

Simulation study of Savonius tandem blade wind turbine using an adjustable deflector

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Abstract. The conventional Savonius wind turbine has two inverted cylindrical blades, it can indeed receive fluid impulses from all horizontal directions and produce a greater drag force than other wind turbines. The weakness of Savonius is the resistance in one blade side. Efforts to improve that has been done is to add a blade that serves to increase the local velocity of fluid flow to resist the resistance which is termed Savonius tandem blade (STB). This research was conducted to further reduce the resistance value of one side STB with the addition of an adjustable deflector. The purpose of this study is to obtain information on changes in the torque of the STB wind turbine on variations in the deflector angle and stream velocity. The research method used is numerical simulation using CFD software. A two-dimensional view of the rotor model using deflector was considered. The deflector angle varies start from 15 degrees with an increase also every 15 degrees until the torque decreased. The CFD simulation show there is a significant increase in torque with the addition of a deflector. Maximum torque is not achieved at one deflector angle value but is also influenced by stream velocity. At higher stream velocity there is a tendency to reach the maximum torque required larger deflector angle. Then at a certain point, the torque will decrease when the deflector angle is enlarged.

1. Introduction

The conventional Savonius wind turbine has two cylindrical blades in reverse pairs. This form can receive fluid impulses from all horizontal directions and produce a greater drag force than other forms of wind turbines. A conventional Savonius turbine blade has an overlap at the center of the turbine rotating point which functions as the entrance of the first blade exit flow towards the second blade. The first blade (advancing blade) get a direct boost from the main free flow while the second (returning blade) get a directional impulse opposite the outflow blade through overlap so that a pair of coupling forces can generate torque and power in the wind turbine (Fig.1).



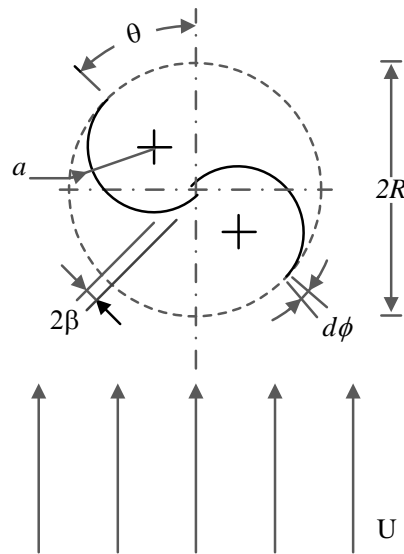


Figure 1. Conventional Savonius turbine blade with overlap [1].

There are so many studies that to reduce resistance on the returning blade side either experimentally, simulating or comparing both. Experimental research among them is done by Burcin [2], Kamoji [3], Akinari [4], Mahmoud [5] and others. Burcin experimental with the curtain arrangement was placed in front of the rotor [2]. The maximum power coefficient of the Savonius wind rotor is increased to about 38.5%. Kamoji conducted an experiment by modifying Savonius rotors [3]. The study compared geometric parameters for turbine performance. The parameters studied were overlapping ratio, blade arc angle, aspect ratio, and Reynolds number. The result is a modified Savonius rotor with an overlap ratio of 0.0, blade arc angle of 124 and an aspect ratio of 0.7 has a maximum coefficient of power of 0.21 at a Reynolds number of 150,000, which is higher than that of the conventional Savonius rotor (0.19). Akinari conducted a study on the interaction of flow fields in the installation of 2 turbines, that knowledge is useful for the installation of multiple Savonius turbines [4]. Mahmoud found that the two blades rotor is more efficient than three and four ones [5]. The rotor with end plates gives higher efficiency than those of without end plates. Double stage rotors have higher performance compared to single stage rotors. The rotors without overlap ratio (β) are better in operation than those with overlap.

