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SUSTAINABLE DEVELOPMENT OF WATER RESOURCES, WATER SUPPLY AND ENVIRONMENTAL SANITATION

Wind pumping based water supply schemes for remote villages in Sri Lanka*S. B. Weerakoon and A. P. K. De Silva, Sri Lanka*

In the remote rural villages in Hambantota district (located in South-East of Sri Lanka) there is no easy access to potable water, and conventional community water supply schemes by pumping water from deep wells is far from the reality. Present study investigates the feasibility of community water supply schemes for sparsely distributed houses in these villages by the installation of a wind rotor coupled to a hand operated deep well pump at a favourable location in the village and storing of water in a tank at a higher elevation. Based on field measurements of wind data, power requirement for hand pump installed in a deep well, the scale model testing of two horizontal axis wind rotors and the performance of a pilot wind pump, potential for introducing wind pumping based community water supply schemes in the district is emphasized.

Introduction

Though Sri Lanka receives an average annual rainfall of 1850 mm, the spatial and temporal variation of rainfall distribution is significant due to the monsoonal climatic pattern. As a result, a large fraction of the population, especially in the dry zone of the island where annual rainfall is less than 1500 mm has no easy access to potable surface water. Deep wells driven to harness water from deep aquifers are the only source of potable water for them. Deep wells are generally sparsely driven and thus villagers have to walk long distances to fetch water spending much of their energy and time. Due to the prevailing poverty levels in these remote villages a family can hardly afford a deep well and water pump of their own to enjoy an improved standard of life with a pipe borne water supply. Conventional community water supply schemes by pumping water from deep wells is only a dream as the electrification of these remote villages from the national grid is far from the reality.

In order to provide water at an affordable price to the rural villagers who generally have a low income, the operation and maintenance cost of the scheme could be minimized by pumping of water from deep wells by harnessing wind energy or solar energy, which is generally available in the dry zone. Records of wind data in Hambantota district shows that wind set up is conducive for wind pumping applications. Daily mean wind velocity exceeds 6 m/s except in two months of the year from middle of November to middle of January (85% probable) in Hambantota district (located in South-East of Sri Lanka) as per the wind velocity data 10m above the ground level measured in Hambantota (Dept. Meteorology, 1992). Therefore, this study investigates the feasibility of a community water supply scheme for a typical remote village with sparsely distributed houses in Hambantota district,

where only 25% of the population has easy access to potable water, consisting of

- installation of a wind rotor coupled to a hand operated deep well at a favourable location in the village and storing of water in a tank at a higher elevation, and
- water distribution network from the tank to supply pipe borne water to the houses in the village under gravity, after a primary treatment as may be necessary.

Wind pumps have been used in China about 2000-3000 years ago, and in Iran in 200 BC. By 12th century, wind pumping had been popular in Europe but with the invention of steam engine in 19th century a decline of their use is recorded (Restogi, 1982). The present day wind pumps employing horizontal axis rotors ranging from four to twenty blades are popular in farmhouses for supplying water for farming in developed countries. In Sri Lanka, a few wind pumps are in operation to pump water from shallow wells (e.g. Centuria Hotel in Embilipitiya to lift water from shallow well for gardening, Mahagama farm at Embilipitiya in Southern Province, Mahailluppallama in North Central Province, etc.). However, wind energy source is not much used for pumping water from deep wells in Sri Lanka, though there are wind pumps commercially available today for pumping water from deep wells in the world. For example, Bergey Windpower Co., of Norman, Okla., has installed 1.5kW wind turbines in two North-Eastern Brazilian states for rural water pumping applications. The machine drives a 10-stage submersible pumps and is equipped with 10 cubic meter storage tanks to deliver 20 cubic meters of water per day.

In this study, energy required for pumping water from a typical deep well is first estimated by field test. Scale model tests of wind rotors are then carried out to estimate the power that can be obtained from a prototype rotor at different wind speeds. Following the successful operation of a pilot wind

pump, feasibility of wind pumping based water supply schemes for rural villages in the dry zones is discussed.

Force estimation for hand pumping from deep well

Commonly installed hand operated deep well pumps in Sri Lanka include Shallow well pump for heads less than 15m, Lever operating pumps for deep wells, with counter weight-lever mechanism for extra deep wells (e.g. Mark II and Mark III, R&C, 2000). The operation range of them are: 5 - 90m of head, 12-18 l/min of discharge.

Several tests were carried out to estimate the energy requirement to pump water by installed hand operated deep well pumps at the Peradeniya region in the Central Province of Sri Lanka. The deep well at the premises of the Faculty of Engineering, University of Peradeniya is 200 mm diameter, 55 m deep and the hand pump model Mark II (piston diameter, $D = 75$ mm, piston stroke = 100 mm) has been installed in the deep well at 40m depth.

