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Submission date: 12-Apr-2023 03:34PM (UTC+0700)
Submission ID: 2062384974
File name: CT_OF_DISCHARGE_VARIATION_ON_THE_PERFORMANCE_OF_SINGLE_BLADE.pdf (444.84K)
Word count: 3241
Character count: 16379

International Journal of
Innovation in Mechanical Engineering & Advanced Materials (IJIMEAM)
https://publikasi.mercubuana.ac.id/index.php/ijimeam

Vol.3 (No.2). 2021. pp. 71-76
Published online: Sept. 4, 2021
ISSN: 2477-541X

EFFECT OF DISCHARGE VARIATION ON THE PERFORMANCE OF SINGLE BLADE ARCHIMEDES SCREW TURBINE: PREDICTION WITH COMPUTATIONAL FLUID DYNAMIC

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Abstract

Constructing a small-scale hydroelectric power station that can run efficiently at a head lower than 10 m is one possible method for reducing the impact of the electricity crisis in remote areas of Indonesia. The Archimedes Screw turbine is one type of turbine that is ideal for discharges below 10 m. In this study, the simulation results show that the value of Turbulence, Kinetic Energy is directly proportional to the increase in flow rate but inversely proportional to the level of immersion. This type of turbine is unless well in Indonesia due to a lack of information regarding the application of low head power plants. The turbine model that is suitable for the low head is investigated in this study. Before being tested, the turbine is first designed theoretically and then numerically evaluated. With discharges of 1 l/s, 2 l/s, and 3 l/s and turbine immersion levels of 30%, 50%, and 70%, ANSYS CFD (Computational Fluid Dynamic) software was used to investigate flow rate and level of immersion in the turbine. According to the investigation findings, the discharge has a considerable impact on the turbine's movement; the higher the flow rate, the higher the power to the turbine, which produces a torque on the turbine. The simulation findings indicate that the value of Turbulence Kinetic Energy is proportional to the increase in flow rate but inversely proportional to the level of immersion.

Keywords: *Discharge, Archimedes Screw Turbine, Performance, CFD*

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1. Introduction

Among renewable energy sources, energy from water in mini/micropower plants gets the highest appeal due to their environmentally friendly operation. Hydro energy is vital for a sustainable future because it is a clean, cheap and environmentally friendly electricity generation [1]. The low head characteristics turbine can be an option for the best economics for electrification of remote areas in developing countries [2]. Researchers worldwide are constantly trying to find the most efficient products that have the most negligible impact on the environment. From this point of view, the Archimedes Screw Turbine has tremendous potential [3]. In research conducted by Williamson the Archimedes Screw (AS) Turbine is most suitable for low head and low flow. Comparing several micro-hydro turbines relative to design selection criteria for a given site, the Archimedes Screw Turbine was found to perform favorably over traditional turbines for locations with a headless than 5 m as this type of turbine remains highly efficient even when the available head is close to zero [4].

The low flow rate entering the turbine inlet will be affected by the low head position and slope. Kaldellis JK experimentally conducted a small-scale AS study for power plants in various parameters such as tilt angle, flow rate, and rotational speed [5]. They concluded that the maximum efficiency was 64%, with a tilt angle of 21° and a flow rate of 10 l/s. A computational design can be used to investigate the behavior of the parameters employed. In both laboratory and field tests, computational fluid dynamics (CFD)-based design is the method of choice for designing AS before it is deployed. The selection of the CFD method will determine the results and quality of the designed system. Bouvant M et al, conducted a study to determine the performance of the Archimedes screw turbine (AST) in terms of the Power Coefficient (CP). Inner-diameter (Di) and outer-diameter (Do), axis length (L), blade slope concerning the longitudinal axis of the screw (a), and stride blade (p) were determined to be adjusted by applying response surface methods and experiments on the central composite design (CCD) to maximize the CP value. The test is carried out by comparing the initial turbine design with the configured turbine design.

