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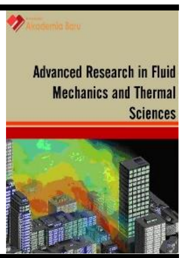

Experimental Study of The Effects of Blade Twist on the Performance of Savonius Water Turbine in Water Pipe

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ABSTRACT

The investigation of Savonius turbine for water application is still a bit left behind compared to the Savonius wind turbine. From this view, this investigation and development needs to be exhaustively carried out, give that Savonius has a promising potential for renewable energy. The major objective of this study was to investigate the effect of twist angles (α) on the horizontal axis Savonius rotor in the generation of electric power. The rotor is designed with two blades and endplates. The experiments were conducted on apparatus tests with twist angles of 0°, 12.5°, 30°, 45°, and 60°. From the experimental results and analyses, it was observed that the coefficient of performance (Cp) on twisted Savonius blades surpassed the rotor with without twists (α=0°) for discharge range from 2.95 x 10^{-3} m^3/s to 8.16 x 10^{-3} m^3/s. However, at a higher discharge 11.9 x 10^{-3} m^3/s, the coefficient of performance of the twisted blades was lower than the rotor with without twists. Therefore, it can be concluded that twisted Savonius rotors are more efficient in terms of Cp at the discharge under or equal to 8.16 x 10^{-3} m^3/s. Whereas, at a higher discharge, the performance of the twisted blades is decreased compared to those without twists. Further improvements have to be put in place to increase the efficiency of twisted horizontal axis Savonius rotor.

Keywords:
Savonius, Twist, Power electrical, Coefficient of power

1. Introduction

Renewable energy promises a solution to human dependence on fossil fuels. Water power is one of the clean energy and environmentally friendly sources for the reason that it does not produce pollution or waste. Regarding on the water power, Pico hydro is a small-scale electric power generator driven by water energy. Previous studies have reported that this power plant makes use of the head height and the amount of water discharged to generate power less than 5KW [1]. Various types of drag turbines have been widely used to convert water energy into motion which rotates generators to produce electricity [2]. Furthermore, the previous ones have been experimentally

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studied to obtain optimum designs fitted into pipelines [3]. Savonius Turbine is a type of drag turbine with simple and easy construction in its manufacture [4] [5] but is low in efficiency [6]. To date, this has been a major problem with this particular turbine [7] which led to various efforts to improve its efficiency [8] [9]. The blade shape is an essential component of the turbine, capturing the energy potential of the water. Hence, experimental methods and simulations have been conducted to determine the performance of various blade designs [10]. Accordingly, Savonius blades have been studied to obtain the optimum angle shape for capturing the water flow energy in the pipe [11]. The modification of endplate design has been applied in this research to obtain optimal performance on Savonius [12]. This modification is growing with the twisted blade capable of generating a power coefficient of 0.13 compared to Savonius blade without twist [13]. Furthermore, a research was conducted in which twist blades were modified, and resulted in the performance coefficient of 0.049. Recent developments in the field of Savonius turbine have led to a renewed interest in twisted blades, which are twisted at specific angles. Test results performed on these blades with twist angle α=0° to 25° indicated better performance than conventional or non- twist Savonius rotors (α=0°) such as higher efficiency parameters, better starting characteristics, and a more excellent spin [14]. However, these rapid changes are bringing about some modifications to the Savonius blade, one of the most significant current discussions in twisted blade as it has become very interesting to study, given that it has been considered to be one of the key factors to increasing the coefficient of performance of the turbine. This study aims to investigate the coefficient of performance results between twisted Savonius blades and rotors without twists on apparatus tests using twist angles 0^0, 12.5^0, 30^0, 45^0, and 60^0 for a discharge range between 2.95 x 10^{-3} m^3/s and 8.16 x 10^{-3} m^3/s. This study tests the Savonius Horizontal Axis Water Turbine (HAWT) with the semi-circular blade angle variability of the water flow in the pipe. The test was performed by observing the effect of twist angle on the electric power generated. From the data, the most optimal torque to generate electrical power can be obtained.

