

WINDPUMPING*

Introduction

Windpower technology dates back many centuries. There are historical claims that wind machines which harness the power of the wind date back to the time of the ancient Egyptians. Hero of Alexandria used a simple windmill to power an organ whilst the Babylonian emperor, Hammurabi, used windmills for an ambitious irrigation project as early as the 17th century BC. The Persians built windmills in the 7th century AD for milling and irrigation and rustic mills similar to these early vertical axis designs can still be found in the region today. In Europe the first windmills were seen much later, probably having been introduced by the English on their return from the crusades in the middle east or possibly transferred to Southern Europe by the Muslims after their conquest of the Iberian Peninsula. It was in Europe that much of the subsequent technical development took place. By the late part of the 13th century the typical 'European windmill' had been developed and this became the norm until further developments were introduced during the 18th century. At the end of the 19th century there were more than 30,000 windmills in Europe, used primarily for the milling of grain and water pumping. The first half of the 20th saw further development, particularly a move toward propeller type wind machines for electricity production.

The major advances in the design of the windpump, however, took place in the USA. The technology was taken up and developed by the early pioneers or settlers who needed a method of lifting ground water for irrigation, for watering of livestock and later for providing water for steam locomotives which began to spread across the country. There were several significant technical developments to the commercial machines during this time; the ability of the machine to turn into the prevailing wind automatically; the development of a self governing mechanism which automatically turned the machine out of the wind when the wind velocity became high enough to cause damage; various improvements in rotor design and general durability and the introduction of gearing mechanisms. The technology was soon taken up worldwide, especially in the newly settled arid regions, such as South Africa, Australia and Argentina, where previously a lack of water had always prevented settlement and economic development in remote areas. By the 1920's 6 million windpumps were being used in the USA alone and their manufacture and use had become commonplace on every continent.

But the glory of the windpump was short-lived. With the advent of cheap fossil fuels in the 1950's and 1960's and the development of pumping technology the windpump became almost obsolete in the USA. Nowadays, with regular fuel crises and rising prices there has been a revival of interest in windpower but the windpump has yet to regain the status it held during its heyday.

Windpumping for rural areas of the developing world

There are manufacturers in several developing countries now producing windpumps. The uptake of wind machines for water pumping, however, has been generally very slow even though the technology is well suited to the demand of many regions of Africa, Asia and Latin America. Where they are used, the demand is for one of the following end uses:

- village water supplies
- irrigation
- livestock water supplies

Water pumping is one of the most basic and widespread energy needs in rural areas of the world. It has been estimated that half the world's rural population does not have access to clean water supplies.

Technical

The power in the wind

The wind systems that exist over the earth's surface are a result of variations in air pressure. These are in turn due to the variations in solar heating. Warm air rises and cooler air rushes in to take its place. Wind is merely the movement of air from one place to another. There are global wind patterns related to large scale solar heating of different regions of the earth's surface and seasonal variations in solar incidence. There are also localised wind patterns due to the effects of temperature differences between land and seas, or mountains and valleys.

Windspeed data can be obtained from wind maps or from the meteorology office. Unfortunately the general availability and reliability of windspeed data is extremely poor in many regions of the world. However, significant areas of the world have mean windspeeds of above 3m/s which make the use of windpumps an economically attractive option. It is important to obtain accurate windspeed data for the site in mind before any decision can be made as to its suitability. Methods for assessing the mean windspeed are found in the relevant texts (see the 'References and resources' section at the end of this fact sheet).

The power in the wind is proportional to:

- the area of windmill being swept by the wind
- the cube of the wind speed
- the air density - which varies with altitude

The formula used for calculating the power in the wind is shown below:

$$P_w = \frac{1}{2} \rho A V^3$$

where, P_w is power in watts available in the wind (W)
 ρ is the air density in kilograms per cubic metre (kg/m^3)
 A is the swept rotor area in square metres (m^2)
 V is the wind speed in metres per second (m/s)

The fact that the power is proportional to the cube of the wind speed is very significant. This can be demonstrated by pointing out that if the wind speed doubles then the power in the wind increases by a factor of eight! It is therefore worthwhile finding a site which has a relatively high mean wind speed.

