3D NUMERICAL STUDY OF SURFACE ROUGHNESS ON CONVEX SURFACE TURBINE SAVONIUS FOR AERODYNAMIC PERFORMANCE IMPROVEMENT

Nadhif Rayhan Abhista[1*], Gunawan Sakti[2], Ajeng Wulansari[3]

[1,2,3)]*Civil Aviation Polytechnics of Surabaya, Jemur Andayani I/73 Wonocolo Surabaya, Jawa Timur, Indonesia, 60236*
**Corresponding Author Email: nadhifrayhan27@gmail.com*

ABSTRACT

The purpose of this study is to improve efficiency by modifying the roughness of the Savonius turbine with the use of sandpaper on its convex surface. This research uses numerical methods using ANSYS software and Fluent CFD simulations with a 3D model of the Savonius wind turbine. The Savonius wind turbine used has a blade diameter of 100 mm, with variations in sandpaper surface roughness no 120, 180, and 320. The research used Reynolds Number Re = 6.34×10^4 with a speed of 5m/s. The results of this study Savonius turbine with surface roughness has not been able to improve the performance of the conventional Savonius turbine. The addition of variations has not obtained better results, both from the coefficient of moment experiencing a performance decrease of 0.83%, coefficient of power experiencing a performance of 12.8%, coefficient of drag increasing by 3.21% and coefficient of lift increasing by 3.11%.

Keywords: *Aerodynamic, Savonius Wind Turbine, Sandpaper*

1. INTRODUCTION

Wind is a very abundant natural resource in Indonesia [1]. This can happen because Indonesia is an archipelago that has a cluster of islands stretching from Sabang to Merauke. Indonesia's wind energy potential has been estimated at approximately 978 MW, with average wind speeds between 3.5 and 7 m/s [2]. The utilization of wind energy is still not optimal. "The installed capacity of wind power plants in 2014 only reached 3.61 MW, namely 1.77 MW interconnected with the PLN network (on grid) and 1.84 MW (off grid)." [3]. Wind energy can be utilized, one of which is for power generation [4]. Utilization of wind energy is an ideal idea in the development of renewable energy. Thus, it is very appropriate to use wind turbines for the utilization of electrical energy generation.

There are various types of wind turbines that have been used by humans in the present era. One type of turbine that can be utilized is a vertical type wind turbine, namely the Savonius wind turbine [5]. Savonius turbines are widely used because they have characteristics that are superior to other Wind Turbines, which do not depend on the direction of the wind [6]. Savonius turbine is a type of turbine that is able to rotate even though the wind speed is very low. These wind turbines produce considerable torque even though they work at relatively low wind speeds [7]. However, from a performance perspective, these wind turbines are still less efficient due to the large pressure drag on the returning blade, which causes the resulting RPM to remain low [8]. Various efforts have been made to overcome these problems, including modification of rotor material, shaft, number of blades, number of stages, overlap ratio. [9]

This research aims to increase efficiency and reduce pressure drag on the Savonius turbine. One way is to apply the principles of aerodynamics to airplanes. Many researchers have attempted to limit this problem, starting from modifying the rotor, shaft, number of blades, twist, material, and other modifications. The hypothesis of this research refers to [10] by adding roughness to the surface will increase skin friction drag, and reduce pressure drag.

Referring to the opinion of [10], it is concluded that research that modifies surface roughness needs to be carried out in more depth.

2. METHOD

This research uses 3D numerical simulation method using ANSYS Fluent 19.2 software and Computational Fluid Dynamics (CFD) method. Numerical methods are employed because they can effectively manage large systems of equations, nonlinearities, and complex geometries, which are often unsolvable analytically in engineering practice [11]. There are 3 processes in this study, namely, pre-processing, processing, and after processing. Geometry creation uses the design modeler contained in the software. Meshing is also done in the software. Tecplot 360 software will be used for post procession results.

2.1 Pre – Processing

The Pre-processing stage is the first step in the simulation process, aimed at preparing the fluid computing method. This stage involves several steps, including designing the research object, boundary conditions, meshing, and conducting a grid independence study.

