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# Journal of APPLIED ENGINEERING SCIENCE

ISSN 1451-4117

no. 4 - year 2020 - vol. 18

# EXPLORATORY RESEARCH FOR DEVELOPING ADVANCED PUMPING AND COMPRESSOR EQIPMENT ADAPTED TO ABNORMAL OPERATING CONDITIONS OF OIL AND GAS PRODUCTION

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**Editorial Note**
**Thank you to our retiring Editor, prof. Dr Dragan Milutinovic**

September 2021

As from September 2021, prof. Dr Dragan Milutinovic has retired as Editor Board Member of Journal of Applied Engineering Science. Prof. Dr Dragan Milutinović has been a long serving Editor for 6 years, beginning this role on September 2015. During this time, he has served the science community with dedication, commitment, and diligence while bringing to the journal a strong vision and a wealth of knowledge that has improved the visibility and impact of Journal of Applied Engineering Science. It is clear that JAES and the community which it serves, has benefited under prof. Dr Milutinovic tenure and we will miss his energy, enthusiasm and passion for production engineering.

**Publisher:** Institute for research and design in Industry, Belgrade, Serbia

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**Muhammad Alfian Mizar**
*State University of Malang, Faculty of Engineering, Department of Mechanical Engineering, East Java, Indonesia*

**Poppy Puspitasari**
*State University of Malang, Faculty of Engineering, Department of Mechanical Engineering, East Java, Indonesia*

**Ahmad Taufiq**
*State University of Malang, Faculty of Mathematics and Natural Sciences, Department of Physics, East Java, Indonesia*

**Muhammad Trifiananto**
*University of Jember, Faculty of Engineering, Department of Mechanical Engineering, East Java, Indonesia*

**Aripriharta**
*State University of Malang, Faculty of Engineering, Department of Electrical Engineering, East Java, Indonesia*

***Key words:*** *coefficient of power, darrieus HC-rotor, darrieus turbine, performance, savonious turbine, wind turbine*

**doi:**10.5937/jaes0-25010

***Cite article***:
Mizar, A. M., Puspitasari, P., Taufiq, A., Trifiananto, M., & Aripriharta. [2020]. An experimental test of the effect of cup diameter on the power performance of novel design HC-type VAWT. *Journal of Applied Engineering Science*, 18(4), 631 - 636.

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Istraživanja i projektovanja za privredu
Journal of Applied Engineering Science

Original Scientific Paper

doi:10.5937/jaes0-25010
Paper number: 18(2020)4, 738, 631 - 636

# AN EXPERIMENTAL TEST OF THE EFFECT OF CUP DIAMETER ON THE POWER PERFORMANCE OF NOVEL DESIGN HC-TYPE VAWT

*Muhammad Alfian Mizar[1]*, Poppy Puspitasari[1], Ahmad Taufiq[2], Muhammad Trifiananto[3], Aripriharta[4]*
*[1]State University of Malang, Faculty of Engineering, Department of Mechanical Engineering, East Java, Indonesia*
*[2]State University of Malang, Faculty of Mathematics and Natural Sciences, Department of Physics, East Java, Indonesia*
*[3]University of Jember, Faculty of Engineering, Department of Mechanical Engineering, East Java, Indonesia*
*[4]State University of Malang, Faculty of Engineering, Department of Electrical Engineering, East Java, Indonesia*

