

Effect of the turbulence model on the aerodynamic structure around a Savonius wind rotor

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Résumé:

Ce travail vise à étudier l'effet du modèle de turbulence sur les caractéristiques aérodynamiques de l'écoulement à l'aide du code CFD Fluent. Le modèle numérique est basé sur la résolution des équations de Navier -Stokes. Ces équations sont résolues par une discrétisation volumes finis. Deux modèles de turbulence sont considérés : le modèle $k-\varepsilon$ et le modèle $k-\varepsilon$ RNG. Particulièrement nous sommes intéressés à visualiser le champ de vitesse, la vitesse moyenne et la pression statique. L'accord entre nos résultats numériques et les résultats antérieurs confirme la validité de la méthode d'analyse adoptée.

Abstract:

This study aims to investigate the effect of the turbulence model on the aerodynamic characteristics of the flow around a Savonius wind rotor. For thus, we have developed a numerical simulation using the commercial CFD code Fluent. The considered numerical model is based on the resolution of the Navier-Stokes equations. These equations were solved by a finite volume discretization method. Two turbulence models are considered: the standard $k-\varepsilon$ and the $k-\varepsilon$ RNG. Particularly, we are interested to visualize the velocity field, the mean velocity and the static pressure. The good comparison between our numerical results and anterior results confirms the validity of the numerical method.

Key words: turbulence model, Wind rotor, Savonius, CFD

1 Introduction

Renewable energy is energy that is generated from natural processes that are continuously replenished. This includes sunlight, geothermal heat, wind, tides, water, and various forms of biomass. This energy cannot be exhausted and is constantly renewed. In recent years, an interest in wind energy has been growing and wind turbines are developed to generate electricity from the kinetic power of the wind. Wind turbines can rotate about either a horizontal or a vertical axis. One advantage of the vertical-axis wind turbines is that the turbine does not need to be pointed into the wind to be effective. Savonius wind turbines are a type of vertical-axis wind turbine. It is a drag-type device. Although with less efficiency compared with three-bucket wind turbine, the Savonius wind rotor, has the advantage of being compact, economical and aesthetic. This allows it to be easily integrated into buildings. Savonius wind turbines have good starting characteristics, operate at relatively low operating speeds and have ability to accept wind from any direction. For several years, many works have significantly improved the performance of Savonius rotors. For example Kamoji et al. [1] investigated the performance of modified forms of conventional rotors with and without central shaft between the end plates. Menet and Bourabaa [2] tested different configuration of the savonius rotor and found that the best value of the static torque coefficient is obtained for an incidence angle equal to $\theta = 45^\circ$ and a relative overlap equal to $e / d = 0.24$. They compared their numerical results with those obtained by Blachwell et al. [3] and a good agreement was obtained. Ushiyama and Nagai [4] tested several parameters of the Savonius rotor including gap ratio, aspect ratio, number of cylindrical buckets, number of stages, endplate effects, overlap ratio, and bucket design. The highest efficiency of all configurations tested was 24% for a two-stage, two-bucket rotor. Saha and Rajkumar [5] compared the performance of a bladed metallic Savonius rotor to a conventional semi-circular blade having no twist. The twist produced good starting torque and larger rotational speeds and gives an efficiency of 0.14. The best torque was obtained with blades twisted by an angle $\alpha = 12.5^\circ$. Akwa et al. [6] studied the influence of the buckets overlap ratio of a Savonius wind rotor on the averaged moment and power coefficients by changing the geometry of the rotor. They notice that the maximum device performance occurs for buckets overlap ratios with values close to 0.15. Khan et al. [7] tested different blade profiles of a Savonius rotor both in tunnel and natural wind conditions and they varied the overlap. The highest C_p of 0.375 was obtained for blade profile of S-section Savonius rotor at an optimum overlap ratio of 30%. Driss et al. [8] conducted a computational fluid dynamic study to present the local characteristics of the turbulent flow around a Savonius wind rotor. They compared their numerical results with experimental results and a good agreement was obtained. In this context, we are interested in studying the flow around a Savonius wind rotor. For thus, we have developed numerical simulations of the turbulent flow using a CFD code and we have investigated the effect of the turbulence model on the aerodynamic characteristics of the flow.