2. Methodology

The design (Figure 1) uses a conventional/semi-circular blade, and is then given a twist as much as the angle based on the research literature [14]. Also, the blades had the following specifications as the aspect ratio H/D = 1; end plate Do/D = 1.1; turbine diameter (D) = 82mm and plate thickness 2mm [15]. The specimen to be tested is the Savonius turbine with twist angles of 0°, 12.5°, 30°, 45° and 60°, each using a water point angle of 30° [9]. The turbine material is Acrylonitrile butadiene styrene (ABS), and was manufactured using the 3D printing method which is one of the fastest prototyping techniques, but requires a special design of software. The results can be seen in Figure 2. After the preparations are complete, the turbines are tested one after the other in an apparatus test. Each of them were tested with 4 discharge variations, namely 2.9 x 10^{-3} m^3/s, 5.7 x 10^{-3} m^3/s, 8.1 x 10^{-3} m^3/s and 11.9 x 10^{-3} m^3/s. Based on the discharge variation and the pipe diameter, there is a different head on each discharge variation. The resulting heads respectively from the lowest discharge are 1.4m, 1.5m, 1.7m, and 2.0m. This research is conducted by pumping water upwards and then dropped freely for it to have only the potential of gravity force from a maximum height of 2 meters. The generator connected to the multimeter shows the data of electrical power which is the multiplication of electric current and the voltage shown on the multimeter. The turbine rotation data are measured using a tachometer. Then it is processed and interpreted in graphical form in the discussion.

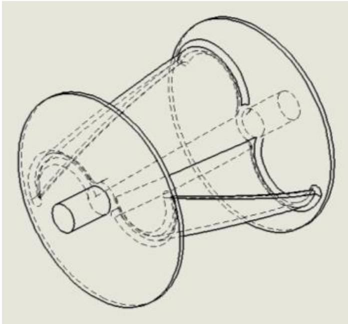

Fig. 1. Turbine design

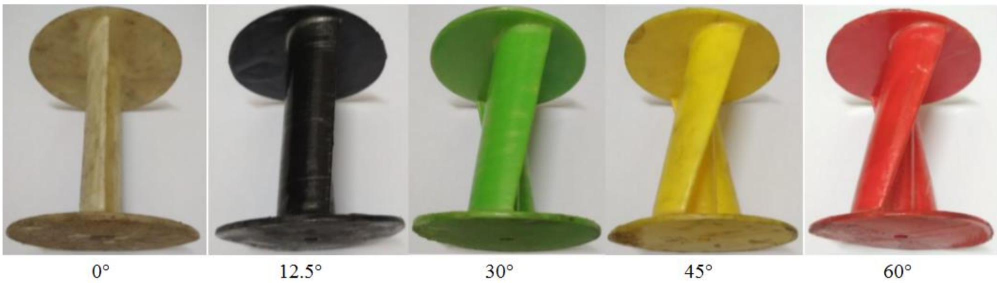

Fig. 2. 3D printing turbine

3. Results

Figure 3 shows a graphical demonstration of fluid power values that have increased in line with the fluid discharge. These values were obtained from the multiplication of gravity, density of water, discharge, and head. The graph shows that this result is in agreement with the fluid power theory where the higher the discharge value (Q) and the head (h), the higher the fluid power value. The resulting fluid power values in this study are 40.24, 84.31, 135.60, and 232.65 Watts. The results of this potential power value are then used as a basis to determine the power coefficient value of the Savonius turbine.

