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DESIGN AND FIELD TESTING OF SAVONIUS WIND PUMP IN EAST AFRICA

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ABSTRACT

We present here improvements in the wind-scoop geometry and efficiency of a double-stack Savonius rotor, developed through a series of wind tunnel and field testing in East Africa. On an aerodynamic performance basis, the Savonius rotor cannot generally compete with other types of wind turbines. This is entirely due to its mode of operation. Unlike its counter-parts that operate by rotating around a horizontal axis, it rotates around a vertical axis. This has the unfortunate effect of lowering its efficiency, but it has several compensating factors. Its main advantages are that it has better starting torque performance with operating characteristics independent of the wind direction. In addition, it is simple in structure and the fabrication technology required is less sophisticated when compared to similar types of windmills. This makes it a suitable system for small scale applications in wind energy conversion; especially in remote rural regions in developing countries.

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1.0 Introduction

From the technological point of view, the Savonius wind pump [1] is the most important piece of equipment that people in the rural parts of the developing countries would love to acquire, when one takes a closer look at the level of water availability in these areas. From the World Bank statistics [2], it is noted that more than a fifth of the world's population resides in areas designated as high risk areas. The risk is basically due to poor quality water supply (or use of polluted rivers and stagnant waters) as the main cause of diseases, and hence, poor health to these people. In this type of scenario, it is a well-known fact that it is mostly the women and children who are the most affected [2].

In Africa, in particular, the situation is even desperate as the bulk of the population (with up to 70% in some countries) resides in rural areas where taped water is almost non-existent, and if there are any, they are sparsely located that the women and at times with their children have to trek long distances, spending several hours per day just to get a few gallons of water. There are two sectors of the economy which suffer from this situation:

1) *Agriculture and Health* - The unavailability of water means that there is little to be used for irrigating the farms, leading to poor crop productivity and low nutrient yields thus, contributing to poor health. Further more, because the women spend most of their time looking for water, there is very limited time left for them to tender their gardens, and as such when rains arrive, it always catches them unaware with their farms not fully prepared, and hence, resulting in a poor harvest that can not sustain the family food requirements. Moreover, during rainy seasons, these rural folks have a tendency to draw water for their domestic use from stagnant rain water ponds/pools. These water ponds also serve their domestic animals, which get into them in order serve themselves, and while doing so, urinate and dump their waste making the water highly polluted and a health hazard to the people. These leads to rampant water bone diseases amongst these people, and hence, another cause to poor health. It is kind of a vicious cycle.

2) *Education* - In Africa, if children are to fetch water, most of the times it will be the girls who are also as a custom, suppose to help their mothers with kitchen etiquette. This means that they will devout less time for school work, leading to a high dropout rate among them. To some extent, boys are affected, particularly those from families without girls off-spring. This is a bad scenario for Africa's (and many developing countries alike) future socio-economic development, in terms of human resource development.

However, the situation is now improving due to the presence of non-governmental and charitable organisations working in the East African region. A country like Kenya has quite a good share of these bodies working in areas such as education, family planning and primary health care with quality water supplies among their highest priority. There is a lot of well digging going on in all parts of the country, but with hardly any adequate pumping systems to draw the water; the mass access to it is not improving adequately to alleviate the situation. Further, since the level of income and also technology are low in this part of the world, the system if there is to be one must be cheap, easy to use and has a low maintenance requirements - in all it must be a cost-effective system. To be successful, such a system must be geared towards exploitation of the local wind and hydrological resources, and human resources for construction and local management. This is why a pumping system like Savonius windmill is most suitable.

Savonius rotors are the vertical-axis drag devices that exhibit high starting torque and are well-suited for pumping water [1,3,4]. They can be fabricated from readily available, cheap materials such as plywood, oil drums, pipes, and sheet metals. Fig. 1 shows an example of Savonius windmill. From this figure it can be observed that, in really hard hit areas with very low income, the Savonius rotors can be easily constructed by literally splitting an oil drum (which are in abundance as left overs from petrochemical companies) down the middle and offsetting the two halves on to a spindle, the 'windmill' is made. This is a tremendous village

technology, and hence, an excellent technological transfer material that can easily be carried out through local initiative training programs under the rural-based community networks. Another factor which makes Savonius rotor an excellent choice is, it is environmental friendly, as there are no use of expensive fossil fuels or biomas. For its working, the system depends completely on renewable energy source - wind energy.

From performance data of the Savonius rotor collected by several researchers and organisations for a variety of rotor geometry [3,4,5], with a view of obtaining an optimum design, an improved design of the Savonius rotor is currently being tested in some rural parts of East Africa, initially in Kenya. Geographically, Kenya lies right at the Equator, but due to its high altitude most parts of the country register moderate climate during the year. The areas to the north, north eastern and eastern parts of the country are designated as semi-arid to arid, with very limited to severe water shortage. But the plus thing which made Kenya to be chosen as a pioneering centre, is basically because it has better infrastructure when compared to its neighbours.