*Wind energy is one solution to overcome the energy problem in Indonesia. This study aimed to analyze the effect of cup diameter on the power performance of an HC-type vertical axis wind turbine (VAWT). The wind turbine used a combination of an H-type Darrieus wind turbine and a type-C rotor VAWT. The Darrieus HC-rotor wind turbine blade has a height H = 800 mm and diameter D = 800 mm with C-rotor variations on the tip with diameters of 76,2, 101,6, and 152,4 mm. The wind tunnel used an electric motor with a power of 1 HP (740 Watt) and 1400 rpm connected to a fan. The variation of wind speed was set to 2, 3, 4, 5, 6 and 7 m/s. The results showed that: (a) the highest rotation speedal speed was achieved by the HC-rotor diameter of 76,2 on 105 rpm with a wind speed of 7 m/s; (b) the highest value of the coefficient of power (Cp) is achieved by the HC-rotor diameter of 101,6mm (c) the highest value of the coefficient of torque (Ct) is achieved with the HC-rotor diameter of 152,4mm (d) the Darrieus HC-rotor wind turbine is suitable to be used in tropical regions that have low wind speeds. This result provides important information about the effect of the C rotor radius on the performance of HC-rotor Darrieus wind turbine blade vertical axis.*

*Key words: coefficient of power, darrieus HC-rotor, darrieus turbine, performance, savonious turbine, wind turbine*

## INTRODUCTION

In recent years, the demand for electrical energy has been rising significantly due to industrial growth and the increasing quality of life. This situation has an effect on the supply of electrical energy. In order to meet the electrical demand, it is necessary to utilize alternative renewable energy based on non-conventional sources such as solar, hydropower, geothermal, biomass, wind and so forth [1]. Wind energy is becoming a popular energy resource and is now being used in several countries.

Mikhail in [2] reported that the wind energy conversion system (WECS) is very appropriate for application in agriculture because it can provide mechanical power at the shaft to minimize the loss of energy conversion. In general, it can be applied as a pumping drive, for grinding, and for other tools that require mechanical power. Practically, a wind turbine system does not require a larger space than that needed for solar energy. Furthermore, the cost of generating each kilowatt of power in such an installation is relatively inexpensive.

Indonesia has an extensive coastline 81,000 km in length with average wind speed in coastal areas of between 2 and 6 m/s [3]. This opens an opportunity for Indonesia to develop wind power, and it is predicted to be able to generate power of about 9 GW. Therefore, there is also great potential for converting to wind energy to ensure national energy security in the future. In general, the wind in the tropics has a relatively low potential compared to the wind in sub-tropical regions. A survey conducted by National Institute Of Aeronautics And Space Of Indonesia (LAPAN) showed that several locations in Indonesia have an annual average wind speed of 5.86 m/s with the potential to generate power of approximately 225 W/m² [4]. Furthermore, a survey conducted by NREL in 2001 showed that the wind in some regions of eastern Indonesia such as Bali, West Nusa Tenggara, and East Nusa Tenggara has a high speed, which provides a big opportunity to install wind turbines. Therefore, by means of wind power plants, the energy supply to these regions can be improved significantly.

Savonius and Darrieus are two types of vertical axis wind turbine (VAWT) [5, 6]. A VAWT has several advantages compared to the horizontal axis wind turbine (HAWT) because it can receive the wind from any direction without the need for wind steering. The VAWT is also capable of operating well at low wind-speed conditions, with low noise, with efficient moving parts, and can fit easily with various shapes of the rotor, as well as being inexpensive to construct [7, 8]. Due to the lower blade tip speed, the VAWT is less noisy than the HAWT. A comprehensive list of the advantages of VAWT over HAWT has been reported by Toja-Silva et al. [9]. Analysis of the vertical axis turbine can be conducted by particle image velocimetry

*alfianmizar@um.ac.id

[10, 11]. In order to predict accurately the VAWT performance, grid resolution and fine azimuthal increment are required [12]. However, the performance of the VAWT is strongly determined by the wind turbine shaft power, torque, and the efficiency of the turbine generators [13] Therefore, the study focuses on the effect of the C rotor radius at the end on the performance of the HC-rotor of a Darrieus wind turbine blade's vertical axis.

