# Effect of Runners on Laboratory-Scale Vortex Turbine Efficiency

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*Abstract:* Electricity is an important thing in human life. Currently, the source of electrical energy is obtained by utilizing fossil energy, such as coal and gas, which results in the longer the source of power generation, the less it will be while the need for electrical energy continues to increase due to the times and population growth. Thus, a micro-hydro power plant is a water-powered power plant that is made with the aim of meeting the need for electrical energy and as a renewable energy source that is practical to use. The vortex turbine is a micro-hydro power plant that works with a low head called a Gravitational Water Vortex Power Plant (GWVPP). The laboratory-scale Vortex turbine is called a whirlpool turbine because this turbine utilizes the input power of water that passes through the basin channel so that the water is pressurized and forms a vortex when it rotates the turbine blades, which will generate electrical energy due to the rotation of the blades. This research was conducted to find out which runners are suitable for application in laboratory-scale vortex turbines and to find out the performance of several runners, including Kaplan, Francis, and Vortex turbine runners, to determine the highest efficiency value of the types of runners so that they can be implemented on a larger scale. The research was carried out using the quantitative method by collecting data on runners that had been made with the specifications of 5 blades with a slope of 45° and a diameter of 12 mm given a constant flow rate of 240 l/min. The data taken includes torque (T), angular velocity (ω), water input power (Pa), and water output power (Pt). The data obtained will produce efficiency values for each runner, namely the Francis runner by 21%, Vortex by 21%, and Kaplan by 74%. It can be concluded that the vortex turbine is more suitable for use with Kaplan runners because these runners produce the highest efficiency compared to Francis and Vortex runners.

*Keywords:* Renewable Energy, Turbin Vortex, Runner Kaplan, Francis, Vortex and efficiency.

## 1. Introduction

The development of an area, such as industrialization, urbanization, and population growth, can lead to a higher demand for energy. As a result of these advances, the global community requires a lot of energy, so it must find alternative energy that is more modern and can be used easily by all populations [1][2][3]. One of them is the demand for energy in power generation. This is so because one of the things that affects a country's progress is electrical energy. Fossil fuels like coal, oil, and gas are used to generate the majority of the country's electricity, which raises the price of electricity and depletes these resources [4]. The use of fossil fuels will also result in greenhouse gas emissions, air pollution, and global warming [5]. People around the world, not only in Indonesia, are having the same issue. 1.2 billion people, or 15% of the world's population, have trouble using power properly; most of these issues affect individuals who live in rural areas. According to predictions, the lack of fossil-based energy won't become stable until 2030. [6].

To reduce carbon emissions and reduce how much fossil energy is used, we need to find new sources of energy to replace fossil energy. One way to do this is to use natural resources like photovoltaic solar, wind, and water, which are plentiful in rural areas and easy to manage [7]. This is to use natural resources like photovoltaic solar, wind, and water, which are plentiful in rural areas and easy to manage [8]. Looking at the potential of natural resources, Indonesia has quite a large amount of hydropower, namely 75,000 MW spread across all regions, but the hydropower that is owned has not been utilized optimally because there are still many areas that have not received a supply of electricity resources [9]. Because of these problems, scientists created Micro Hydro Power Plants to use natural resources in a way that is good for the environment and doesn't harm it [5] [10].

