In Table 4 above it can be explained that the experimental torque results when the optimum water flow rate or full opening is 0.02 m^3/s and the minimum or open water flow rate is 1/3 0.009 m^3/s on the Archimedes Double Screw Turbine produces experimental torque values (The optimum and minimum *T*) have the same value, namely 2.00 Nm. Meanwhile, the simulated torque results are slightly different from experiments, namely when the optimum water flow rate or full opening is

0.02 m^3/s, the optimum simulated torque (*T*) value is 2.50 N/m and the minimum simulated torque (*T*) value. of 2.09 occurs at a minimum or open water flow rate of 1/3 0.009 m^3/s. So it can be seen that the larger the pipe opening entering the *V-Notch*, the greater the water level coming out of the *V-Notch* and the greater the flow rate entering the turbine.

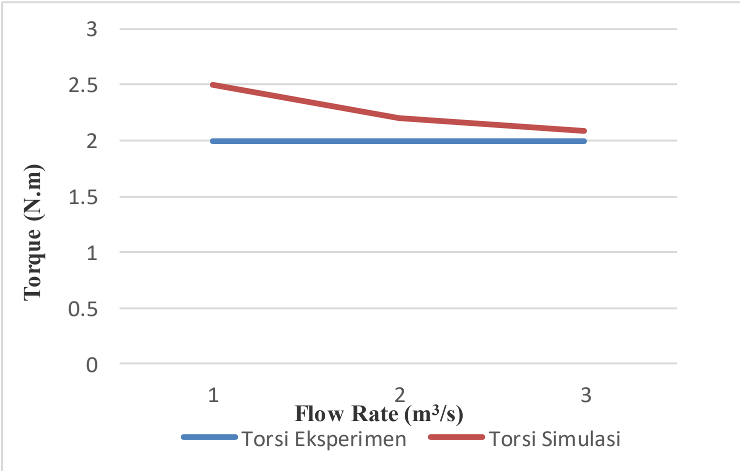
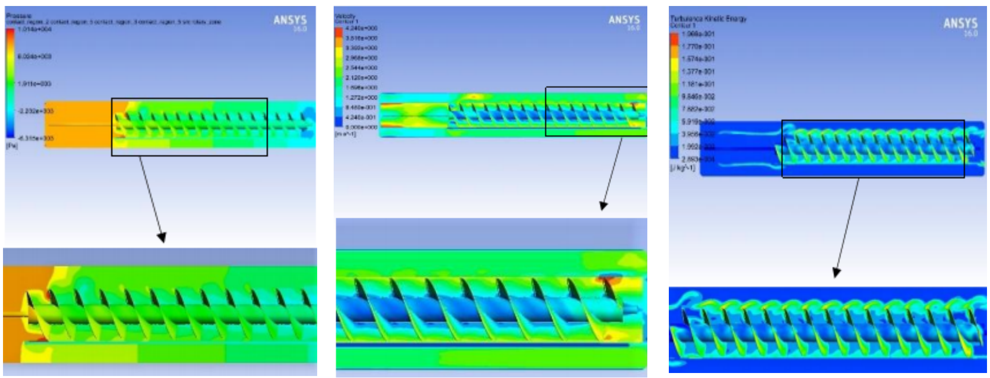


Fig. 12. Graph of Comparison of Experimental Torque (*T*) Measurement Results with Numerical Simulations on Archimedes Double Screw Turbines

In the graph in Figure 12 it can be seen that the torque (*T*) value from the experimental results with numerical simulations on the Archimedes Double Screw Turbine for all conditions of variation in flow rate (*Q*) is not much different, this proves that the simulation results carried out can be used as comparative data for get more accurate results. The graph shows that the highest torque (*T*) value in the experiment was 2.00 Nm and the highest torque value in the numerical simulation was 2.50 Nm. So the comparison of the torque (*T*) value from the experimental results with the simulation is 30%.

H. Analysis of Computational Fluid Dynamic (CFD) Results

With numerical simulations we can see the differences in distribution in the turbine. Differences in distribution that can be seen from numerical simulations include the distribution of pressure, flow velocity and turbulent kinetic energy acting along the turbine. For each variation of the inflow discharge to the turbine, it can be seen in Table 5. From the three variations in flow discharge, the distribution of pressure, flow velocity and turbulent kinetic energy acting along the turbine can be seen in Figure 13.



