Title: PREDICT THE PERFORMANCE OF THE MULTI-BLADED TYPE WINDMILL PUMP AND COMPARISON WITH THE MEASURED DATA AT A SITE

Author: M Narayana
Institution: National Engineering Research and Development Centre of Sri Lanka
Country: Sri Lanka
E-mail: narayana@nerdc.lk

1. Introduction

Agriculture is the main livelihood of most of the population in the dry zone in Sri Lanka. Dry zone receives low and uneven distribution of rainfall during the year. Therefore, lift irrigation is essential to practice agriculture intensively. Therefore, the introduction of a reliable energy source is essential for lift irrigation. Wind energy has been identified as one option to fulfill the energy requirement for lift irrigation in the dry zone (Elliott et al, 2004).

The National Engineering Research and Development Centre (NERDC) has developed a multi bladed water pump windmill for this purpose and it has been installed at several sites for field trials. Picture of a windmill pump, which was installed at Higurakgoda in the North central part of Sri Lanka, is shown in Figure. 2. In this wind pump, a reciprocation pump is connected to a wind rotor with a diameter of 4m by a crank mechanism. This pump is consisting of two-cup seals and inlet/outlet air vessels.

The main objectives of this study were to predict the performance of the existing NERDC windmill pump and validated by the actually collected data from a site and then verify whether it can be fulfilled the irrigation requirement in the dry zone of Sri Lanka.

2. Characteristic of The Wind Rotor

In the analysis of the characteristic performance of a wind-rotor, the main parameters are thrust force on the rotor, torque generated by the rotor, and rotational speed of the rotor. These parameters should be found at different values of wind speeds in order to analyse the characteristic performance of the wind-rotor. A wind-rotor, in general, is designed so that optimum energy conditions are satisfied at a given specific tip-speed ratio. But in practise wind rotors do not always function at optimum conditions. It may run at various other tip-speed ratios.

In this exercise, power output of this wind rotor should be evaluated for different wind speeds. The main objective here is to theoretically find out the C_p values for different λ_0 values of the NERDC wind-rotor. Geometry of wind rotor blade is shown in Figure. 1. Geometrical parameters of the rotor are presented in Table 1. Performance of the existing wind-rotor can be analyzed by using the blade element theory (BET) and momentum theory (MT) (Gourieres, 1982). This rotor consists of eight blades with arc shape Profile. The radius of the rotor is 2000 mm, and the hub radius is 313.75 mm.

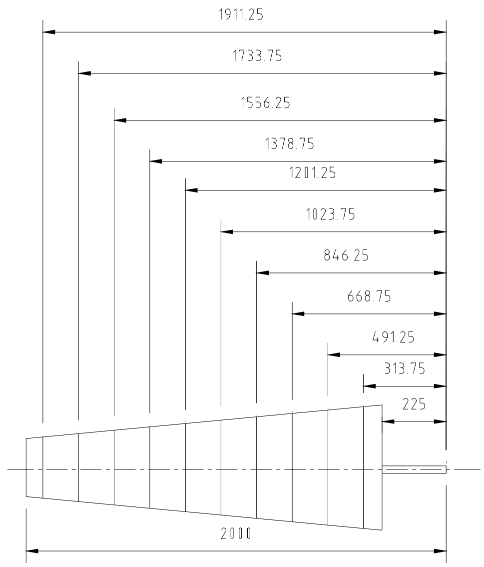


Figure.1: ***curved plate (f/l= .1, α=5) blade geometry of NERD Multi bladed wind water pump***

Figure .2*: water pumping wind pump, installed in the North Central part (Higurakgoda) of Sri Lanka*

Table.1: ***Geometrical parameters of wind rotor***

Section	r (mm)	Cord length	Blade angle
1	313.75	696	45.6
2	491.25	688	41.8
3	668.75	680	38.0
4	846.25	672	34.2
5	1023.75	664	30.4

Section	r (mm)	Cord length	Blade angle
6	1201.25	656	26.6
7	1378.75	648	22.8
8	1556.25	640	19.0
9	1733.75	632	15.2
10	1911.25	624	11.4

The wind rotor is divided in to 10 equal sections and C_p value for each section was calculated by using the iterative search procedure. The curve of coefficient of lift (C_l) and of coefficient of drag (C_d) verses the angle of attack (α) of the blade profile curved plate (*f/l = 0.1* α *=5*) was used for this calculation (Gourieres, 1982). Mathematical relationships of C_l and C_d with α was determined by using the curve fitting methods.