Micro hydro power plants is a generator that uses a water turbine energy conversion engine to turn mechanical energy into kinetic energy and potential energy, which are then turned into electrical energy [11]. Unlike hydroelectric power plants, which need big water storage tanks, micro hydro power plant can use the flow of water in a river. Currently, micro hydro power plant uses a high head of water, so rivers in rural areas that have a low head cannot be utilized evenly [12] [13]. A gravitational water vortex power plant is a complementary technology that belongs to the micro-hydro power plant because this type of power plant has the power to produce electrical energy of no more than 100 kW [14]. Of several types of generators, the gravity water vortex power plant has a major advantage, namely, working at a very low hydraulic head so that people in remote villages can easily use it in irrigation areas or small rivers [15] [16], this turbine works on the dynamic force generated by rotation; when the water rotates perpendicularly in the free surface area, it will produce a whirlpool shape [17] [18] [19] [20]. The vortex provides the dynamic force because the working concept of this turbine uses a low head, so there is no water pressure on the runner of the turbine [21]. Several components must be considered to design a hydroelectric power plant, one of which is the determination of the runner [22]. conventional turbines, which are divided into two types, namely, impulse turbines and reaction turbines, with examples of impulse turbines such as Pelton, Turgo, and cross-flow [23] [24] [25], and reaction turbines include turbines that are easier to apply than impulse turbines because this type of turbine is not too complicated; only by utilizing the pressure from a flow can this turbine operate [4] [26]. Several types of turbines are classified as reaction turbines, namely Francis turbines, Kaplan turbines, and vortex turbines [27], [28], and [29].

Reaction turbines are a type of turbine that is easy to operate at low head flows; besides that, this turbine has the potential to produce high efficiency values [23] [30], many researchers say that turbines that are classified as reaction turbines, such as the Francis turbine, including the first modern turbines, produce high efficiency [31], a Kaplan turbine that uses a runner with four blade variations [32], and a Vortex turbine that varies the height of the Vortex vortex will potentially have an efficient value [33]. The energy from the whirlpools is used for a microhydro power plant known as a "gravitational water vortex power plant" (GWVPP). The Vortex water turbine can be used with the lowest water flow height of 0.7 m. Even though it works with a low head, the Vortex turbine has an efficiency value of 80%, and in real situations, the efficiency can reach up to 73% [21].

Based on research, the best way to use the flow head with a vortex turbine is to look at the outlet hole diameter ratio as a way to figure out the optimal strength in a vortex flow. The height of the vortex is directly proportional to the water's capacity and maximum power [34]. The vortex flow reaction turbine will affect its efficiency value when varying the angle area, number of blades, water inlet, and flow rate [35]. Numerous studies have looked at the vortex turbine in terms of the number of blades, rather than the angle of the blades, but no one has studied the vortex turbine by experimenting with different types of runners that may be used with the vortex turbine. Then, using studies on three different types of runners, but with the same number of blades and runner diameter, we conducted research on the flow vortex turbine laboratory scale. In locations where electricity has not been distributed equally, and more usable and practical, and this was done to address the shortage of electric energy. The research was conducted using quantitative methods, with the process of collecting several variables of data to obtain the efficiency values of the three runners and determine which one is higher. As a result, the findings of this study can be used as a source of information for the efficient manufacture of turbines in places where energy cannot flow effectively. The runners used were the Francis turbine runner, the Kaplan runner, and the Vortex runner.

## 2. Literature review

### 2.1 Definition of Water Turbine

A water turbine is a machine that is used to harness the power of water, which is converted into electricity. The performance of the water that is utilized, namely to turn the turbine, so as to produce mechanical energy that is connected to a shaft with a generator [10]. The resulting mechanical energy will be converted by the generator so that it becomes electrical energy [11].

### 2.2 Turbine Types

#### 2.2.1 Impulse turbine

Turbine Impulse is a turbine that converts the potential energy of water in a nozzle into kinetic energy. Water that came outsped tall touch turbine blades. After about two spoons of turbine, speed genre changed direction, so that caused a change in momentum (impulse) to rotate the wheel turbine. Turbine impulse is turbine-pressurized, pressure water that goes out from a nozzle. The same is true of the pressure air in the surrounding area. A number of examples of turbine impulses are Pelton And turbine genre cross [10] [23].

### 2.2.2 Reaction turbines

In a turbine reaction, only some of the energy that comes in through the inlets and is changed into kinetic energy. The rest stays as compressed energy. Moment water flowed through runners, energy compression in a manner gradually changed into kinetic energy. Pressure on the inlet side is greater than pressure on the outlet side of the turbine, where pressure varies in accordance with the rate of fluid flow through the turbine. So that the change in pressure makes the turbine work, the runners must be sealed from the outside air and completely filled with water. A number of examples of turbine reactions are the Francis, Kaplan, and Vortex turbines [10] [23].

