An experimental study on improvement of a Savonius rotor performance with curtaining

Burçin Deda Altan a,*, Mehmet Atılgan a, Aydoğan Özdamar b

aDepartment of Mechanical Engineering, Faculty of Engineering, Pamukkale University, Kanklı 20070 Denizli, Turkey
bDepartment of Mechanical Engineering, Faculty of Engineering, Ege University, Bornova, 35100 Izmir, Turkey

**Abstract**

This study introduces a new curtaining arrangement to improve the performance of Savonius wind rotors. The curtain arrangement was placed in front of the rotor preventing the negative torque opposite the rotor rotation. The geometrical parameters of the curtain arrangement were optimized to generate an optimum performance. The rotor with different curtain arrangements was tested out of a wind tunnel, and its performance was compared with that of the conventional rotor. The maximum power coefficient of the Savonius wind rotor is increased to about 38.5% with the optimum curtain arrangement. The experimental results showed that the performance of Savonius wind rotors could be improved with a suitable curtain arrangement.

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1. Introduction

Savonius wind rotor that is composed of two vertical half cylinders is also considered to be a kind of wind rotor. Power performance of Savonius wind rotor ($C_p \approx 15\%$) is rather low when compared with that of the wind rotors with a horizontal axis ($C_p \approx 45\%$) and Darrieus-type wind rotor with a vertical axis ($C_p \approx 35\%$) [1,2]. However, Savonius wind rotor has many advantages over others in that its constructions are simpler and cheaper, it is independent of the wind direction and has a good starting torque at lower wind speeds. Therefore, available in the literature are a lot of studies that have been conducted to improve the performance of a Savonius wind rotor.

In these studies, a number of scientists have experimentally and numerically examined the effects of various design parameters of Savonius wind rotor such as the rotor aspect ratio, the overlap and the separation gap between the rotor buckets, the profile change of the bucket cross section, the number of buckets, the presence or absence of rotor endplates, and the influence of bucket stacking [3–8]. Many experimental and numerical studies have been carried out on Savonius wind rotors to investigate the flow field and the pressure distribution on blades [9–19]. In addition, the effect of the swinging angle of the rotor blades on rotor characteristics and power has been investigated by Aldos [20]. The optimum swinging angle of rotor blades increased the maximum power coefficient of the rotor from 1.5% to 17%. Some other experiments have been carried out to improve the performance of the Savonius wind rotor by allowing both downwind and upwind rotor blades to swing back through an optimum angle [21]. The power coefficient of the rotor tested in this study is increased to about 23.5% with the optimum swinging angles. Reupke and Probert [22] have performed dynamic-torque tests for Savonius wind rotor with hinged blades to improve the performance of the rotor. Furthermore, Ogawa et al. [23] have investigated the effects of the deflecting plate parameters to improve the performance of the Savonius wind rotor by using deflecting plates. In this investigation, it is found that the rotor power is approximately 30% greater than that of a rotor without the deflecting plate. Saha and Rajkumar [24] have examined the twisted blade in a three-bladed rotor system in a low speed wind tunnel and compared its performance with semicircular blades. They have found out that the twisted blade showed a maximum of $C_p = 13.99\%$, whereas the semicircular blade showed a $C_p = 11.04\%$. Moreover, an experimental study with the twisted blades fabricated from the bamboo strips has been performed by Saha et al. [25] for small-scale power generation in the rural areas. There are also some other studies for designing and developing small Savonius wind rotors for local electricity production [26,27].

The objective of this study is to introduce a curtain arrangement without changing the basic structure of a Savonius wind rotor to improve the performance and increase the efficiency of the rotor. In this study, the curtain arrangement used is a wind deflector consisting of a simple construction.
2. Experimental apparatus and procedures

The detailed results of the experimental study and information on the experimental apparatus used and procedure have been given by Deda Altan [28]. A summary of that information is presented in this study along with the results.

