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Design, Fabrication, and Testing of Small Wind Pump

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ABSTRACT

The demand for energy used to pump water for irrigation has been increasing, resulting in the need for alternative renewable energy sources to reduce costs. A study was conducted to develop a small wind pump that could be used to irrigate crops. The wind pump's efficiency, discharge, and actual power generated were evaluated, and regression analysis and the coefficient of determination were used to determine the goodness of fit. Results showed that the wind pump required a minimum wind speed of 0.3 m/s and produced a discharge of 0.95 L/min, while a 4.13m/s wind speed produced a water discharge of 5.45 L/min. The efficiency of the wind pump was measured using the regression equation $E= - 04075(ws)^2 - 0.6375(ws) + 14.36$, where $R^2 = 0.6201$, resulting in a maximum efficiency of 20.56% and a minimum of 5.57%. This indicates that the wind pump was efficient at low wind speeds due to the dynamic stress of the pump lift rod and a mismatch between the rotor and pump characteristics. Lastly, the net benefit of Php 25,083.61 per year was derived, with a return on investment of 100.66%, which will be paid back in 0.99 months.

Keywords: *Discharge, Efficiency, Fabrication, Small Wind Pump, Wind Speed*

INTRODUCTION

Water pumping is a significant and most basic widespread energy need in rural areas (Gandhi et al., 2015). Water pumping from reliable renewable energy is a challenge worldwide to minimize the cost of fuel like wind energy. According to Olabi et al. (2023), wind energy rapidly expands and contributes to many countries' efforts to decrease greenhouse gas emissions. Wind energy is a renewable energy source that progresses day by day. Renewable energy sources, which have great potential in the agricultural sector, can contribute to agricultural activities. (Yelmen et.al (2021). In addition, Abdul B. et al. (2022) state that a sustainable energy supply could be attained by employing renewable energy sources. Increased energy production from renewable energy sources is one approach that can help reduce gas emissions from burning fuels and lay the groundwork for a clean and green world.

However, constructing a wind energy pumping system is a vital concern that could affect the pump's performance. According to (Ramakuma & Uthayakumar, 2015) windmill for water pumping is a complex process that involves the selection of the appropriate wind turbine, rotor, and pump. Several things must be considered for wind power development, such as noise generated, maintenance costs, waste, and so on (Aslami et al., 2023). Asamoah et al. (2018) showed the performance of a windmill water pumping system at a rate of 2.4 liters per minute at a wind speed of 4 m/s. (Alhijji et al. 2017) recommended that using a horizontal turbine by adding a greater number of blades, more torque, and revolution at lower wind speeds could attain high efficiency. A wind pump prototype with 3.6 m rotor diameter, 19 m hub height above ground, and 0.22 mm reciprocating pump stroke. The measured average daily discharge with the 55 mm pump was 20 and 19 m^3 at 8 m and 12 m head, respectively. The average daily discharge with the 70 mm pump was 41 m^3 and 30 m^3 at 8 m and 12 m head, respectively (Bayray et al., 2019).

In the Philippines, numerous studies and a government mandate accelerated the utilization of renewable energy sources (Aquino and Albeleda, 2014). A study by (Mendoza, Guinto & Ortiz, 2018) identified potential wind farm sites in the province of Batangas using a combination of wind resource mapping and spatial analysis techniques. Daily discharge of the wind-pump system fluctuated from 0.7 m^3day-1 to 22.1 m^3 Day-1 with an average of 9.2 m^3 day-1. Based upon the relationship between wind speed and discharge of the wind-pump system, annual average daily wind speed of 1.78 m s-1 in Nueva Ecija, central Luzon, Philippines will make it possible to discharge 8.38 m^3 day-1 of water with the wind pump (Bautista, et al., 2015).

In Nueva Vizcaya, an assessment of historical wind speed with an average of 3 m/sec could be a potential power source on a water lifting device (Danilo and Guillao, 2022). To harness this power potential in the said location, a proposed design of a small wind pump that could used to lift water from the water source. This adaptation of technology reduces water scarcity and minimizes the use of fossil fuel water pumping devices. The study aims to develop, make, and test a small wind pump designed with a horizontal axis rotor assembly that can draw water from a significant water source.

