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Preliminary Analysis of Mini Portable Hydro Power Plant Using Archimedes Screw Turbine

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***Abstract*— The design of portable hydro power plant requires data from measurement results at one of the research locations. Observational data is from the authors get when reviewing directly to the objectivity place. This data is obtained through 3 stages, namely Survey location, Quantitative and Analysis of the data obtained. From the results of the survey to the field, the authors get the data needed in this case like differences of elevation water (Head), Flow water distribution (V), functional width (L) and Area of the river (A) and also Water discharge (Q). According to the calculations that have been calculated using Archimedean Screw implementations, the turbine thread design selected is 22 degrees and the turbine angle is 30 degrees and the calculations results is Outer Diameter (D) 30 cm, Inner Diameter (d) 9 cm and Efficiency of turbines (η) is 59,6%. So, it can be inferred that with that Archimedean screw design and calculation, the designs completely enter into portable design within income energy we can get from theoretical power generated of 1114.42 Watts, the Power Capability of the Turbine is 664.2 Watts, the Power from the generator is 564 Watts and Efficiency from Hydropower itself 117.8%.**

***Keywords*— turbines design, archimedes screw, water energy, mini portable hydro power plant**

I. Introduction

Energy is unarguably the key factor for today's economic and social development within nations [23]. In Globalization Era, demand of electrical energy is getting bigger along with the increasing population growth and various community facilities that depend on electrical energy. As we know, Indonesia is rich in natural resources, but it has not been optimally utilized [16]. Generally, renewable energy resource selection is a very challenging issue due to various factors like local availability, purpose of installation, expected energy demand and atmospheric conditions [22]. However, the availability of electrical energy from PLN has not been sufficient to meet the needs of the Indonesian people. Therefore, it is necessary to conduct research on the potential utilization of renewable energy sources, especially water energy, where South Sumatra is one of the provinces that is fed by rivers and irrigation canals. The energy potential of water in river flows/irrigation canals can be applied to a hydroelectric power plant. In addition to its unlimited amount, the utilization does not cause pollution that can harm the environment [17]. Because Environment, water and land resources are the most fragile component of the earth [25].

In a hydroelectric power plant itself, there are many types of water turbines that we already know and are applied in a hydropower plant such as cross flow turbines, Kaplan turbines, Propeller turbines, Turgo turbines, Francis turbines, and Pelton turbines. Choosing of turbine type that will be used in micro hydro power plants (PLTMH) design depends on the flow of river water and water falling height [7]. In this case, the author has an interest in studying the Archimedes Screw type turbine, which is a type of water turbine that has only been studied in this decade, by adopting the Archimedean screw theory where one of the advantages of this turbine, among others, is that it can operate at low heads (H<10 m), doesn't require a fast pipe, is easy to install, easy to maintenances and doesn't damage river ecology or is fish-friendly (Clean Energy) [3]. The Archimedes screw/turbine is made around the central tube/ shaft that has its own diameter (inner diameter), while the central tube/shaft has an extension on both ends [18].This screw turbine is categorized as a type of reaction turbine that can be used at low heads. The kinetic energy and potential energy of the water flow are converted into mechanical energy in the screw blades resulting in the rotation of the turbine shaft which can be converted into electrical energy in the generator through transmission [14]. The specific gravity of water in the blade that causes the thread to rotate. Assuming that all the potential energy in the water flow can produce a maximum efficiency until 100% or more [2].

As we know Indonesia is very rich in water resources such as rivers, tributaries and lakes which if we can use and develop it by utilizing the available water energy, it becomes a power plant which we call hydroelectric power. Micro hydro power plant is renewable electrical energy that is environmentally friendly since this plant uses water as its driving force [8]. Hydropower itself is a source of electricity for the community that provides many benefits, especially for riverside communities throughout Indonesia who have limited electricity needs. Palembang city which is the capital of South Sumatra Province has many tributaries that can be used as alternative energy sources of electrical energy.

There are several classifications of hydropower based on the power produced, with Micro Hydro under 100 kW, Mini Hydro with 100 – 500 kW and Small Hydro 500 – 10.000 kW [6]. From this classification, it can be explained that Micro Hydro Power Plant is one of the effective ways to produce electrical energy that is environmentally friendly (Clean Energy) with a supported capacity of under 100 kW. This is aimed at the people in the South Sumatra area, especially the city of Palembang which has the potential for

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water energy but is not utilized optimally to be used as a hydroelectric power plant, when the operating principle of an ASG is fundamentally different than most other types of microhydro power turbines [19]. By looking at the potential of existing water energy, the author will review a research and create a Mini Portable Hydroelectric Power Plant Design Using Archimedes Screw Turbine to apply it to all waters in South Sumatra Province.