2.1. A conventional Savonius rotor and a new design

A conventional Savonius wind rotor has blades formed from two half cylinders in rotation around a vertical axis with or without a gap in between. The wind force is exerted on both the convex blade and concave blade as shown in Fig. 1. Since the generated torque on the convex blade of the Savonius wind rotor is lower than that on the concave blade, the rotor rotates in the direction of the positive torque. However, it is important to prevent the negative torque opposite to the rotor rotation to be able to increase the power of the rotor. Therefore, in order to prevent the negative torque on the convex blade in this study, a curtain arrangement has been designed in front of the Savonius wind rotor intended to increase the low rotor performance.

Design of the conventional Savonius wind rotor used in this study has been made in accordance with the dimensions of the wind tunnel used in the experiments and with the information in the literature for the purpose of making comparisons with the studies in the literature [10–12]. In examined literature studies, various overlap ratio values (\(e/d\)) have been investigated and the optimum overlap ratio value has been found as 0.15 [3,4,10–12]. Therefore, the overlap ratio value has been taken as 0.15 in this study.

Geometrical parameters and a view of the Savonius wind rotor are given in Fig. 2. The rotor diameter \(D\) and the rotor height \(H\) are 32 cm, and according to the optimum ratio of \(e/d = 0.15\), the gap distance \(e\) is 2.6 cm. The thickness of the blades is 2 mm. The two end-plates have been made from 4 mm thick steel sheets with a plate diameter \(D_0\) of 35.2 cm. The Savonius wind rotor shaft has been supported near the top and bottom with ball bearings to minimize the friction force. The rotor has been attached to the experimental set-up by the fasteners to facilitate assembly and disassembly.

A curtain arrangement as a new design has been investigated to increase the efficiency of a Savonius wind rotor by preventing the effect of the negative torque on the rotor [28,29]. The curtain arrangement with geometrical parameters is illustrated in Fig. 3. The curtain blades (a and b curtains) are the wind-deflecting plates as shown in figure. Construction of these deflecting plates is simple and cheap, since their materials are composed of flat sheet plates. The curtain arrangement has been designed in such a way as not to remove the properties of a Savonius wind rotor, which takes in wind from all directions. To do this, a sensor has been placed to turn the curtain arrangement to the wind direction.

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Nomenclature

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>(C_p)</td>
<td>power coefficient (dimensionless)</td>
</tr>
<tr>
<td>(P_f)</td>
<td>useful power (W)</td>
</tr>
<tr>
<td>(P_r)</td>
<td>wind power (W)</td>
</tr>
<tr>
<td>(M^+)</td>
<td>positive torque (Nm)</td>
</tr>
<tr>
<td>(M^-)</td>
<td>negative torque (Nm)</td>
</tr>
<tr>
<td>(V_t)</td>
<td>wind velocity (m/s)</td>
</tr>
<tr>
<td>(U)</td>
<td>circumferential velocity of the rotor (m/s)</td>
</tr>
<tr>
<td>(n)</td>
<td>rotational speed (rpm)</td>
</tr>
<tr>
<td>(H)</td>
<td>height (m)</td>
</tr>
<tr>
<td>(A)</td>
<td>rotor swept area (m²)</td>
</tr>
<tr>
<td>(D)</td>
<td>rotor diameter (m)</td>
</tr>
<tr>
<td>(D_0)</td>
<td>endplate diameter (m)</td>
</tr>
<tr>
<td>(d)</td>
<td>rotor blade diameter (m)</td>
</tr>
<tr>
<td>(e)</td>
<td>gap distance (m)</td>
</tr>
<tr>
<td>(l_1)</td>
<td>length of a curtain plate (m)</td>
</tr>
<tr>
<td>(l_2)</td>
<td>length of b curtain plate (m)</td>
</tr>
<tr>
<td>(t)</td>
<td>thickness of plate (mm)</td>
</tr>
<tr>
<td>(Re)</td>
<td>Reynolds number</td>
</tr>
<tr>
<td>(\omega)</td>
<td>angular speed of rotor (rad/s)</td>
</tr>
<tr>
<td>(\rho)</td>
<td>air density (kg/m³)</td>
</tr>
<tr>
<td>(\lambda)</td>
<td>tip speed ratio (dimensionless)</td>
</tr>
<tr>
<td>(\alpha)</td>
<td>angle of a curtain plate</td>
</tr>
<tr>
<td>(\beta)</td>
<td>angle of b curtain plate</td>
</tr>
<tr>
<td>(\nu)</td>
<td>kinematic viscosity of fluid (m²/s)</td>
</tr>
</tbody>
</table>