## METHOD

### Darrieus HC-rotor wind turbine prototype

A Darrieus VAWT prototype is shown in Figure 1. This prototype was designed able to change C-rotor blade diameter manually. The rotor material of the Darrieus HC-rotor wind turbine from aluminum sheet with a thickness of 0.3 mm. Figure 2 shows the mechanical details of the shaft in the shape of J to facilitate the change of the C-rotor, which is subsequently locked with bolts. Moreover, the C-enter 10 mm rotor mounted on the end of the shaft. Besides the main shaft, we also prepared several rotor cups of different sizes (A = 76.2 mm, B = 101.6 mm, C = 152.4 mm) with a turbine blade of 800 mm height (H) and 800 mm diameter (2R) as depicted in Figure 3.

### Experimental set-up

In this study, we used 2 independent variables, wind speed and C-rotor blade diameter.The control variable used is the number of blades. The control variable is the three pieces of the blade as shown in Figure 2 a.

We conducted an experiment using our prototype with several trials. The prototype of the Darrieus HC-rotor wind turbineis placed in front of the wind tunnel in order to obtain different wind speeds. We used an electric motor with a power of 1 HP (740 Watt) and 1400 rpm connected to a fan with a diameter of 104 cm to produce wind in the wind tunnel. The wind speed can be adjusted according to the level by using an electric control device, as easy as we adjust the fan speed in the guest room. This artificial wind speed is adjusted to wind speed which is common in tropical regions, especially eastern Indonesia which ranges from 3 m/s to 7 m/s. In this experiment, each C-rotor blade has been

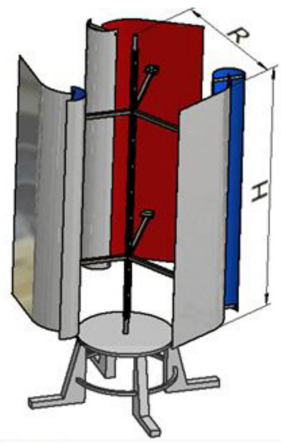



*Figure 1: Darrieus HC-rotor wind turbine prototype*

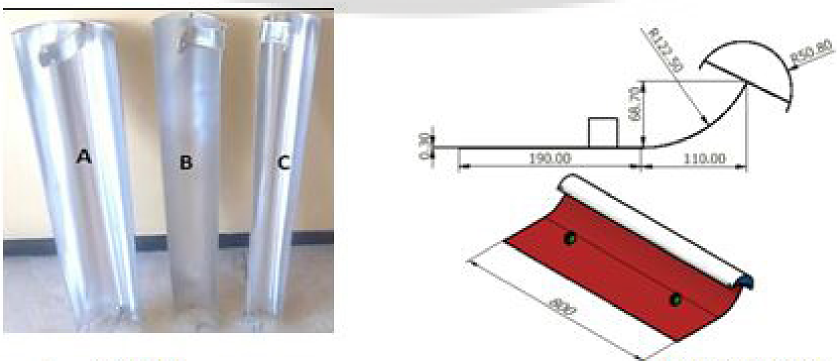
tested one by one in front of the wind tunnel, exactly at a distance of 30 cm from the air outlet wind tunnel (Figure 3).The wind speed was measured using a digital anemometer. The data was collected in a closed room to avoid air movement from other directions. One of the aerodynamic parameters of the HC-rotor measured in this experiment was the torque. The torque was calculated using Eq. (1):T = m. g. R, where m is the mass, R is the radius of the pulley, and g is the gravitational acceleration. The braking torque was measured with a steel wire that set the density using the turnbuckle to a pulley measuring 16 cm in diameter until it stopped. The braking load was measured using a digital scale.