2 Geometric parameters

The examined Savonius rotor consists of two half-cylinder buckets characterized by the diameter $d=0.3$ m. These buckets are collected on a common axis. The overlap is equal to $e=72$ mm (Figure 1).

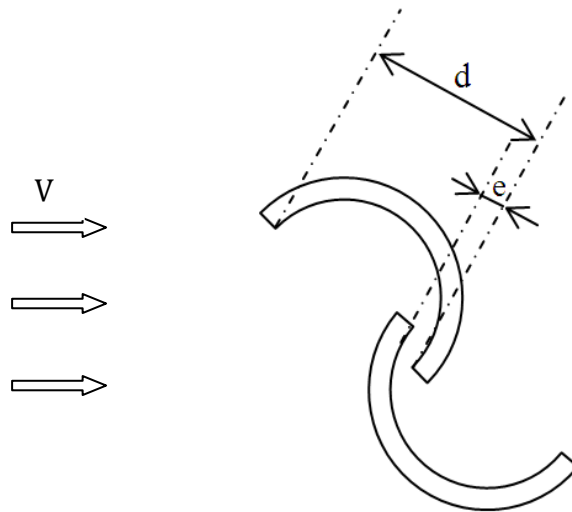


Fig. 1 Savonius rotor

3 Numerical model

Computational fluid dynamic (CFD) simulations were conducted using the commercial CFD code Fluent. The boundary conditions are defined by a velocity inlet equal to $V=5 \text{ m.s}^{-1}$ and a pressure outlet equal to $P=1 \text{ atm}$. For the choice of the numerical model, we are interested on the study of the standard $k-\varepsilon$ and the RNG $k-\varepsilon$ turbulence model.

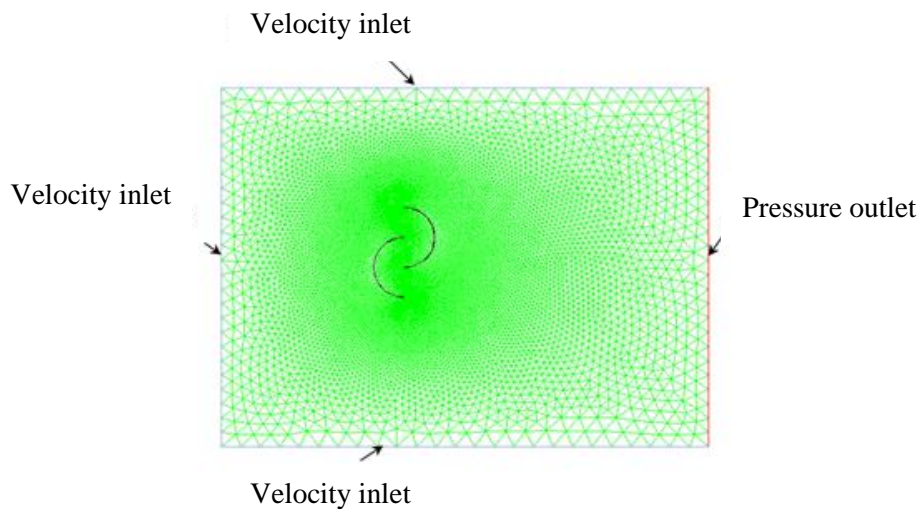


Fig. 2 Boundary conditions

3.1 Velocity fields

Figure 3 shows the distribution of the velocity fields for different turbulence models. Based on these results, it has been noted that the flow appears uniform and has a value of $V = 5 \text{ m.s}^{-1}$ in the inlet of the control volume. However, in the internal attack side of the upper bucket, there is a rapid increase of the velocity values which is followed by a decrease. This increase has been also observed at the external attack zones of the buckets. From both these sides, two wakes characteristics of the maximum

values of the velocity are developed. These two wakes extend downstream of the attack zones. Furthermore, a rapid deceleration of the velocity values and the formation of two recirculation zones downstream of the two buckets have been observed. By comparing these two results, it has been noted that the velocity values obtained by the RNG k- ϵ model are higher than those obtained by the standard k- ϵ model. Under these conditions, the maximum values of the velocity obtained with the k- ϵ model and the k- ϵ RNG model are respectively equal to 7.35 ms^{-1} (Figure 3.a) and 7.7 ms^{-1} (Figure 3.b).