Wind into Watts

Although the power equation above gives us the power in the wind, the actual power that we can extract from the wind is significantly less than this figure suggests. The actual power will depend on several factors, such as the type of machine and rotor used, the sophistication of blade design, friction losses, the losses in the pump or other equipment connected to the wind machine, and there are also physical limits to the amount of power which can be extracted realistically from the wind. It can be shown theoretically that any windmill can only possibly extract a maximum of 59.3% of the power from the wind (this is known as the Betz limit). In reality, for a windpump, this figure is usually around 30% to 40% and for a large electricity producing turbine around 45% maximum (see the section on coefficient of performance below)

So, modifying the formula for 'Power in the wind' we can say that the power that is produced by the wind machine can be given by:

$$P_M = \frac{1}{2} \cdot C_p \rho A V^3$$

where, P_M is power (in watts) available from the machine
 C_p is the coefficient of performance of the wind machine

It is also worth bearing in mind that a wind machine will only operate at maximum efficiency for a fraction of the time it is running, due to variations in wind speed. A rough estimate of the output from a windpump can be obtained using the following equation;

$$P_A = 0.1 A V^3$$

where, P_A is the average power output in watts over the year
 V is the mean annual windspeed in m/s

Principles of wind energy conversion

There are two primary physical principles by which energy can be extracted from the wind; these are through the creation of either lift or drag force (or through a combination of the two). The difference between drag and lift is illustrated by the difference between using a spinnaker sail, which fills like a parachute and pulls a sailing boat with the wind, and a Bermuda rig, the familiar triangular sail which deflects with wind and allows a sailing boat to travel across the wind or slightly into the wind.

Drag forces provide the most obvious means of propulsion, these being the forces felt by a person (or object) exposed to the wind. Lift forces are the most efficient means of propulsion but being more subtle than drag forces are not so well understood.

The basic features that characterise lift and drag are:

- drag is in the direction of air flow
- lift is perpendicular to the direction of air flow
- generation of lift always causes a certain amount of drag to be developed
- with a good aerofoil, the lift produced can be more than thirty times greater than the drag
- lift devices are generally more efficient than drag devices

Types and characteristics of rotors

There are two main families of windmachines: vertical axis machines and horizontal axis machines. These can in turn use either lift or drag forces to harness the wind. The horizontal axis lift device is the type most commonly used. In fact other than a few experimental machines virtually all windmills come under this category.

There are several technical parameters that are used to characterise windmill rotors. The *tip-speed ratio* is defined as the ratio of the speed of the extremities of a windmill rotor to the speed of the free wind. Drag devices always have tip-speed ratios less than one and hence turn slowly, whereas lift devices can have high tip-speed ratios (up to 13:1) and hence turn quickly relative to the wind.

The proportion of the power in the wind that the rotor can extract is termed the *coefficient of performance* (or power coefficient or efficiency; symbol C_p) and its variation as a function of tip-speed ratio is commonly used to characterise different types of rotor. As mentioned earlier there is an upper limit of $C_p = 59.3\%$, although in practice real wind rotors have maximum C_p values in the range of 25%-45%.

Solidity is usually defined as the percentage of the area of the rotor, which contains material rather than air (see Figs 1 & 2 below). High-solidity machines carry a lot of material and have coarse blade angles. They generate much higher starting torque (torque is the twisting or rotary force produced by the rotor) than low-solidity machines but are inherently less efficient than low-solidity machines. The windpump is generally of this type. Low-solidity machines tend to be used for electricity generation. High solidity machines will have a low tip-speed ratio and vice versa.



Figure 1: Low solidity rotor ©ITDG

The choice of rotor is dictated largely by the characteristic of the load and hence of the end use. Some common rotor types and their characteristics are shown in Table 1 below.