Simulation-based studies have been done many researchers, including Alessandro [6], Mohamed [7], Tong [8], Dhirgham [9], Wahyudi [10,11], Sugiharto [12] and others. Alessandro conclude that a computational methodology able to calculate the flow field around the rotor was also developed [6]. RANS equations were solved in order to obtain accurate information about the flow field. Mohamed in simulation use an obstacle shielding the returning blade which results in a relative increase of the power output coefficient by almost 40% [7]. Tong explore the non-linear two-dimensional unsteady flow over a conventional Savonius-type rotor and a Bach-type rotor and develop a simulation method for predicting their aerodynamic [8]. The Bach-type rotor is demonstrated to have better performance for torque and power coefficient than the conventional Savonius-type rotor. Dhirgham investigated aerodynamic parameters and the flow pattern of the turbulent flow through a three buckets Savonius rotor model on Savonius wind turbine performance [9]. It is concluded that the sliding mesh method is suitable for the prediction of flow patterns around wind turbine. Wahyudi conducted a simulation by adding a tandem blade to the Savonius (STB) rotor without overlapping the hydrokinetics turbine [10,11]. It was reported that the addition of the tandem blade caused the jet nozzle effect on the returning blade which increased the rotor torque. Sugiharto reported multi-deflector improves the Savonius performance by increasing the Coand-like flow, dragging flow and overlap flow, and reduce of three other streams [12].

Other studies compare simulations with experiments, such as Ivan [13], Wahyudi [14]. Ivan observed the principle of operation and the continuous variation of flow angle with respect to blades, strong unsteady effects including separation and vortex shedding 3D Model [13]. the turbulence modeling by means of $k-\omega$ and DES permits to obtain good results compared to experiments. Experimental investigation in wind tunnel is carried out using PIV to validate simulations. Wahyudi conclude that the addition of a tandem blade a narrowing compartment (which can function like a nozzle) will be formed which can flow through the fluid in order to reverse direction while strengthening the pressure gap needed to push the returning blade [14]. With the increasing number of blades from two blades to four blades in addition to producing greater drag force, there is also a jet effect at the tip of the nozzle which produces a momentum force proportional to the speed of the squared fluid. The overall surface area of the blade will increase with the addition of a tandem blade, in addition to the tandem blade which makes the formation of a narrow compartment in the central rotor able to produce the main driving force (advancing force) and returning force.

Akwa has concluded that Savonius rotor performance is affected by operational conditions, geometric and airflow parameters [15]. The range of reported values for maximum averaged power coefficient includes values around 0.05–0.30 for most settings. Performance gains of up to 50% for tip speed ratio of maximum averaged power coefficient are also reported with the use of stators.

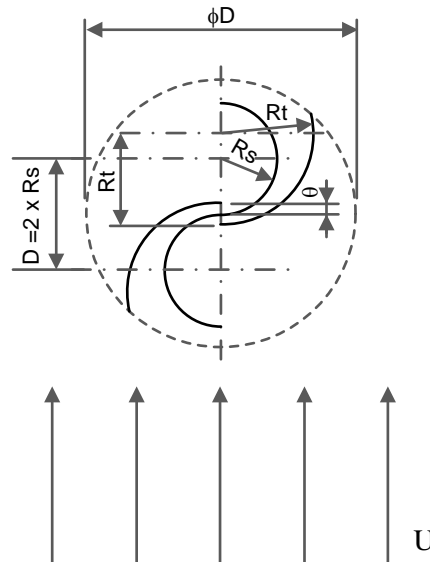


Figure 2. Modification of Savonius turbine without overlap using tandem blade [14].

From previous research, it is known that Savonius tandem without overlap has better performance [3,5]. Savonius without overlap given the tandem blade also gives a good contribution to the increase in turbine performance [10,11,14]. Other studies mention the addition of curtain [2], end plate [5], obstacle shielding [7], multi-deflector [12] to increase the efficiency of Savonius turbines. This study combines turbine rotor modification (STB) with the use of a guide vane (deflector). This research was conducted to further reduce the resistance value of one blade with the addition of an adjustable deflector. This deflector is designed to be able to move to adjust the turbine needs according to the wind speed. The purpose of this study is to obtain information on changes in the performance of Savonius tandem wind turbines on the variation of deflector angle and wind speed.