The numerical results show good agreement with the experimental data. The highest CP value is obtained for the configured turbine, which is based on CFD of 0.5515 and the predicted value comes from a

Vol.3 (No.2). 2021. pp. 71-76
Published online: Sept. 4, 2021
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validated reduced second-order regression model of 0.5137, on parameters a Di/Do (0.1), L (360mm), a (73 .94) and p (220mm). [6,7]. In another study, Dellinger et al (2018) used the OpenFoam CFD application to perform AS simulations and study the structure of 3D turbulent flow and energy loss in the screw using the classic Navier Stokes turbulence model or Reynolds-Averaged Navier-Stokes (RANS) equation [8]. The torque and efficiency model values are in agreement with the experimental test results in the meshing process employing 5 million cells. In addition, numerical simulation has becomes a reliable tool for predicting AS performance and is able to achieve results higher than 80% [9]. Several studies use the turbulence model, namely the k-ω (k-omega) model with the type of Shear Stress Transport (SST). Through this model, in free flow, we need k-ε and k-ω in the near-wall domain with low Reynolds number [10–12]. For further research, it is recommended to involve different AS inclination angle parameters with various water flow conditions. in this study used a water flow rate of 3 l/s [8]. Meanwhile, Erinofiardi et al research considers the use of turbines in irrigation canals with low flow rate of 1.2 l/s.[13] So it is possible to consider the flow rate in the irrigation canal for further research on the variation of the flow rate between 1 l/s to 3 l/s.

As a result, the AS turbine model is developed to be used in irrigation/water channels with low flow discharge variations in this study. The inner and outside geometry of the turbine are taken into consideration during the design process. The classical Navier Stokes equation turbulence model or Reynolds-Averaged Navier-Stokes (RANS) is involved in the CFD process and uses a hexahedron meshing method with a specified number of elements and nodes. While sizing uses proximity and curving. The simulation will observe the effect of variations in the flow of water (1,2, and 3 l/s) on the velocity, pressure, and kinetic energy of the turbulence.

2. Simulation Method

The increasing demand for energy and the regulations on fossil energy have led to the importance of using environmentally friendly energy. Archimedes screw turbines can be an alternative option to generate electricity from hydrokinetic energy of water with the low-head potential energy [7]. This simulation study takes into account the condition of the turbine when it is submerged in water that takes full advantage of the impulse from the flowing water. Unsteady flow conditions and more turbulence make observations of the velocity and fluid flow in the turbine very difficult to detect experimentally. As a result, the simulation study uses the Ansys Fluent software's finite volume method to examine the flow pattern and pressure in the turbine as a function of water flow variations.

2.1. Governing Equation / Basic Equation

One of the numerical methods that can be used to determine the flow phenomenon is to use the Navier Stokes equation in this case. In general, the basic Navier Stokes equation is as follows[14]:

$$\rho(\frac{Dv}{Dt}) = -\nabla p + \nabla.\mathrm{T} + \mathrm{f} \tag{1}$$

Where T is a symmetric tensor which can be written as follows:

$$T = \begin{pmatrix} \sigma_{xx} & \tau_{xy} & x \\ \tau_{yx} & \sigma_{yy} & \tau_{yz} \\ \tau_{zx} & \tau_{zy} & \sigma_{xx} \end{pmatrix} \tag{2}$$

Where σ is the normal stress and $\tau$is the shear stress. The flow phenomenon that occurs in the turbine is dominated by turbulent flow, so it is necessary to use appropriate flow modeling. The K-epsilon method is one of the turbulent flow modeling methods. Fluid velocity and irregular movement of fluid particles causing flow turbulence.