### Average method for data analysis

A set of readings of the instruments were taken from several trials, where the individual readings may differ from each other. Thus, we should be concerned with the average readings of the same trial. Let xi be the reading of each instrument and n be the number of readings, thus the average is given by

$$x_{avg} = \frac{1}{n}\sum_{i=1}^{n} x_i$$

where i =1,2 , 3,...n is the ith readings. Finally, we collected data from 20 trial for each C-rotor blade, in order to obtain reliable estimates of standard deviation.




a. C-rotor b. dimension

*Figure 2: Rotor blade*

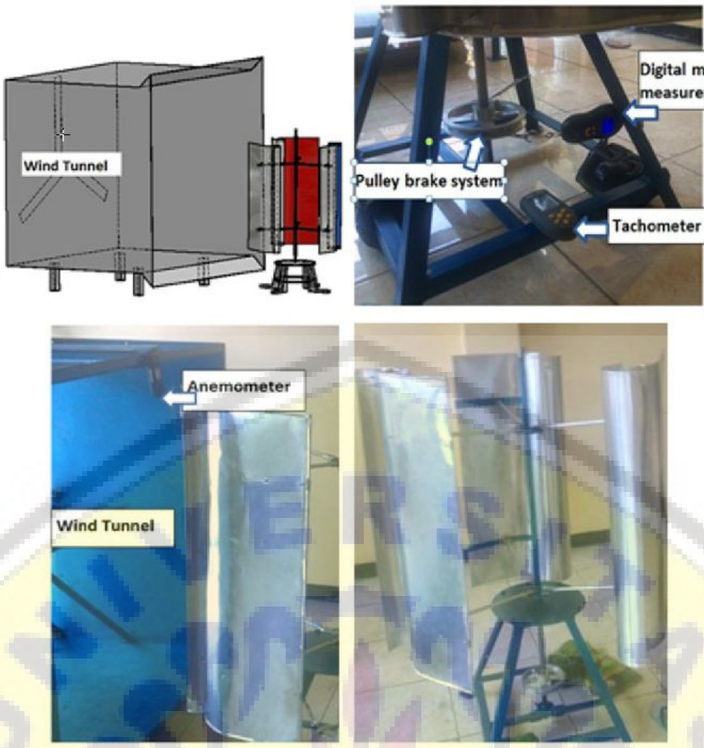



*Figure 3: Experimental setup*

### *ANALYSIS*

The performance of the Darrieus wind turbine HC-rotor can be determined by how well the wind energy is converted into shaft power, the rotation speed, torque, and coefficient of power produced by the wind turbine.

#### *Rotation speed shaft*

Figure 4 shows the relationship between the wind speed of the turbine shaft rotation speed measured by the tachometer. The highest rotation speed at any wind speed was reached by the HC-rotor with the 76,2 mm diameter. This phenomenon was caused by the larger diameter of the tip (C-rotor), and the fact that the greater the mass of the C-rotor, the greater the negative drag. Based on the theoretical physics, the translated kinetic energy of wind speed is converted into rotation speed kinetic energy at a rate of ½ mv2 = ½ I ω2, where m, v, I, and ω are the mass, translation velocity of the wind, and inertia and angular velocity of the turbine, respectively [14].

Furthermore, it shows that the turbine HC from the lab-scale test results can rotate with a minimum wind speed of 2 m/s. The ability of HC wind turbines to rotate at a wind speed of 2 m/s indicates a good potential because the wind turbine generators sold on the market are capable of producing electric power at wind speeds of 1.5–2 m/s.