## 2.3 Vortex

Vortexis flow area of fluid in which genre the turn to axis imaginary. Pattern movement this is called vortex flow. Vortex, or a vortex that is formed by fluids, including fluids, gases, and plasma. A general example is clumps or swirlsmoke, vortex, which is frequently caused by movement of a boat, wind typhoon, and tornado, or wing aircraft fly. A vortex is an important component in the turbulent genre. With no external style, friction viscous on fluid tends to direct Genre togathering, which is known as vortex rotating or irrotational vortices. In this vortex, the speed of the fluid is greatest near the imaginary axis and slows down as you move away from the imaginary axis [36], strength vortex is very tall in area core around axis and almost zero in tail vortex, whereas pressure experiences a large decline moment approaching area core. After forming, vortices can move, stretch, turn, and interact with each other using complex methods [37].

Figure.1 Vortex [36]

### 2.3.1 Vortex turbine (whirlpool)

Victor Schauberger, a German researcher, came up with the vortex flow in 1982. He used irrigation flow, which was changed into a vortex flow, as a way to model modern water turbines. [38] [39]. A vortex turbine, or whirlpool, is a turbine that utilizes the input power of water to rotate the turbine blades so as to produce electrical energy due to the rotation of the blades [40]. The vortex turbine is also known as the Gravity Water Vortex Power Plant (GWVPP) by Austrian inventor Frans Zotleterer because the water level (head) required for this turbine is only 0.7–2 m and the discharge is around 1000 liters per second. These turbines are simple, easy to maintain, small, strong, and can last 50–100 years [37] [21].

Figure.2 Prototype Vortex Turbine

## 2.4 Water turbine performance measurement

### 2.4.1 Hydraulic power/water input

Water flowing from a height is the source of hydraulic power. In this case, the hydraulic power is obtained from the water power generated by the pump [41]. In a gravity system with a water turbine utilizing the difference in water level, hydraulic power can be obtained by measuring the flow rate or discharge (Q) and the difference in water level with the bottom of the basin (Hv). If the density of water is expressed by ρ and the acceleration due to gravity is expressed by g, then the hydraulic power is calculated as follows.

$$Pa = \rho . g . Hv . Q \quad (1)$$

Description: Pa = water power (watts)
ρ = Density of water (kg/)$m^3$
g = acceleration due to gravity (m/)$s^2$
Hv = vortex height (m)
Q = Water discharge ($m^3$/s)

### 2.4.2 turbine torque

The distance between the shaft axis and the braking force measurement point multiplied by the braking force (F) yields the turbine torque (t). If the distance between the shaft axis and the braking force measurement point is expressed in L, then the torque (T) can be found as follows:

$$T = F.L \tag{2}$$

Description: T = Turbine torque (Nm)
F = Force (N)
L = distance from the axis point (m)

### 2.4.3 Angular speed (angular)

The angular velocity (ω) is often referred to as the rotational speed, and the scalar quantity is the rotational speed, which depends on the rotation of the turbine (n). If n is expressed in revolutions per minute (rpm) then the angular velocity (ω) can be found as follows:

$$\omega = \frac{2\pi n}{60} \tag{3}$$

Information :ω = Angular speed(rad/s)
n = RPM (rpm)
π = Phi(3,14)

### 2.4.4 Turbine output power

Turbine power is the power generated by a water turbine by converting the kinetic energy of water into mechanical energy in the form of shaft rotation [41]. The turbine output power can be calculated from the turbine mechanical power (Pt). The mechanical power (Pt) is obtained from the product of the angular velocity (ω) multiplied by the torque (T). From equations 2 and 3, the turbine mechanical power (Pt) can be calculated by the following equation:

$$Pt = \omega.T \tag{4}$$

Description: Pt = Turbine mechanical power (watts)
$\omega$ = Angular speed(rad/s)
T = Torque(Nm)