The K-epsilon method uses 2 types of equations. The first equation is to calculate the turbulence kinetic energy (3) and the second equation is to describe the dissipation at the velocity of the energy turbulence (4). The equation can be written as the equation below[15].

$$\frac{\partial}{\partial x_i}(\rho k) + \frac{\partial}{\partial x_i}(\rho k u_i) = \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_k}\right)\frac{\partial_k}{\partial x_j}\right] + G_k + G_b - \rho\epsilon - Y_m + S_k \tag{3}$$

$$\frac{\partial}{\partial t}(\rho\epsilon) + \frac{\partial}{\partial x_i}(\rho\epsilon u_i) = \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_k}\right)\frac{\partial_\epsilon}{\partial x_j}\right] + C_{1\epsilon}\frac{\varepsilon}{k}(G_k + C_{3\epsilon}G_b) - C_{2\epsilon}\rho\frac{\varepsilon^2}{k} + S_\epsilon \tag{4}$$

Where G_k is the generation of kinetic energy turbulence due to the average velocity gradient. G_b is the generation of kinetic energy turbulence due to buoyancy. Y_m is the contribution of dilatation fluctuations in compressible turbulence to the total flow dissipation.

2.2. Turbine Model

The turbine is designed using Autodesk Inventor with three main components of the turbine, (turbine shaft, turbine blades, and turbine housing). In total there are 6 blades with the overall length of the turbine and shaft extension reaching 1.1 m. The blades are in

Vol.3 (No.2). 2021. pp. 71-76
Published online: Sept. 4, 2021
ISSN: 2477-541X

the form of a radius of 161.08 mm, the distance between the blades (pitch) is 147.04 mm and the blade thickness is 2.95 mm. The total area of the turbine inlet and outlet is 0.25753 m^2. Archimedes turbine specifications can be seen in Fig. 1.

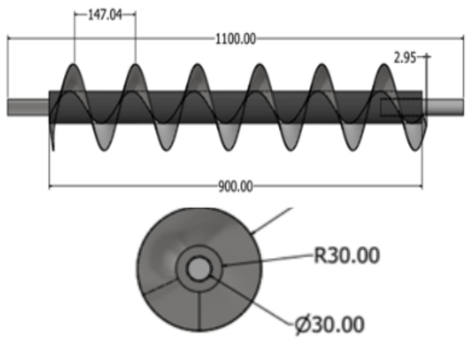

Fig. 1. Archimedes turbine dimension

2.3. Meshing

Next is to divide the turbine volume into small parts (meshing). The meshing process is carried out using Meshing AUTODYN PrepostAnsys with a curvature size function and the normal angle is 12°. Fig. 2. shows the results of the meshing performed.

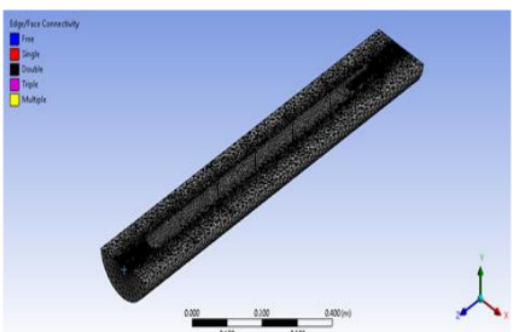

Fig. 2. Meshing on the part of turbine

2.4. Input Data Parameters

In this simulation, the initial data used are as shown in Table 1. The material of the turbine is designed using aluminum so that it is light and can be moved so that this turbine can be portable in its use. These parameters are repeated in the case of the inlet velocity representing different flow rates, namely: 39 m/s (1 l/s), 78 m/s (2 l/s), and 117 m/s (3 l/s).

Table 1. Simulation Parameter Data of The Properties Measurement

Property	Value
Water viscosity, μ	0.001003 kg/m.s
Water density, ρ	998.2 kg/m^3
The density of material (aluminum), ρ_l	2719 kg/m^3
Inlet Speed, v	39 m/s
Initial Pressure, P	9801 Pa

3. Results and Discussion

3.1. Effect of flow rate, immersion level on torque, and efficiency

Fig. 3 shows that the increase in flow rate is followed by an increase in the level of immersion and torque.