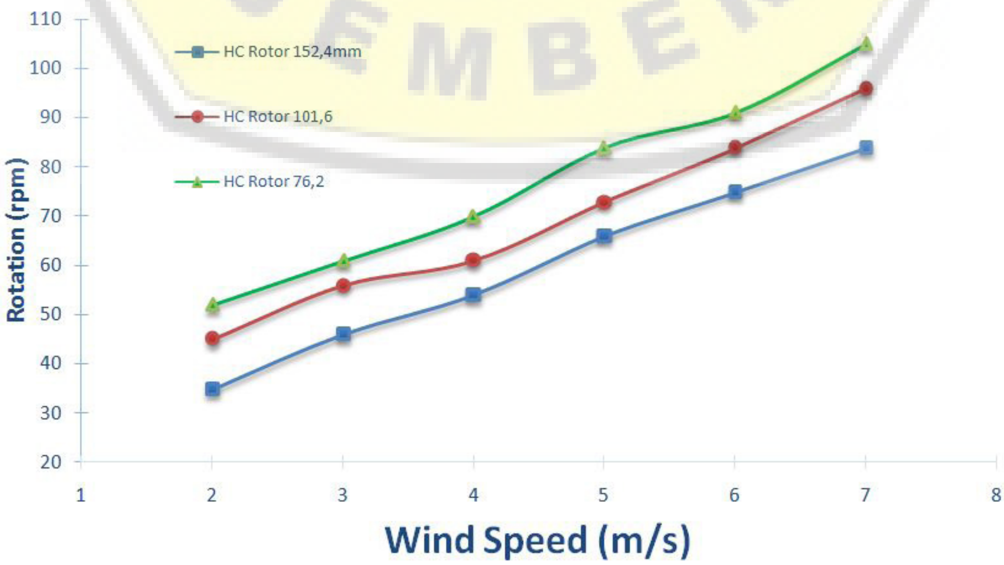



*Figure 4: Shaft rotation speed*

The maximum power of a wind turbine generator can be reached at around 200–500 rpm, and to increase the rotation speed of gear ratio can be used so it can be accelerated to reach peak power at wind speeds of 7–10 m/s.

### *Torque*

Figure 5 shows that the highest torque (4.630 Nm) was achieved at a wind speed of 7 m/s for the 152,4 mm HC-rotor, whereas the 101,6 HC-rotor has a maximum torque of 4.159 Nm and the 76,2 mm HC-rotor has a maximum torque of 3.846 Nm. The higher the wind speed, the greater the potential air converted. The HC-rotor with 152,4 mm diameter catches a larger wind area, so the torque generated is also great, but does not significantly increase in torque at a wind speed of 2 to 5 m/s. This is because the greater impact is on the front of the rotor so that the negative drag is also increased. Based on the theoretical physics, the higher the wind speed, the higher the torque according to the equation T = P/ω, where T, P, and ω are the torque, mechanical power, and angular velocity of the turbine, respectively [15].

### *Actual power*

Figure 6 shows the actual power, which increases as wind speed increases. The highest power of 42.262 W was obtained at 7 m/s wind speed for the 76,2 mm HC-rotor. The increase in power at a wind speed of 6–7 m/s for the 76,2 mm HC-rotor is slightly higher than that of the 101,6 and 152,4 mm HC-rotors because the rotor shaft rotation speed of HC-76,2 mm is greater than that of the other HC- rotors. In general, the performance of the HC-rotor with 76,2 mm, 101,6, and 152,4 mm diameters produces very similar power, which actually increases with the variations of wind speed.


*Figure 5: Wind speed vs torque*

Theoretically, the actual power will increase exponentially with the increase of wind speed [16]. However, in this work, the actual power tends to increase approximately linearly with the increase of wind power. This indicates that the wind turbine is not perfectly efficient. The actual power that can be achieved at this lab scale is still around 40 Watts, where there is a possibility of friction loss arising from the bearing. Increased power can be obtained by increasing the swept area to be connected to a generator.

### *Coefficient of power and tip speed ratio*

The coefficient of power (Cp) is the ratio of power compared with the airflow in the area of wind turbine exposure. This is the coefficient of the performance of wind turbines and shows the value of the turbine efficiency in converting the potential wind power into the power of wind turbines. Meanwhile, the tip speed ratio (TSR) is the ratio between the tangential speed of the tip of the rotor blade and the actual speed of the wind. In general, each wind turbine has different characteristics, so the Cp is also influenced by the tip speed ratio. For a wind turbine that has a graphic close to the Betz limit, the coefficient of its power will be higher as well as more efficient. The wide area under the graph shows that greater wind speed will have a greater effect on the turbine blades. So, these turbines are capable of utilizing the high wind speed to be converted into a high-speed turbine.