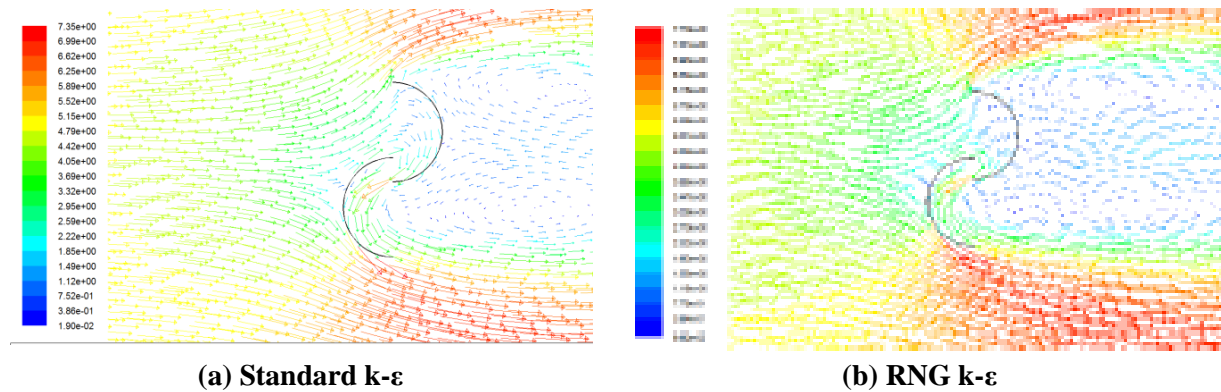


Fig. 3 Distribution of the velocity fields

3.2 Mean velocity

Figure 4 shows the mean velocity for different turbulence models. Based on these results, it has been noted that the flow appears uniform and has a value of $V = 5 \text{ m.s}^{-1}$ in the inlet of the control volume. Upstream of the rotor, there is a decrease of the mean velocity, it reaches zero at the meeting of the two buckets. However, in the internal attack side of the upper bucket, there is a rapid increase of the mean velocity values which is followed by a decrease. This increase of the mean velocity is also observed at the external attack sides of the two buckets. From these two attack zones, the maximum value of the mean velocity is localized in both wake zones. Behind the rotor, it has been noted that the mean velocity value decreases quickly. This decrease has begun just downstream of the rotor and extends to the limits of the domain. Comparing these results, it has been observed that the higher values of the mean velocity are obtained with the RNG k- ϵ model.