2.0 Scope of the present work

The investigation of the rotor performance geometry was carried out in an entirely natural wind conditions for the purpose of water pumping and, possibly electricity generation to a lesser extent. However, the rotor geometry has been chosen from several independent tests carried out in wind tunnels (which simulates an almost ideal wind conditions) [3,4,6].

This work was done with a view to:

1. Establishing an optimum structural sturdy leading to a cheap design that can withstand the harsh climatic conditions of the tropics, while producing sufficient amounts of water for domestic units and small scale irrigation - in effect an all round cost-effective system.

2. Obtaining the simplest and effective (efficient) drive mechanism or design that can be manufactured locally and maintained by the end-users (i.e., by the local users).

3. Comparing the performance of the Savonius design with other types i.e., its competitiveness in terms of production and maintenance cost, thereby deciding which design is best suited for a given area and end-user acceptability.

4. Establishing water output rates for different parts of the country under various natural wind conditions especially for regions with suitable wind regimes.

3.0 Test site

3.1 The field testing station.

This was undertaken at a site in Kathiani Division (Eastern Province of Kenya) some 269 km south of the Capital Nairobi on the boundary of the Tsavo West National Park. As was earlier stated, this area is well within the country's arid area. Two test sites were chosen within a radius of 2 km where already dug water wells existed. Apparently, this is a region with the lowest winds and through oversight, efforts were not made to obtain sufficiently detailed data on the annual and seasonal wind distributions. It was, however, later established by the local community and afterwards confirmed from the Kenya Meteorological Department data office, that 'strong winds' only exist between June and November during most times of the day. Fortunately, it later became apparent that in order to fully test the system (Savonius windmill), we needed to work in a locality which displays a full windspeed spectrum i.e., from the lowest to the maximum possible wind regimes.

3.2. Prototypes

For comprehensive testing, two similar double stack Savonius rotors having a bucket diameter of 475 mm and height of 2000 mm were constructed from 12.5 mm thick plywood sheets and 26 gauge plain galvanised iron sheets. The bach type buckets were attached to the circular end and middle plywood discs using small bolts and nuts. This configuration was attached to the rotor shaft (made from 37.5 mm mild steel tubes) using flanges at both ends. To minimise friction, the rotor shaft was supported with two self-aligning bearings of very low friction and the assembly mounted on a low tower (2 m) high. The wooden parts were thoroughly treated with wood preservative to protect them from termites and adverse weather. The set-up for the field test is shown in Fig. 2. An overlap ratio (s/d) of approximately 0.14 was set for both rotors with the aspect ratio (H/d) being set at 4. (Note that the recommended values from wind tunnel experiments are: overlap ratio of 0.1 - 0.15, and an aspect ratio of 4.29). The bach type is preferred due to it's superiority to the usual semicircular type in both torque and power characteristics at low tip speed ratio range. The double-stack rotor is slightly superior to the corresponding single-stack in both power and torque characteristics, while that with end plates is greatly superior to that without end plates in power output and the width of the operating tip speed ratio range. Bucket end plates are therefore essential. This is the type that will be used to collect the test data.

Before mounting the rotor on the tower on both occasions, it was carefully balanced to avoid vibrations at high rotor speeds, by first mounting the assembled rotor on horizontal straight edges and adding weights to the circumference as when necessary. In addition, nylon ropes were used secure the structure, see Fig. 2.

Slightly different drive assemblies were used for the two test models. One had the drive pin directly connected to the rotor shaft, while the other had a gear system comprising of two gears, the first gear being attached to the rotor shaft with the drive pin connected to the second gear. A transmission system consisting of a horizontal drive shaft made from 9.4 mm round bar, a bell crank assembly and a vertical pump rod (12.5 mm galvanised steel pipes) were used. The bell crank 'amplifies' the oscillations by a factor b/h dependent on it's dimensions (where b and h are the base and height dimensions of the bell crank, respectively). For this application a simple and affordable cylinder type piston pump was chosen due to it's ease of installation and low maintenance. A screen was fixed at the intake to prevent solid particles from entering the pump. All the prototype components (i.e., rotor, tower and transmission system) were initially fabricated at the Faculty of Science workshop (Department. of physics, University of Nairobi). But these were later undertaken at rural-based community workshops. Care was taken to make the parts strong enough to withstand the large torque during pumping from sufficiently deep wells. A counter weight assembly was included to assist the rotor in the lifting process.

