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# Efficiency And Hydraulic Power Of Poldaw Windpump Systems At Some Locations In Northern Nigeria

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**ABSTRACT**

*The overall efficiencies and mean hydraulic power outputs for the 1.8m, 2.2m, 3.5m and 5.0m Poldaw windpump systems were evaluated for Jos, Kano, Sokoto and Zaria, which are all, locations in northern Nigeria. The overall efficiencies for the four windpump systems ranged between 10% and 16 %. The overall efficiency for each windpump system was found to increase with increase in the hydraulic equivalent load and decrease in wind speed. The hydraulic power outputs were found enough to irrigate more than one hectare of agricultural land in Jos, Kano and Sokoto for the 5.0m windpump system; Jos only for the 3.5m windpump system; none for the other two. However, the 5.0m and 3.5m windpump systems were found capable of supplying domestic water to more than 500 inhabitants in the four locations; 2.2m windpump system in Jos, Kano and Sokoto; Jos only for the 1.8m windpump.*

***KEYWORDS :*** *Hydraulic Equivalent Load, Hydraulic Power, Overall Efficiency, Wind Speed, Windpump System*

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## I. INTRODUCTION

The most important consideration for selecting a windpump is the hydraulic power requirement, which is the power required to lift a certain quantity of water needed within a specific time period over a certain height. This power depends heavily on the hydraulic equivalent load, being the product of the pumping head, $H$ (m), and daily volume of water pumped, $Q$ (m$^3$/day). The wind supplies this power, which turns the rotor. The diameter of the rotor, which is related to its area, is the main characteristic of a windpump.

There is a limit to how much power that can be extracted by the rotor. The theoretical maximum power that can be extracted by a wind rotor, is only about 59.3% (known as betz limit) of what is available in the wind. This is only the efficiency of the rotor, otherwise known as the power coefficient $C_p$. In practice, the maximum for windpumps is less than the betz limit. The efficiency of the various components of a windpump system in converting the kinetic energy per second of the wind into useful power can be categorized as follows [1]:

- Conversion of wind power to rotor power ($C_p$ = 0.2 to 0.4)
- Transmission and pump (efficiency, $\eta$ = 0.4 to 0.8)

The losses as a result of the above two factors are obviously mechanical in nature. Another loss that is incurred is due to improper wind matching. It has its origin in the fact that a windpump runs optimally only at the wind speed to which it has been matched. A wind regime, however, has its wind speed continually varying, resulting in sub-optimal operation of the windpump most of the time. This improper wind matching accounts for up to 50% of wind power loss. Considering these three factors ($C_p$, $\eta$ and matching), the wind-to-water power conversion is done with an overall efficiency estimated at 5% to 15% [1].

The Poldaw Windpumps are a range of medium sized low cost machines, designed and developed by Neale Consulting Engineers Ltd (NCEL), UK, intended for application in developing countries. The performance of Poldaw Windpumps depends on pumping head and wind speed. There are four models of the

Poldaw Windpump: 1.8m, 2.2m, 3.5m and 5.0m machines. Alkatbu Technologies Ltd, Bauchi, Nigeria, manufactures the machines under license from NCEL.

This paper is intended to evaluate the overall efficiency of Poldaw Windpump systems as a function of the hydraulic equivalent load at wind speeds of 3 m/s and 4 m/s and also to estimate the mean hydraulic power output and hence, the mean daily water output from these windpump systems operating at 10 m height at the following locations: Jos, Kano, Sokoto and Zaria. The hydraulic power estimates would be conservative, because the wind speed data used is from airports, which are situated in sheltered sites in these four locations.

