Effect of Tilt Angle on Archimedes Screw Pump Driven by Savonius Helical Windmill on Water Debit

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A B S T R A C T

One of the most abundant sources of renewable energy is wind energy. Indonesia has potential for low-speed wind because it is dominated by low-lying areas. Wind turbines consist of two types, namely horizontal turbines and vertical turbines which have differences in the turbine shaft. Based on the description above, one of the solutions that can be proposed is the design of a windmill with a more practical and lightweight transmission system so that the wheel is able to produce the expected final rotation even though the wind speed that hits it is relatively low, as well as the construction of a pump that can work in low rotation. The results showed that the fastest time to fill 1000 ml of water was at an angle of 48º. Changes in the amount of angle are directly proportional to the shaft rotation speed. The highest pumping discharge is at the 48º pump tilt angle variation. The greater the rotation of the shaft, the greater the discharge value produced up to the 48º angle variation. However, for pump inclination angles of 41º and 54º there is a decrease in discharge value which is influenced by the more upright slope of the pump. This causes the potential force on the water to also be greater, so that the gap area traversed by water is getting bigger. The purpose of this study is to determine the effect of the tilt angle of the Archimedes screw pump driven by the avonius helical windmill on water debit.

I. INTRODUCTION

Wind energy is recognized as one of the most abundant and sustainable sources of renewable energy available today. In Indonesia, the potential for harnessing wind energy is particularly promising due to the country's geographical characteristics, which are predominantly comprised of low-lying areas that experience low-speed wind conditions (Hidayat, and Sari., 2020). Despite these challenges, significant efforts are being made to effectively utilize wind energy through the development of innovative technologies, such as the Savonius helical type vertical axis wind turbine (Johnson, and Clarke., 2023). This turbine design is emerging as a competitive option for renewable energy conversion systems, specifically tailored to optimize performance in low wind environments (Liu, and Zhang., 2023). To maximize the efficiency of such systems, it is essential to conduct a thorough analysis of the optimal geometric configurations that can enhance the conversion of low-speed wind energy into usable power. This analysis involves examining key non-dimensional parameters, including the tip speed ratio (λ), the coefficient of moment (Cm), and the coefficient of power (Cp), all of which are critical in assessing the turbine's performance under varying wind conditions. By utilizing localized wind speed data from Indonesia, researchers can derive insights that inform the design and implementation of Savonius helical windmills, thereby establishing them as viable wind energy conversion systems capable of harnessing the low wind potential prevalent in the region. Consequently, the adoption of this technology is highly recommended, as it presents a sustainable solution to meet energy demands while contributing to the broader goals of renewable energy utilization in Indonesia (Nguyen, T. and Hoang., 2020).

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Wind turbines are primarily categorized into two distinct types: horizontal axis wind turbines and vertical axis wind turbines, each characterized by unique configurations and operational mechanisms pertaining to their turbine shafts (Lee, and Park., 2020). Vertical axis wind turbines, in particular, feature a shaft orientation that is parallel to the wind direction, allowing them to harness wind energy effectively from all directions. Among the various designs of vertical axis wind turbines, the Savonius helical turbine stands out due to its capability to operate efficiently at low wind speeds, making it particularly suitable for environments where wind conditions are less than ideal. This turbine design is notable for its ability to capture wind from any direction, thereby enhancing its operational flexibility and reliability (Aditya, and Kurniawan., 2021). The Savonius helical turbine offers several advantages, including an aesthetically appealing design that can be integrated into various settings without detracting from the surrounding environment. Furthermore, it exhibits a low torque change rate, with efficiency levels typically below 40% (Garcia and Martinez., 2021). This characteristic is beneficial as it contributes to a more stable performance during operation. Additionally, the torque variation across the blades of the Savonius helical turbine is relatively uniform, ensuring that the energy capture is consistent and reliable throughout its operational cycle. These attributes collectively position the Savonius helical turbine as a compelling option for wind energy applications, particularly in regions characterized by variable wind conditions. (Rosyid et al., 2020).

Research on a lobe pump model driven by a Savonius windmill was conducted. The pump model produced a small capacity (discharge 15 l/min and head 70 cm), so that to be applied in the field requires a very large Savonius dimension. This type of pump model is only suitable for areas that have wind potential with a minimum speed of 5 m/s. If the rotation is too low, the discharge produced by the pump is very little. Therefore, optimization of the length of the piston stroke and speed reduction in the transmission system are needed to produce optimum pump output (O'Reilly, and Smith., 2021) and (Patel, and Kumar., 2022).