**Fig. 1.** Direction of the torque affecting on the rotor blades by the wind force.

**Fig. 2.** Geometrical parameters and a view of the Savonius rotor.
There are four variables on the curtain arrangement. These are lengths of the curtain blades \((l_1 \text{ and } l_2)\) and the angles of the blades \((\alpha \text{ and } \beta)\). The minimum value of \(\alpha\) has been determined as 30° which can prevent the wind force on the convex blade. The angle has been increased up to 60° with 5° increments in the study. \(\beta\) angle \((0–30^\circ)\) has been considered in the experiments. The lengths of the curtains have been initially adjusted to cover the effective flow field. Then, \(l_1\) and \(l_2\) lengths have been increased gradually to find the optimum lengths which generate maximum torque, power and power coefficient. In this paper, three different curtain arrangements are given as curtains 1, 2 and 3. The curtain 1 has the optimum lengths. The lengths of the curtains 2 and 3 are 75% and 50% of the optimum lengths, respectively. The lengths of the curtains used in the experiments are given in Table 1. A protractor has been placed on the lower plate of curtain arrangement to be able to measure the curtain angles.

2.2. Experimental set-up and other equipments

A schematic diagram of the experimental set-up that has been used in this study is shown in Fig. 4. The experimental set-up consists of the wind tunnel, Savonius wind rotor, curtain arrangement and measurement devices. The wind tunnel used in the experiments is an open-circuit type with the power capacity of 5.7 kW and has a circular exit \((\phi = 50 \text{ cm})\). Its wind velocity could also be changed with the use of an adjustable damper. The Savonius wind rotor, curtain arrangement and measurement devices have been installed away from the exit of this wind tunnel. The Savonius rotor and curtain arrangement have been placed on a steel profile table. The Savonius rotor shaft has been supported near the top and bottom by a very low friction ball bearing to minimize the friction force. The constructed curtain arrangements have been placed in front of the Savonius wind rotor. And then measurements of rotor torque, wind velocity and the number of revolution have been measured by a torque meter sensor, multifunctional anemometer and a revolution counter (tachometer). The torque meter sensor and a revolution counter (tachometer) have been coupled to the upper part of the rotor. A digital torque transducer unit connecting IMADA HGT-10 torque meter sensor with a measuring range of 0–10 Nm has been used to measure the torque that forms on Savonius wind rotor shaft and the accuracy of torque meter sensor is ±0.5%. A TESTO 435 multifunctional anemometer with the measuring range of 0.6–40 m/s has been used to measure the wind velocity and the accuracy of multifunctional anemometer is ±0.2 m/s. The rotational speeds have been measured on TESTO 465 optic tachometer equipment with the measuring range of 1–499,999 rpm and the accuracy of tachometer equipment is ±0.02%.

In order to provide uniform flow, Savonius wind rotor has been placed approximately \(l = 5 \text{ m away from the exit of the wind tunnel} [30]\). The rotor with and without curtain placed at the exit of the wind tunnel is schematically shown in Fig. 5. The rotor with and without curtain has been installed at the same position for each measurement. The rotor with and without curtain has been performed under the same wind speed condition to compare with each other. The conducted experimental study with implementing curtains has been repeated at an average wind speed of 10–13 m/s and higher ones, but it has been impossible to get the expected performance increase. This makes one think that the curtain leads to the effect of blockage at high wind speeds. Because rotor performance has been found out to be better only at the lower wind speeds in this study, the experiments have been maintained at an average wind speed of 7 m/s \((Re = 1.5 \times 10^5)\). This 7 m/s wind speed has been measured on a speed-measuring mesh placed 1 m away from the centre of Savonius wind rotor on which the experiments have been made. As seen in Fig. 5, Savonius wind rotor with and without curtain takes place in the free flow exiting from the wind tunnel. From the speed scanning made on the