2. Methods

A two-dimensional view of the rotor model was considered. It is because the rotor blades rotate in the same plane as the approaching airflow stream. The computational domain was discretized using two-dimensional unstructured mesh (triangular mesh). The left boundary had Velocity Inlet condition while

the right boundary had Outflow condition. The top and bottom boundaries for the open channel sidewalls had symmetrical conditions. The moving wall condition was employed for the rotor model to study the effect of fluid motion in and around the rotating Savonius rotor. The dimensions of the computational domain were 5000 mm in length and 3000 mm in width, which were also similar to the experimental conditions. For the various model conditions, the geometry of the rotor was changed and accordingly different meshes were generated for each condition.

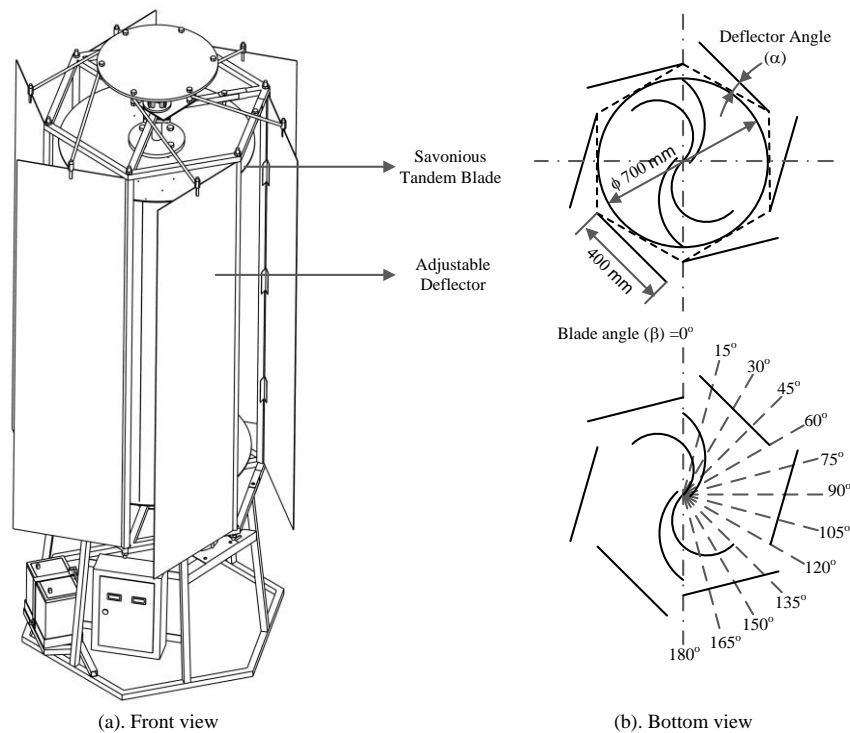


Figure 3. Position of blade angle (α) and deflector angle (β).

Steps in the simulation solutions consist of:

- | | |
|------------------------------|--|
| a. Mesh Report | : Nodes 70714, Element 65352 |
| b. Solver | : Pressure Based, Steady, 2D |
| c. Viscous Model | : Standard k-epsilon (turbulent intensity 5%, turbulent viscosity ratio 10) |
| d. Material | : Air ($\mu = 1.7894 \times 10^{-5}$ kg/m-s, $\rho = 1.225$ kg/m ³) |
| e. Boundary Conditions | |
| • Inlet | : velocity magnitude (4m/s, 5 m/s, 6 m/s, and 7 m/s) |
| • Outlet | : gauge pressure (pascal) 0 |
| • Wall | |
| - Wall motion | : stationary wall |
| - Shear condition | : no slip |
| f. Operating conditions | : Atm. Pressure (1.0132 bar) |
| g. Solution controls | |
| • Pressure-Velocity Coupling | : SIMPLE |
| • Spatial Discretization | : fluids |

The deflector angle varies start from 15 degrees with an increase also every 15 degrees until the torque decreased.