Then, coefficient of performance of the wind rotor (C_p) with respect to different tip speed ratios (λ_0) was calculated. Performance curve of the NERDC wind-rotor is shown in the Figure.3.

Figure. 3*: Performance curve of the NERDC wind-rotor*

3. Characteristics of Reciprocating Pump

4.1 Specifications of the pump

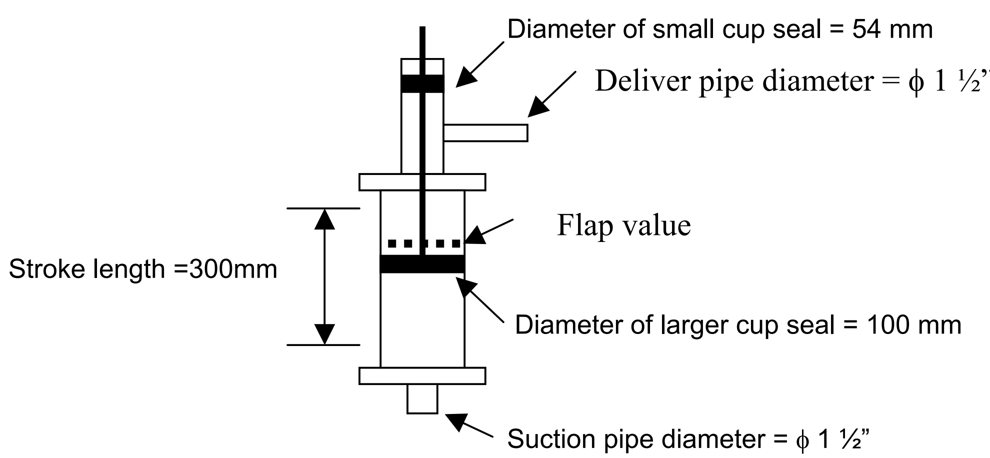


Figure 4: *Configuration of reciprocating pump*

This pump can be used to pump water from shallow wells and it was designed to pump water up to 20m-water lift. This reciprocating pump is consisting of two cup-seals with different diameters. These different sizes of cup-seals help to work with low compression force relative to tensile force apply to the pump rod. In this system, wind rotor crank mechanism is directly connected with the pump rod, and then low compression and high tensile force pump arrangement helps to avoid buckling effect of the long connecting rod. Pump configuration is shown in Figure. 4.

4.2 Performance of reciprocating pump

This pump is a positive displacement type pump and then its theoretical flow rate is proportional to the rotational speed of the rotor for specified stroke displacement. Power consumption of pump is proportional to the rotational speed of the rotor and water head.

4.2.1 Calculation of theoretical power input to the pump

Theoretical power input to the pump was calculated based on the work done of the pump for each piston. Mathematical relationship of power in put with number of revolutions is given by equation (1) (Jain, 1987).

Required theoretical power to drive the pump

$$P_{Theo} = A(H_d + H_s)\gamma \times \frac{L(A-a)N}{60} + a(H_d)\gamma \frac{LaN}{60} \qquad (1)$$