3.3 Installation and maintenance costs:

The total installation cost for each wind machine was about US$ 600 inclusive of all the expenses, while maintenance costs were minimal. It is further estimated that, a wholly steel structure would cost about US$ 1,000 and, would last more than five times longer than the wooden structure. The durability of a plywood structured system under operation is estimated to have a life span in the range of three years. This is mainly due to the adverse effects of weather on the material (plywood).

4.0 Instrumentation and testing techniques

Unlike all previous investigations of the Savonius rotor, the performance testing was not confined to the aerodynamic aspect [6,7]. However, it was confined to the material and design aspect as well as the actual field performance of the rotor under natural wind conditions. The detailed stress analysis on the individual components was not conducted, however, physical examination of the components was carried out over a period of time with the parts being

modified accordingly.

4.1 Test results

In performing the field test, a simple wind speed detector placed at the height of the rotor was used to obtain windspeed data. A 30-litre water tank was used for measuring the amount of water produced. The pump head was located at 10 m. This was done on continuous basis throughout the day, for the purpose of determining the water output versus the windspeed characteristics of the rotor. The initial field test lasted six months. These were spread over to cover the period of low and high wind regimes. Fig. 3 shows the windspeed versus the amount of water pumped out.

It is important to point out that not all the power of the wind can be extracted on continued basis, because this would cause undesirable accumulation of air at the windmill. The maximum amount of power that can be extracted from the wind is given by [8]:

$$P = C_p(I/A) \qquad (1)$$

where the intensity $I = (1/2)\rho v^3$, with ρ being the mass density of air, v the velocity of the air and A the area swept by the rotor. It is only possible to extract about 60% of theoretical energy of the wind energy in any such systems. The term C_p is known as the peak power coefficient and is generally given as:

$$C_p = 0.593 \; (\textit{efficiency fraction}) \qquad (2)$$

Fig. 4 shows C_p versus tip speed ratio (u/v). The C_p for our rotor was found to be ~0.24, which is approximately a factor of two when compared to that of a high-speed propeller which is normally quoted at 0.45. Also see Fig. 5, for the comparison of Savonius' rotor power coefficient with other types of individual rotors.

6. Conclusion and recommendations

The aerodynamic design and dimensions of the rotor used in the field tests were the optimum values obtained. Considering that the test area was in the region of lowest winds regime, the general performance of the improved Savonius pump was found to be satisfactory. This can clearly be observed from Fig. 3, that at relatively moderate speed of ~3.5 m/s, the pump was able to produce ~6 m^3/day (~1200 gallons of water per day). For a locality like Kathiani, which is a typical rural setting in Kenya, this output corresponds to a daily domestic water requirements for about 80-120 people on the average. Hence, in conclusion, we can say that with further slight modifications of some components, this type of rotor system can be said to be suitable for small scale wind energy conversion in regions with better wind regimes (which is reasonable for most parts of the country). However, further research and field testing with improved designs in regions with better wind regimes should be encouraged.

The beauty of Savonius (or any similar kind of windmills) is that they can also be coupled into an hybrid system to alternate between electricity generation and water pumping. This is very important, because it further enhances the energy resources of the rural-based communities. Moreover, the ease of construction and design modification meant that the system is well suited for technological transfer to rural-based community groups or organisations working in developing countries, and that at the end of the learning period, they (i.e., the rural people) would have gained sufficient skills to enable them to continue with the maintenance and further innovation upon the design.

Some recommendations arising from the field tests are listed below:

(i) The gear system shows improved performance. Further modification of the gear and transmission system is therefore necessary for better starting of the rotor and the general

output of the wind pump. Introducing a starter device would also ensure an efficient starting of the rotor at relatively low wind speeds.

(ii) Building the entire structure from cheap and affordable steel alternatives would ensure that the wind pumps can withstand the harsh weather conditions in the tropics. This would also facilitate easier raising of the tower, thereby improving the wind catchment of the rotor, and hence, the general performance of the machine.

(iii) While modifying the components, the availability of raw materials locally and the skill to manufacture and maintain the technology must be considered. User affordability and needs as well as other complexities must also be taken into account.

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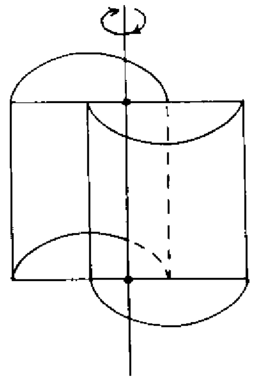

Fig. 1 The Savonius windmill.