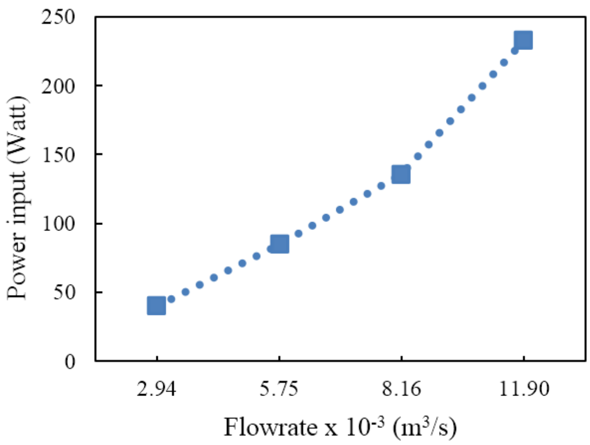

Fig. 3. Graph relation between discharge with power input

Electrical power analysis can describe the performance of the turbine [4]. Figure 4 shows the electrical power per minute.

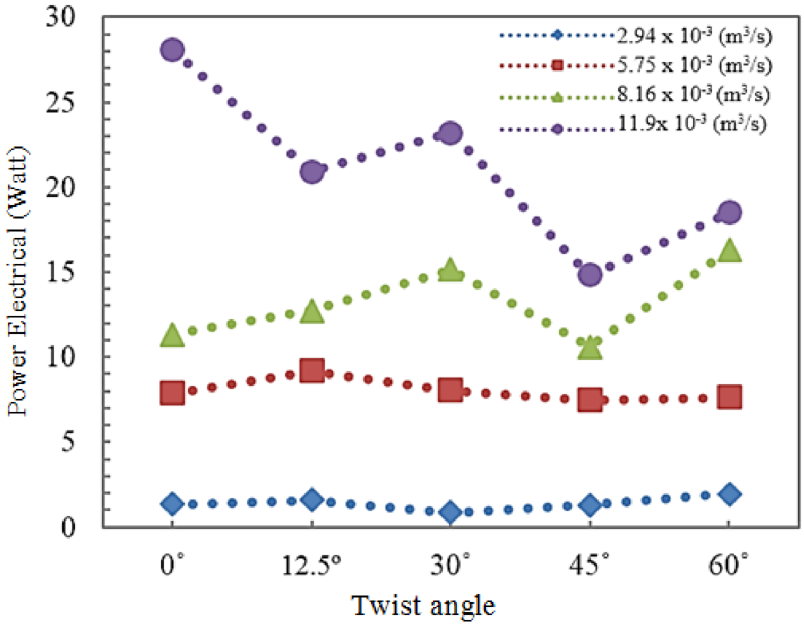

Fig. 4. Graphical relation between twist with power electrical

At a discharge of 2.94 x 10^{-3} m^3/s, the twist angle of 60° reaches its highest electrical power of 1.94 Watts with an almost linear trendline and a small difference in value. The twist angle of 12.5° reaches its highest electrical power at the discharge of 5.75 x 10^{-3} m^3/s of 9.20 Watts. From the graph, it appears that at the discharge of 5.75 x 10^{-3} m^3/s, the electrical power decreases after the twisting angle of 12.5°. Then at the discharge of 8.16 x 10^{-3} m^3/s the highest electrical power value was generated by the twisting angle of 60° with a value at 16.27 Watts. Moreover, at the discharge of 11.9 x 10^{-3} m^3/s, the highest power of 28.05 Watts was obtained by the blade of 0 degrees. The 0° blade (without twisting) precisely reaches the highest power due to its characteristic, which can accommodate more water flow than the twisted blades. In view of this fact, it has a more significant pressure on the positive torque blade than the twisted. However, graphic illustration of the results shows that the value of electric power obtained from the test is quite volatile. In general, it can be concluded that the blades with twist produce more optimal electrical power than the without twist blades, especially at the discharge of 8.16 x 10^{-3} m^3/s. This can be attributed to the surface profile of the sloped blade which has a broader and evenly spaced water field on each blade, resulting in a more substantial starting torque on each blade invariably. It is strengthened by a research which states that the starting torque on each blade can improve the performance of the Savonius turbine [14].