3. Results and discussion

By using simulation software ANSYS it's the following boundary conditions that have been applied. The stationary domain has a free stream velocity. The pressure conditions are applied and the initialization is done. Inlet and outlet are default boundary conditions in simulation software. Inlet requires the speed of inlet velocity of the air and the outlet requires the relative pressure, 1.0132×10^5 [Pa], at the initial conditions. The blade surfaces can be used as a wall condition. This condition enables the calculation of properties such as force on the surface. Once the domains have been specified, a default fluid-fluid interface is detected between the rotating and stationary domain.

Figure 4 show pressure contour of Savonius tandem blade without deflector at various wind speed. This is a pressure contour Savonius tandem blade without deflector. We can see that the pressure between the two sides of the blade is almost uniform, at an angle of 150 degrees at a speed of 6 m/s. There is an increase in pressure when there is an increase in speed, but the increase in pressure is received almost uniformly on both sides of the blade. When the pressure received is close to the same, the torque produced will low.

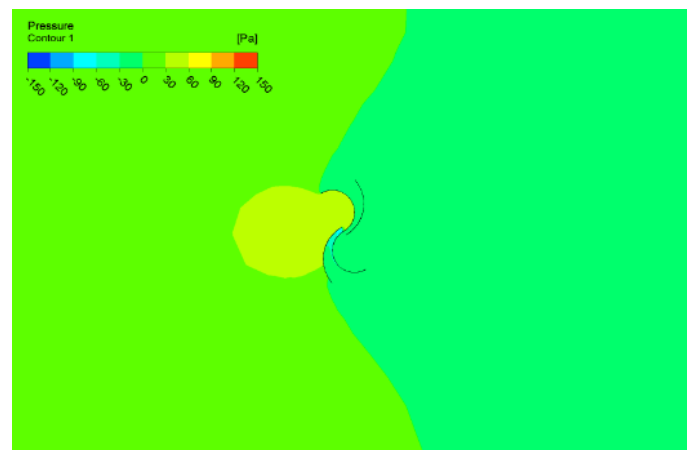


Figure 4. Pressure contour of Savonius tandem blade without deflector, $\beta = 150^\circ$, $U = 6$ m/s.

Figure 5 is pressure contour produced by the STB with the deflector. The angle of the deflector is 75 degrees with variations of the turbine blade angle 150 degrees. Stream velocity 6 m/s. The result appears that the advancing blade that is in charge of capturing the flow energy does get more pressure than the returning blade that is against the flow. Deflector performs the function of directing the flow towards the right side of the blade and blocking the flow to the other side. The deflector also creates a vacuum on the side of the blade that is against the flow, so the blade's drag is reduced. Excellent double effect for maximum torque.

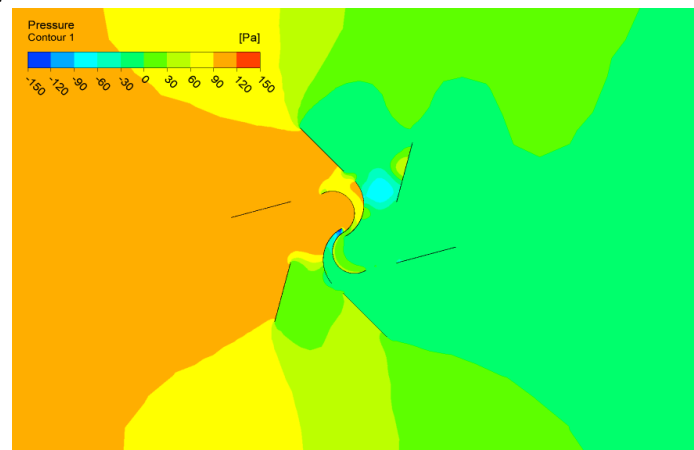


Figure 5. Pressure contour of Savonius tandem blade using $\alpha = 75^\circ$, $\beta = 150^\circ$, $U = 6$ m/s.