Figure 1: High solidity rotor ©ITDG

Type	Speed	Torque	C_p	Solidity (%)	Use
Horizontal Axis					
Multi blade	Low	High	0.25 - 0.4	50 – 80	Mechanical Power
Three-bladed aerofoil	High	Low	up to 0.45	Less than 5	Electricity Production
Vertical Axis					
Panemone	Low	Medium	less than 0.1	50	Mechanical Power
Darrius	Moderate	Very low	0.25 - 0.35	10 - 20	Electricity Production

Table 1. Comparison of Rotor Types

Water pumping

Matching rotor and pump

When installing a windpump it is important to match the characteristics of the pump and the wind machine. A good interaction between pump and rotor is essential. The most common type of pump used for water pumping (especially for borehole water pumping) in conjunction with a windmill is the reciprocating or piston pump. The piston pump tends to have a high torque requirement on starting because, when starting, the rotor has to provide enough torque to overcome the weight of the pump rods and water in the rising main - once the rotor is turning, the torque requirement decreases because of the momentum of the revolving rotor. The windspeed can then drop to about 2/3 of the start-up windspeed before the windpump will stop.

Other common pump types used for windpumping are the progressive cavity or 'Mono' pump and the centrifugal pump. Both have advantages in certain circumstances but both also tend to be expensive and less commonly used.

Figure 3. illustrates a typical example of a modern multi-bladed windpump. The high solidity means high starting and running torque and low running speed which is desirable for use with the piston pump.

It is obviously important to match the water pumping demand with the available wind and hence decide upon a suitable rotor size. To calculate the demand we need to know the following data:

- The head to which the water is to be pumped - in metres
- volume of water to be pumped per day - in metres cubed

For water at sea level the approximate energy requirement can be calculated using the following equation:

$$E = 0.002725 \times \text{volume} \times \text{head} \quad (\text{in kilowatt-hours})$$

Typically pumping heads can vary between a few metres and 100m (and occasionally more), whilst the volume of water required can vary from a few cubic metres a day for domestic use to a few hundred cubic metres for irrigation.

Anatomy of windpump

A borehole is by far the most common water source from which the windpump will draw water. A classic multiblade farm windpump has a piston pump pumping to an elevated storage tank. There are many other configurations possible, depending on the nature of the water source and the demand. These machines have rotor diameters of between 1.5 and 8 metres but seldom exceed 4 or 5 metres. The power is transmitted from the rotor to the pump rods via a gearing system or via a direct drive mechanism. The movement of the pump rods cause the pump to lift water to the tank. Water can then be fed into the distribution network from the tank. The function of the tail vane is to keep the rotor orientated into the wind. Most windpumps have a tail vane, which is designed, for automatic furling (turning the machine out of the wind) at high wind speeds to prevent damage.

Windpumping with electricity

Although the multiblade windpump is by far the most common windpump in use, it is not the only option available.



Figure 3: The Kitjito Windpump. Used to pump ground water in the Bhel region of Turkana for the Nomadic Pastorlists
©ITDG

Another option, especially where there is a requirement for the pump to be sited remote from the wind machine, is to use an aerogenerator to provide electricity for an electric pump. Although they tend to be more expensive, they do have the advantage that the electricity can be used for other applications when not pumping and also that the electricity can be stored in batteries for use when the windspeed is insufficient for direct electricity supply.

Other Issues

Local manufacture

Windpumps are manufactured in small numbers in various countries throughout the world. There are manufacturers producing windpumps in Europe, Australia, South Africa and the USA for export, but there are also commercial enterprises in developing countries manufacturing windpumps. One such manufacturer, RIIC (the Rural Industries and Innovations Centre) is mentioned below.

There have been several projects over the last couple of decades with the aim of transferring windpump technology to manufacturers in the South, and there has been some success. One such success story is the Kijito windpump (See figure 3), manufactured in Kenya. This windpump was originally developed by the Intermediate Technology Development Group (ITDG) based in the UK in conjunction with Bobs Harries Engineering Ltd. (BHEL), Kenya. BHEL have further developed the Kijito design and currently produce about 25 windpumps a year with a capacity to produce up to 50 machines.