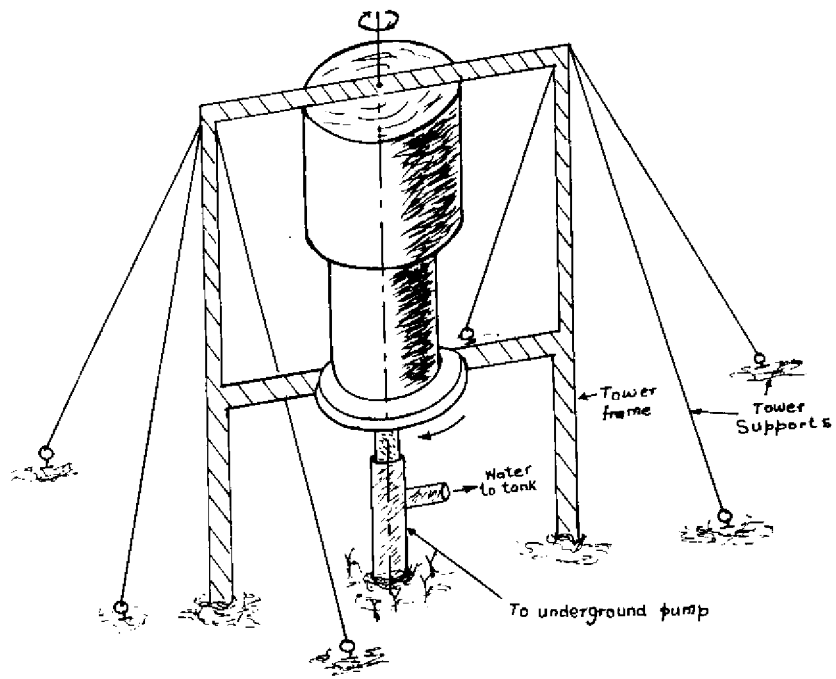

Fig. 2 The double-stark Savonius windpump - *A schematic set-up for the field test.*

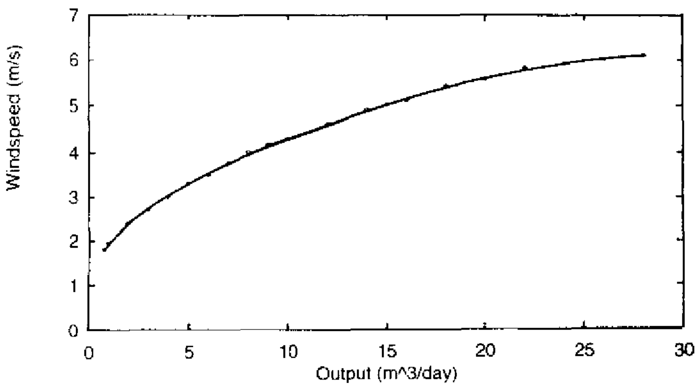

Fig. 3 Shows the plot of windspeed versus the amount of water pumped out.

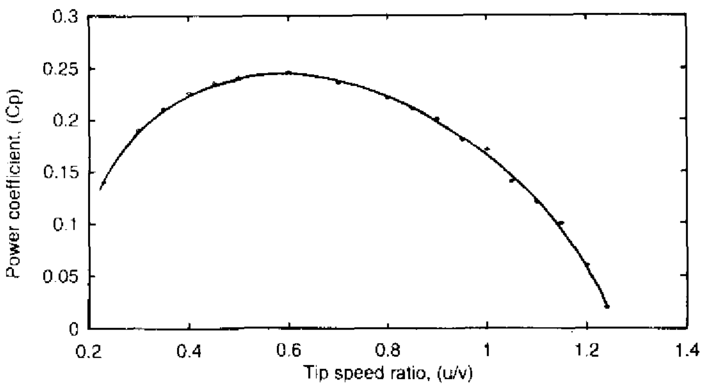

Fig. 4 Shows the plot of power coefficient versus tip speed ratio.

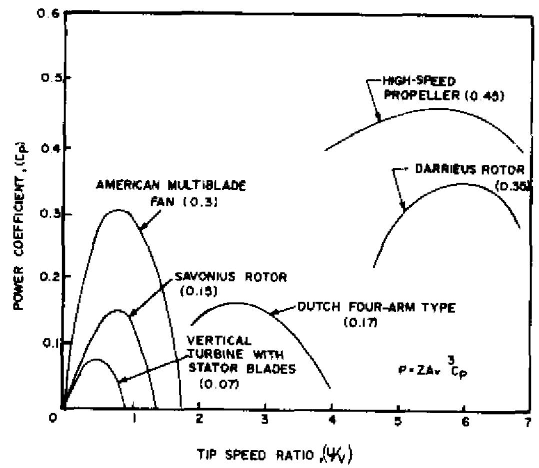

Fig. 5 Shows the comparison of power coefficient versus tip speed ratios for various individual rotors (Ref. 8).