A. Hydropower Plant

Hydropower is a power plant that utilizes air power as an energy source to produce electricity. The use of renewable energies including hydropower energy is growing throughout the world [20]. Hydropower is a renewable energy source and deserves to be called clean energy because it is environmentally friendly. The power production cost form hydro is the least so designing it to supply for the base load significantly decreases the cost of production of electricity [21]. Water power that comes from the flow of a small tributary or lake that is dammed and then from a certain height and has a suitable discharge will drive a turbine with an electric generator. Hydropower plants, large and small, have fix by far the most important of the "renewable energy" for electrical power production worldwide and provides 19% of the planet's Electricity [10]. The higher the water drop, the greater the potential energy of the air that can be converted into electrical energy. The higher the water drop, the greater the potential energy of the air that can be converted into electrical energy.

Hydroelectric power is a form of energy change from air power with a certain height and discharge into electric power, using air turbines and generators. Several hydropower classifications vary based on the power generated, with Micro Hydro under 100 kW, Mini Hydro with 100 – 500 kW and Small Hydro 500 – 10,000 kW [6]. Hydropower is produced from a generator driven by water turbines that convert the energy of fast-flowing water into mechanical energy [11]

However, the working procedure is same, from conversion of potential energy into electrical energy. These energy changes don't convert directly, but success through the following changes [5]. The main process of energy income is form Potential energy becomes kinetic energy, Kinetic energy into mechanical energy, mechanical energy into electrical energy. Potential energy is hydropower because it is at a height. Kinetic energy is the power of water because it has speed. Mechanical energy is the energy of the speed of water that continues to spin a wheel or turbine.

B. Archimedes Screw Turbine

The water turbine is one of the key and costly elements of micro-hydro power plants depending on the particular requirements of any given site [24]. Archimedes screw is one of the oldest machines still in use and serves to lift water for irrigation and drainage. The screw turbine originates from an ancient concept by the mathematician and physicist Archimedes (287 – 212 BC). The Archimedes screw consists of a helical surface surrounding a central cylindrical shaft inside a hollow pipe as shown in fig. 1.

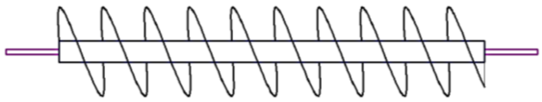

Fig. 1 Archimedes Screw Turbine

Archimedes Screw Turbines (AST) can become a popular device to generate electricity from hydraulic power at low head or nearly zero-head places [1]. When it used as a pump, the screw is usually turned by a generator or manual labor. When the shaft rotates, the lower end rolls up a volume of water which is referred to as a bucket. This water will slide down the spiral tube as the screw rotates, until it eventually drains out of the top of the screw. Screw pumps are used primarily to drain water out of mines or other areas of low water. The open trough and overall screw design allow debris passage without clogging.

Besides being known as a screw turbine, according to its initial concept, this turbine is also called an Archimedean screw (Archimedes screw). Screw turbines are more suitable for use with low head or elevation differences between the upstream and downstream flows of low or even zero. Archimedes screw turbines can be used in low-water hydro sites as a means of generating electricity. This is done by running the Archimedes screw in reverse, i.e. dropping the water from above and allowing the screw to rotate as the water drops.

It is an economical and efficient way to generate electricity from small streams. The screw rotates and generates electricity due to the hydrostatic pressure of the water on the screw surface. As water fills the screw from the inlet at the top of the slope, the pressure in the helical plane of the screw allows for screw rotation [4].

C. Benefits of Using Archimedes Screw Turbine

The working principle of this Archimedes screw turbine is that water from the upper end flows into the space between the blade screw range (bucket) and exits from the lower end. This causes the gravity of the water and the hydrostatic pressure difference in the bucket along the rotor to push the blade screw and rotate the rotor about its axis. Then the turbine rotor rotates an electric generator which is connected to the top end of the turbine shaft screw. The AST is one type of water turbine that has the potential for small-scale electricity generation that is environmentally friendly, where the screw-type water turbine is very suitable for rivers in Indonesia because the operation of this turbine only requires a low turbine head [9].

The benefits of the Archimedes Screw turbine compared to other types of turbines are as follows:

- Well developed in areas that have a water source with a fairly large discharge (river) but only has a low head,
- It does not require a very complicated control system like other turbines.
- The water pressure that occurs in the turbine does not damage the ecology in this case the impact on aquatic life (fish),
- It does not require a draft tube, so it can reduce costs for digging the installation of a draft tube,
- It has high efficiency, with large discharge variations and is very good for small water discharges,
- Does not require fine mesh to prevent debris from entering the turbine, thus reducing maintenance costs.