### 2.4.5 Efficiency

The ratio of output to input, or between turbine power and hydraulic power, is known as the turbine efficiency [41]. The efficiency figure must be sought in order to determine the water turbine's performance parameters and determine the study's overall conclusion. Using the results output turbine (Pt) and input water (Pa), which can be determined using the formula below, the efficiency can be calculated:

$$\eta = \frac{Pout}{Pin} . 100\% \tag{5}$$

Description : η = Efficiency(%)
$Pout$ = output power(watts)
$Pin$ = Input Power(watts)

## 3. Problem solution

### 3.1 Method

At the testing stage, the method used is the quantitative method on the runner section of the Vortex turbine power plant. The runners used to carry out this experiment were the Kaplan turbine runner, the Francis turbine runner, and the Vortex turbine runner. This vortex turbine power plant was made to conduct research on the device and find out the values of the independent variables, including the following: the value of the flow rate (Q), the rotational speed of the turbine (n), and the torque value (T) in the turbine, so that from the value With this variable, the researcher can find the mechanical power of the turbine and can determine the type of generator that is suitable for use with the turbine by looking at the relationship between rotational speed and torque. From this relationship, the researcher can find out the efficiency value produced by the turbine that has been made.

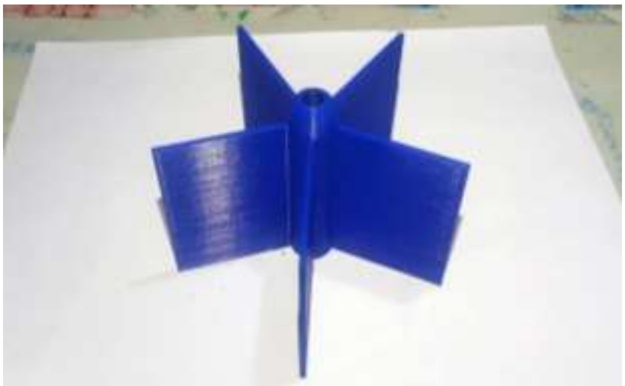
### 3.1.1 Runners specifications

Table 1 Runner size specifications

| NO | Runners | Diameter | Corner | Material | Blade |
|---|---|---|---|---|---|
| 1 | Kaplan | ø12 | 45° | PLA+ | 5 |
| 2 | Francis | ø12 | 45° | PLA+ | 6 |
| 3 | Vortex | ø12 | 90° | PLA+ | 5 |

Kaplan turbine runner in figure 3.

Francis turbine runner in Figure 4.



vortex turbine runner in Figure 5.

## 3.2 The working principle of the vortex turbine

The vortex turbine works by connecting the panel plug to a 220V AC power source, which allows electrical energy to enter by seeing the red indicator light on. Arduino is then turned on to check whether the incoming sensor information is in good condition which is displayed on the LCD screen. Then turn on the centrifugal pump to fill the line; the water will circulate through the basin, and the pressurized water will rotate the runner in the middle.

## 3.3 Data source

The research process requires variable values to support the processing of research data. Sources of variable values can be obtained from several sensors that have been installed on parts of the vortex turbine, including: a force sensor, a discharge sensor, a rotation sensor, and a measuring ruler.

These tools function as signals that produce variable values and can be read by the Arduino Uno microcontroller program so that the results of the flow rate, braking force, flow height, and rotation rpm can be known.

## 3.4 Results and Discussion

The vortex turbine research process is carried out by collecting data using the experimental method on runners of the Kaplan, Francis, and Vortex types, which will be given a braking force against the rotation of the runner until the runner stops. At this stage, the rotating runner is set to the same discharge speed, namely 240 L/min, so that it is easy to determine the performance of each runner with the same discharge speed.

Figure.6 Data collection process

The method for collecting data on Kaplan, Francis, and Vortex runners is shown in Figure 6, and involves applying a braking force while the runners rotate at the same speed. The braking force given is located on the shaft pole which is connected to the runner. From the highest lap (0 braking), braking force is applied gradually to the runner's rotation until the runner stops. Data is collected as shown on the LCD panel for each set of 1N increase in braking load. It is known that the higher the braking load, the faster the rotation will decrease, until it reaches the axis of the greatest braking force, where the rotation stops. So that it will be easy to find the angular velocity, input power, and output power values and get the cross between the torque and the efficiency of the Kaplan, Francis, and Vortex runners, the torque value will be obtained by entering the braking force multiplied by the length of the braking arm distance, which has a constant value of 0 .09m.