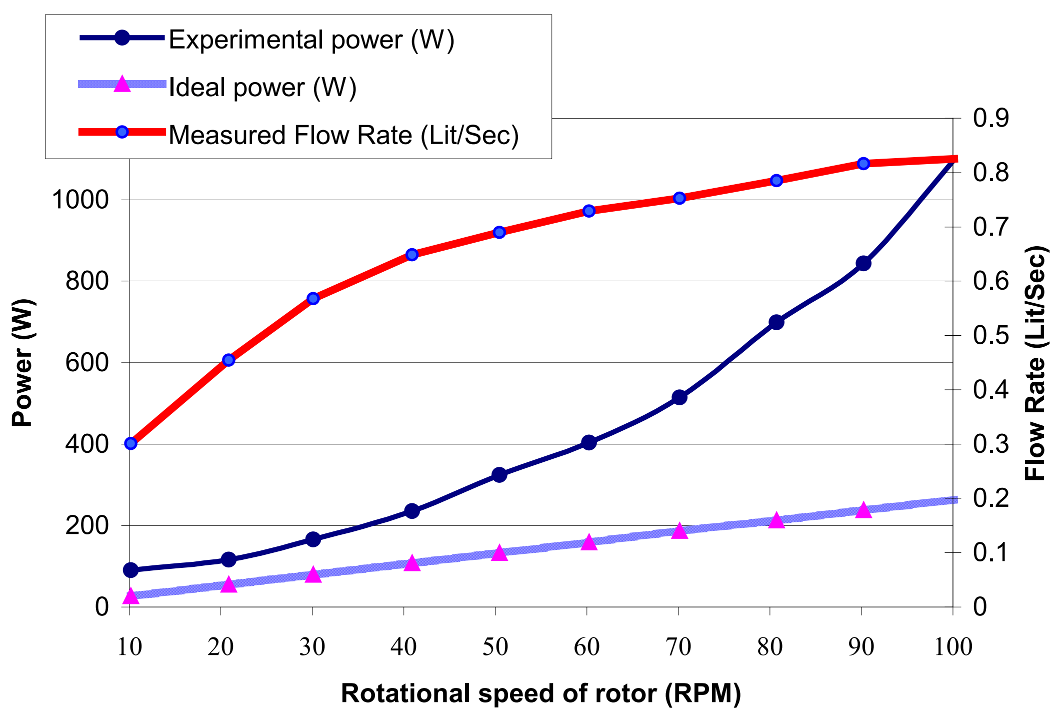
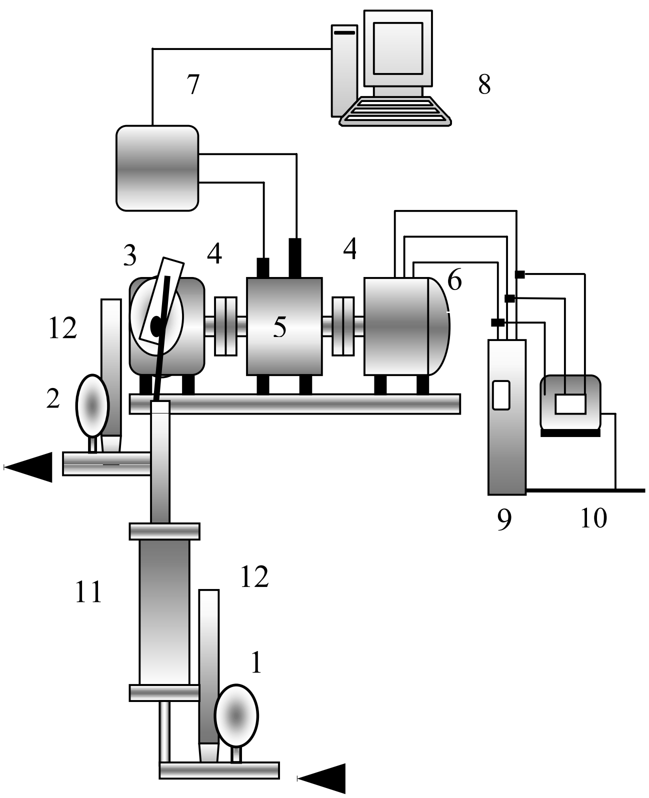


Figure. 5*: Characteristics Performance Curves of the Reciprocating Pump*

In this calculations friction loss of cup-seals, water leakage through the cup-seals and leakage of non-return valves are not considered. Amount of water leakage varies with the rotational speed of the rotor and the applied water head on cup-seals. Amount of power losses could not be predicted unless prototype is tested. Therefore, to predict the actual performance of the pump, real testing on a test rig is important. The above pump was tested in the NERDC hand pump-testing laboratory. Schematic diagram of test facility is shown in Figure 6 and Characteristics Performance Curves of the Reciprocating Pump is shown in Figure 5.