The starting point chart shows that the wind turbines will begin to work at a particular TSR value. If the starting point is at a low TSR, this means that the turbine is able to work at low wind speed. From Fig. 7, it appears that the 76,2 mm HC-rotor has a Cp value as high as 0.414 with a 0.703 TSR. The 101,6 HC-rotor has a Cp value of

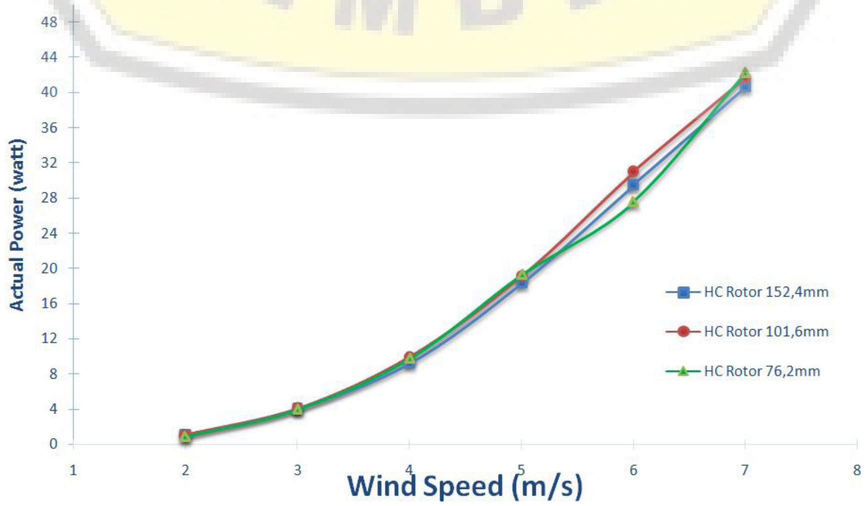



*Figure 6: Actual power*

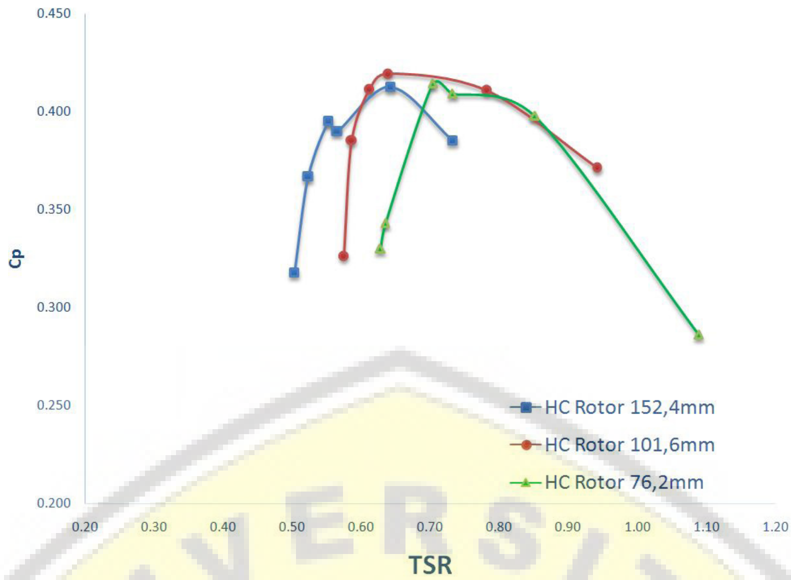


*Figure 7: Coefficient of power*

0.420 with a 0.638 TSR, while the 152,4 mm HC-rotor has a Cp value of up to 0.413 with a 0.642 TSR. If the TSR value > 1, this means that there is more lift force acting on the blade, but if the TSR value is <1, there will be a lot of drag force acting on the blade. In general, each turbine chart also indicates that the increase in the TSR does not directly increase the Cp. At a certain moment, the Cp is at its maximum, as shown in the graph in Fig. 7 comparing the TSR with the Cp. According to Fox et al., the increase of the TSR is not always related to the increase of the Cp, because the Cp will become saturated at the maximum position [17].