Analysis of the force required

Pumping stroke in the hand pump which is a positive displacement piston pump, has to operate not only to overcome the delivery head and the friction head of the delivery pipe but also the inertia pressure head of the water column in the delivery pipe. The vertical force (F) required by the rod to initiate the pumping stroke of the piston can be written as;

$$F = F_1 + F_2 + F_3 + F_4 \quad (1)$$

Where, F_1 = Force due delivery head h ; F_2 = Inertia force to accelerate the water column through delivery pipe of diameter d and length h ; F_3 = Inertia force to accelerate and lift the steel rods of length h connecting the piston to the surface; F_4 = Force to overcome friction head in the delivery pipe. F_3 and F_4 are negligible compared $F_1 + F_2$

$$F_1 = \frac{\pi}{4} h d^2 \rho g \quad (2)$$

$$F_2 = \left(\frac{2\pi N}{60} \right)^2 R \left(\frac{D}{d} \right)^2 \left(\frac{\pi}{4} \right) d^2 h \rho \quad (3)$$

where N = lever rotary speed; R = Lever arm to the hinge.

For $d = 75$ mm; $D = 200$ mm; $h = 40$ m; $R = 50$ mm; $N = 20$ rpm, required vertical force (F) on the piston is computed from equations (1) to (3) as 1750 N.

Force required by field experiment

The force required to initiate pumping stroke water was obtained by measuring the load required to move the lever of the pump using a spring balance attachment. Delivery head of the pump was 40 m. Discharge for 20 strokes were recorded at each test. Tests were repeated and a sufficient time period was allowed between two tests to settle the well. Force required at the vertical connecting rod to initiate the pumping stroke are given in Table 1.

Force application efficiency (Theoretical value of F /

Table 1. Torque required for hand-operated deep well pump; Pump Model: Mark II, Water delivery head = 40 m, Stroke rate 20/ min,

Force required at the connecting rod (N)	Discharge per stroke (l)
2350	.35

Measured value of F) is 74% and the overall pump efficiency (useful work to obtain the discharge by one stroke / Measured work for a stroke) is 58%.

Performance of wind rotors

Two types of horizontal axis wind rotors are proposed to couple with the deep well pumps:

- Wind Rotor R1: 8 blades, 3m diameter
- Wind Rotor R2: 18 blades, 3m diameter

Model analysis

The performance parameters of the wind rotors are torque (T) and power (P) developed and efficiency.

$$P, T, \eta = f(N, D, V, \rho, \mu) \quad (4)$$

Applying Buckingham theorem, considering D , V , as repeating variables, following non-dimensional relationships can be derived while neglecting the effect of Reynolds Number since the flow is highly turbulent.

$$\frac{T}{N^2 D^5 \rho} = \phi_1 \left(\frac{V}{ND} \right); \quad (5)$$

$$\frac{P}{N^3 D^5 \rho} = \phi_2 \left(\frac{V}{ND} \right); \quad (6)$$

$$\eta = \phi_3 \left(\frac{V}{ND} \right) \quad (7)$$

where, D = rotor diameter; N = rotor speed; V = wind speed; ρ = efficiency and μ = air density.

Model testing

Scale models of the rotors R1 and R2 constructed to 1: 5 scale (Figs. 1 and 2) were tested using the wind tunnel facility of the Fluid Mechanics Laboratory of the Faculty of Engineering, University of Peradeniya. The non-dimensional



Figure 1. Scale model of rotor 1



Figure 2. Scale model of rotor 2 and wind tunnel testing facility

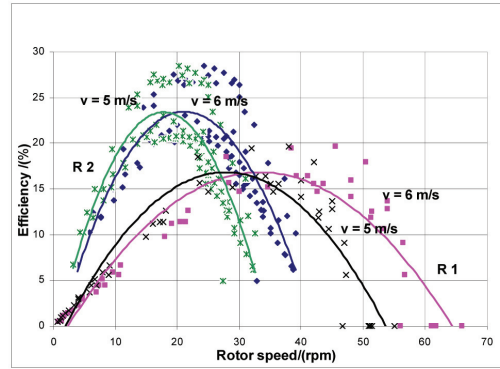


Figure 5. Rotor speed vs. efficiency (D = 3 m)

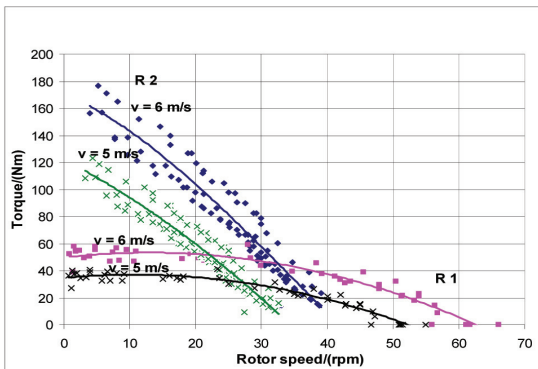


Figure 3. Rotor speed vs. torque (D = 3 m)

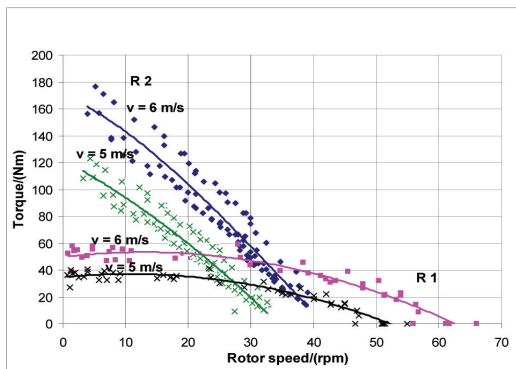


Figure 4. Rotor speed vs. Power (D=3 m)

parameters given in equations (5) to (7) were computed to derive the performance curves from the model test.