1. Digital pressure gauge
(Suction side –PSI-TRON1X PG-30G)
2. Digital pressure gauge
(Suction side - PSI-TRON1X PG-500G)
3. 1: 30 reduction worm & wheel gear box with crank mechanism
4. Flexible coupling (Falk freedom disc coupling, Type – FD-N10)
5. Torque meter
(700series, Himmelstein & company, USA)
6. 3 phase 3 Hp, 1450 RPM. Induction motor
7. Torque and speed transducer
(700series, Himmelstein & company, USA)
8. Computer
9. VSD, 3 phase, 18 kW, (RUDOLF CX / CXL /CXS Frequency converter)
10. System in put power analyzer.
(VIP System energy analyzer, ELCONTROL energy,)
11. NERDC fabricated single acting water Pump.
12. Air vessels (Suction pipe and delivery pipe)

Figure. 6*: Schematic diagram of test facility*

5 Combined Performance of The Wind Rotor and the Reciprocating Pump

The combined characteristics of the windmill pump system can be predicted based on the individual characteristics of the rotor and the reciprocating pump. Wind rotor and pump characteristics are presented together in Figure 7, which shows the variation of power generated by the rotor at different wind speeds, and power output as a function of rotational speed. Meanwhile the reciprocating pump performs optimally at a certain rotational speed or within a specific range of rotational speeds. Hence, for the optimum overall performance, the pump characteristics curve should pass through the maximum power of the rotor characteristics curves. However, this ideal matching is not possible at all wind speeds. The wind turbine should function under optimum condition at least at its design wind speed so that wind rotor and pump must be properly matched at this point. In order to generate maximum energy at a given site, the design wind speed of the windmill pump should be selected as highest-energy content wind speed at that site.

Overall characteristics of the windmill pump can be determined by referring to the intersection points of both the power input curve of the reciprocating pump with each rotor power curves corresponding to different wind speeds (Figure.7). The system should give its maximum efficiency, when the input curve of reciprocating pump passes through the peak points of the rotor curves at each wind speed. Water pumping flow rate for each wind speeds can be calculated by referring the intersecting point of combine performance graph (Figure 7) and relationship between the water flow rate with the number of stroke per minute of the pump. Measured flow rate with the number of strokes per minute of the pump is shown in Figure 5. Then overall characteristics of the windmill pump can be represented by amount of water flow rate for each wind speeds. Graphical presentation of windmill output with each wind speeds is shown in Figure 8.