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**Table 1**

<table>
<thead>
<tr>
<th>Type of curtain arrangement</th>
<th>Distance (l_1) (cm)</th>
<th>Distance (l_2) (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Curtain 1</td>
<td>45</td>
<td>52</td>
</tr>
<tr>
<td>Curtain 2</td>
<td>34</td>
<td>39</td>
</tr>
<tr>
<td>Curtain 3</td>
<td>22</td>
<td>26</td>
</tr>
</tbody>
</table>

**Fig. 3.** Geometrical parameters of the curtain arrangement.

**Fig. 4.** Schematic view of experimental set-up.
speed-measuring mesh, it has been observed that this free flow has expanded about 2.4 m.

2.3. Error analysis of the experiment

The uncertainty of parameter obtained from the experimental study is given in Table 2 and calculated by Eq. (1) [31,32]

\[
W_R = \left( \frac{\partial R}{\partial x_1} \cdot W_1 \right)^2 + \left( \frac{\partial R}{\partial x_2} \cdot W_2 \right)^2 + \cdots + \left( \frac{\partial R}{\partial x_n} \cdot W_n \right)^2 \right)^{1/2}
\]

where \(R\) is the calculated parameter of the experiments and \(W_R\) is the uncertainty in the parameter. The parameter \(R\) is a given function of the independent variables \(x_1, x_2, \ldots, x_n\).

3. Experimental results and discussion

A series of experiments have been carried out with and without the curtain arrangement to find its effects on the performance. The effects of the four variables which are the lengths \((l_1\) and \(l_2\)) and angles of the curtains \((\alpha\) and \(\beta\)) on the torque, the power, and the power coefficient have been examined. For different curtain blade length values, variations in the maximum power coefficient of a Savonius wind rotor are shown in Fig. 6, and the magnitudes of the maximum power coefficient of a Savonius wind rotor are given in Table 3. As seen from figure and table, the power coefficient of a Savonius wind rotor obtained from curtain 1 has been found out to be the maximum.

The effects of curtain angles \((\alpha\) and \(\beta\)) have been determined on curtain 1 because the maximum power has been obtained from curtain arrangement 1. The effects of rotational speed with respect to the curtain angles are shown in Fig. 7. To analyze the effects of curtain angles \((\alpha\) and \(\beta\)), which are influential in the curtain design and on the performance, the experiments have been continued by increasing the values of curtain angle \((\alpha)\) between 30° and 60° by 5° both because negative torque increases when the flow comes on the convex blade at the values of curtain angle below 30° \((\alpha < 30°)\) in the earliest experiments and because the rotational speed values obtained tend to be small as the flow separations increase at the values of curtain angle above 60° \((\alpha > 60°)\). Similarly, the experiments for the \((\beta)\) curtain angle have been continued between the values of 0° and 30°. According to the results obtained from these experiments, in which enough flow cannot be collected at the values of the other curtain angle \((\beta)\) below 15°, the rotational speed values have been measured to be low; at the values of the curtain angle \((\beta)\) above 15°, the rotational speed values have also been measured as low. The experiments for the curtain angles have been continued with the values of \(\alpha = 45°\) and \(\beta = 15°\) because they are higher between these values.