II. OBJECTIVE MEASUREMENT DATA

The design of portable hydro power plant requires data from measurement results at one of the research locations. Observational data is from the authors get when reviewing directly to the objectivity place. This data is obtained through 3 stages, namely Survey location, Quantitative and Analysis of the data obtained. From the results of the survey to the field, the authors get the data needed in this case like differences of elevation water (Head), Flow water distribution (V), functional width (L), Area of the river (A) and also Water discharge (Q).

A. Differences of Elevation Water (Head)

Most of the research related to hydropower focus on the energy conversion depending on the high head or high flow condition or to the higher output that could be generated [12]. It is known that when the author measured the peak height (h_1), it was at a water level elevation between the range of 60 cm and the lowest altitude (h_0) was at a water level elevation of about 20 cm. So, calculations of Head Measurement is 40 cm. The following fig. is a sketch of the Head measurement at the research site.

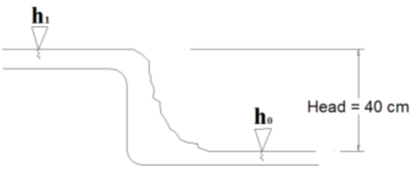

Fig. 2 Sketch of the Head measurement at the research site.

If head resource is low, the cost of the commercially available low head water turbine is considerably high per kilowatt output, more research need to be done on lowering the cost of these low head hydro power systems [13] it can be portable size in planning.

B. Flow Water (V)

When measuring the flow velocity of the water, the author used a small buoy and a rope to measure the velocity of the flow in locations. The combination of a relatively high working flowrate and an ultra-low nominal head requires the use of two Archimedes screws (AS) [15].The following is a sketch of the results of flow measurements.

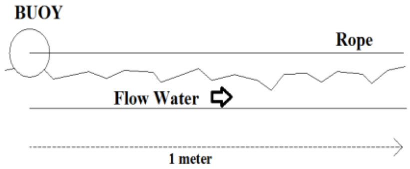

Fig. 3 Flow Measurement (V)

When buoy start moving into Grip base of rope, the buoy move out 1 meter with 4.5 seconds. It means, the water flow it can be calculated. The results is, every second flow water move out 0,222 meter in every second. It can be inferred that Flow water is 0,222 m/s.

C. Functional Width (L)

The next research data is to know the width of the river or the functional width of the discharge flow to be studied.

Fig. 4 Width River Measurement (L)

The measurement of the width functional of this river uses a Roll Meter. So, the data obtained are as follows, L_{River} = 3.2 meters.

D. Water Area (A) & Water Discharge (Q)

From the data above, we can calculate the Water Area (A) and Water Discharge (Q). So, the results is Area (A) = 1.28 m^2 and Water Discharge (Q) = 0,284 m^3/s

III. DESIGN OF ARCHIMEDES SCREW TURBINE

After analyzing the recent state-of-the-art regarding Objective Locations performances, we should design the Archimedes Screw Turbine based on the data and objective calculation

Look Eq. 1, it's explain the first step of design blade based on Water Discharged (Q).

$$Q = k.n.D^3 \quad (1)$$

And we can simplify the Eq.1 with Eq. 2.

$$D = \sqrt[3]{Q / (k.n)} \quad (2)$$

Data k and n, it's refer to k as Constant Screw (k) and n as the Rotation of Turbine (r). For k, the selected data is 22 degrees screw angle, with d/D = 0.3 and turbine angle 30 degrees, then k = 0.335. For r, the rotation speed is taken from the fast category with a range of 29-31 rpm. And after that we know the Outer Diameter of Archimedes Turbine Screw, and next calculation is calculated the Inner Diameter with following Eq. 3.

$$d/D = 0.3 \quad (3)$$

For simplify the Eq. 3, we can use the Eq. 4 to make easy in calculation.

$$d = 0.3 \times D \quad (4)$$

The next step is choosing the turbin angle (θ), the author choose 30 degrees cause from the literature what the authors read from "*The Turn of The Screw Optimal Design of An Archimedes Screw*" we must choose the angle between 25-40 degrees turbines angle (θ).

So the authors choose 30 degrees for implementation of this topic. For the next calculation, we should calculated the Length of Turbine with Eq. 5.

$$\sin \theta = H / L \quad (5)$$

Following the fig. 5, it's explain about Length and Pitch Turbine.