MATERIAL AND METHODS

Design of small wind pump

The pump head determines the size of the wind pump blades, and the amount of hydraulic power required must match the wind power that can be harnessed. The number of blades can vary from 8 to 24, depending on the design and wind conditions. The blades are curved and placed at an angle in the direction of the wind, which helps them operate more efficiently. To achieve the optimal angle of attack, it is recommended that the angle be set in the range of 25° to 35° (Jayanarasimhan, et al., 2022). Equation 1 was used to size the wind pump based on the average wind speed in the area.

$$\frac{1}{2}\rho_a A v^3 C_p = \rho_w g Q H \quad (1)$$

Where: ρ_a is the density of air (kg/m^3), A swept area of rotor, m^2, v^3= wind speed (m/s), cp is the coefficient, ρ_w is the water density (kg/m^3), g is the gravitational acceleration in m/s^2, Q is water discharge, and h is the head in meters.

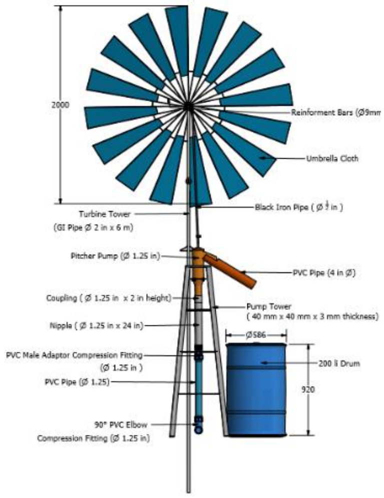

Figure 1. Design of the wind pump

Fabrication

The wind pump is designed based on locally available materials. The wind blade base and shafting are welded using a pillow block, angled bars, and a crankshaft. The wind pump has 16 blades with an angle of attack of 30° for optimal efficiency. The tower is made of 2-inch G.I pipes with a height of 6 meters and is secured with concrete. The wind pump and pump rod are assembled on a crankshaft, which converts wind force into rotating motion, automatically pumping the pitcher pump.

Testing

The pump (Figure 2) was tested by manually applying the pitcher pump to assess the water produced. Determining the wind pump's safety and functionality would enable an efficient output. Observations of the problems encountered were noted for further adjustments after the preliminary testing. The initial test was done for 3 days. A collection of wind speed and rpm was conducted to add accuracy to the data and identify lapses before performing the final test. The preliminary testing results had an average minimum starting velocity of 0.3m/s and an average maximum windspeed of 7.248 m/s. The minimum windspeed produced 14 rpm, while the maximum windspeed produced 95 rpm. During the preliminary test, the water loss upon pumping water is also observed, resulting in adjustment and tightening of the pipe. Table 1 shows the equipment and materials used for the testing of a small wind pump

Figure 2. Testing of Small wind pump

Table 1. Equipment and materials

Material	Specification
Anemometer	An instrument used to measure the wind speed in an area.
Volumetric Method	Measurement of water discharge of the wind pump (14-liter capacity)
Timer	A time interval was used to measure the pump's water discharge. Data recording starts as the wind speed is measured with an hour interval.
Methodology sheet	The collected data was written in the record book for transparency and accuracy

Data gathered and analysis

The following parameters were measured to gather the data: (a) wind speed was measured using an anemometer in meters per second (m/s), (b) revolutions per minute were counted manually with a timer for one minute, (c) discharge was calculated using the volume formula. The head of the water in the pale was measured using a ruler, (d) terminating time is when the wind pump functioned, and it was recorded using a timer. The collected data were analyzed using regression analysis. The collected data included wind speed, revolutions per minute, discharge, power input, power output, and wind pump efficiency. By analyzing the data in regression, we could project the equation relationship with wind speed as the independent variable and determine the correlation coefficient (R). This method helps us to gain valuable insights into the relationship between wind speed and other variables, which is crucial for making informed decisions and developing effective strategies.

Cost analysis

The following parameters were used to determine the financial indicators to ascertain the device's financial viability. Table 2 presents the basic assumptions for computing annual cost, custom rate, net income, return on investment, and payback period.

