Numerical and Experimental Study of Gravitational Water Vortex Turbine at Different Number of Blade

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Abstract. In this study, the author wants to further identify, especially the influence of variations in the number of blades on cylindrical basin-type vortex turbines on their performance. The method used is simulation using CFDs and experimental. Variations in the number of blades used are 5 and 7 blades. The results of this study show that the increase in the number of blades will affect the amount of torque and power produced. In the simulation results, the highest torque in a 5-blade turbine was 13.44 N.m while in a 7-blade turbine, a maximum torque of 14.6 N.m. The results of this simulation were validated by experimental data with a percentage of acceptable errors. The experimental results showed that the highest efficiency occurred in turbine 7 blades of 43.5% and the minimum efficiency occurred in turbines of 5 blades of 40.4%. This study analytically shows that the increase in the number of blades will increase the number of areas in contact with water which will increase the absorption of water energy by turbines.

Keywords: Gravitational vortex water turbine, Number of blades, CFD.

1 Introduction

In this era, electrical energy is the most important and considered thing in every country [1]. Based on the Energy Access Outlook 2017 published by the International Energy Agency (IEA), in 2015, as many as 193 developed and developing countries have developed clean and sustainable sources of electrical energy [2]. Adverse environmental impacts and the nature of non-renewable fossil fuels have led researchers around the world to turn to renewable energy sources to meet the growing demand for electricity [3].

Power plants using water energy are one of the most economical resources. Among hydroelectric power plants, micro-hydro powerplants are easier to apply because they require a lower head and a smaller flow rate to generate electricity [4].

Water flowing from the highlands to the lowlands can be harnessed as the driving energy in power plants [5]. Currently, the generation of hydroelectric power with a low head has been based on various forms of turbine generation which include: horizontal spiral turbines, waterwheels, Kaplan hydro turbines, and gravity vortex power plants called gravitation water vortex turbine

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GWVT. The utilization of energy through the flow of water can be carried out using the vortex flow method. Water turbine type of gravity vortex, consisting of a runner or called a turbine blade and a tank called a basin, the flow of water flowing through the basin will form a vortex of influence from gravity, then the kinetic energy generated from the whirlpool will rotate the runner contained in the basin and the rotation of the runner will be forwarded to the generator so that it will produce an electric current [9,10]. This water turbine is capable of generating electricity with a low head and low flow discharge with a relatively simple structure.

In recent studies that have been carried out in laboratory tests, whirlpool turbines have an efficiency of about 30-40% with a water head height lower than 1 meter. Nauman Hanif Khan (2016) conducted several studies with CFD (Computational Fluid Dynamic) simulations on several types of blades, namely inverted conical blades, crossflow blades, curved rectangular blades, and twisted blades with four blades and cylindrical basins [6]. The results of the study concluded that maximum efficiency occurs in the crossflow blade type of 48.38% at a revolution of 139 rpm with a water discharge of 4.2 liters per second and a head of 0.5m.

In general, the performance of whirlpool turbines is influenced by several factors, namely the influence of aspect ratios, variations in the number of blades, the shape of the blade angle, the interference of shafts and accessories, the amount of water discharge flowing through the turbine [7]. From the study conducted by Nauman Khan, the author would like to further examine the use of crossflow type turbine blades in these vortex turbines. The right number of blades to produce the highest efficiency is of concern to the author in order to produce a suitable design parameter for the vortex turbine. Therefore, researchers want to conduct experimental and simulated testing as validation to find the right number of blades on the prototype of a cylindrical basin-type vortex turbine. The expected result of this study is the number of blades that produce the highest power or torque after being tested experimentally and simulated. The simulation data will be validated by the experimental data.

2 Methods

The author conducted research with 2 methods, namely experimental and simulation. For the design and manufacturing of tools carried out at Sustainable Energy Research Center, university of Sumatera Utara. A study conducted by Wanchat Sujate [8, 9] said that a cylindrical basin with an outlet hole in the middle is most suitable for increasing the velocity of tangential eddies into the basin. They also suggested that the ratio of the optimal outlet diameter to cylindrical basin diameter ratio is 0.14-0.18. The cylindrical basin design is shown in the figure 1.

