Experimental Investigation of Three Bladed Inclined Savonius Hydrokinetic Turbine by using Deflector Plate

B Jeeva1*, S Jai Sandeep2, N Ramsundram3, M Prasanth4 and B Praveen5

1* Assistant Professor, Department of Mechanical Engineering, Kumaraguru College of Technology, Coimbatore, India. Email ID: jeevmech@gmail.com
2 PG Scholar, Department of Mechanical Engineering, Kumaraguru College of Technology, India. Email ID: jaisandeep03@gmail.com
3 Associate Professor, Department of Civil Engineering, Kumaraguru College of Technology, Coimbatore, India. Email ID: ramsundram.civil@kct.ac.in
4 UG Student, Department of Mechanical Engineering, Kumaraguru College of Technology, Coimbatore, India. Email ID: prasanth.18me@kct.ac.in
5 UG Student, Department of Mechanical Engineering, Kumaraguru College of Technology, Coimbatore, India. Email ID: praveen.18me@kct.ac.in

Abstract This paper discusses the development of experimental test rig for an inclined Savonius hydrokinetic turbine with improvement in coefficient of power by using deflector plates. The hydrokinetic turbine was designed for different water flow velocities ranging from 1.37 m/s to 2.28 m/s in an open channel with an area of 0.0891 m². The hydrokinetic turbine with tip speed ratio (λ) = 0.8, aspect ratio (AR) = 0.72 was designed with 222 rpm as the maximum speed. To capture maximum energy from the water, the deflector plate was used to increase the velocity at the advancing side of the blade. The experiment was conducted with a deflector plate and without deflector plate conditions. The extreme coefficient of power obtained was 0.24 for a returning blade angle of 60° with deflector as compared to returning blade angle of 21° and 107°. The coefficient of power without deflector and an inclined shaft was obtained as 0.11. The experiment was performed with deflector plates with various configurations, and the torque was measured for different flow velocities.

Keywords: hydrokinetic turbine, coefficient of power, tip speed ratio.

1. Introduction
The hydrokinetic turbine extracts power from the moving energy of water without a potential head. However, a hydropower turbine requires the head of water to produce electrical energy. In a hydrokinetic turbine, the flow stream of water is from upstream to downstream. Generally, the hydrokinetic turbine is not expensive and requires minimum maintenance (Kailash et al., 2011), and the Savonius turbine construction is straightforward (Wnehenubun et al., 2015).

A vertical axis Savonius turbine is operable at a shallow head and with remarkable self-begin potential (Sarma et al., 2014). The major driving force for the operation of Savonius turbines is the drag force (Kailash, et al., 2012). The hydrokinetic turbines are characterised as horizontal axis turbine or axial turbines and a vertical axis turbine or cross-flow turbines (Kailash et al., 2011). Generally used vertical axis turbines are the Savonius turbine and Darrieus turbine. Kamoji et al., (2009) investigated experimentally on the modified Savonius turbine and deduced an extreme coefficient of power as 0.32.
The three-bladed Savonius turbine resulted in the most exceptional performance at the higher tip speed ratios (Wnehenuhun et al., 2015). Various efficiency techniques to measure the performance of hydrokinetic turbines of different researchers had been reviewed by Verma and Saini, (2015). Sahim et al., (2014) investigated the consequence of deflector position on Darrieus turbine and Darrieus-Savonius turbine blade using NACA 0015 in a water canal. Wahyudi et al., (2013) studied three types of tandem blade Savonius rotor namely, overlap, symmetrical and convergence. The CFD simulation predicted that the Savonius convergence type rotor had better performance than symmetrical and overlaps design rotors. Wahyudi et al., (2015) developed a crossflow vertical axis turbine with Savonius type rotor, moving deflector blade and Savonius diffuser blade and concluded that use of deflector results in a positive moment compared to without deflector condition. Wahyudi and Adiwidodo, (2017) have performed the CFD simulations for a tandem blade with radial and tangential moving deflector for a Savonius configuration and validated with the experiments. The investigation revealed that the tandem blade with a tangential moving deflector had higher efficiency than the tandem blade with a radial moving deflector for a Savonius configuration.

Although, many experimental works were performed to increase the coefficient of power of a vertical Savonius hydrokinetic turbine. Variation of various deflector positions and inclination of the turbine shaft was not studied. In the present work, experimentation was performed for three-bladed curved type blades profile with various deflector angles to increase the velocity of the water. A comparative study of the coefficient of power of an inclined hydrokinetic turbine with and without deflector is investigated.