Table 2. Basic assumption in calculating the cost of using the small wind pump

BASIC ASSUMPTIONS	Value
Investment Cost, PhP	31,575.60
Salvage Value (SV) 10% of IC, PhP	3,157.56
Useful Life, yrs.	5
Interest Rate, i	12.5
Taxes, Insurances and Shelter,3% of IC, PhP	947.268
Labor Cost, PhP/day	450
R & M 5% of IC, PhP/yr	1578.78
Operating time, days/yr	250
Operation Period (8hrs/day), hrs/yr	2000
Pumping Capacity, m^3/hr	0.33

RESULTS AND DISCUSSION

Description of Wind Pump

The wind pump design has certain specifications, including a starting wind speed of 0.3 m/s at 6 m above the ground, a design head of 12.5 m, and a rotor with a diameter of 2 m. The rotor has 16 multi-blades made up of reinforcement bars with a sieve diameter of 9 mm and an umbrella cloth designed to capture available wind with aerodynamic principles. The pumping rod is 4 m long and uses a black iron pipe with a ½ diameter connected to the rotor and running down to the pitcher pump. The wind pump tower comprises a GI pipe with a diameter of 2 m and is supported by connected tire wires.

The pitcher pump, with a diameter of 1.25 in, is used to lift water. It consists of a tower ladder and a wind pump base connected using bolts and nuts. The coupling has a height of 2 in by 1.25 in, and the nipple has a diameter of 1.25 in by 24 in. The PVC male adaptor compression fitting has a diameter of 1.25 in, and the PVC pipe has a diameter of 1.25 in. The PVC elbow compression fitting has an angle of 90o and a diameter of 1.25 in, while the PVC pipe with a diameter of 4 is connected to the pitcher pump discharge outlet.

The pump tower has dimensions of 40mm by 40mm by 3mm thickness, and a 200-liter drum with a diameter of 586 and a height of 92 is connected to a coupling (2 in) connected to the pitcher pump. The pillow block and base are composed of 2 pillow blocks with ¾ in diameter and an angle bar, a motorcycle sprocket screwed using bolts and nuts. Shafting and fulcrum are welded to the rotor in connection to the pumping rod. Most of the components are readily available in junk shops and small workshops.

Figure 5 shows the wind pump design. Wind blades are sewn with umbrella cloth with aerodynamic principles. They are composed of 16 multi-blades that catch the wind and convert the mechanical drive to lift water. The wind pump shafting and crankshafts are tools assembled to hold and respond to the rotation of the wind pump rotor, which relies on the varying wind velocity in the area.

A wind pump tower is a structure held in place, serving as the foundation of the wind pump. It is 6 meters from the ground level and supports the pitcher pump. Discharge storage is used to store water lifted by the pump.

Average wind speed

Figure 4 displays the average wind speed recorded between April 16, 2023, and May 14, 2023, from 9:00 AM to 6:00 PM. During this period, the highest wind speed was recorded between 5:00 PM and 6:00 PM, with an average of 4.30 m/s, whereas the lowest maximum wind speed was recorded between 9:00 AM and 10:00 AM, with an average of 1.27 m/s. According to Danilo and Guillao's 2022 analysis of wind speed per month, the average mean wind power for April and May is 8.50 watts and 8.92 watts, respectively. Another study by Lucas, Sato, and Ohba in 2021 indicates that onshore wind speeds decrease during the transition period between the land breeze and sea breeze, especially over coastal regions with high-sloping topography. The decrease in wind speed during morning hours is quite significant, as it often coincides with the extreme electricity undersupply caused by the morning increase in energy demand

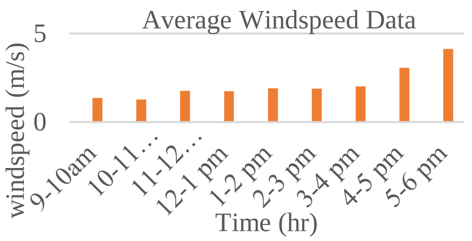

Figure 4. Average windspeed on site

Rotation of wind turbine as affected by wind speed

Figure 5 shows the relationship between wind speed and RPM (revolution per minute). The graph shows that at the lowest wind speed of 0.3 m/s, the wind produces 8 revolutions per minute, and at the highest wind speed of 4.13 m/s, the wind pump produces 35.63 revolutions per minute. The regression equation is R= 7.5856(ws) + 1.4928, and the coefficient of determination is 0.8943. This means that there is a strong correlation between the average wind speed and RPM. According to a study by McGowan, Lozano, and Raghav in 2012, tip speed ratios should have a relatively high solidity but not so high as to compromise their efficiency.