Table 2 the average value of the overall data for Kaplan runners

| NO | n (Rpm) | F (N) | Q (L/min) | t (Cm) | ω (Rad/s) | T (N.m) | Pt (watt) | Pa (Watt) | η (%) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 323 | 0.0 | 240 | 9 | 33.82 | 0.00 | 0.00 | 3.52 | 0% |
| 2 | 211 | 1.0 | 240 | 9.5 | 22.04 | 0.09 | 2.04 | 3.72 | 55% |
| 3 | 148 | 2.0 | 240 | 9.5 | 15.45 | 0.18 | 2.75 | 3.72 | 74% |
| 4 | 27 | 3.0 | 240 | 10 | 2.83 | 0.27 | 0.77 | 3.91 | 20% |
| 5 | 0 | 3.28 | 240 | 10 | 0.00 | 0.29 | 0.00 | 3.91 | 0% |

The average value of Kaplan runners is shown in Table 2. As can be seen, the Kaplan runner generates the comparison value between torque and efficiency. The table above displays the data that the Kaplan runner produced, which has four torque values derived from the braking force. The values used for comparison are as follows: When 1 N of braking force is applied, 0.09 Nm of torque is produced with a 55% efficiency value. When 2 N of braking force is increased, 0.18 Nm of torque is produced with a 74% efficiency improvement, then 3 N of braking force gets a torque of 0.27 Nm, and the efficiency results decrease to 20% because the rotation is slower due to braking. The last runner stops with a braking force of 3.28 N with a resulting torque of 0.29 Nm, which makes the efficiency value 0%. So it can be concluded that the results of a good crossover on the Kaplan runner, namely with a braking force of 2N, produce a torque of 0.18 Nm and an efficiency value of 74%. At this intersection, the water input power provided with a flow rate of 240 L/minute circulates well at 148 Rpm rotation, causing the highest efficiency of 74%.

Table 3 the average value of the overall data for runner Francis

| NO | n (Rpm) | F (N) | Q (L/min) | t (Cm) | ω (Rad/s) | T (N.m) | Pt (watt) | Pa (Watt) | η (%) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 312,6 | 0 | 240 | 12 | 32.74 | 0.00 | 0.00 | 4.69 | 0% |
| 2 | 101,6 | 1,03 | 240 | 12 | 10.64 | 0.09 | 0.99 | 4.69 | 21.0% |
| 3 | 0 | 2 | 240 | 12 | 0.00 | 0.14 | 0.00 | 4.69 | 0% |

By examining how torque affects the efficiency of the Francis type runner, the total statistics of Table 3 for the Francis runner are shown. It is known that when the runner Francis starts without braking force (0 N), the torque and efficiency values are both zero. When the runner is given a braking force of 1 N, the torque value changes to 0.09 Nm, and achieves an efficiency of 21%. When the runner is given a braking force of 2 N, the torque generated is 0.14 Nm which causes the rotation to stop and the efficiency value becomes 0%. The best value for this runner based on these data is a torque value of 0.09 Nm with a brake load of 1N to achieve a stable circulation position between runner rotations of 101.6 Rpm with a given discharge and get the highest efficiency value of 21%.

Table 4 The average data value of the entire vortex runner

| NO | n (Rpm) | F (N) | Q (L/min) | t (Cm) | ω (Rad/s) | T (N.m) | Pt (watt) | Pa (Watt) | η (%) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 197 | 0 | 240 | 11 | 20.60 | 0.00 | 0.00 | 4.30 | 0% |
| 2 | 94 | 1,04 | 240 | 11 | 9.82 | 0.09 | 0.91 | 4.30 | 21.2% |
| 3 | 0 | 2,41 | 240 | 11 | 0.00 | 0.22 | 0.00 | 4.30 | 0% |