## II. BASIC THEORY

The hydraulic power, $P_h$, needed to lift a volume of water per second over a total pumping head is given by [2]:

$$P_h = \rho_w g H Q, \quad (1)$$

where,
$g$ is acceleration due to gravity (m/s$^2$)
$\rho_w$ is density of water (kg/m$^3$)
$H$ is total pumping head (m)
$Q$ is water output (m$^3$/s).
Substituting $\rho_w$ = 1000 kg/m$^3$, $g$ = 9.81 m/s$^2$ and $Q$ in m$^3$ per day, equation (1) becomes:

$$P_h = 0.1135HQ, \quad (2)$$

The real scenario is that more power than indicated in equation (2) is required to lift water. The input power for the pump passes through a number of components before it is made available as useful hydraulic power (In the case of a windpump: the rotor, gear box and transmission shaft). Each component has an associated loss of power, meaning that the input energy needed for pumping is generally far greater than the useful hydraulic energy output.
The power available at any instant in a wind blowing through an area, is a function of its speed and air density, and is given by [3]:

$$P_a = (1/2)\rho_a A V^3 \quad (3)$$

where,
$P_a$ is available power (W)
$\rho_a$ is air density (kg/m$^3$)
$A$ is area (m$^2$)
$V$ is wind speed (m/s).

The hydraulic power output from a windpump can also be estimated from [4]:

$$P_h = (1/2)\eta_{ov}\rho_a A_r V^3 \quad (4)$$

where,
$P_h$ is hydraulic power (W)
$\eta_{ov}$ is overall efficiency of windpump system
$A_r$ is rotor area (m$^2$).

Equating equations (2) and (4), and substituting $\rho_a$ = 1.2 kg/m$^3$, the rotor area $A_r$ by $0.25\pi d^2$, where $d$ is the rotor diameter, the overall efficiency of a windpump system becomes:

$$\eta_{ov} = 0.24(HQ/d^2V^3) \quad (5)$$

The mean hydraulic power, $\overline{p_h}$, from a windpump within a certain interval of time, at a particular location can be shown from equation (4) to be:

$$\overline{P_h} = 0.47\,\overline{\eta_{ov}}\,K_e d^2\,\overline{V}^3 \quad (6)$$

where,
$\overline{\eta_{ov}}$ is mean overall efficiency of the windpump system,
$K_e$ is the energy pattern factor of a location given by $\overline{V^3}\big/\overline{V}^3$,

$\overline{V^3}$ is the mean cube of wind speeds within the same time interval as in equation (6)

$\overline{V}$ is the mean of wind speeds within the same time interval as in equation (6).

## III. METHOD OF ANALYSIS

### 3.1 Pump Performance Data, Wind Speed Data and Energy Pattern Factor

The pumping performances of 1.8 m, 2.2 m, 3.5 m and 5 m Poldaw windpumps in litres per day for various total pumping heads and at wind speeds of 3 m/s and 4 m/s were obtained from [5]. These were converted to metre cube per day. Reference [6] obtained long-term observed wind speed data at 10 m height, for a number of locations including the four used in this paper from the Nigerian Meteorological Agency, Oshodi, Lagos, Nigeria. The observed wind speed data is daily averages in knots and was measured from surface anemometers. The wind speed data was summarised into a form suitable for analysis by [6]. The wind speed data used in this analysis is annual mean wind speeds obtained from [6]. This is shown in Table 1.

Energy pattern factor is another variable required for the estimation of the mean hydraulic power output from the Poldaw Windpumps at the four locations. It was obtained for the four locations from [7]. It is also shown in Table 1.

### 3.2 Overall Efficiency

The overall efficiencies at various hydraulic equivalent loads at 3 m/s and 4 m/s, were calculated by means of equation (5) for each of the four Poldaw Windpump systems, using the pumping performance data obtained from [5]. The overall efficiency (i.e. between 3 m/s and 4 m/s) at each hydraulic equivalent load and the mean overall efficiency for the range of hydraulic equivalent loads used in the analysis were then obtained.

3.3 Mean Hydraulic Power The mean hydraulic power from the four Poldaw Windpump systems at the four locations, were estimated by means of equation (6). This requires knowledge of the energy pattern factor of the locations, the mean overall efficiency of the windpump systems, the mean wind speed at the locations and the diameter of the windpumps. By equating the hydraulic power requirement to the mean hydraulic power output (equation (1) to equation (6)) an estimate of the mean daily water output is obtained.