Ownership, usage, maintenance and environmental impact

User Perspective - Windpumps in Botswana

A survey was conducted in Botswana on owners/ users of windpumps. The aim was to determine the ownership, procurement and installation, use, environmental impact and promotion of windpumps. The survey revealed that 54% of the windpumps were owned by households and 23% by farmers groups or syndicates. The rest (23%) were owned by the community. The majority of the windpumps (85%) were purchased and the rest were donated. Fifty-six per cent of the respondents purchased windpumps or raised the money from the banks to purchase them, whereas 18% utilised group contributions. Most of the respondents purchased the windpumps from RIIC, the local supplier. The installation of the windpumps was done by RIIC in 69% of the cases and by owners and foreign dealers in 23% and 8% respectively. Ninety-two per cent of the respondents were of the opinion that the installation was done satisfactorily. The operators had been trained by the supplier in 39% of the cases and the remainder had either taught themselves (31%) or been taught by the local technicians (8%).

All respondents revealed that windpumps were used for pumping water for livestock as well as for irrigation and domestic purposes. Ninety-two per cent of the respondents were of the opinion that the windpump had significantly improved their water supply. Eighty-four per cent thought that windpumps satisfied the water needs of the community. Thirty-one per cent depended on windpumps entirely for their water pumping, while 69% had other systems. The respondents perceived windpumps as a good technology mainly because they were cheaper to use. One of the problems associated with the use of windpumps was the high frequency of breakdowns. Forty-six per cent indicated that they broke down once a year, 31% twice a year and 23% more than three times a year. Major repairs were done by RIIC (54%), local technicians (8%) or a combination of the two (8%).

The study also investigated the perception of respondents of the environmental impact of the use of windpumps. The majority (85%) thought the windpumps improve the scenery, whereas 15% said they do not make a difference. No negative impacts were reported. It was also the view of 92% of the respondents that the noise from the windpumps is not a nuisance. The respondents thought that the adoption of the windpump technology was constrained by factors such as the lack of appropriate policies, lack of awareness of the technology, high costs of maintenance and inadequate wind regimes.

Source: Mosimanyane et al 1995 (cited in Karekezi & Ranja 1997)

References and resources

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Manufacturers

Note: This is a selective list of suppliers and does not imply ITDG endorsement.

Neale Consulting Engineers Ltd., Highfield,
Pilcot Hill, Dogmersfield, Hants. RG27 8SX,
UK.
Tel: +44 (0)1252 629199
Fax: +44 (0)1252 815625
Manufacture the Poldaw 3.5m Windpump.
Website: <http://www.tribology.co.uk/poldaw.htm>

Abachem Engineering Ltd., Jessop Way,
Newark, Notts. NG24 2ER, UK.
Tel: +44 (0)1636 676483
Fax: +44 (0)1636 708632.
Manufacture and supply windpump and
'submerged control leakage pump'.

Southern Cross Industries (Pty.) Ltd.,
P.O. Box 627, Bloemfontein 9300,
South Africa.
Tel: +27 (0)51 4343861
Fax: +27 (0)51 4343575
Manufacture and supply windpumps.

Stewarts & Lloyds, 37 Leopold Takawira St.,
Harare, P.O. Box 784, Zimbabwe.
Tel: +263 4 708191
Fax: + 263 4 790972
Manufactures of the IT Windpump.

The Rural Industries Innovations Centre,
(Subsidiary of Rural Industries Promotions
Company. Website: <http://www.ripco.co.bw>),
P/Bag 11, Kanye, Botswana.
Tel: +267 340392
Fax: +267 340642

Bobs Harries Engineering Ltd., P.O.Box 40,
Thika, Kenya.
Tel: +254 151 47234 or 47250
Fax: +254 151 47233

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