Figure 6 observe the velocity vector that occurs in the STB without a deflector. There is indeed an acceleration in the tandem blade compartment which narrows. The acceleration of flow on the side of the blade that opposes the flow of current also makes the static pressure go down which reduces the blade load.

Figure 7 shows an STB velocity vector with additional deflectors. There is an apparent increase in velocity in the tandem gap which increases the impulse of the blade. The interaction between the deflector and the outer tandem blade that results in a narrowed flow plane also encourages acceleration of the flow, especially seen at an angle of 120 degrees. The acceleration of the flow in the area will reduce its static pressure which will reduce the drag force of the Savonius blade.

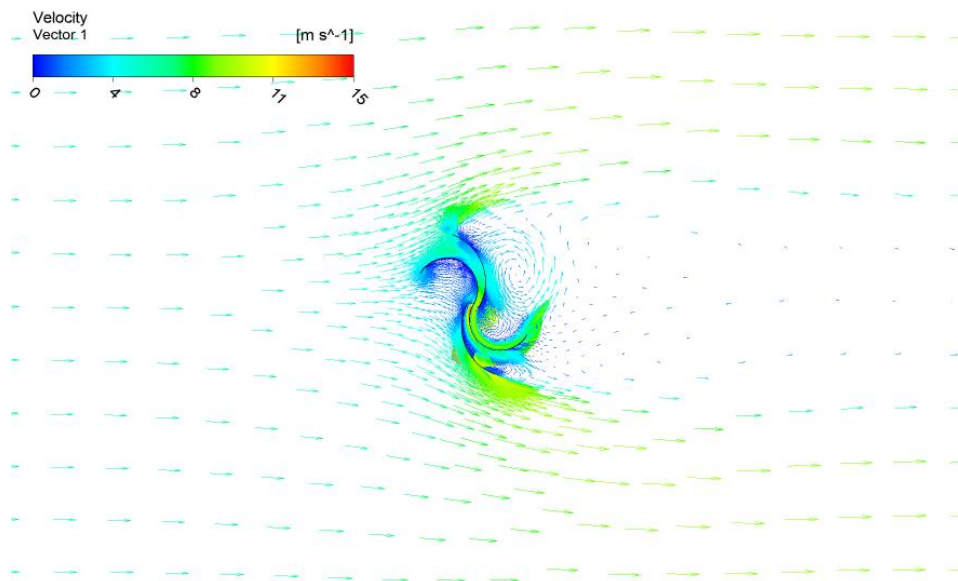


Figure 6. Velocity vektor of Savonius tandem blade without deflector, $\beta = 120^\circ$, $U = 6$ m/s.