### *Coefficient of torque*

Figure 8 shows that the Darrieus wind turbine's HC rotor has a good self-start, because the TSR is low, though the fact that the value of Ct is greater than zero indicates that these wind turbines produce enough torque to overcome friction and losses at the start, so it is a very easy initial spin even though the wind speed is small. The highest Ct, obtained by the HC rotor with a diameter of 152,4 mm, amounted to 0.715 at 0.553 TSR. According to Adaramola, it can be seen that wind turbines with TSR ranging between 1 to 2 can be classified as having a low value, while a value of 10 or more refers to a high category of TSR [18]. The TSR value can be used as a parameter of the utilization, torque, efficiency, centrifugal stress, aerodynamic stress, area of solidity, aerodynamic and noise. A low TSR value indicates that the torque is held high, so it has a large drag force and can be used in designs for low wind speeds, while its aerodynamic level is included in simple categories. As the TSR small area of solidity increases, the stability of the rotor improves.

## *CONCLUSION*

Based on the results and discussion, it can be concluded that: (1) the highest rotation speed with a value of 105 rpm is achieved by the 76,2 mm HC-rotor at the wind speed of 7 m/s; (2) the torque and actual power continue to increase as the wind speed increases. However, the

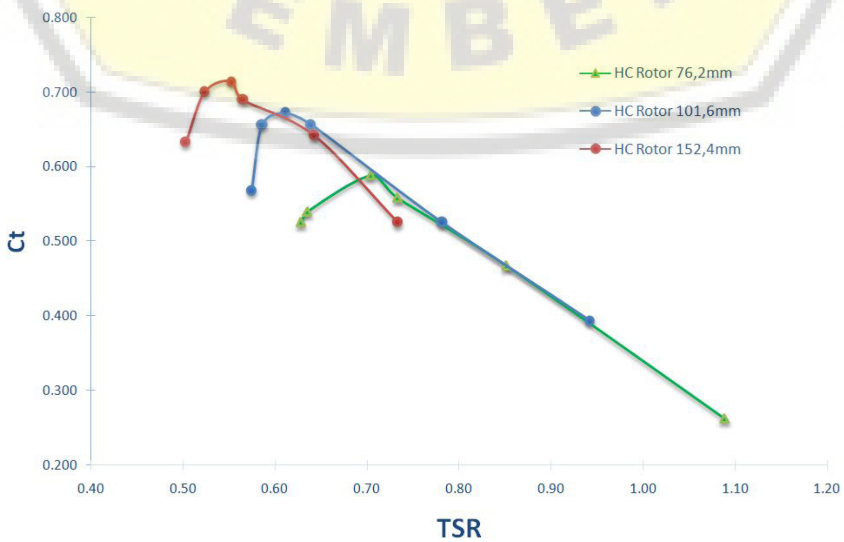


*Figure 8: Coefficient of torque*

torque elevation decreases when the wind speed reaches 6 m/s (3) the performances of the 76,2 mm, 101,6, and 152,4 mm HC-rotors which have an actual increase in power tend to be similar in all the variations of wind speed; (4) the highest value of 0.420 Cp is achieved by the 101,6 HC-rotor at a TSR of 0.638; (5) the highest Ct value obtained by the 152,4 mm HC-rotor amounted to 0.715 at 0.553 TSR; and (6) the Darrieus HC-rotor wind turbine is suitable for use in tropical regions that have low wind speeds because it has a good self-starting capability. It is recommended to conduct further tests on the use of electric generators on HC wind turbines with a minimum capacity of 200 W for lighting needs. The ability to start rotating at low wind speeds is a significant advantage of the HC rotor wind turbine.

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*Paper submitted: 30.01.2020.*
*Paper accepted: 21.08.2020.*