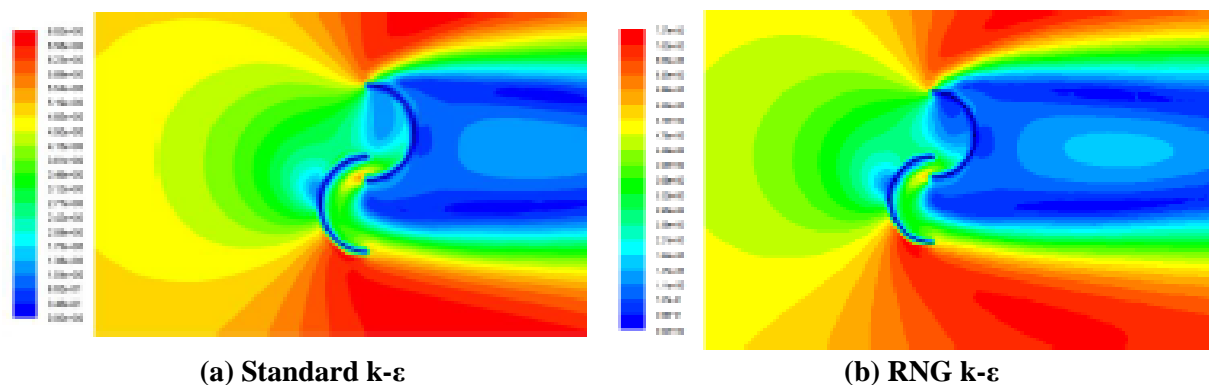


Fig. 4 Distribution of the mean velocity

3.3 Static pressure

Figure 5 shows the distribution of the static pressure for different turbulence models. From these results, it has been observed a surpression zone in the upstream of the Savonius rotor which increases in the concave surface of the upper bucket and on the convex side of the lower bucket. At the concave surface of the lower bucket, there is a rapid decrease of the static pressure values. However, a depression zone appears in the convex surface of the upper bucket. The most important depression zones appear in the two attack zones of the upper bucket of the Savonius rotor. This depression zone extends in the downstream of the rotor to the outlet of the domain. Comparing these results, it appears that the higher values of the static pressure are obtained with the standard k- ϵ model. Under these conditions, the pressure values obtained with the k- ϵ model and the RNG k- ϵ model are respectively equal to 32.2 Pa (Figure 5.a) and 28 Pa (Figure 5.b).

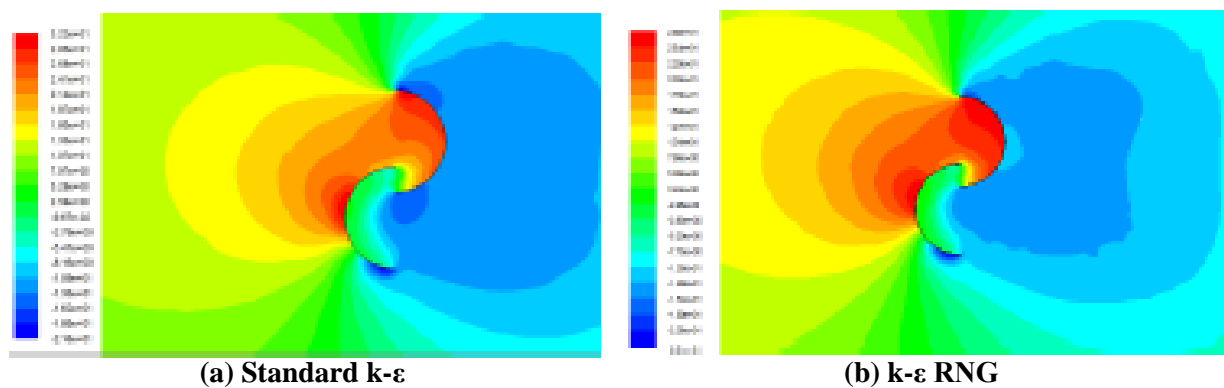


Fig. 5 Distribution of the static pressure

3.4 Comparison with anterior results

The values of the static torque coefficients found for different turbulence models are presented in the Table 1 and compared with those obtained by Menet and Cottier [9]. According to those results, it has been observed that the standard k- ϵ model gives the best results. Indeed, in these conditions, the calculated value is very close to that found by these authors [9].

	Turbulence models		Menet and Cottier [9]
	Standard k- ϵ	k- ϵ RNG	
C_{Ms}	0.34	0.38	0.33

Table 1: Static moment coefficients for different turbulence models

4 Conclusions

In this work, numerical simulations have been developed to study the effect of the turbulence model on the aerodynamic characteristics of the flow around the Savonius wind rotor. Particularly, we are interested on the presentation of the velocity, the mean velocity and the static pressure. According to the numerical results, it has been observed that the turbulence model has a direct effect on the aerodynamic characteristics. The comparison of the static torque coefficients with those given by anterior results is performed. A good agreement was obtained and confirmed the numerical method. In the future, we propose to study the effect of the incidence angle and the overlap of the buckets.

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