**Table 2**

<table>
<thead>
<tr>
<th>Calculated value</th>
<th>Uncertainty (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(R)</td>
<td>2.85</td>
</tr>
<tr>
<td>(P_f)</td>
<td>0.50</td>
</tr>
<tr>
<td>(P_r)</td>
<td>8.57</td>
</tr>
<tr>
<td>(k)</td>
<td>2.83</td>
</tr>
<tr>
<td>(C_p)</td>
<td>8.59</td>
</tr>
</tbody>
</table>

**Table 3**

<table>
<thead>
<tr>
<th>Type of curtain arrangement</th>
<th>(C_p)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Curtain 1</td>
<td>0.38533</td>
</tr>
<tr>
<td>Curtain 2</td>
<td>0.34154</td>
</tr>
<tr>
<td>Curtain 3</td>
<td>0.26273</td>
</tr>
</tbody>
</table>

**Fig. 5.** Schematic of rotor with and without curtain arrangement.

**Fig. 6.** The effects of curtain lengths with respect to the maximum power coefficient of rotor.

**Fig. 7.** The effects of rotational speed with respect to the curtain angles \((\alpha\) and \(\beta)\) at curtain 1.
The effects of the curtain lengths on the torque with respect to the rotational speed are shown in Fig. 8. Although the Savonius wind rotor with curtains 2 and 3 shows better torques than the conventional Savonius rotor in all speeds, these are below from the torques obtained with curtain 1, which has the optimum lengths generating the highest torques in all speeds. The curtain lengths which are higher than the optimum values have resulted in negative effects on the torque due to the higher friction, separation of flow and sudden contraction in the flow area.

Fig. 8. The effects of curtain lengths on the torque with respect to the rotational speed ($\lambda = 45^\circ$ and $\beta = 15^\circ$).

The effects of the curtain lengths on the torque with respect to the rotational speed are shown in Fig. 8. Although the Savonius wind rotor with curtains 2 and 3 shows better torques than the conventional Savonius rotor in all speeds, these are below from the torques obtained with curtain 1, which has the optimum lengths generating the highest torques in all speeds. The curtain lengths which are higher than the optimum values have resulted in negative effects on the torque due to the higher friction, separation of flow and sudden contraction in the flow area.

In this study, an experimental study has been carried out in order to improve the performance and increase the efficiency of Savonius wind rotor without changing the basic structure of the rotor. Therefore, a curtain arrangement made up from wind-deflecting plates has been designed and placed in front of the rotor so as to prevent the negative torque that affects the convex blade surface of the Savonius wind rotor. Those below are the results obtained from this experimental study:

- In this study, experiments have been conducted by using the arrangement of Savonius wind rotor without curtain and with three different curtains. Experiments have been carried out with curtain arrangements at different curtain angles ($\alpha$ and $\beta$) and the optimum curtain angle has been found as $\alpha = 45^\circ$ and $\beta = 15^\circ$. The highest power coefficient has been obtained with the curtain 1 arrangement, so curtain 1 has been determined as the optimum curtain arrangement.

- When the optimum curtain arrangement (curtain 1) has been used with the conventional Savonius rotors, the performance and efficiency of the rotor are significantly improved. The power coefficient of the Savonius wind rotor has been increased to about 38% with the optimum curtain arrangement. In addition, this is fairly good value and higher than that obtained with other studies which have applied different modifications on the Savonius rotors.

- Although the power coefficients of curtains 2 and 3 are not as high as the one obtained with curtain 1, they are higher than the power coefficient ($C_p$) of 16% obtained from Savonius wind rotor without curtain.

- Thanks to the curtain designed and placed in front of the rotor without modifying the original shape of Savonius wind rotor, a narrowing entrance section has been formed in front of the rotor, thus increasing the speed of the wind flow into the rotor and improving the performance of the rotor.

- The sweeping area width of curtain 1 is approximately two times with respect to the diameter of Savonius rotor. So the curtain 1 arrangement is capable of deflecting and collecting more wind flow than the other curtains, thus transferring it to the rotor.

Savonius wind rotors are today used for water pumping, ventilation, small power requirements and for meeting the electrical needs of the rural part in particular. The rotor with such a wide field of usage can find a wider range of use, thanks to the improved rotor performance as outlined and described in this study.

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References