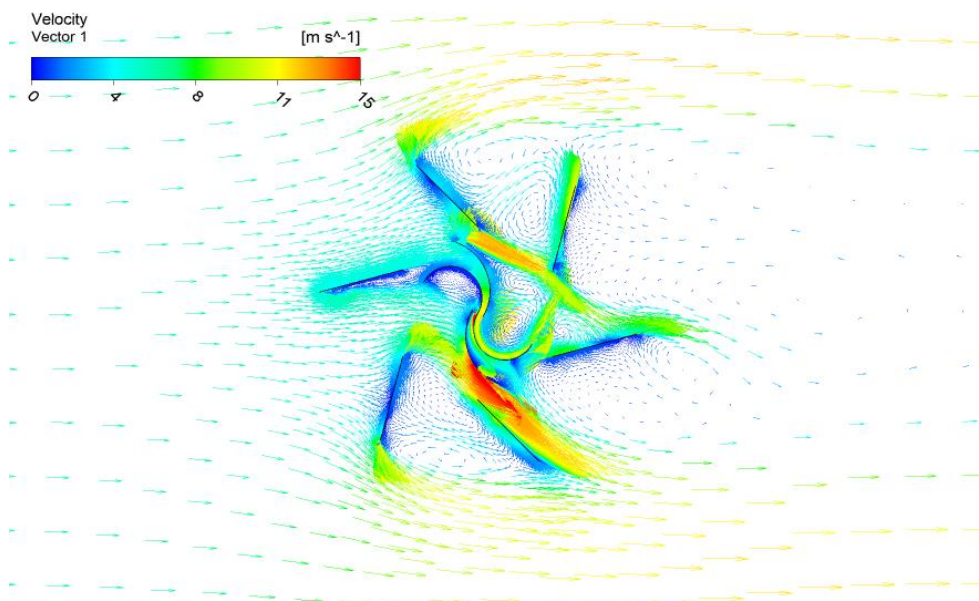


Figure 7. The velocity vector of Savonius tandem blade using $\alpha = 75^\circ$, $\beta = 120^\circ$, $U = 6$ m/s.

From the simulation, we can extract the torque data generated at each rotation angle (Figure 8). We can see that the torque produced is not always the same for every angle of rotation, at an angle of 120-150 and 300-330 degrees, produces maximum torque. At other angles the torque is smaller and there is even zero. Savonius kept spinning because of inertia. For a small deflector angle, Savonius without a deflector produces greater torque but with an increase in the deflector angle produces greater torque when compared to Savonius that does not use a deflector. Increased flow velocity also increases the maximum torque that can be achieved.