## IV. RESULTS AND DISCUSSION

The overall efficiency was plotted against the hydraulic equivalent loads for each of the windpump systems. The plots are shown in figs. 1 - 4 for 1.8 m, 2.2 m, 3.5 m and 5 m Poldaw Windpumps respectively.

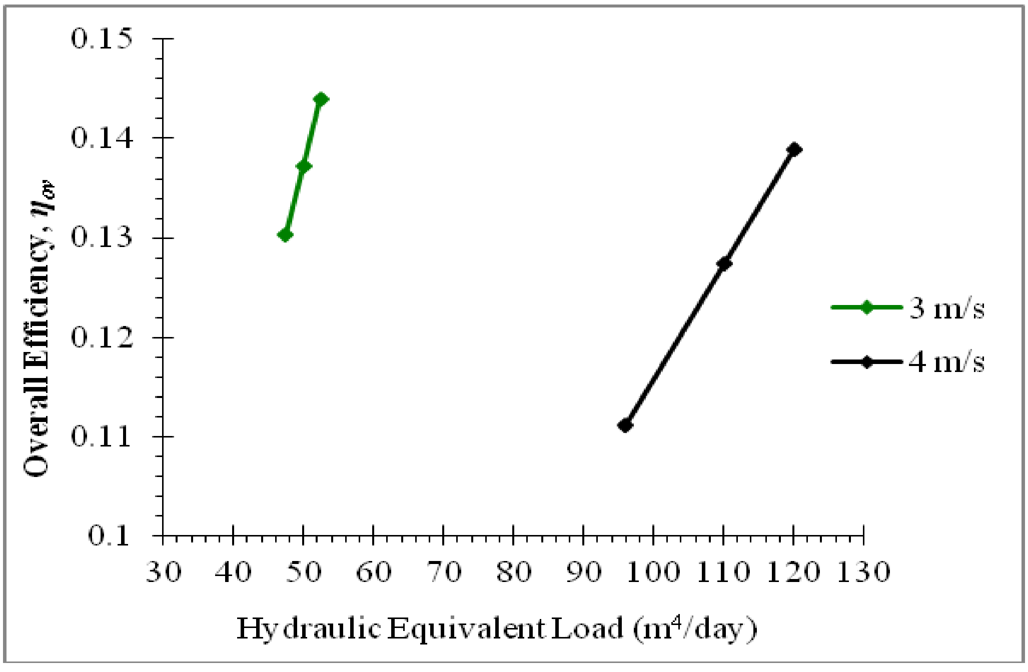


Figure 1: Overall efficiency versus the hydraulic equivalent load for the 1.8 m Poldaw windpump system