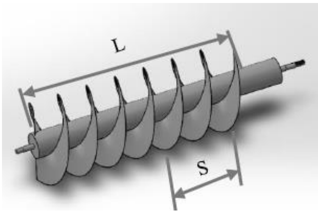

Fig. 5 Length and Pitch Screw Tubine

Pitch Turbine showing about screw in every single blade in one pitch within turbin angle 30 degrees. That's also calculated it with Eq. 6.

$$S = 1.2\,D \quad (6)$$

After we know L and S, we calculated the number of threads in turbine with Eq.7.

$$N = L / S \quad (7)$$

After design the turbines, we have to calculate the efficiency of the turbine that have to designed using formula Eq. 8 until Eq. 11 and following the Figure 6 to know data that we sure to use for the calculation.

$$\Delta h = x \sin \theta \quad (8)$$

$$A = ho / \Delta h \quad (9)$$

$$x = (1/N) . S \quad (10)$$

$$\eta_{Turbine} = ((2a+1)/(2a+2)) . ((1 - 0.01125 \times D^2 / Q)) \quad (11)$$

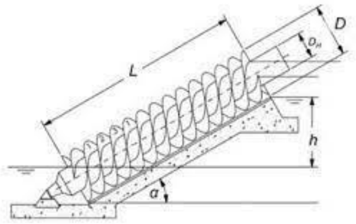

Fig. 6 Parameters of Turbine Calculation

After we know the efficiency turbine, the next step of design is calculating the theoretical hydropower ($P_{Theoritical}$), the power capability of the turbine ($P_{Hydraulic}$) and the calculation of the resulting generator power ($P_{Generator}$) following Eq. 12 until Eq. 14.

$$P_{Theoritical} = 9{,}81 \times \rho \times Q \times H_{eff} \quad (12)$$

$$P_{Hydraulic} = 9{,}81 \times \rho \times \eta_t \times Q \times H_{eff} \quad (13)$$

$$P_{Generator} = 9{,}81 \times \rho \times \eta_g \times \eta_t \times Q \times H_{eff} \quad (14)$$

Last, calculating the hydropower efficiency using Eq. 15.

$$\boldsymbol{Eff}_{\boldsymbol{HydroPower}} = (P_{hydraulic}/P_{generator}) \times 100\% \quad (15)$$

IV. CALCULATION ANALYSIS RESULTS

After knowing what stages will be studied, the authors continued to calculating the turbine design and the amount of electrical power that can be generated. In the calculations that are adjusted to the design calculation stages, and then the authors get the following calculations in Table 1. The following Table 1 is the result of the Turbine Design calculation analysis.

TABLE 1. CALCULATION DESIGN RESULTS

Data	Calculation Results
Turbine Type	Archimedes Screw
Screw Angle (Degrees)	22 Degrees
Rotational Speed (rpm)	31 rpm
Outer Diameter (m)	30 cm or 0,3 m
Inner Diameter (m)	9 cm or 0,09 m
Turbine Angle (Degrees)	30 Degrees
Length Turbine (m)	80 cm
Pitch Turbine	1,2 D - 0,36
Number of Screw (pcs)	2,222 pieces in 80 cm
Efficiency Turbine (%)	59,6%

It can be seen in the turbine design that the calculated size is included in the portable category, this is because the size does not exceed 1 meter in size. So it can be included that portable tools that are easy to apply in any waters and can be carried anywhere. For further calculations regarding the calculation of electrical power that can be generated at the hydropower plant that has been designed in accordance with the measurement data and turbine design calculation data.

In calculating the electric power generation, the researcher presents the results of the data in the form of the theoretical power of hydropower in general, turbine generation power, generator generation power, and the efficiency of hydropower performance itself against the type of turbine that has been designed. The following Table 2 is the result of the calculation of the power that will be generated in the hydropower performance aspect.

TABLE 2. CALCULATION PERFORMANCE RESULTS

Data	Calculation Results
$P_{Theoritical}$ (Watt)	1114,42 Watts
$P_{Hydraulic}$ (Watt)	664,2 Watts
$P_{Generator}$ (Watt)	564 Watts
$Efficiency_{Hydropower}$ (%)	117,8%

V. CONCLUSIONS

The design of portable hydro power plant requires data from measurement results at one of the research locations. Observational data is from the authors get when reviewing directly to the objectivity place.

This data is obtained through 3 stages, namely Survey location, Quantitative and Analysis of the data obtained. From the results of the survey to the field, the authors get the data needed in this case like differences of elevation water (Head), Flow water distribution (V), functional width (L) and Area of the river (A) and also Water discharge (Q).

According to the calculations that have been calculated using Archimedean Screw implementations, the turbine thread design selected is 22 degrees and the turbine angle is 30 degrees and the calculations results is Outer Diameter (D) 30 cm, Inner Diameter (d) 9 cm and Efficiency of turbines (η) is 59,6%. It's refer to we know that the size of turbines can be in into portable Size Aspect, that we can apply the device into all waters.

So, it can be inferred that with that Archimedean screw design and calculation, the designs completely enter into portable design within income energy we can get from theoretical power generated of 1114.42 Watts, the Power Capability of the Turbine is 664.2 Watts, the Power from the generator is 564 Watts and Efficiency from Hydropower itself 117.8%.

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