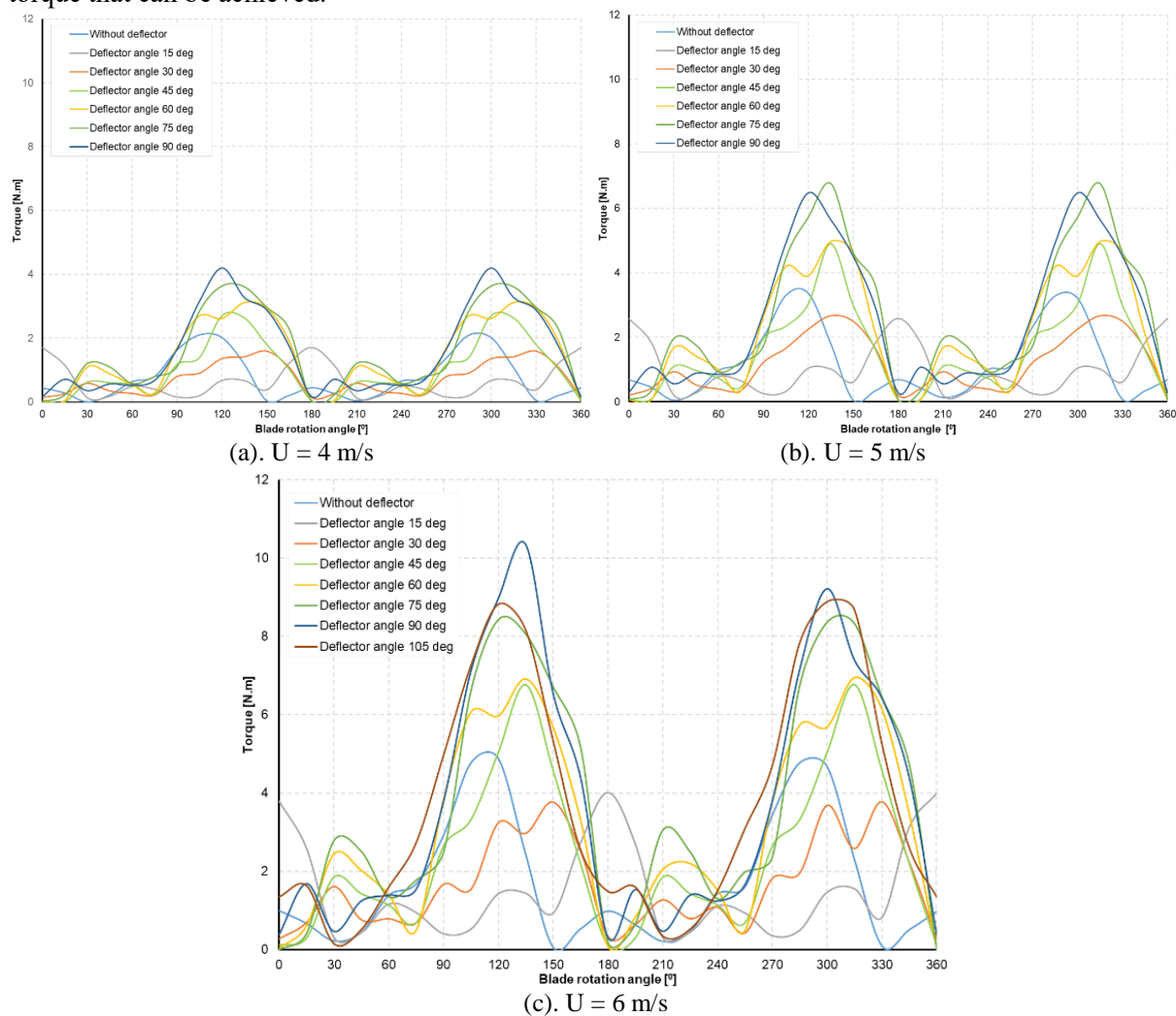


Figure 8. Torque at various stream velocity.

Figure 9 shows the comparison of torque achieved when without using a deflector compared to using a deflector at various deflector angles. The resulting pattern is the same for speed variations i.e. at an angle of 15 and 30 degrees of torque without a deflector is superior to that using a deflector. At greater angles, the STB torque with the deflector leaves the STB without the deflector. The increase in torque becomes more significant when the flow velocity increases. $U=4 \text{ m/s}$, $\alpha=75^\circ$ torque increase 111.69%, $U=5 \text{ m/s}$, $\alpha=75^\circ$ torque increase 123.53%, $U=6 \text{ m/s}$, $\alpha=90^\circ$ torque increase 116.86%.

