The Effect of Deflector Angle in Savonius Water Turbine with Horizontal Axis on the Power Output of Water Flow in Pipe

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Abstract. Savonius turbine is one type of turbines with simple design and low manufacture. However, this turbine has a relatively low efficiency. This condition can be solved by installing fluid deflectors in the system’s circuit. The deflector is used to direct the focus of the water flow, thus increasing the torque working moment. In this study, a single stage horizontal axis Savonius water turbine was installed on a 3 inch diameter pipeline. This experiment aims to obtain optimal deflector angle design on each water discharge level. The deflector performance is analyzed through power output, TSR, and power coefficient generated by the turbine. The deflector angles tested are without deflector, 20º, 30º, 40º, and 50º with a deflector ratio of 50%. The experimental results at 10.67x10⁻³m³/s discharge show that turbine equipped with 30º deflector has the most optimal performance of 18.04 Watt power output, TSR of 1.12 and power coefficient 0.127. While with the same discharge, turbine without deflector produces only 9.77 Watt power output, TSR of 0.93, and power coefficient of 0.09. Thus, it can be concluded that the deflector increases power output equal to 85%.

1. Introduction
Buildings drainage water has the potential for a picohydro scale power plant. However, its relatively small head and discharge conditions require a particular turbine design. The Savonius turbine is one of the drag type wind turbines which has a simple and inexpensive design to manufacture [1]. Based on this, Savonius turbine design is a solution to the problem. The water momentum which is greater than air is also a reason for the application of the Savonius turbine for water [2]. Drag turbines such as the Single Stage Savonius which is applied to water flow in a vertical pipe have produced the biggest power output [3]. Various methods have been undertaken to increase the output power provided by the Savonius turbine [4]. One method used to increase the turbine’s power output is adjusting the fluid velocity to increase torque [5]. The fluid flowing within the pipe is directed by a steering mechanism to increase the turbine’s efficiency [6].

The fluid flow direction arrangement has the principle to reduce the negative torque on the turbine convex surface and increase the positive torque on the turbine concave surface [7]. In this condition, the fluid flow will completely blade the concave blades, and the flow rate that will blade the convex blades of the turbine blade is inhibited by the steering. The angled design of the steering position is one of the important methods for obtaining fluid flow profile which will increase the torque. A simulated study has also been performed to obtain a profile image of the fluid direction that will blade the turbine blades so
that the shape and direction of the fluid flow can be identified [8]. Furthermore, to obtain accurate data, simulated research and experiments on the design of deflector forms have been carried out over several generations [9]. In the last generation, 88.2 Watt power output result has been obtained, but this method resulted in a pressure drop of ±5m.

2. Research Method
The designs of the Savonius turbine have been studied in previous references to produce the best efficiency. Turbine design uses 5 blades. Moreover, the curve angle of the turbine blades applies an angle of 70º [10], as in the following Figure 1.

![Figure 1. Turbine Design.](image)

The Savonius turbine was manufactured by a 3D printing process in order to obtain the appropriate size of the designed model, see Figure 1. Turbine and deflector are installed by adjusting to the direction of turbine rotation so that it can give positive torque effect on the direction of turbine rotation. Data retrievals are rpm, electrical current, and electrical voltage. The rpm data is obtained from the tachometer reading, while the electrical current data and electrical voltage are obtained from the multimeter readings [11]. Figures 2 show the specimen of deflector variation for data retrieval.

![Figures 2. Deflector angle of (a) 20º, (b) 30º, (c) 40º, and (d) 50º.](image)

The study used test apparatus arranged with the working principle of moving the fluid from the bottom reservoir which is then pumped upward. The fluid flow from the upper tub is a simulation of rainwater and wastewater from a multi-story building. Water from the upper tub will flow to turn the turbine to produce electricity. The water will rotate the turbine that is connected directly to the generator. The amount of discharge is set by using the valve to get the correct data.