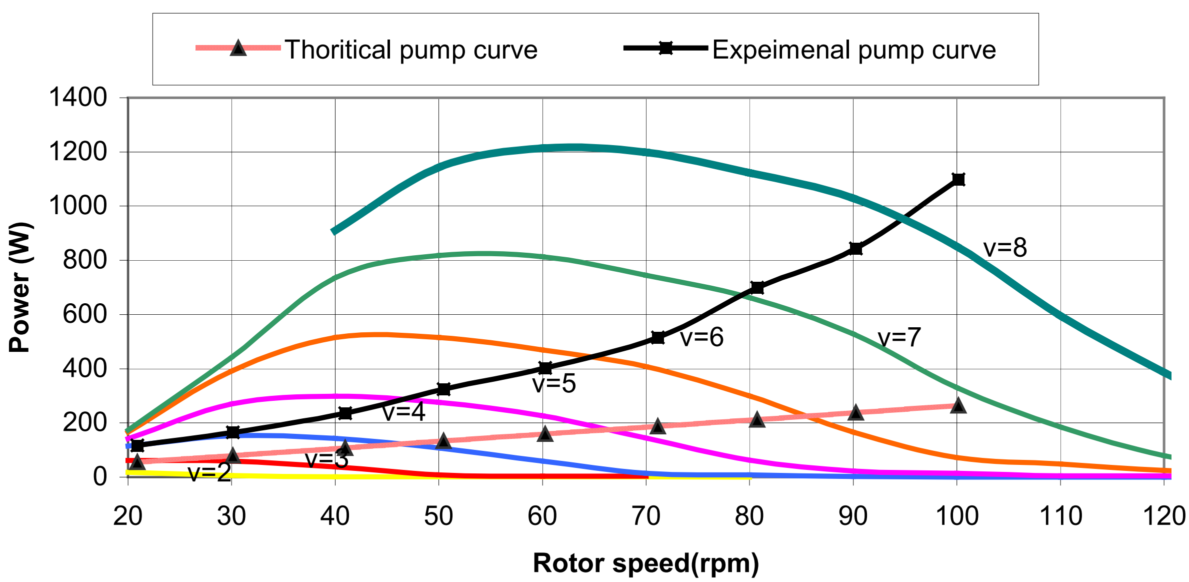


Figure. 7: ***Combine performance characteristics performance wind rotor and the reciprocating pump***

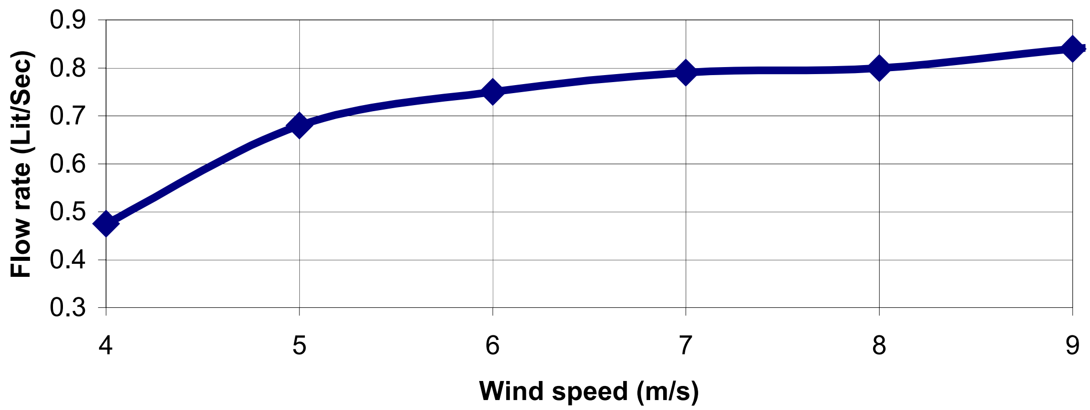


Figure. 8*: Characteristic performances of windmill pump*

6 Wind potential in Dry Zone of Sri Lanka

The easterly trade winds of both hemispheres converge at an area near the equator called the "Intertropical Convergence Zone" (ITCZ), producing a narrow band of clouds and thunderstorms that encircles portions of the globe.

The earth is not a smooth sphere and its surface varies greatly with large ocean and landmasses. The Monsoon is to variation in temperature between the Asian continent and the sea. In the summer the Asian continent is strongly heated, and a low-pressure area is built. The local sea surface temperatures are somewhat lower, and the beginning of June cool humid wind from the Indian Ocean penetrates over India. This is the start of the summer or southwest monsoon. From June to September the sea winds continue, bringing the bulk of India's precipitation. In winter the continent is cooled and a high-pressure area is formed. The sea temperatures cool very much less rapidly. The winds are now from land to sea.

The climate of Sri Lanka is "tropical- monsoon" with a marked seasonal rhythm of rainfalls. The changes in the gradient of pressure (which induced the wind) are determined by the seasonal movement of the ICTZ. In January, the ICTZ is located at about 10^0 South while in July it is about 25^0 North. With its displacement southwards, the Winter Monsoon or North West Monsoon sets in and lasts for three months from December to February. The summer monsoon or Southwest Monsoon occurs from May to September due to the displacement of ICTZ northwards.