2.1.1 Reaserch Object

In this study, the turbine geometry used is as shown in Figure 1. Table 1 shows the size of the Savonius turbine geometry. The advancing and returning blades have a diameter of 102.5 mm, with the dimple located on the returning blade. The Savonius wind turbine has a diameter of 200 mm, an end plate diameter of 220 mm, a shaft diameter of 25 mm, a blade thickness of 6 mm, a blade height of 154 mm, and an end plate thickness of 5 mm. Among others, the conventional Savonius turbine and with the addition of surface roughness. Surface roughness uses sandpaper no 120, 180 and 320.

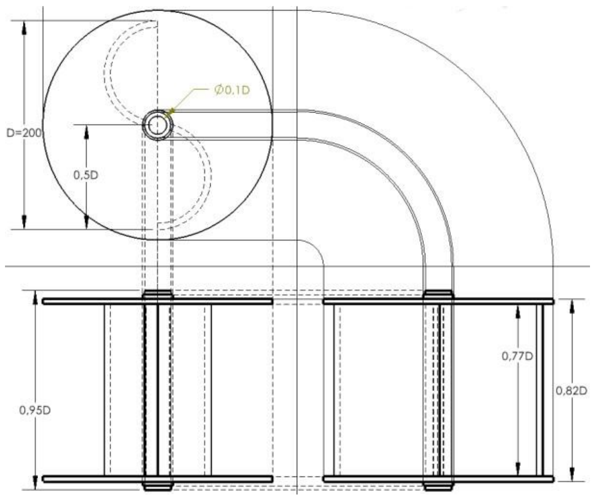


Figure 1. Design Turbine Savonius

Table 1. Turbine Savonius Geometry

Advancing Blade Diameter	Turbine Savonius Diameter	End plate Turbine Diameter	Shaft Diameter	Blade Thickness	Blade Height
102,5 mm	200 mm	340 mm	25 mm	5 mm	165 mm

2.1.2 Boundary Conditions

Boundary conditions specify the parameters for calculating fluid flow through the research object. In this study, the boundary conditions are categorized into fixed zone, wake zone, and rotating zone, tailored to the shape and configuration of the turbine being tested. The boundary size used is taken based on research [12], as shown in Figure 2.

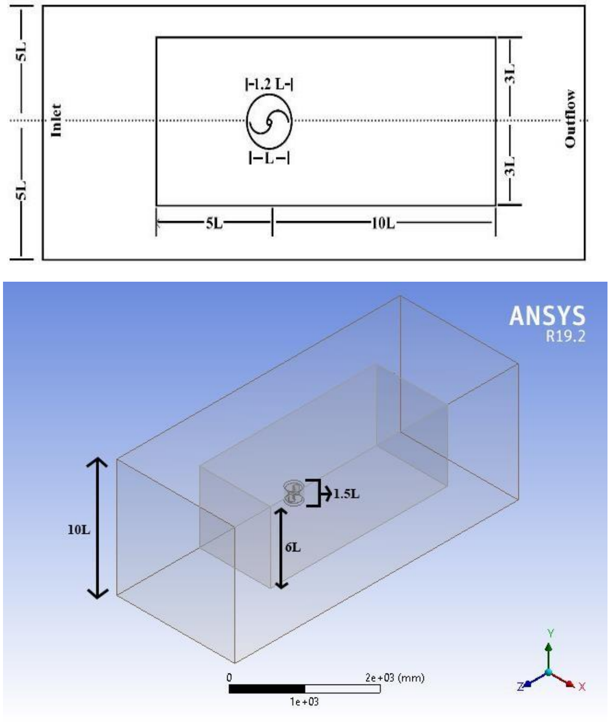


Figure 2. Boundary Layer Turbine Savonius

2.1.3 Meshing

Meshing involves dividing the turbine geometry into small elements to enhance the accuracy of the simulation results. This process creates a fine mesh while taking into account the necessary computational power. The meshing process is carried out several times with several different configurations, which aim to find the most optimal point when grid independence. as shown in the table 2.