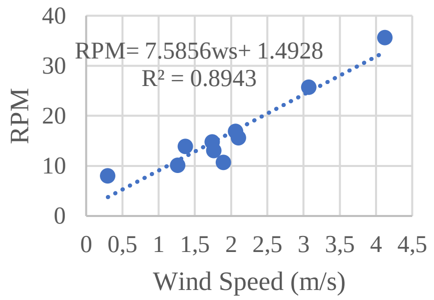

Figure 5. Rotation of wind blade (RPM) as affected by windspeed

Windpump discharge as affected by wind speed

Figure 6 displays the performance evaluation of the wind pump in relation to the average wind speed and water discharge. The graph reveals that the wind pump produces a discharge of 0.95 L/min at the lowest average wind speed of 0.3 m/s, while at the highest wind speed of 4.13 m/s, the discharge increases to 5.45 L/min. Additionally, the regression equation between the wind speed and discharge is equal to $0.3937(ws)^2$ - 0.5417x(ws) + 0.9964. The coefficient of determination is 0.9687, indicating a strong correlation between the average wind speed and discharge. The graph also illustrates that as the wind speed increases, the water discharge produced by the wind pump also increases.

According to research by Syahputra (2015), the wider the leaf of windmills, the more water discharge can be produced. However, there is an optimum width of the windmill leaf beyond which the discharge will decrease. The discharge increases with an increase in the diameter of the blade, but it falls back down if the blade diameter is enlarged after the maximum discharge.

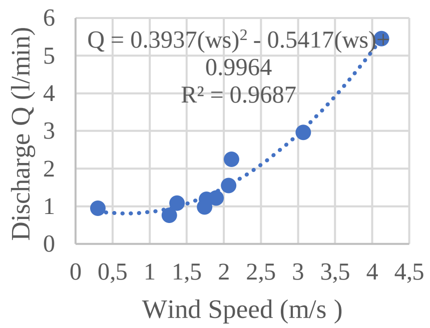

Figure 6. Windpump discharge (li/min) as affected by windspeed

Theoretical power of the wind

Figure 7 presents the performance evaluation of the relationship between the average wind speed and the power generated by the wind. The graph shows that when the average wind speed is at its lowest of 0.3 m/s, the power produced is 0.13 watts. Conversely, when the wind speed is at its highest of 4.13 m/s, the power generated is 169.71 watts. Furthermore, the regression equation Pw = 13.935(ws)^2 - 18.319(ws) + 7.0404 shows the correlation between the wind speed and the power of the wind. The coefficient of determination of 0.9945 indicates a strong correlation between the two variables. The graph also reveals that as the wind speed increases, the power generated by the wind increases as well. Lastly, Kalmikov (2020) stated that the efficiency of wind power extraction is a balance between slowing down the wind and maintaining a sufficient flow.

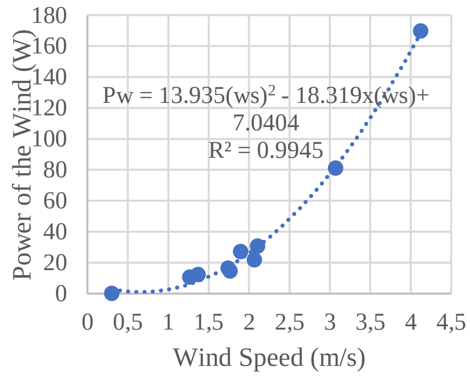

Figure 7. Wind Power Produced (W) as Affected by the Windspeed

Hydraulic power small wind pump to lift water

In Figure 8, we can see the performance evaluation of the wind pump, comparing the average wind speed and power produced. At the lowest average wind speed of 0.3 m/s, the wind pump produces a power of 1.68 watts. At the highest wind speed of 4.13 m/s, the wind pump produces a power of 9.60 watts. The regression equation (Po= 0.6945(ws)^2 - 0.9604x(ws)+ 1.7625) between wind speed and power of the pump indicates a strong correlation between the two, with a coefficient of determination of 0.9686. Furthermore, the figure shows that the power of the wind increases as the wind speed increases. According to Kalmikov (2020), the efficiency of wind power extraction depends on finding a balance between slowing down the wind and maintaining a sufficient flow.