Based on the description above, one of the solutions that can be proposed is the design of a windmill with a more practical and lightweight transmission system so that the wheel is able to produce the expected final rotation even though the wind speed that hits it is relatively low, as well as the construction of a pump that can work in low rotation. So in this study will use an Archimedes screw pump that can work in low rotation. The steps that can be taken to achieve this target are to make an appropriate Archimedes screw pump experimental tool with a suitable transmission system that can be used as an experimental study tool in utilizing wind potential in Indonesia.

II. METHOD

A. *Planning the Archimedes Screw Pump Experiment Station*

In design, there are many aspects that must be ensured. In designing a mechanical system, there are certainly requirements or criteria that must be met. This also applies in designing the Archimedes screw pump. The design of the Archimedes screw pump in this study is motivated by the prototype of the Savonius Helical windmill in the Energy Conversion Laboratory, Mechanical Engineering, Universitas Trunojoyo Madura which is designed for power generation. The design of the Archimedes screw pump in this study utilizes the output of the existing Savonius helical windmill as a driving force. Based on that, some components in the previous design will be used as initial data for designing Archimedes screw pumps such as blades and tool frames. This Archimedes screw pump has criteria that must be met, including criteria regarding the pumping needs itself, specimens, to the transmission system, and so on. In designing this Archimedes pump, design is carried out on engine components, determining engine specifications and sizes, and selecting materials that are in accordance with the design.

B. *Maintaining the Integrity of the Specifications*

A pre-existing helical savonius windmill is used as the motion input in this archimedes screw pump design. The construction of the helical savonius windmill uses a stainless steel plate as shown in Figures 1 and 1. The power of the windmill can be calculated using Equations

$$q = \frac{1}{2}\rho v^2 \quad (1)$$

$$P = F.v \quad (2)$$

$$F = q.A \quad (3)$$

obtained from wind speed data and the sweep area of the windmill blade.

Fig. 1. Construction of a helical savonius windmill.

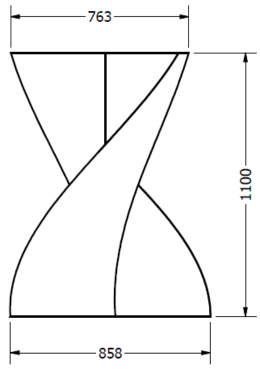

Fig. 2. 2D helical savonius windmill design in mm

Experiments in this study were conducted using a subsonic type wind tunnel. The wind speed parameter was varied from 1 m/s to 5 m/s. In addition, the pinwheel was also varied to its twist angle, which was 0˚, 22.5˚, 45˚, and 90˚ with the addition of an end plate ratio of 1.1. Windmill testing in the wind tunnel was carried out to determine the effect of variations in wind speed and twist angle on the rotation of the pinwheel produced..

III. RESULT AND DISCUSSION

The experiment was conducted using a wind speed of 8 m/s with a rotation of 52 rpm. Measurements were made of the time required for the pump to raise water to 1000 ml in each angle variation. Measurements made for each variation were repeated 3 times. The experimental data can be seen in Table 1.

TABLE I. AVERAGE TIME NEEDED TO PUMP 1000 ML OF WATER.

Angle	Universal Joint Angle	Replication 1 (sec)	Replication 2 (sec)	Replication 3 (sec)	Average time (sec)
36º	27º	257,4	256,2	253,2	255,6
39º	25,5º	205,2	207	208,8	207
42º	24º	186	181,8	184,8	184,2
45º	22,5º	132	123	126,6	127,2
48º	21º	86,4	87	82,8	85,40
51º	19,5º	120,6	122,4	121,2	121,40
54º	18º	135	136,8	137,4	136,40

Experimental results for a wind speed of 8 m/s that hit the blade of the Savonius windmill showed that the fastest time to fill 1000 ml of water was at an angle of 48º, while the longest time needed to fill 1000 ml of water at an angle of 35º. As for the highest discharge value of water pumping occurs at a shaft angle of 48º (amounting to 11.7 L / s) and the lowest discharge is obtained at a pump angle of 35º (amounting to 3.8 L / s). Water debit increased in the experiment shown on Table II.