2. Experimentation Methodology

The experiment was performed in the open channel. figure 1 shows the representation of the experimental setup with the hydrokinetic turbine, which is positioned in the open channel with a cross-sectional area of 330 mm × 240 mm. The water in the open channel is provided from a water tank with a 1m head. The height of the turbine is 160 mm, the diameter of the blade is 110 mm, the diameter of the turbine is 240 mm, and the thickness of the blade is 1.5 mm. The swept area of the blade is 0.0384 m². Fig. 1 also shows the representation of the experiment set up with the torque measurement by the spring balance method, figure. 2 shows the representation of the inclined turbine arrangement with a 15º inclination to the vertical shaft and 1.7 m from the tank discharge. Due to the inclination of the turbine blade, the drag force has increased. Thus, the higher the drag force, the more power is generated. The velocity of water was measured using the Pitot tube.
When the water strikes the blades, the turbine blade rotates with speed. The weights were added in the spring balance set up from 100, 200, 300, 400 and 500 grams respectively to the setup to measure the torque for various conditions. A nylon thread of 1 mm was used for loading the weights.

The deflector plate was used to maximize power extraction. Due to the deflector plate, the water flow speed has increased. There are two deflector plates which are placed in the open channel, namely returning blade, and advancing blade. Advancing blade (α) angles are 35° and 15° and returning blade (β) angles are 107°, 60°, and 21°. Fig. 3 indicates the representation diagram of the deflector plates in the open channel. Advancing blade angle of 35° was useful during the experiment; hence, α = 35° was set for the rest of the experiment. Fig. 4, Fig. 5 shows the arrangements of the deflector plate at 107° and 60° respectively. Fig. 6, Fig. 7 shows the arrangement of the deflector plate at β = 20°, α = 35° and β = 20°, α = 15° respectively used in the experiment. Fig. 8 shows the pictorial view of the hydrokinetic turbine system.

**Figure 1.** Representation of the experimental setup.

**Figure 2.** Representation of the turbine inclined at 15° angle.

**Figure 3.** Representation of the hydrokinetic turbine with space position parameter for deflector plate.
The specification of the deflector plate configurations is itemized in Table 1. The optimum parameter for the deflector plate in the experimental study was $X_1/R = 1.254$, $Y_1/R = 0.545$, $X_2/R = 2.618$ and $\beta = 60^\circ$ by fixing $Y_2 = 164$ and $Y_2/R = 1.490$ fixed. For $\beta = 60^\circ$, a high-water velocity of 2.28 m/s was observed at the upstream of the turbine.
2.1 Experimentation Parameters

The performance of the Savonius hydrokinetic turbine can be validated in the method of a coefficient of power ($C_p$) and the coefficient of torque ($C_T$) with a comparison with tip speed ratio TSR ($\lambda$). The TSR is related to speed of the turbine and diameter of the rotor. The ratio between speed of the blade tip and water velocity through the blade is called the TSR. TSR ($\lambda$) can be written as,

$$TSR = \lambda = \frac{v_{blade}}{v} = \frac{\omega R}{v} \tag{1}$$

Where $\omega$ is the speed of the rotating turbine in rad/s, $R$ is the radius of turbine blade in m and $v$ is the water flow velocity in m/s.

In the experimentation, the spring balance method was used to determine the actual torque and estimated as,

$$T = \frac{(S-L) (r_{shaft}+r_{rope}) g}{1000} \text{Nm} \tag{2}$$

Where, $S$ is the weight balance reading in grams, $L$ is the slotted weight in grams, $r_{shaft}$ is the radius of the shaft in m, $r_{rope}$ is the radius of the rope in m and $g$ is the acceleration due to gravity.

The coefficient of torque ($C_T$) is the relation between the torque generated by turbine ($T$) and the theoretical torque ($T_w$) from water velocity as,

$$C_T = \frac{T}{T_w} = \frac{4T}{\rho A_d V^2} \tag{3}$$

Where, $\rho$ is the density of water 1000 kg/m$^3$, $T$ is the actual torque developed by the rotor in N-m and $A_d$ is the swept area in m$^2$.

The coefficient of power $C_p$ is the relation between the high power captured from the water flow stream ($P_m$) and the theoretical power available in water velocity ($P_t$) as,

$$C_p = \frac{P_m}{P_t} = \frac{P_m}{\frac{1}{2} \rho A_d V^3} \tag{4}$$

Where the maximum power captured from the water flow is determined as,

$$P_m = T \text{e} \text{oin} (Watt) \tag{5}$$

2.2 Error analysis

The uncertainty of the instruments ($\psi_o$) is determined as,

$$\psi_o = \left[ (\psi_{pt})^2 + (\psi_{tm})^2 \right]^{\frac{1}{2}} \tag{6}$$

Where $\psi_{pt}$ is the percentage error of the Pitot tube and $\psi_{tm}$ is the percentage error of the digital tachometer. The uncertainty of the instruments is decided from the manufacturer catalog and by repeating the experiments. The uncertainty of the instruments used in experimentation is ±1.885%.
3. Results and Discussion

The experimentation was performed with various velocity conditions by varying the deflector angles. Fig. 9 shows the speed vs. load for different returning blade angles as compared to without deflector plate. It was observed that as the load increased the speed reduced.

![Speed vs. Load](image1)

**Figure 9.** Speed vs. Load for different deflector positions.

Figure 10 shows the hydrokinetic turbine’s torque vs. load for different deflector positions as compared to without deflector plates. The torque increased when there was an increase in the load. Further, the torque reduced from the maximum torque value due to the reduction in the speed of the turbine at higher loads. This trend was observed for all conditions except for the deflector plate angle of 60°. The maximum torque could not be determined for a deflector plate of 60° due to limitations in the experiments.