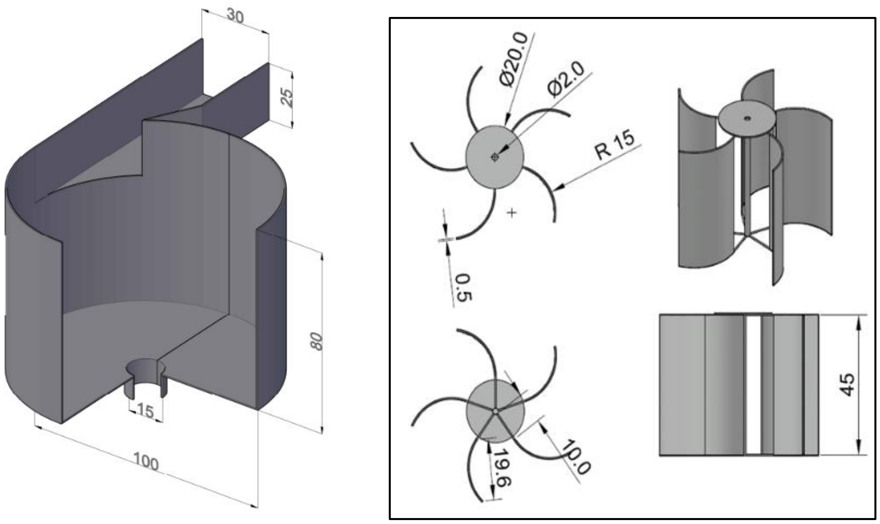

Fig 1. (a) Geometry design of cylindrical basin, (b) Turbine Blades Design

The selection of the design above is in accordance with the suggestions from previous research. [10] The blade design is based on the design found in the research of Nauman Hanif Khan with a crossflow turbine type design. From the results of research on simulations that have been carried out, the efficiency value for the Crossflow Blades produces a maximum efficiency of 48.38%. The difference from the design found in Nauman Hanif Khan's research (2016) is from the geometric shape and the number of blades which are varied from the number of blades of 5 and 7 blades. The purpose of varying the number of blades is to find out if there is an increase in turbine performance. To conduct research, it is necessary to do a test, where this test is made a prototype of a gravity vortex turbine.

2.1 Experimental Method

In the figure 2 below, we can be seen that water will be circulated using a pump from the lower reservoir to the upper reservoir, then water from the upper reservoir will exit through the channel to the basin, as a result of gravity the water passing through the basin will form a vortex and rotate the turbine, then after passing through the basin water will come out to the lower reservoir to be recirculated.

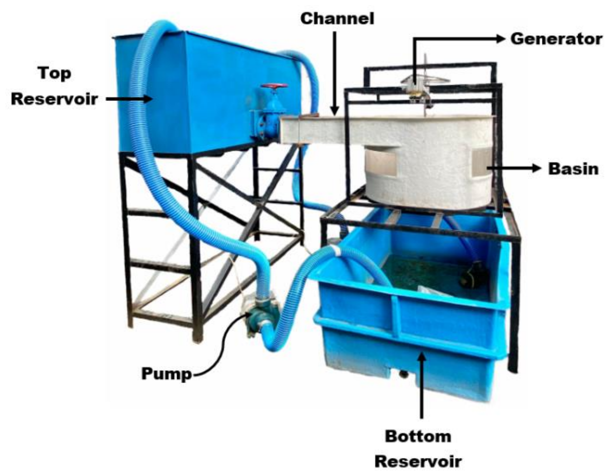

Fig 2. Gravitation water vortex turbine testing tool

The speed of the water flow will be determined and varied by 2.5 m/s, 2.2 m/s and 2 m/s, then the resulting water discharge is 22.5 l/s, 15.4 l/s and 10 l/s. After obtaining the water flow velocity and the resulting discharge, the water power calculation is carried out. [11] Factors that affect the amount of power in the turbine is the amount of torque and shaft rotation. So, to know the performance of the vortex turbine, data is needed to carry out a calculation and analysis. Factors that affect the amount of power in the turbine are the amount of torque and shaft rotation [12]. So, to know the performance of the whirlpool turbine, data is needed to carry out a calculation and analysis. The calculation is based on previous research where to find torque the formula is used:

$$\tau = F.r_p \quad (1)$$

Where F, is the force measured when the measurement is made. r_p is the pulley diameter. The torque measurement mechanism refers to a previous study where when the turbine is run, the pulley on the shaft is held in place by a rope connected to the load. The other end is connected to a brake dynamometer (OFX_001_CHEAP_LUGGAGE: +0.02kg) to show how much force is generated. The load on one end of the rope will be increased periodically until the friction between the rope and the pulley is able to stop the rotation of the turbine shaft. used is 20 cm. Each additional load will be measured how many rotations of the shaft by using a tachometer (DT-2234C: +(0.05% = 1 Digit)) and the load on the load balance. The torque measurement mechanism is clearly shown in Figure 6 below.

(a) (b)

Fig 3. (a) torque test setup and (b) rpm test setup

Moreover, ω as the angular velocity is obtained due to the rotation of the whirlpool flow acting on the runner, therefore the number of revolutions on the shaft is measured using a tachometer measuring instrument.

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

When the torque and rotation values are obtained, the turbine power can be calculated by the formula:

$$P_{turbin} = \tau \,.\, \omega \tag{3}$$

The amount of water power that enters the turbine can be calculated by the formula:

$$P_{water} = \rho \,.\, Q \,.\, g \,.\, H \tag{4}$$

Where ρ is the density of water (kg/m^3), Q indicates the inflow discharge (m^3/s), g is the acceleration of gravity of the earth, and H is the height of the vortex formed in the basin. When the water power and turbine power are obtained, the turbine efficiency can be calculated by the formula:

$$\eta_t = \frac{P_{water}}{P_{turbine}} 100\% \tag{5}$$

2.2 Numerical Analysis Method

Basically, all types of CFD use the basic equations (governing equations) of fluid dynamics, namely the equations of continuity, momentum, and energy. The governing equation for a whirlpool, which is a steady, incompressible, viscous, and turbulent flow; are the Continuity Equation and Navier Stokes Equation, which are described in cylindrical coordinates as follows [7]:

$$\frac{\partial V_r}{\partial r} + \frac{\partial V_z}{\partial z} + \frac{V_r}{r} = 0 \quad (6)$$

$$V_r \frac{\partial V_\theta}{\partial r} + V_z \frac{\partial V_\theta}{\partial z} - \frac{V_r V_\theta}{r} = v\left(\frac{\partial^2 V_\theta}{\partial r^2} + \frac{\partial V_\theta}{r\partial r} - \frac{V_\theta}{r^2} + \frac{\partial^2 V_\theta}{\partial z^2}\right) \quad (7)$$

$$V_r \frac{\partial V_r}{\partial r} + V_z \frac{\partial V_r}{\partial z} - \frac{{V_\theta}^2}{r} + \frac{\partial \rho}{\rho \partial r} = v\left(\frac{\partial^2 V_r}{\partial r^2} + \frac{\partial V_r}{r\partial r} - \frac{V_r}{r^2} + \frac{\partial^2 V_r}{\partial z^2}\right) \quad (8)$$

$$V_r \frac{\partial V_z}{\partial r} + V_z \frac{\partial V_z}{\partial z} + \frac{\partial \rho}{\rho \partial z} = g + v\left(\frac{\partial^2 V_z}{\partial r^2} + \frac{\partial V_z}{r\partial r} + \frac{\partial^2 V_r}{\partial z^2}\right) \quad (9)$$

Where V_r, V_θ, and V_z are the radial, tangential and axial velocities respectively, g is the acceleration due to gravity, v is the kinematic viscosity, and ρ is the density of the fluid. Due to the complexity of the equation, it is almost impossible to solve the equation analytically. Moreover, the presence of multiple domains takes the analytical solution of this equation to a higher level of difficulty. For this reason, ANSYS Fluent is used for the solution of this equation.

In the simulation of a gravity vortex turbine using CFD, there are two domains, the first is the basin as the outer domain and the second is the turbine as the inner domain. The prototype geometry design will be exported to Ansys Fluent for computational analysis to produce torque values with three variations of water velocity. The setup from the experiment is adjusted to resemble the setup for computational analysis. For experimental testing, the torque obtained uses a dynamometer and a rope as a braking force.