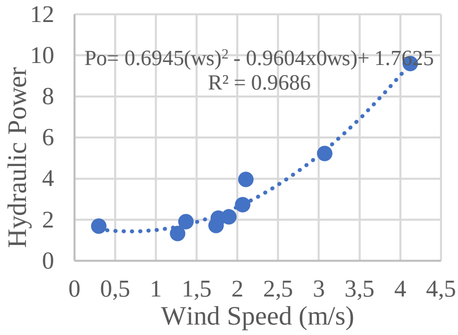

Figure 8. Hydraulic power of wind pump (W) as affected by windspeed

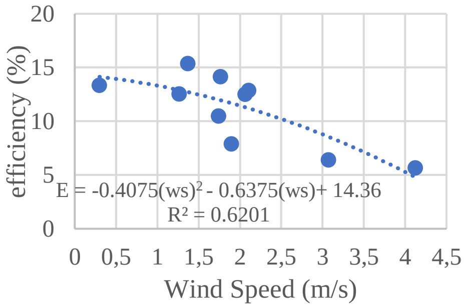

Figure 9. Efficiency of Wind Pump as Affected by Wind speed

Efficiency of small wind pump

Figure 9 displays the performance evaluation of the wind pump's efficiency against the average wind speed. The results indicate that the wind pump produces an efficiency of 12.53% at the lowest average wind speed of 1.27 m/s and 5.65% at the highest wind speed of 4.13 m/s. The regression equation E=0.4075(ws)20.6375(ws)+14.36 shows the relationship between wind speed and the efficiency of the wind pump. The coefficient of determination is 0.6201, indicating a moderate correlation between the average wind speed and pump efficiency.

Furthermore, the overall system efficiency is calculated as a function of wind speed. The pump system shows a high efficiency of 15% at the cut-in speed and performs best at lower wind speeds. However, the efficiency continuously decreases with the increase in wind speed. This is due to the dynamic loading of the pump lift rod and the mismatch between the rotor and piston pump's characteristics, which is expected from wind pumps with piston pumps (Bayray, et al., 2015).

Simple Cost Analysis of Wind Pump

Using the small wind pump, the cost of water delivery varies from ₱31,575.60. Assuming a single operation and an 8-hour daily operating time, and considering a total of 64,800.00 annual work production hours per year, the wind pump has an annual fixed cost of 8,995.94 and a variable cost of 44.26. These parameters are obtained using financial analysis equations that determine the viability of the device. The wind pump requires an investment cost of Php 31,575.60 with a useful life of 5 years and an interest of 12.5 percent referred to Agri Bank Philippines, a labor cost of Php 450.00 per day, and a pumping cost of 0.33 m^3/hr. Based on this data, the pumping capacity is cost-effective for water consumption, considering the basic assumptions in calculating the financial analysis. Based on the assumptions in the cost analysis, the wind pump was analyzed financially with an investment cost of Php 31,575.60. The wind pump’s pumping capacity is computed to be 0.33 m^3/hr, which costs 138.37 Php/m^3. The breakeven of the pump was 2,534.4 m^3 with a net benefit of Php 25,083.61 per year. The return on investment has a percentage of 100.66, which will be paid back in 0.99 months.

The results show the financial viability of the small wind pump as it goes along with the results of the assessed cost of energy of different sources for irrigated shallot farming in some coastal regions of Ghana by S. Abdul-Ganiiyu et. al. (2024). The 5.0 m Poldaw wind pump is the most economical compared to other energy sources studied (except for grid electricity). However, the study results show the gains of grid electricity over the 5.0 m Poldaw wind pump are quite marginal and could be eroded with increasing electricity prices, and wind pumps mounted at increased heights with better wind speeds.

As to the results of this study, the small wind pump water cost of 138.37 Php/m³ based on its water pumping capacity resulted in a relatively high cost of water compared to the existing water cost of 25 Php/m³. However, frequent fluctuating electricity charges in the province would affect gradual changes in water cost charges, resulting in marginal differences. Considering also that the pumping system shall be strategically located at higher heights to harness better wind speeds.

CONCLUSION

After conducting a study, it was found that the designed wind pump is effective at low wind speeds. The wind pump's performance was directly proportional to the wind speed regarding blade rotation, discharge, wind power, and hydraulic power. However, the pump's efficiency decreases as the wind speed increases due to the dynamic loading of the pump lift rod and the mismatch between the rotor and pump characteristics. Based on the study's findings, future researchers can improve their research papers by following the following recommendations: Firstly, the wind pump should pivot to collect all available wind in any direction. Secondly, it is recommended to fabricate the wind pump with a wind tail and wind vane to balance the wind pump blades and direct wind positions. Finally, optimizing the pumped water produced would be beneficial for the wind pump for irrigating crops.

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