As can be seen in Table 4, namely the average value of all data for the vortex runner, it is known that the value of the influence of torque on the efficiency produced by the vortex runner is not much different from the Francis type because this runner also collects data three times, namely data without any braking force given only produces high Rpm rotation while the torque and efficiency is 0 because there is no load, then at that rotation a braking force of 1N is given a decrease in rotation but produces a torque value of 0.09 Nm and efficiency becomes 21% then additional force is added braking becomes 2N the torque increases to 0.22 Nm but the efficiency value becomes 0% because the additional braking force becomes 2N causing the runner rotation to stop so that the efficiency becomes 0 %. So by looking at the results of the data obtained, the vortex runner has the best value, namely the braking number of 1N with a torque obtained of 0.09 with an efficiency of 21%, so it can be combined that the highest intersection level between rotation and circulating air discharge is 94 Rpm with a discharge of 240 L/minute to obtain an efficiency of 21%.

Looking at the comparison of the several graphs obtained, it can be seen that the Kaplan runner is superior to the Francis and Vortex runners because only the Kaplan runner has four torque values generated with the level of force given to the rotation and obtains the highest efficiency value of 74%.

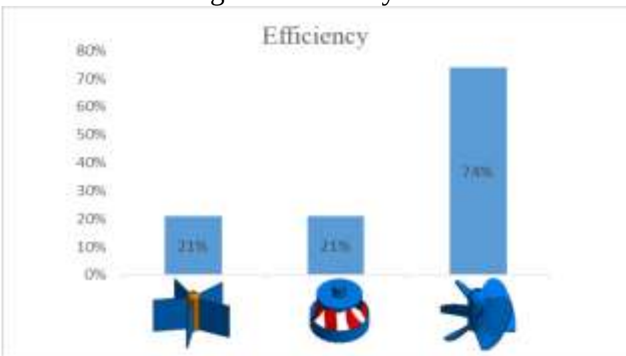



Figure.7 Efficiency of Kaplan, francis and vortex runners

Graph 7 is the result of the efficiency of the three runners, namely runners Vortex, Kaplan, and Francis. From the results obtained, it can be seen that the runners Vortex and Francis have the same efficiency value of 21%, while the runner Kaplan has the highest efficiency value, reaching 74%, so that based on the experimental results obtained by the researchers, they stated that the Kaplan runner is more recommended for Vortex turbines because it is superior compared to the Vortex and Francis runners.

# 4. Conclusion

Based on the results of the analysis of micro power plants, laboratory-scale hydro vortex turbines using Kaplan, Francis, and Vortex runners were evaluated to determine the performance comparison produced by vortex turbines using Kaplan, Francis, and Vortex runners. From the tests carried out by the researchers, they applied the same amount of force and discharge to the Kaplan, Francis, and Vortex runners with a discharge rate of 240 l/min. The highest rpm with a braking force of 0 N is for runner Kaplan at 323 rpm, Francis at 312 rpm, and Vortex at 197 rpm, with the highest torque causing the rotation to stop at 0 rpm because the braking force is very influential, and inversely, when the braking force is high, the rotation experiences a decrease in the resulting value, namely for runners Kaplan at 0.29 N.m, Francis at 0.14 N.m, and Vortex at 0.22 N.m. While the efficiency value generated by the Kaplan runner is 74% with 148 rpm rotation and 0.18 N.m. torque, the Francis runner is 21% with 102 rpm rotation and 0.09 N.m torque, and the Vortex runner is 21% with 94 rpm rotation and torque 0.09 N.m. The Kaplan runner is more suitable for use in vortex turbine micro-hydro power plants, according to the results of the data study, because it has good performance and stable air circulation above it. By using the Kaplan runner as a turbine player, the results of this study can be practically applied to meet the needs of electrical energy in rural areas or areas that do not have good electricity. Large-scale vortex turbines can also be used to meet these needs. Due to the vortex turbine defrosting problem in the braking arm during data collection caused by scuffing of the rotating shaft iron, it was necessary to discharge the vortex turbine in the braking arm during the study. Therefore it is necessary to develop by choosing a suitable material for the braking arm so that it does not melt when exposed to friction.

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