Efficiency of the rotor at a given speed was estimated with respect to the power carried by a free flowing wind mass with a speed V in a cross sectional area A swept by a horizontal

axis wind rotor can be written as $0.5\rho A V^3$.

Results and discussion

The performance curves viz. torque, power and efficiency variations with rotor speed for 3m diameter prototype rotors R1 and R2 at wind speed range of 6m/s -12 m/s, which is the reliable range of evident in the collected wind data of Hambantota district were derived from nondimensional performance curves, Figs.3 to 5.

The performance curves show that rotors R1 or R2 could be used for wind pumping from deep wells of different depths under the wind speed of 5 -6 m/s though R2 rotor which is a multiblade rotor with 18 blades is superior in performance.

The lifting force required for the delivery stroke of the pump is 2350 N (Table 1), and thus the work done during a delivery stroke is 235 Nm. When the rotor is connected to the pump (Fig. 6), this work is to be done by the rotor. Considering a coupling mechanism with an efficiency of 80%, matching of the power required with the rotor power generated (Fig. 4), it is shown that the rotor R1 can be coupled to the hand operated deep well pump with a gear ratio of 1:3. The overall efficiency of the wind pump will be about 50% of the efficiencies given in Figs. 5 due to the losses in the coupling and the pump. However, the wind rotors could be coupled to deep well pumps directly, with a counter weight, with a gear mechanism depending on the depth of water table.

Pilot wind pump

A pilot wind pump was installed at the premises of the Faculty of Engineering, University of Peradeniya. A 3m diameter prototype rotor with 8 blades (rotor R1) was installed at an elevation of 12.5 m above ground and coupled to an Indian Mark II deep well pump installed in the 200 mm diameter and 55m deep well. Water level in the well was between 10 m - 27 m.

Performance of the wind pump under wind speed of 6 m/s was investigated under different delivery heads of the



Figure 6. Pilot wind pump assembly

hand pump.

- Up to a delivery head of 10m, rotor can be coupled directly to operate the pump at the same speed of rotor.
- Up to a delivery head of 20m, rotor can be coupled directly to operate the pump at the same speed of rotor but with the counter weight supplied with the pump
- Up to delivery head of 40m, rotor can be coupled with a reduction gear system of 1:3 to operate the pump at one third of the speed of rotor.

Wind pumping based water supply systems

The results of the model tests and the pilot wind pump show a greater potential of using wind pumps to set up village water supply schemes for the remote villages in Hambantota district as wind resource is available during most part of the year. The wind pump can be used to continuously fill a water storage tank at an higher elevation in the village from where the distribution system can be fed to supply pipe borne water to the houses. Though the pipe borne water supply may not be sufficient to all water needs at households, such as the water need for bathing and washing, the impact made to the living standard of the villagers by the scheme would be significant. Nevertheless, the reliability of the scheme depends on the availability of wind energy source. Thus, alternative mode of operating the pump is required when sufficient wind is not available. One of the promising method identified to use manpower is the connecting of an attachment to use a peddling bicycle to apply the force required to operate the pump, by temporarily de-linking the rods from the rotor.

The rotor R1 which is cheaper than rotor R2, and also used in the pilot wind pump could be used. The use of multi-blade rotor, R2 which is more efficient than R1, for pumping from deep wells would form a more effective and reliable wind pump for the scheme. However, monitoring of water level and wind data for sufficient period before an installation, awareness and participation of the community building are

essential for a sustainable water supply scheme.

Concluding remarks

- Field measurements were carried out to estimate the force required to operate a deep well pump (Mark II) installed at 40 m depth in 55 m deep well.
- Two types of wind rotors are proposed for coupling the deep well, and their performance curves were obtained using scale model tests. The feasibility of coupling the rotors operating at 6 m/s wind speed to pump water from the deep wells was investigated.
- A Pilot wind pump was installed using one type of rotor. Performance of the wind pump under wind speed of 6 m/s shows that the wind rotors could be coupled to deep well pumps directly, with a counter weight, with a gear mechanism depending on the pump delivery head.
- Wind pumping based community water supply schemes are feasible in remote villages in Hambantota district with a reliable operation during 85% of the year.

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Contact addresses

S. B. Weerakoon
Senior Lecturer, Department of Civil Engineering
University of Peradeniya, Sri Lanka