Table 2. Quality of each mesh variation

Jumlah Mesh	Nama *Mesh*	*Face Sizing (Rotating Zone – Wake Zone)*	*Face Sizing (Turbinewall)*	*Inflation Layer*
900k	A	4,1	16	20
925k	B	4,05	16,5	20
975k	C	4	16	20
1000k	D	3,95	15	20
1100k	E	3,7	15	20
1200k	F	3,5	15	20
1300k	G	3,4	13	20
1400k	H	3,3	12	20

First Layer Thickness	*Growth Rate*
0,10783	1,2
0,10783	1,2
0,10783	1,2
0,10215	1,2
0,0965	1,2
0,09081	1,2
0,08513	1,2
0,07945	1,2

2.1.4 Grid Independence

Accurate data is essential in both the Pre-Processing and Post-Processing stages of software-based simulation. To ensure the results closely match real-world conditions, a grid independence test is necessary to identify the optimal grid structure [13]. The goal of grid independence is to identify the number of mesh elements that produce consistent results. [14]. The lowest value of each meshing is then determined by comparing the numerical Cm graph after meshing is divided into numerous categories [15]

The grid independence test involves dividing the mesh into eight distinct categories. The numerical Cm graphs from each category are then compared to identify the mesh with the smallest variation in values. Table 3. shows the profile of each meshing on the Savonius turbine divided into various categories. Meshing E is retained as a reference for further simulations as it has shown the stability of the entire mesh.

Table 3. Quality of each mesh variation

Mesh Name	Number of elements	Avg. skewness	Cm
MESH A	895497	0,33549	0,11224
MESH B	931960	0,33509	0,11266
MESH C	968429	0,33058	0,11322
MESH D	100640	0,32921	0,11290
MESH E	110090	0,33058	0,11296
MESH F	123446	0,32717	0,11287
MESH G	129552	0,32667	0,11287
MESH H	139240	0,32427	0,11296

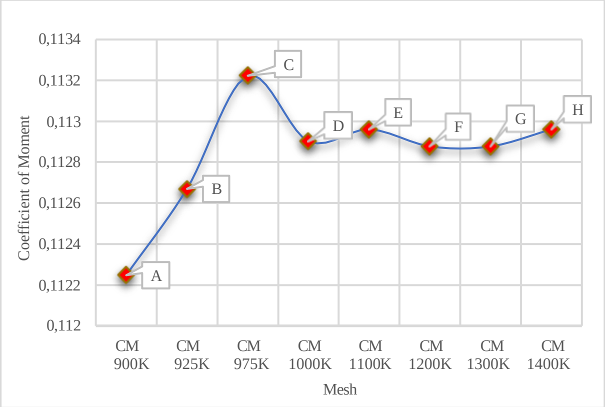


Figure 3. Numerical simulation independence grid with moment coefficients (Cm)

Figure 3. Shows grid independence on a conventional Savonius turbine. According to Figure 5, the constant Cm value is observed in meshing categories D, E, F, G, and H. Increasing the number of elements during the meshing process impacts computer performance and the simulation time. Therefore, this study will use meshing D, which consists of 1,000,000 mesh elements, for the simulation process.

2.2 Processing

At this stage, the solution process involves performing iterations until a convergent condition is reached. If convergence is not achieved, the meshing process can be repeated and refined. Numerical calculations using the CFD method are employed to address the problems in this study, including simulating the modified Savonius turbine geometry with the same boundary condition configuration and grid independence test.

3. RESULTS AND DISCUSSION

The results of numerical simulations are compared with the performance data of conventional Savonius wind turbines with the aim of knowing the initial performance of the Savonius turbine and then given variations in the form of adding surface roughness to the convex surface of the Savonius turbine blade. The data is compared as a validation stage with the data obtained in the Salim experiment in the form of coefficient of moment (Cm), coefficient of power (Cp), coefficient of lift (Cl), coefficient of drag (Cd) and visualization of pressure contour and velocity contour.

3.1 Coefficient Of Moment (Cm)

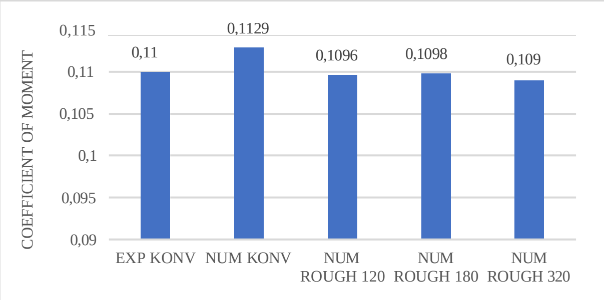


Figure 4. Comparison Chart of coefficient of moment of experimental and numerical test results

The comparison of conventional turbines and turbines with the addition of surface roughness on the convex blade surface is shown in Figure 4 as a function of coefficient of moment (Cm) value. The impact of surface roughness on turbine performance is not considered effective, as there is a 3.38% reduction in peak performance after applying surface roughness variations to the turbine blade. The numerical conventional Savonius turbine has a higher coefficient of moment value than the turbine given a surface roughness with the largest difference at sandpaper no. 320. Thus, the addition of surface roughness can affect the performance of the Savonius wind turbine, but it does not enhance the performance of a conventional Savonius wind turbine.