3. Results and Discussion
In this section will discuss and analyze the performance of each deflector of any variation of discharge. The data of turbine without deflector are used as references to compare the efficiency generated on each deflector. This study tested the angle of deflector 20º, 30º, 40º, and 50º. Then, each deflector is tested with four large variations of discharge. Each deflector will produce different input discharge. The amount of discharge produced by each deflector is shown in Figure 3 below.
Figure 3 shows a trend which illustrates that the discharge decreases as the deflector angle increases. This is due to the difference in the shape of the reflector resulting in a change in the direction of fluid flow. The turbine without deflector (0°) produces the greatest discharge which then decreases as the deflector angle reach 50°. This will affect the input power which will be generated at each variation of the deflector angle. The input power is the magnitude of the potential power of the fluid to generate electricity. Figure 4 shows the input power graph on each deflector.

Figure 4 shows the amount of input power generated by each deflector. On each variation of the discharge, the 20° deflector always produces the highest input power. This is due to the slope plane of each deflector variation causes different fluid drag forces. In this condition, water experiences resistance due to the deflector. On the other hand, with the deflector, the water can be set to blade the concave turbine blades and block the water that will blade the convex turbine blades. This will increase the working torque on the turbine.

The deflector performance is analyzed based on the generated electrical power. The electric power observed is the multiplication of electrical current and electrical voltage. Figure 5 below shows the electrical power generated by the deflector on each variation of the discharge.
Figure 5. Graph of the relation between deflector angle and electrical power.

Figure 5 shows the trend of electrical power generated by the discharge variation for each deflector angle. Turbines without deflectors always produce the lowest power on any variation of discharge. This is caused by the fluid flow bladeing the concave and convex surface of the turbine blades, resulting in unbalanced turbine rotation. These conditions will affect the generated electrical power. At $3.05 \times 10^3 \text{m}^3/\text{s}$ and $6.10 \times 10^3 \text{m}^3/\text{s}$ discharge, the largest electric power is generated at 20° deflector angle with 1.18 Watt value and 4.13 Watt value. Then the electric power decreases as the deflector angle increases up to 50° of angle. This is due to the flow of water at the discharge which does not fill the pipe space so that it can be directed with a 20° deflector. While at $9.05 \times 10^3 \text{m}^3/\text{s}$ and $12.20 \times 10^3 \text{m}^3/\text{s}$ discharge, the largest power is generated by 30° deflector angle with a value of 12.65 Watts and a value of 18.04 Watts. This is because the 30° deflector can direct the water flow right at the turbine blades which produce the highest torque.

Power coefficient illustrates the actual power that the turbine can extract from the working fluid. While Tip Speed Ratio (TSR) is the value of comparison between blade’s tip velocity and fluid velocity which is one of the important parameters to identify turbine performance.

Figure 6. Graph of the relation between TSR and Cp.

Figure 6 shows the relationship between power coefficient and tip speed ratio in which the power coefficient increases as the increase of the tip speed ratio. The 20° deflector angle has the best performance on the $2.2 \times 10^3 \text{m}^3/\text{s}$ and $5.1 \times 10^3 \text{m}^3/\text{s}$ discharge, while the 30° deflector angle has the best performance on $8.5 \times 10^3 \text{m}^3/\text{s}$ and $10.8 \times 10^3 \text{m}^3/\text{s}$ discharge. Savonius turbine with deflector has significant power increase when compared to turbine without the deflector. This proves that, with the
deflector installation, the turbine performance increases [7]. This turbine will produce greater electrical power output than turbine without the equipped deflector.

4. Conclusion
We have investigated the effect of deflector Angle in Savonius Water Turbine with Horizontal Axis on the power output. Based on the experiment, the deflector installation decreases discharge until of 5.8%. Furthermore, the deflector angle produces different power at the various discharge. Turbine without deflector produces power output of 9.77 Watt only, but using installed deflector of 30° the power output increases up to 84.6% of 18.04 Watt with 10.75 x10^{-3} m^{3}/s discharge and 2 meter head as the best performance of the turbine.

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