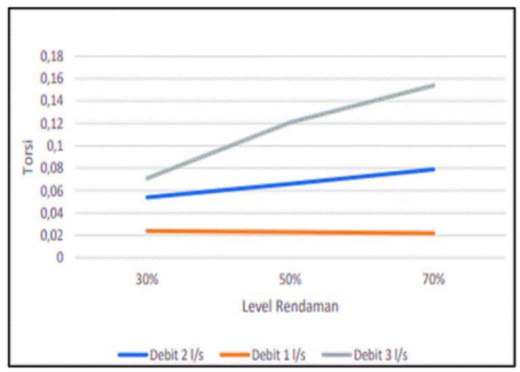

Fig. 3. Relationship between immersion level and torque.

Fig. 3 shows that the flow rate is directly proportional to the level of immersion and torque. The highest torque was obtained at a flow rate of 3 l/s with a 70% immersion level of 0.154 J. The results agree well with the previous research by Dellinger et al., 2018 [8]. They concluded that the higher water immersion will put pressure on the last blade thereby increasing torque. In addition, this study also presents the relationship between flow rate, immersion level and turbine efficiency. In this simulation it was found that the immersion level affects the turbine efficiency (Fig. 4).

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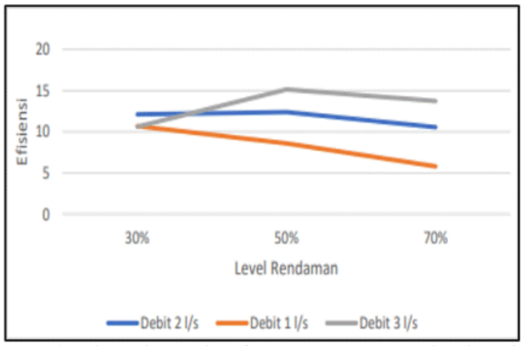

Fig. 4. The relationship between immersion level and efficiency

At the discharge of 1 l/s, the immersion level of 30% turbine efficiency is 10.7% and at the 50% immersion level the turbine efficiency is 8.7%, and at the 70% immersion level the turbine efficiency is only 5.8% %. This is because the low volume of discharge is not able to drive the turbine optimally. At the discharge of 2 l/s the immersion level of 30% turbine efficiency is 12.1% and at 50% immersion level the turbine efficiency is 12.3%. However, at the 70% immersion level the turbine efficiency is only 10.5% this is because the immersion level has passed its optimum point so that the water in the bucket flows back into the turbine and reduces the efficiency of the turbine. This results trend goes along with Dellinger et al. i.e due to water immersion, there is a back pressure on the blades that are submerged in water and the turbine will reach a point optimal when the water immersion corresponds to the water level in the last bucket (bottom). In this study the efficiency increased as the value of I (Immersion) 64% . The water will decide to link to the bucket when the water bath is increased above that level. This phenomenon causes the turbine to slow down and operate inadequately. [8]. The same phenomena occurred in the simulation with a flow rate of 3 l/s where at the 30% immersion level the turbine efficiency was 10.6% and increased to 15.1% at the 50% immersion level but decreased to 13.7% at the 70% immersion level.

3.2. Effect of flow rate on contour visualization (Turbulence Kinetic Energy)

Turbulence Kinetic Energy is the average of the kinetic energy per unit mass associated with changes in velocity in the X, Y, X direction in turbulent flow [16,17]. Fig 5(a), (b), and (c) show turbulence kinetic energy with variations in flow rate.