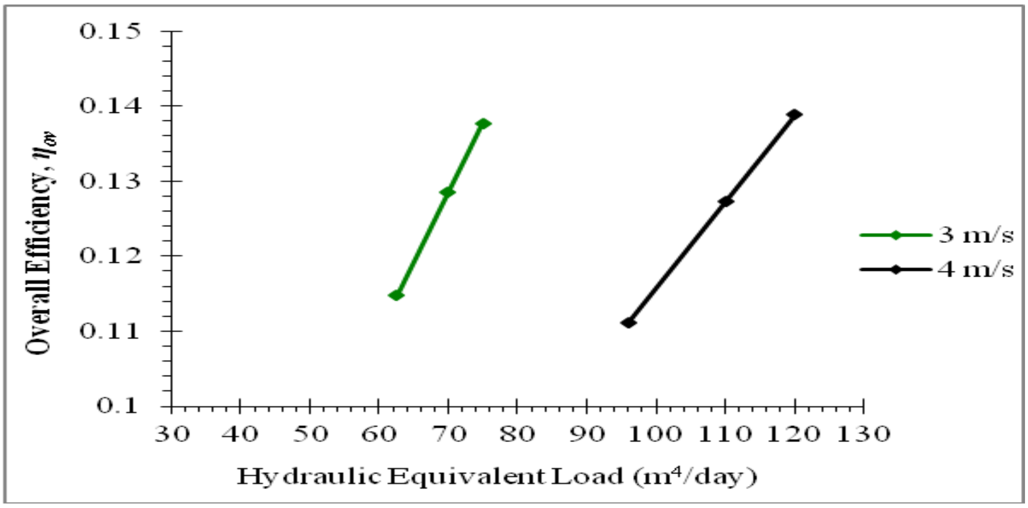


Figure 2: Overall efficiency versus the hydraulic equivalent load for the 2.2 m Poldaw windpump system

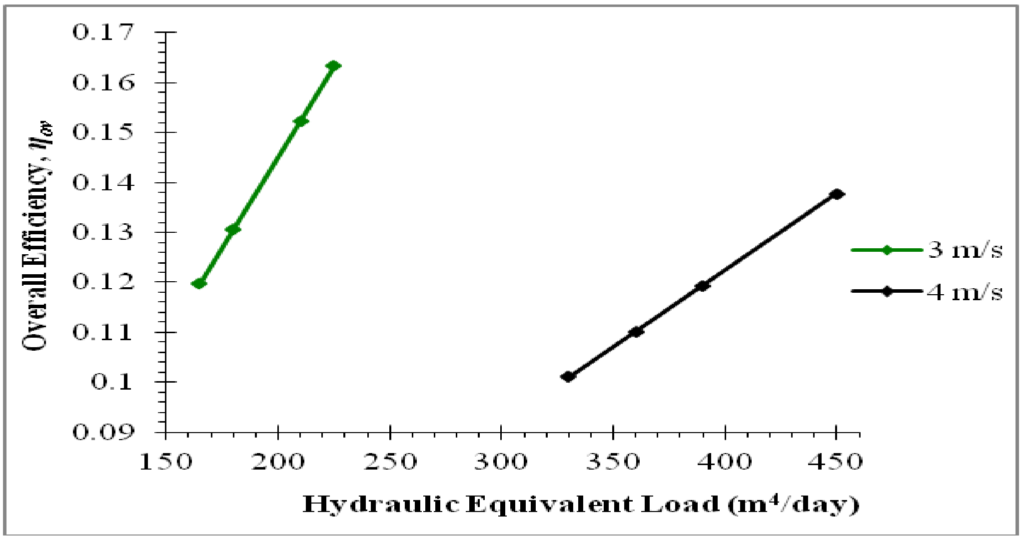


Figure 3: Overall efficiency versus the hydraulic equivalent load for the 3.5 m Poldaw windpump system

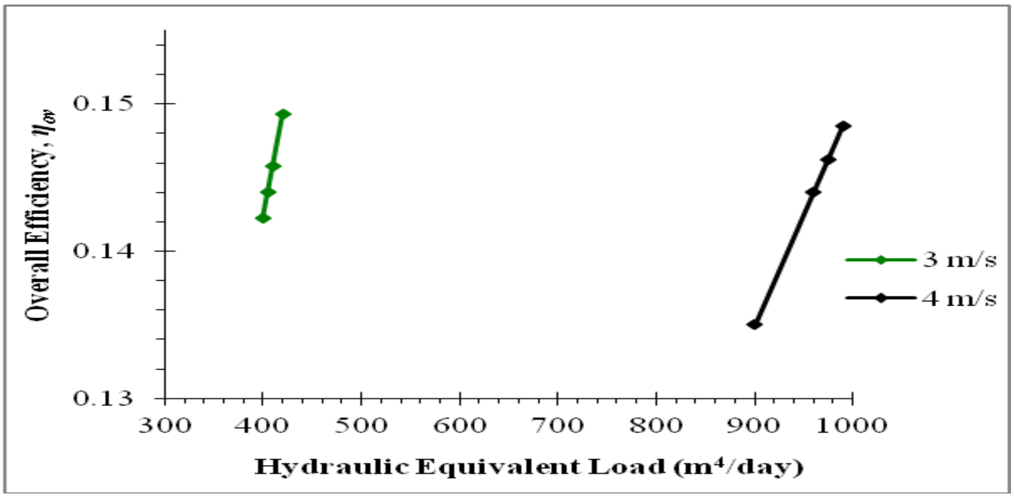


Figure 4: Overall efficiency versus the hydraulic equivalent load for the 5 m Poldaw windpump system