The ICTZ is re-located as a broad belt between 5^0 North to 5^0South in march and April as well as in October and November: these are inter monsoon periods associated with light winds at sea level. Then wind potential in dry zone in Sri Lanka is seasonal and according to the collected wind data, there is good wind potential in Yala season (April-September) that is southwest monsoon and less wind potential in the Maha season (October – March) that is Northeast monsoon.

7 Comparison of Predicted and Measured Performance

7.1 Measured Data at Higurakgoda Site

In Yala season rainfall is very low, because southwest monsoon rains are not effect to the dry zone. The crops like chillies, vegetables, onions and pulses could be cultivated by lift irrigation. Irrigation requirement in dry zone for each month are given Table 2. A Windmill pump was installed at Higurakgoda in dry zone for monitoring the system and pumped water volume and mean wind speed were measured in every month by using a flow meter and anemometer. Summary of measured data is tabulated in Table 3.

Table 2: ***Typical irrigation requirement in dry zone***

Month	Net irrigation requirement m^3/day/ha	Gross irrigation requirement m^3/day/ha)	75% rain fall mm/day
Jan	14	23	2
Feb	36	60	0.5
Mar	43	72	0.6
Apr	26	43	2.3
May	32	62	1.7
Jun	62	103	0.3
Jul	63	105	0.3
Aug	64	107	0.3
Sep	53	80	0.6
Oct	Rainy season		
Nov			

Table 3: ***Measured data at the site***

Month	Measured flow volume (m^3/day)	Mean Wind speed (m/s)
Jan	29.54	1.5
Feb	45.23	1.9
Mar	38.38	2.1
Apr	55.60	1.9
May	58.84	2.7
Jun	60.12	4.4
Jul	55.21	4.5
Aug	57.24	4.4
Sep	59.68	2.8
Oct	29.54	2.5
Nov	45.23	2.3

7.2 Predicted performance of Windmill Pump for Higurakgoda site

Characteristics performance of windmill pump is presented in Figure 8. Then for a certain wind speed, pumping water flow rate of windmill pump can be predicted. At Higurakgoda site, mean wind speeds for each month were gathered. To predict the total pumping water volume by windmill pump for each month, the probability density function of wind speeds for each month should be required. The two-parameter Weibull distribution is often used to characterize wind regimes because it has been found to provide a good fit with measured wind data. Then two-parameter Weibull distribution can be used to generate the probability density function of wind speeds for each month

Two-parameter Weibull distribution is:

$$F(V) = \frac{K}{C}\left(\frac{V}{C}\right)^{K-1} . \exp\left[-\left(\frac{V}{C}\right)^{K}\right] \qquad (2)$$

Where *V* is the wind speed, *K* is a unit less shape factor, and *C* is a scale parameter with the same units as *V*.

To generate probability density function by Weibull distribution for each month, *K* shape factor is taken as 2.2 and *C* scale parameter is taken as mean wind speeds of each month. Then pumping water volume by the windmill pump can be calculated by using performance of windmill pump, which is shown in Figure 8 and generated probability density of wind speed for each month. Prediction of pumping water volume for each month is tabulated in Table 4. Graphical presentation of comparing the predicted and measured pumping water volume for each month with irrigation requirement for 0.5Ha is shown in Figure 9.