3.2 Coefficient Of Power (Cp)

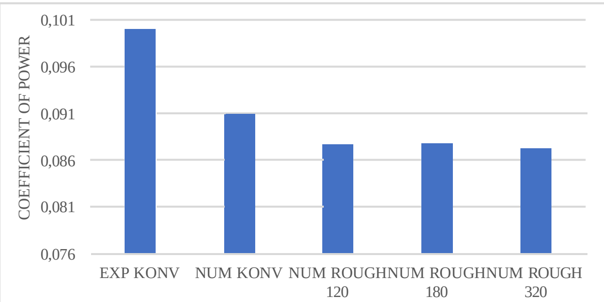


Figure 5. Comparison Chart of coefficient of power of experimental and numerical test results

The comparison of conventional turbines and turbines with the addition of surface roughness on the convex blade surface is shown in Figure 5 as a function of coefficient of power (Cp) value. The effect of surface roughness on turbine performance cannot be said effective because there is a decrease in the highest performance of 3,34% after turbine blade is given a surface roughness variation. The numerical conventional Savonius turbine has a higher coefficient of power value than the turbine given a surface roughness with the largest difference at sandpaper no. 320. Thus, the addition of surface roughness can affect the performance of the Savonius wind turbine, but the addition of surface roughness cannot improve the performance of the conventional Savonius wind turbine.

3.2 Coefficient Of Lift (Cl)

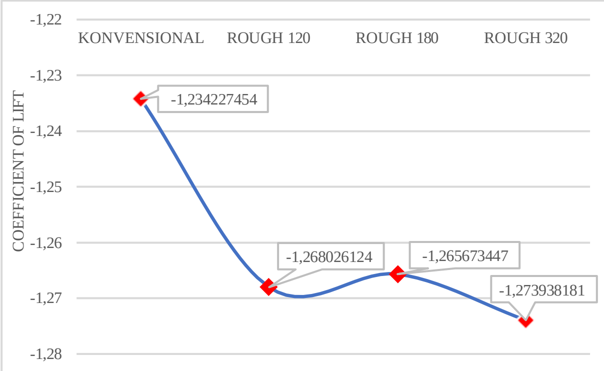


Figure 5. Average Coefficient of lift graph

Based on Figure 5, the average value of Cl of the conventional turbine is Cl = -1.2342. While the difference in the highest average value of Cl turbine with the addition of surface roughness is Cl = -1.2739. Where Cl is obtained at timestep 1080 to 1440. So it can be concluded that there is an increase in the coefficient of lift of -2.48%. This proves that the conventional Savonius turbine has a better coefficient of lift value than the turbine with the addition of sandpaper so that the conventional Savonius turbine has a higher coefficient of power (Cp) value.

3.3 Coefficient Of Drag (Cd)

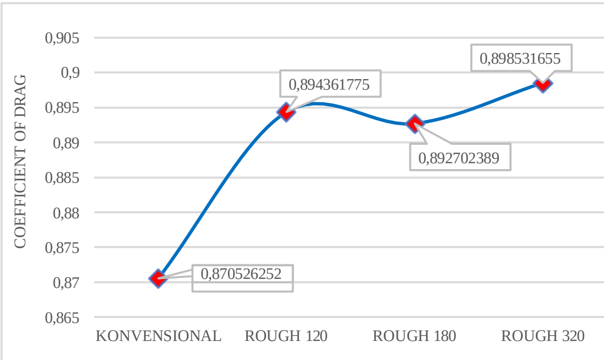


Figure 6. Average coefficient of drag graph

Based on Figure 6, the average value of conventional turbine Cd is Cd = 0.8705. While the highest average value of turbine Cd with the addition of surface roughness is Cd = 0.8927, where Cd is obtained at timestep 1080 to 1440. So it can be concluded that there is an increase in coefficient of drag of 2.547%. This proves that the conventional Savonius turbine has a better Cd value than the turbine with the addition of sandpaper so that the conventional Savonius turbine has a higher coefficient of power (Cp) value.