(1). Pressure Distribution (2). Speed Distribution (3). Kinetic Energy Distribution

Fig. 13. Distribution of Pressure, Speed, Turbulent Kinetic Energy in Turbines

In Figure 13, it can be seen that the flow distribution value in the turbine has decreased along the turbine. This proves that there is a change in the form of energy from pressure to turbine flow velocity. The red gradation that occurs in Figure 13 (1) shows that the turbine inlet section is the section that has the greatest pressure because it is the section that is first hit by the fluid flow and fluid separation occurs, resulting in an initial moment to rotate the turbine. Meanwhile, at the turbine outlet, the pressure will decrease because the moment required is not too large due to the rotation caused by the initial moment. Likewise with Figure 13 (2) which has a red gradient at the turbine outlet, this is an application of Bernoulli's law that if the pressure is large at a cross section, the flow velocity will decrease and vice versa. Meanwhile, Figure 13 (3) has a striking color gradation on the turbine thread section. This indicates that each turbine thread is capable of converting flow velocity into turbulent kinetic energy. After analyzing the Computational Fluid Dynamic (CFD) results, the numerical simulation results obtained in testing the Archimedes Double Screw Turbine are the results of the pressure distribution, the results of the flow velocity distribution and the results of the turbulent distribution of kinetic energy and can be seen in Table 5.

Table 6. Simulation Results of Pressure Distribution (kPa), Speed (m/s), Turbulent Kinetic Energy (J/Kg) in an Archimedes Double Screw Turbine

Flow Rate Variations (Q)	**Pressure (kPa)**	**Speed (m/s)**	**Turbulent Kinetic Energy (J/Kg)**
Q_1 0,02 m^3/s	4,873 3,903 1,975 1,109 0,1536	1,675 1,707 1,988 2,126 2,247	0,247 0,268 0,275 0,313 0,382
Flow Rate Variations (Q)	**Pressure (kPa)**	**Speed (m/s)**	**Turbulent Kinetic Energy (J/Kg)**
Q_2 0,009 m^3/s	2,397 1,63 1,196 0,932 0,143	1,201 1,353 1,367 1,529 1,595	0,119 0,123 0,156 0,172 0,175
Flow Rate Variations (Q)	**Pressure (kPa)**	**Speed (m/s)**	**Turbulent Kinetic Energy (J/Kg)**
Q_3 0,003 m^3/s	1,328 1,009 0,743 0,314 0,265	0,849 0,864 0,878 0,95 0,966	0,062 0,063 0,077 0,105 0,113

In Table 6 above, it can be explained that when carrying out numerical simulations, if the pressure distribution increases by 4.873 kPa, the velocity distribution and turbulent kinetic energy distribution will decrease, namely by 1.675 m/s and 0.247 J/Kg, and vice versa if the pressure distribution decreases by 0. .1536 kPa, then the velocity distribution and turbulent distribution of kinetic energy will increase, namely by 2.247 m/s and 0.382 J/Kg.

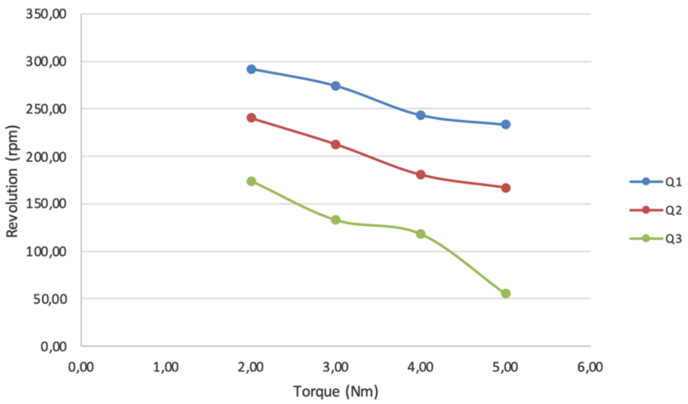


Fig. 14. Graph of Simulation Results of Pressure Distribution in the Archimedes Double Screw

From Figure 14 it can be seen that the pressure drop in the Archimedes Double Screw Turbine has the same trend as previous research. And it can be seen that the first flow discharge Q_1 the Archimedes Double Screw Turbine works very optimally compared to the other flow discharges. Because the pressure at Q_1 experienced the highest point, namely 4.873 kPa, which was distributed optimally along the turbine, so it decreased to 0.1536 kPa.