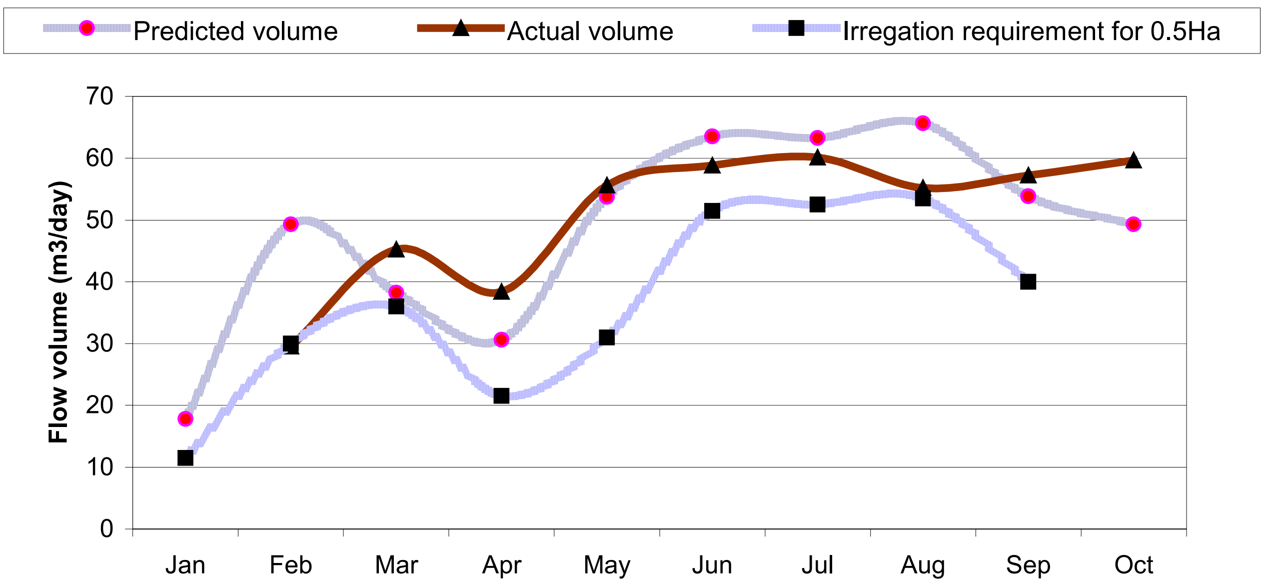


Figure 9: ***Irrigation requirement of 0.5Ha and windmill pump output for each month***

8 Discussion

According to the water requirement of a typical farm at dry zone, the Wind pump, which is designed by the National Engineering Research And Development Centre, can irrigate ½ ha of land area. One of the objects of this project is check whether this wind pump could be fulfilled the irrigation requirement of a farm in dry zone. Net and gross water requirement of a typical farm at dry zone is as follows.

This study has been carried out to predict the performance of existing NERDC windmill pump. Performance prediction of wind rotors is the major part of this study. Performance of wind rotor was determined theoretically. A theoretical model to analyze the rotor performance was developed by considering the flow field around the wind rotor, and using the momentum theory and blade elementary theory. A Sophisticated wind tunnel and precision models should be required to the test wind rotor to obtaining its characteristics performance practically. However, in this study mathematical flow model and performance prediction methodology of windmill pump can be validated, as predicted windmill pump output is tally with measured water volume.

Performance of reciprocating pump was determined practically by pump test-rig. Transmission losses of windmill pump system were assumed as 20% and these losses were assumed to equal with the losses of the test-rig. According to the combined characteristics of rotor and pump (Figure. 7), there is a mismatch between rotor and pump performance. Then, the overall efficiency of the system is low and it is the main cause for poor performance. This study shows, both wind rotor and pump should be redesigned for an optimal system. However, this task is beyond this study.

Also in the present study, inherent characteristics of the control system are not applied to determine the performance of the wind turbine, thus actual output could not be obtained for analyzing the windmills. As the analysis of the characteristics of passive control mechanism, which is used for these windmills, is not a part of this study, ideal characteristics of a control system are used and that is deemed sufficient for a review.

9 References

1. Elliott D, Schwartz M, Scott G, Haymes S, Heimiller D, George R, *Wind Energy Resource Atlas of Sri Lanka and the Maldives*, National Renewable Energy Laboratory, USA,2004
2. Gourieres, D Le. *Wind Power Plants Theory and Design*, Oxford: Pergamon press, 1982, p 76-120.
3. Jain, V.K. *Pump theory and practice ,*New Delhi: Galgotia Booksource publishers,1987
4. Narayana M, *Improved wind rotor design for a small-scale horizontal axis wind turbine suitable for local wind potential*. M.Phil. Thesis, University of Moratuwa, Sri Lanka, 2002, p74 – 87