Table 1 shows, for each of the Poldaw windpump systems, the estimates of the mean hydraulic power output from them at the four locations, at a windpump height of 10 m. For a total pumping head of 10 m, the mean hydraulic power outputs were changed to equivalent mean daily water outputs shown in Table 2 for the four locations

**Table 1:** Estimate of the mean hydraulic power output for the four pump systems at the four locations

| Location | $K_e$ | $\bar{V}$ (m/s) | Mean Hydraulic Output (W) | | | |
|---|---|---|---|---|---|---|
| | | | 1.8 m | 2.2 m | 3.5 m | 5 m |
| Jos | 1.34 | 5.24 | 38.46 | 53.06 | 148.74 | 326.21 |
| Kano | 1.43 | 4.15 | 20.39 | 28.13 | 78.85 | 172.93 |
| Sokoto | 1.55 | 4.03 | 20.24 | 27.92 | 78.27 | 171.65 |
| Zaria | 1.46 | 2.90 | 7.10 | 9.80 | 27.47 | 60.25 |

**Table 2:** Estimate of the mean daily water output for the four locations

| Location | Mean Daily Water Output ($m^3$/day) | | | |
|---|---|---|---|---|
| | 1.8 m | 2.2 m | 3.5 m | 5 m |
| Jos | 33.87 | 46.74 | 130.99 | 287.29 |
| Kano | 17.96 | 24.78 | 69.45 | 152.30 |
| Sokoto | 17.82 | 24.59 | 68.93 | 151.17 |
| Zaria | 6.26 | 8.63 | 24.19 | 53.06 |

For the range of Poldaw windpumps, the overall efficiency ranges between 10 % and 16 %. The most efficient being the Poldaw 5 m windpump system. As seen from Figs. 1 – 4 for all the Poldaw windpump systems, at a particular wind speed, the overall efficiency increases with increase in hydraulic equivalent load.For each of the Poldaw windpump systems, the performance decreases with increase in wind speed, meaning that they operate more efficiently at lower wind speeds. This is seen in, for example, Fig. 1.For all the wind pump systems operating in Jos, Kano, Sokoto and Zaria, the strong influence of the mean wind speed on the hydraulic power output is seen as shown in Table 1. Going from a mean wind speed of 4.15 m/s for Kano to 5.24 m/s for Jos more than doubles the output. It is seen also that a small increase in rotor diameter results in a marked increase in hydraulic power output at the four locations. For example, changing the rotor diameter from 3.5 m to 5 m in Jos, more than doubles the hydraulic power output.Typical water demand for a village of 500 inhabitants is of the order of 20 $m^3$/day and the water requirement for crop irrigation of one hectare (2.5 acres) is approximately 86.4 $m^3$/day [2]. It is seen from table 2 that the 5 m windpump can be used to irrigate more than one hectare of agricultural land in Jos, Kano and Sokoto; the 3.5 m windpump in only Jos; none for the 2.2 m and 1.8 m windpumps. However, the 5 m and 3.5 m windpumps can supply domestic water supply for more than 500 inhabitants in the four locations; the 2.2 m windpump in Jos, Kano and Sokoto; the 1.8 m windpump in only Jos.

## V. CONCLUSIONS

The efficiency of the Poldaw windpump systems increases with increase in the hydraulic equivalent loads and decrease in the mean wind speeds. Though the overall efficiency and the energy pattern factor have some influence on the hydraulic power output and hence the daily water output, the influence of the rotor diameter and mean wind speed are stronger.

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