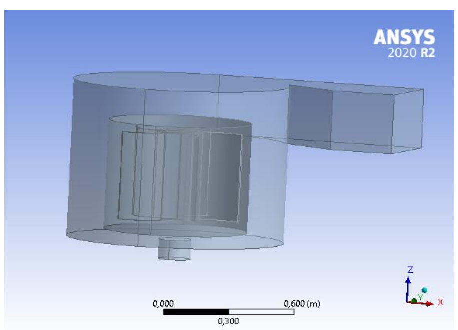

Fig 4. Domain

At this stage, we set the boundary conditions on the geometry model that we created earlier. This includes the inlet and outlet fluid flow domains, as well as the breakdown of the geometry into small partitions called cells. In the meshing process as shown in Figure 5, the size and type of mesh must be considered because it greatly affects the accuracy of the simulation results. The smaller the mesh size, the higher the level of accuracy obtained but the greater the computational power and time required . In this case, the element size for the domain is 10 cm with a tetrahedron type. The number of mesh elements for the 5 blade turbine is 1004616 with a number of nodes of 187393, while for the 7 blade turbine the number of mesh elements used is 1100010 and the number of nodes is 205654.

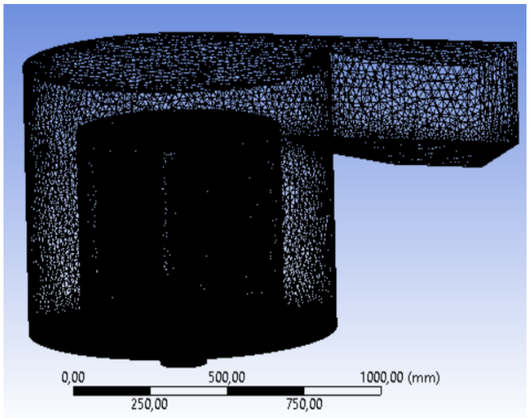

Fig 5. Meshing

The next process is to determine the boundary conditions for each component. This boundary condition is the input in the simulation according to the actual conditions to be simulated. These boundary conditions include simulation types, turbulence models, phases, component materials, and others. For more details, the process of setting this boundary condition is shown in table 1.

TABLE 1. Boundary Condition

Aspect	Setup
Solver Model	Pressure based, 3D, Transient
Viscous Model)	Turbulent k-ε Standard
Fluid	Water with constant density,
Operating Condition	101325 pa / 1 atm
Initialize	Velocity Inlet
Residual Monitor	10^{-6}
Problem type	Multiphase
Normal speed inlet	2 m/s; 2,2 m/s; 2,5 m/s
Turbine mass 5 blades/7 blades	6,6 kg/8,1 kg
Turbine material	acrylic
Basin material	Concrete

3 Result and Discussion

3.1 Experimental Result

Experiments were carried out with variations of the number of blades and variations in flow velocity at the inlet which gave the results as torque and speed (RPM). Speed is measured by a tachometer, while torque is measured using the Rope Brake Dynamometer method.

Table 2. Experimental Data for Torque, Rpm and Efficiency

No	Water Velocity (m/s)	Torque (N.m)	Head (m)	RPM	$P_{turbine}$ (Watt)	$P_{generator}$ (Watt)	P_{water} (Watt)	η_t (%)
5-blades	2	6,8	0,7	44	27,1	20,5	68,4	40,4
	2,2	7,8	0,6	45	36,9	24,6	90,3	40,9
	2,5	8,8	0,6	60	55,4	30,8	132,03	41,9
7-blades	2	7,8	0,7	40	27,9	26.2	68,4	41,9
	2,2	8,8	0,6	47	38,6	29,4	90,3	42,7
	2,5	9,8	0,6	56	57,5	32,1	132,03	43,5

In table 2, we can see the experimental data on the testing of this vortex gravity water turbine, in each test carried out on one turbine, 3 tests are carried out according to the number of variations in water flow speeds. So that with variations in the number of turbine blades as many as 2 turbines, the test data obtained as shown in table 2.