![Torque vs. Load](image2)

**Figure 10.** Torque vs. Load for different deflector conditions.

Figure 11 shows the comparison of the coefficient of power vs. tip speed ratio for different deflector plate conditions. The highest coefficient of power obtained in the experimentation was 0.24 for the deflector plate with $\beta = 60^\circ$ and a tip speed ratio of 0.80. The $C_p$ value had a substantial increase for the returning blade angle of $\beta=60^\circ$ as compared to without deflector plate condition.
Figure 11 shows the coefficient of power vs. tip speed ratio for various deflector plate conditions. The coefficient of power for $\beta=107^\circ$ was highest for the tip speed ratio of 0.4 and 0.5 respectively as compared to the coefficient of power for $\beta=60^\circ$.

Although the coefficient of torque values is higher for the least values of tip speed ratio. For the returning blade angle of $\beta=60^\circ$, the coefficient of power was the highest. The velocity of water measured by the Pitot tube at the upstream of the hydrokinetic turbine for different configurations is listed in table 2.

**Table 2** Velocity of Water for Different Configurations.

| Sl. No. | The advancing angle of the turbine blade | Water velocity measured at the upstream of the turbine (m/s) |
|---------|----------------------------------------|----------------------------------------------------------|
| 1       | Without deflector ($\beta = 0^\circ$) | 1.37                                                     |
| 2       | $\beta = 21^\circ$                     | 1.7                                                      |
| 3       | $\beta = 60^\circ$                     | 2.28                                                     |
Comparing the previous work of Sarma et al., (2014) and Kailash et al., (2012) the $C_p$ was estimated at 0.24 for the aspect ratio of 0.72. The results of the present work with previous work are compared in Table 3.

| Table 3 Comparison Table of Present Work with Previous Work. |
|---|---|---|---|---|---|
| Authors             | Aspect ratio | Velocity in m/s | TSR | $C_t$ | $C_p$ |
| Sarma et al., (2014) | 1.21          | 0.65            | 0.643 | ---   | 0.343 |
| Kailash et al., (2012) | 0.7           | 0.45            | 1.08  | 0.32  | 0.35  |
| Present work        | 0.72          | 2.28            | 0.8   | 0.29  | 0.24  |

4. Conclusion
The following points are concluded:

- The power generated from the hydrokinetic turbine was 45.8 W with the highest coefficient of power as 0.24 for the returning blade angle of $\beta=60^\circ$.
- For the above design conditions, the hydrokinetic turbine without inclination, the coefficient of power was 0.15 for the returning blade angle of $\beta=60^\circ$.
- The inclination of the shaft improves the coefficient of power by 60%, but the only disadvantage is that the loading of forces acts on the side of the bearing of the shaft.

5. References
[1] Kamoji M A, Kedare S B and Prabhu S V 2009 Experimental investigations on single stage modified Savonius rotor. Applied Energy 86, 1064-73
[2] Kailash G, Eldho T I and Prabhu S V 2011 Influence of the deflector plate on the performance of the modified Savonius water turbine. Applied Energy 88, pp 3207-17
[3] Kailash G, Eldho T I and Prabhu S V 2012 Performance study of the modified Savonius water turbine with two deflector plates. Int. J. of Rotating Machinery 2012, pp 1-12
[4] Sarma N K, Biswas A and Misra R D 2014 Experimental and CFD analyses of two-bladed savonius water turbines under low-velocity conditions. Proc. ASME 2014 Power Conference, Baltimore, Maryland, USA
[5] Sahim K, Ihtisan K, Santoso D and Sipahutar R 2014 Experimental study of Darrieus-Savonius water turbine with deflector: Effect of deflector on the performance. Int. J. of Rotating Machinery 2014, pp 1-6
[6] Verma A K and Saini R P 2015 Efficiency measurement techniques of hydrokinetic turbines: A Review. Proc. International Conference on Hydropower for Sustainable Development, pp 268-285.
[7] Wahyudi B, Soeparman S and Wahyudi S 2013 A simulation study of low and pressure distribution patterns in and around of tandem blade rotor of the savonius (TBS) hydrokinetic turbine model. J. of Clean Energy Technologies 1(4), pp 286-291
[8] Wahyudi B, Soeparman S and Hoeijmakers H W M 2015 Optimization design of savonius diffuser blade with moving deflector for hydrokinetic crossflow turbine rotor Energy Procedia 68, pp 244-253
[9] Wahyudi B and Adiwidodo S 2017 The influence of moving deflector angle to positive torque on the hydrokinetic cross flow Savonius vertical axis turbine. Int. Energy Journal 17, pp 11-22
[10] Wenehenubun F, Saputra A and Sutanto H 2015 An experimental study on the performance of Savonius wind turbines related to the number of blades. Energy Procedia 68, pp 297-304