Tip speed ratio is the ratio of the blade tip speed to the speed of the flowing fluid entering the turbine, while the power coefficient (Cp) is the ratio of turbine power to fluid power. This therefore implies that Cp shows the magnitude of power efficiency that can be extracted by the turbine from the fluid power [2]. Based on the relation between TSR and Cp, the performance of the tested Savonius turbines can be analyzed to know which has the most optimum performance. The TSR value is influenced by the discharge of the incoming water flow and the speed of the turbine rotor. TSR calculation results with Cp for each twist variation interpreted the following graph in Figure 5.

The 12.5° blade achieved its highest Cp value of 0.163 at a discharge of 11.9 x 10^{-3} m^3/s with TSR 0.66. Furthermore, the 30° blade achieved its highest Cp value of 0.180 at a discharge of 11.9 x 10^{-3}

m^3/s with TSR 0.69. Based on the graph, its TSR and Cp values are inversely proportional, given the fact that the Cp value increased along with a decrease in TSR value. According to the data report, at discharge 2.94 x 10^{-3} m^3/s, the value of TSR and Cp were 1.34 and 0.029. The blade with a twisted angle of 45° achieved its highest Cp value of 0.124 at a discharge of 5.75 x10^{-3} m^3/s and a TSR value of 0.88. The 60° blade twist angle achieved its highest Cp value of 0.188 at a discharge of 8.16 x 10^{-3} m^3/s, and a TSR of 0.89. By reviewing the discharge variation (Q) in the graphic Figure 5 it can be observed that the TSR value continued to decrease with an increase in discharge (Q) value. This is because the rise in discharge value (Q) results in a higher value of water flow rate (U). Meanwhile, TSR is the ratio of the angular velocity of the turbine blade to water flow rate (U). And consequently, an increase in the water flow rate (U) results in a lower TSR value.

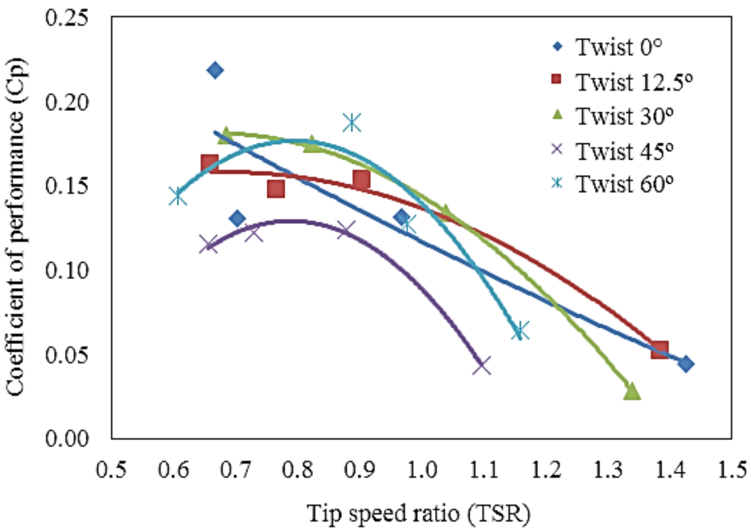

Fig. 5. Graph relation between TSR with Coefficient of power

4. Conclusions

Based on the research conducted, some conclusion points are produced as follows.

i. The twisted blade has a better performance than an without twist blade (twist angle α = 0°). It is evident that between discharges 2.94 x 10^{-3} m^3/s and 8.16 x 10^{-3} m^3/s, the highest Cp value of 0.188 was achieved by the twist angle of 60° at discharge 8.16 x 10^{-3} m^3/s.
ii. The blade performance of Savonius twisted blade of 0^0 had the highest Cp value of 0.218 at discharge 11.9 x 10^{-3} m^3/s. This implies that the twisted blade is optimal at low discharge, which is below 11.9 x 10^{-3} m^3/s.

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