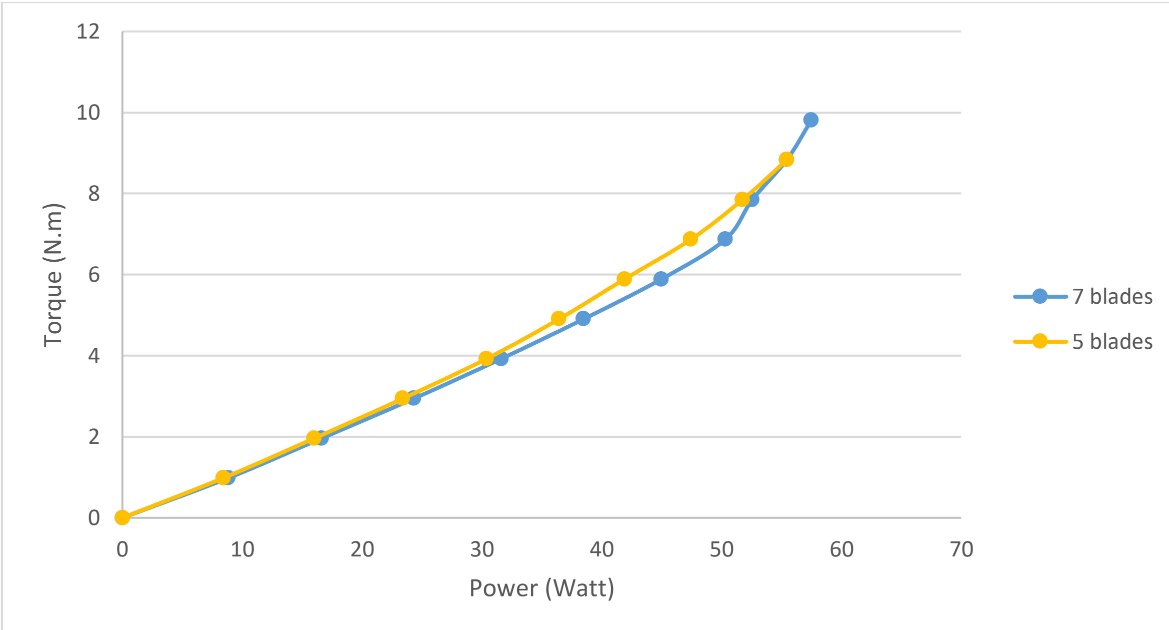

Fig 6. Torque vs. Power at V= 2,5 m/s

The power-to-torque comparison graph seen in the figure above explains that any increase in torque will cause an increase in power in the turbine. This increase in power also occurs in the maximum number of blades, which is 7. The maximum power of the turbine reaches 57.5 Watts. The torque generated by water power is influenced by how much water discharge drives the turbine, so in the table we can find out the torque will increase as the water speed rises. It is this torque that will contribute greatly in generating turbine power. Turbine with a total of 7 blades produces the highest power. This is in accordance with the findings of Wanchat et al doing the testing in the laboratory when the test was carried out at a load of 0-60 W, a turbine with 9 blades was found to produce the highest torque but the power produced was lowest than the other number of blades [7,8].