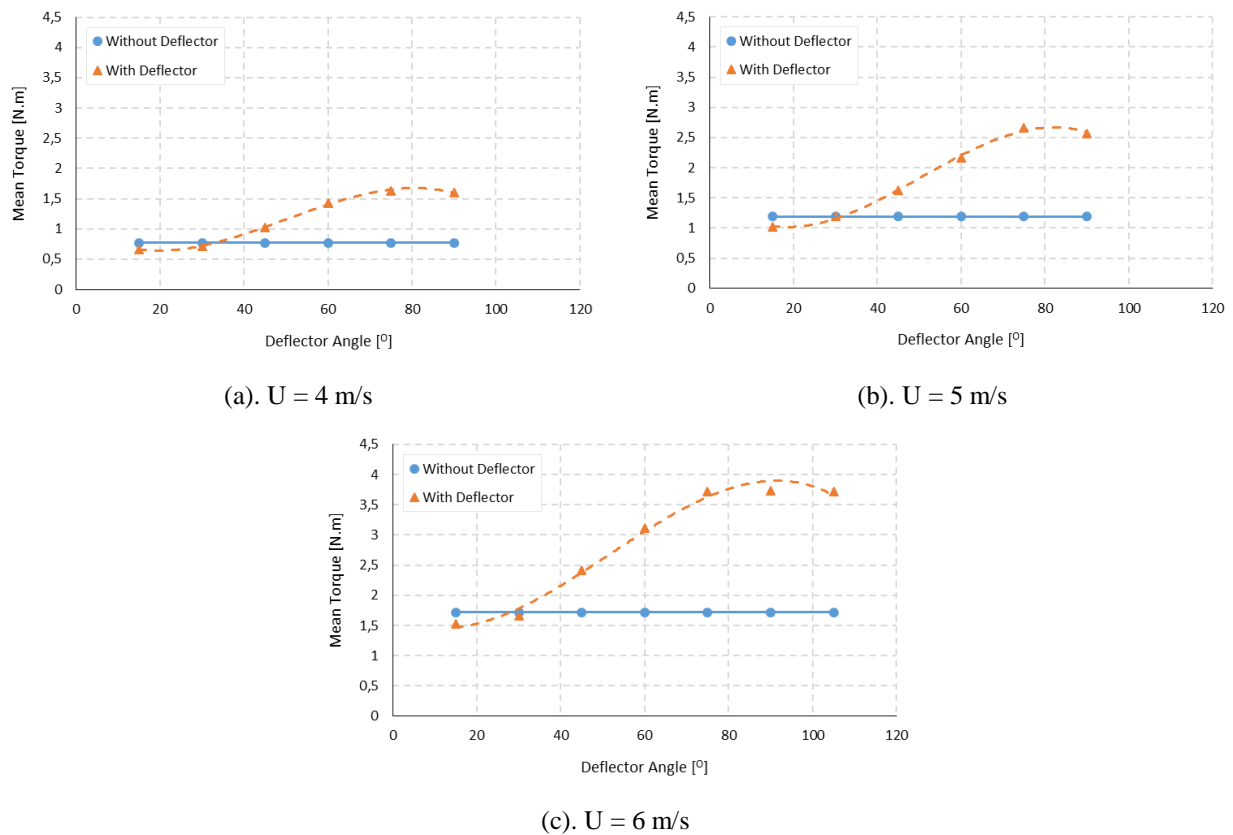


Figure 9. Average torque with deflector angle and without deflector at various stream velocity.

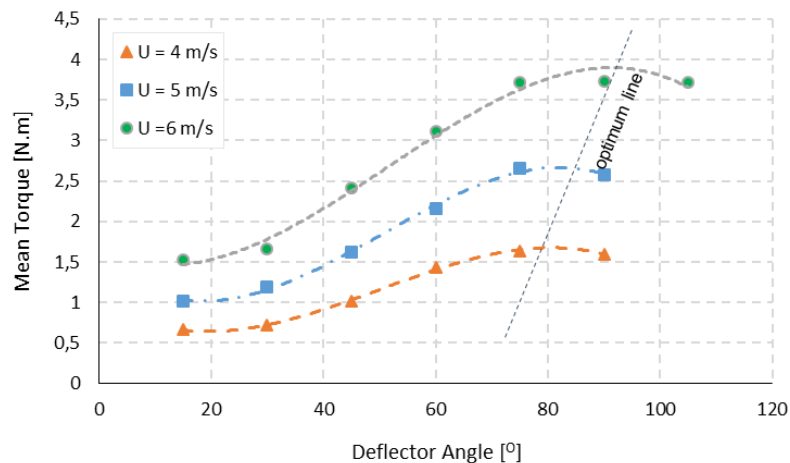


Figure 10. Average torque between deflector angle at various stream velocity.

In figure 10, we compare each STB's performance with the deflector's variation inflow velocity. The result is the flow velocity has a big effect on the maximum value of torque obtained. At higher stream velocity there is a tendency to reach the maximum torque required larger deflector angle. Then at a certain point, the torque will decrease when the deflector angle is enlarged.

4. Conclusions

By using simulation software ANSYS it can be concluded:

- The CFD simulation show there is a significant increase in torque with the addition of a deflector. Maximum torque is not achieved at one deflector angle value but is also influenced by stream velocity.
- At higher stream velocity there is a tendency to reach the maximum torque required larger deflector angle. Then at a certain point, the torque will decrease when the deflector angle is enlarged.

Acknowledgment

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