TABLE II. WATER DEBIT INCREASED IN THE EXPERIMENT

Angle	Universal Joint Angle	Replication 1 (sec)	Replication 2 (sec)	Replication 3 (sec)	Debit (ml/s)	Shaft rotations (RPM)
36º	27º	257,4	256,2	253,2	3,9	47
39º	25,5º	205,2	207	208,8	4,8	48
42º	24º	186	181,8	184,8	5,4	50
45º	22,5º	132	123	126,6	7,9	52
48º	21º	86,4	87	82,8	11,7	53
51º	19,5º	120,6	122,4	121,2	8,2	54
54º	18º	135	136,8	137,4	7,3	55

The designed helical savonius windmill is capable of producing a power of 331.76 kg.m2/s3 and a shaft rotation of 72 rpm without loading the transmission system and pump. After assembly with the transmission system and pump, the shaft rotation obtained can be seen in table 4.3 with a torque value on the universal joint of 59.78 kg.m2/s2. From the calculation results, at an angle of 45º the water discharge that can be raised by the pump is Q = 9.86 ml/s. Meanwhile, from the experimental results, the water discharge that can be raised by the pump is Q = 7.9 ml/s. Thus, there is a difference between the results of theoretical calculations and experiments conducted, Table II shows that the fastest time to pump 1000 ml of water is at an angle of 48º with the longest time is at an angle of 36º. In Figure 4.2 the effect of angle on the rotational speed of the shaft can be interpreted that from an angle of 36º to an angle of 54º there is an increase in the value of rotation speed based on the amount of pump tilt angle. The increase in the trend is influenced by the smaller angle of the universal joint when the pump tilt angle is getting bigger as in table 4.3.

From the experimental results, the length of time to pump 1000 ml of water varies greatly based on the variation of the pump tilt angle formed. In the experimental results, the fastest time is at a pump inclination angle of 48º for 1.42 minutes, which at that time can produce a water discharge of 11.7 ml / s. The relationship between time and the resulting discharge can be concluded that the faster the time to pump water, the greater the discharge will be. In contrast to the research conducted by (Smith, and Brown., 2022) which explains the optimal design results of the pump tilt angle at an angle of 38º. This is because the experiments carried out using the Savonius helical windmill with a universal joint transmission system. Universal joints have distinctive characteristics, namely in one rotation producing fluctuating output angular velocities with the value of the working angular velocity will be more optimal if the working angle on the universal joint is smaller In the Archimedes screw pump design, the pump angle is inversely proportional to the working angle of the universal joint. That is, the greater the pump angle, the smaller the working angle of the universal joint so that the rotational speed of the shaft will be greater and the water discharge will also be greater. However, at angles of 51º and 54º the decrease in discharge value is influenced by the more upright the slope of the pump, which causes the potential force on the water to also be greater. Where, the area of the gap traversed by water is getting bigger as in Figure 3

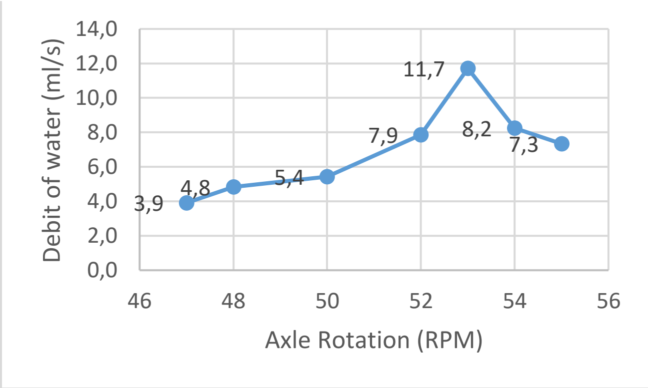

Fig. 3. 2D helical savonius windmill design in mm

IV. CONCLUSSION

The findings of this study indicate that the optimal tilt angle for the Archimedes screw pump, driven by a Savonius helical windmill, is 48º, as it resulted in the fastest time to fill a volume of 1000 ml of water. This optimal angle significantly enhances the efficiency of the pumping mechanism, demonstrating a clear relationship between the angle of inclination and the rotational speed of the shaft. Specifically, as the tilt angle increases towards 48º, there is a corresponding increase in the shaft rotation speed, which directly correlates with the pumping discharge. At this angle, the pump achieves the highest discharge rate, indicating that the design and operational parameters are finely tuned to maximize performance. The results suggest that the increased rotation of the shaft leads to a higher discharge output, illustrating the importance of the tilt angle in optimizing the hydraulic performance of the pump. However, it is noteworthy that at inclination angles of 41º and 54º, a decline in discharge values was observed. This decrease can be attributed to the more upright slope of the pump, which alters the dynamics of fluid flow. As the angle deviates from the optimal 48º, the potential force exerted on the water increases, which in turn affects the gap area through which the water must traverse. The steeper angles lead to a greater resistance against the fluid flow, thereby reducing the effective discharge. This study underscores the critical influence of tilt angle on the performance of Archimedes screw pumps. It highlights the necessity of careful consideration in the design and operational settings of such systems to achieve optimal efficiency and effectiveness in water transport applications. Future research could explore the implications of varying other parameters, such as fluid viscosity and rotational speed, to further enhance the understanding of Archimedes screw pump dynamics in different operational contexts.

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