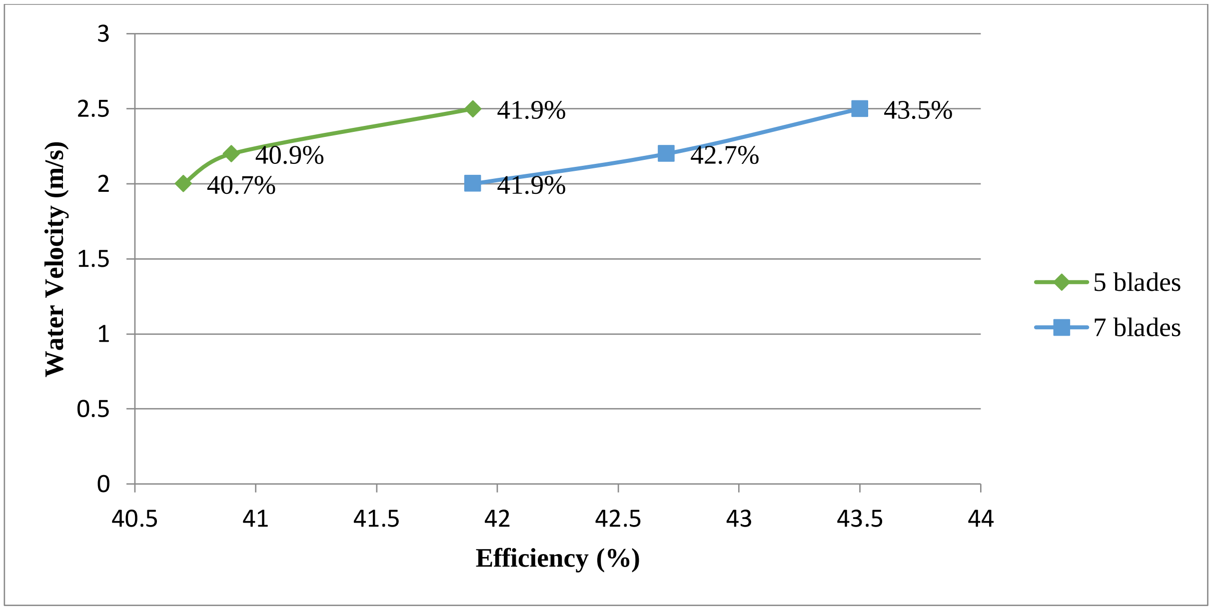

Fig 1. Efficiency vs Water Velocity

The comparison graph of turbine efficiency to water speed shown in the figure above explains that an increase in water speed in a turbine causes an increase in efficiency. As the speed of water entering the basin increases, automatically kinetic energy, the potential of water hitting the turbine will increase. This is what makes at the highest speed the efficiency of each number of blades is in the maximum position. In addition, turbines with a number of blades of 7 showed the highest efficiency in this test, this is due to the area of the turbine increasing when the number of blades is increased. The energy absorbed by the turbine is also getting more and more.

3.2 Numerical Simulation Result

Simulation work is carried out according to the input data in the experiment. Both geometry, number of blades, speed of water, and ect. The results obtained in the simulation are shown in table 3 below.

Table 3. Simulation Result Data for Torque, Rpm and Efficiency

Number of Blades	Inlet velocity [m/s]	Diameter [m]	Torque (N.m)
5-blades	2,5	0.4	13,44
	2,2	0.4	12,61
	2	0.4	12,24
7-blades	2,5	0.4	13,60
	2,2	0.4	12,92
	2	0.4	12,70

From the simulation results, it is found that the torque value increases due to the increase in air speed. The maximum torque value occurs at an air speed of 2.5 m/s with a number of 7 blades, which is 13.60 N.m. While the minimum torque occurs at the minimum air velocity with the number of blades 5. The comparison of the simulation data shows a match with the experimental data with the percent error shown in table 4 below.

Table 4. Numerical Validation

No. of Blades	Inlet Velocity [m/s]	Torque (Simulation) (N.m)	Torque (Experiment) (N.m)	Error (%)
5-blades	2,5	13,44	12,75	5,13 %
	2,2	12,61	11,77	6,66 %
	2	12,24	11,77	3,38%
7-blades	2,5	14,6	15,69	6,94 %
	2,2	12,92	12,75	1,31 %
	2	12,70	11,77	7,32%

The comparison of the torque data above in the condition that the turbine has stopped rotating due to being held by the load in the torque test. The percentage of error shown is still within reasonable limits.

4 Conclusion

In accordance with the objectives of this study, an analysis of the gravity water vortex turbine has been carried out in simulations and experiments. The two methods compare the number of different blades on a vortex turbine to determine their effect on the torque and power produced. The conclusion of this research experiment is that the increasing number of blades in the turbine will increase the performance and efficiency of the gravity vortex water turbine. Experimental test results show that the highest power and torque occur at the maximum number of blades, namely 7 with each value of 9.8 N.m and 57.5 Watt. The increase in the performance of this vortex gravity water turbine occurs at every increase in water flow velocity. Torque measurements at maximum load both in simulations and experiments were carried out for validation. The maximum torque value in simulation is also obtained close to the experimental results of 14.6 N.m with a percent error of 5.13%. The turbine efficiency value clearly shows the highest value in the turbine with the highest number of blades, which is 43.5%.

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