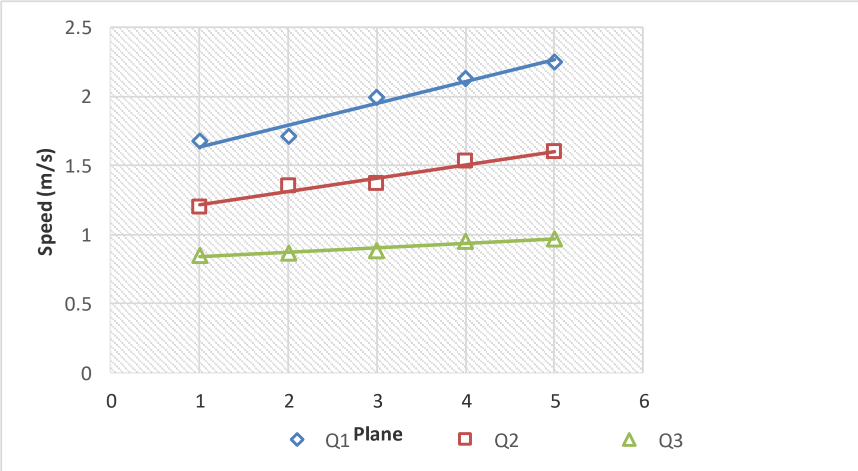


Fig. 15. Graph of Simulation Results of Flow Velocity Distribution in an Archimedes Double Screw Turbine

From Figure 30 it can be seen that the increased flow velocity along the Archimedes Double Screw Turbine is a form of change in the pressure drop, which in Q_1 experienced a good increase because it was above the other discharge value, namely 1.675 m/s and distributed optimally so that it became 2, 47 m/s at the outlet.

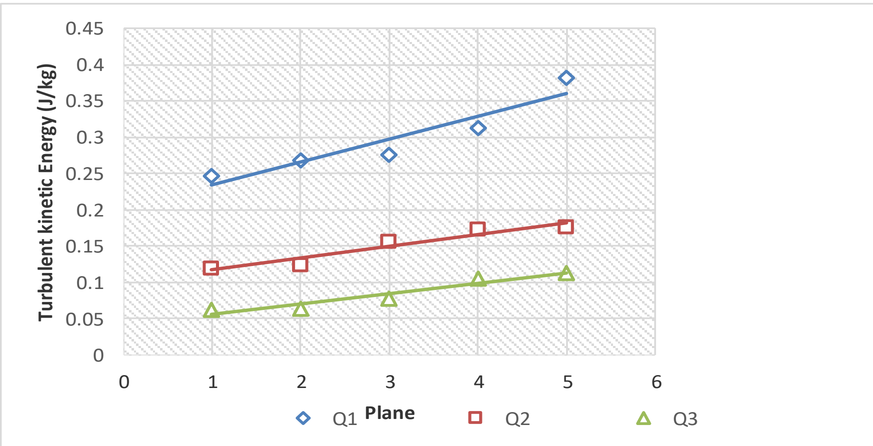


Fig. 16. Graph of Simulation Results of Kinetic Energy Pressure Distribution in Archimedes Double Screw Turbine

From Figure 16 it can be seen that the highest increase in turbulent kinetic energy is at Q_1, because the flow velocity at Q_1 is the flow velocity with the highest increase. The higher the flow velocity, the higher the kinetic turbulence. The higher the value of kinetic turbulence, the greater the power produced. The highest value of increase in turbulent kinetic energy was 0.382 J/Kg at the highest speed of 2.47 m/s.

V. Conclusion

From the results of designing, manufacturing and testing the Archimedes Double Screw Turbine, several conclusions can be drawn as follows:

1. The Archimedes Double Screw Turbine specifications obtained are; The 2 blade turbine has dimensions (R_0) = 260 mm, (R_i) = 140 mm and a pitch of 260 mm, with a turbine length of 2 meters.
2. The Archimedes Double Screw turbine produces optimum rotation (*n*) of 292.10 rpm, optimum torque (*T*) value is the same as the water flow condition Q_2 and Q_3 is 5.00 Nm, optimum power (*P*) is 122.20 Watts at Q_1 and optimum efficiency (η)168% is found in water flow discharge Q_3.
3. Torque comparison of screw turbine test results between experiment and numerical simulation has the same tendency with the highest torque value in the numerical simulation of 2.50 Nm and in the experiment of 2.00 Nm.
4. The results of numerical simulations on the Archimedes Double Screw Turbine show that when the pressure increases by 4.873 kPa, the speed and turbulent kinetic energy will decrease to 1.675 m/s and 0.247 J/Kg.

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