3.4 Pressure Contour

Figure 7 illustrates the static pressure contours for both the conventional Savonius turbine and the turbine with added surface roughness at a 30° angle. Positive pressure is represented by red, while negative pressure is shown in blue.

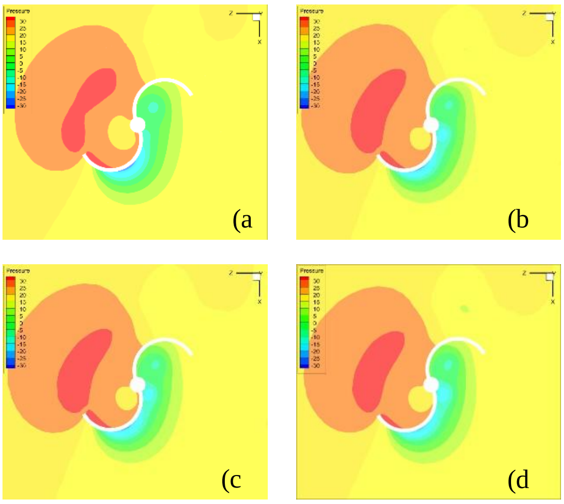
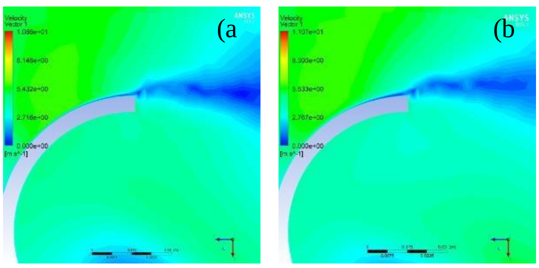


Figure 7. Comparison of static pressure contour at 30° angle a) conventional turbine b) turbine with roughness 120 c)) turbine with roughness 180 d)) turbine with roughness 320

In Figure 7(a), the advancing blade is shown in red, while the returning blade is depicted in blue. This color difference indicates a pressure disparity between the front and rear of the blade, enabling the turbine to rotate in the desired direction. For the returning blade, red indicates pressure only on the convex side, while the concave side shows green pressure. Consequently, the returning blade generates drag, opposing the turbine's rotation and thus being detrimental.

After adding surface roughness variations, in Figure 10, both b, c, and d, there is almost no significant change in the contours. On the shaft side near the returning blade, the blue area with a pressure range of -15 is larger than the conventional turbine. This causes a decrease in pressure so that the coefficient of power (Cp) is lower than the conventional turbine.

3.5 Velocity Contour



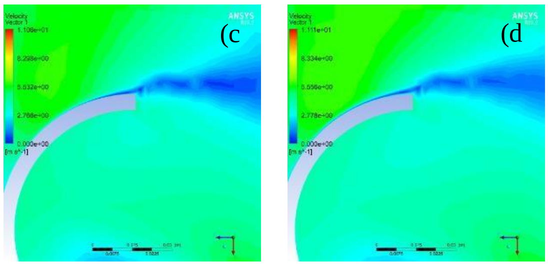


Figure 8. Comparison of velocity contour at 90° angle a) conventional turbine b) turbine with Roughness 120 c) turbine with Roughness180 d) turbine with Roughness 320

Figure 8 shows the velocity contour at a 90° angle, the airflow along the convex surface of the blade. It can be seen the difference, in the conventional it can be seen if the airflow behind the blade which is colored blue in the conventional looks wider than with the addition of surface roughness. This shows that the airflow flows better than the surface roughness, so that the flow becomes more laminar than conventional.

4. CONCLUSSIONS

Based on the above research, conclusions can be drawn, among others:

1. The addition of surface roughness variations can affect the performance of the Savonius turbine but has not been able to improve its performance and has actually decreased performance compared to the conventional Savonius turbine.
2. The addition of surface roughness variations on the convex blade of the Savonius turbine can change the airflow of the Savonius wind turbine. This is evidenced by changes in pressure and velocity found in the returning blade of the Savonius turbine. Surface roughness makes the flow of drag on the Savonius wind turbine even greater and has not shown that the addition of surface roughness variations can provide optimal results.

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