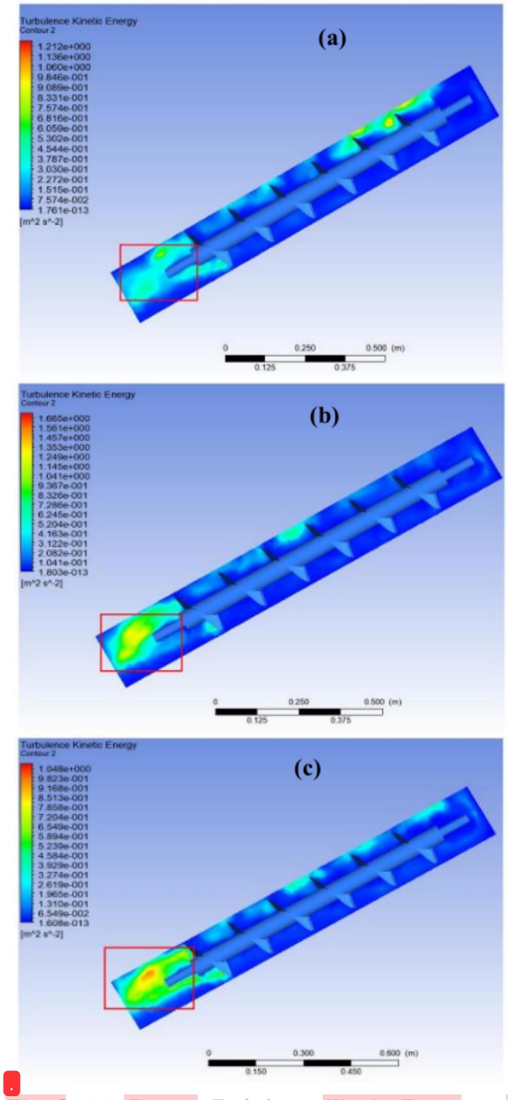

Fig. 5. (a) Contour Turbulence Kinetic Energy at a discharge of 1 l/s (b) 2 l/s and (c) 3 l/s

Fig. 5 (a), (b), and (c) respectively show Contour Turbulence Kinetic Energy at 1 l/s, 2 l/s, and 3 l/s discharges with an immersion level of 30%, it can be shown that the turbine outlet marked with the red box, along with the increase in discharge, the value and range of Turbulence Kinetic Energy is getting bigger. This shows how much backflow occurs in the fluid flow at the outlet.

The higher level of immersion caused the lower of the Turbulence Kinetic Energy. This phenomenon might be due to the volume of fluid at the outlet that resists backflow or backflow at the outlet. The

Vol.3 (No.2). 2021. pp. 71-76
Published online: Sept. 4, 2021
ISSN: 2477-541X

visualization at the 70% immersion level is shown in Fig. 6 below.

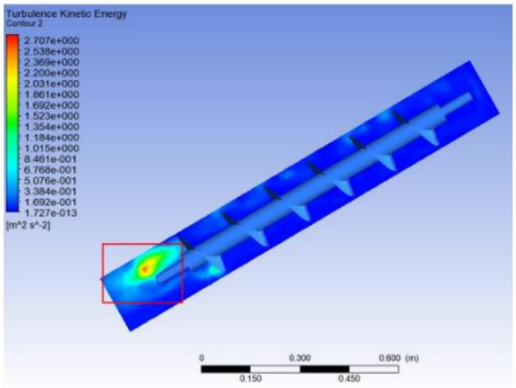

Fig 6. Contour Turbulence Kinetic Energy at 70% immersion level with maximum flow rate (3 l/s)

4. Conclusions

The influence of flow rate on the US turbine is investigated in this study. This numerical analysis was carried out using CFD simulation, and the following conclusions were drawn:

1. The flow rate has a significant impact on the process of moving the turbine; the higher the flow rate, the more power is provided to the turbine, which produces torque on the turbine.
2. The difference in volume of immersion at 30 percent, 50 percent, and 70 percent does not really affect the turbine torque at a flow rate of 1 l/s, but once it has passed the optimum point, the turbine has an effect on the turbine efficiency, which decreases quite significantly due to the large volume of the immersion load.
3. The value and range of turbulent kinetic energy are shown in Contour Turbulence Kinetic Energy. The higher the value of turbulent kinetic energy, the more excellent the flow resistance or backflow. Turbulence Kinetic Energy is inversely proportional to immersion and directly proportional to the increase in discharge.

5. Acknowledgements

The authors would like to thank those who assisted in this research. This research was finally supported by Lambung Mangkurat University, Banjarmasin, through DIPA ULM Number: SP DIPA-023.17.2.677518/2021.

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