it

Faculteit der
Technische Natuurkunde

Vakgroep Transportfysica

DEVELOPING COUNTRIES

Smulders, P.T.

ber 1986 R 817 D

WIND ENERGY FOR WATER PUMPING IN DEVELOPING COUNTRIES

Smulders, P.T.

October 1986 R 817 D

Paper of the 6th European Wind Energy Conferences, October 1986, Rome

TECHNICAL UNIVERSITY EINDHOVEN
Faculty of Physics
Laboratory of Fluid Dynamics and Heat Transfer
WIND ENERGY GROUP
P.O. Box 513, 5600 MB Eindhoven, Netherlands

CONSULTANCY SERVICES
WIND ENERGY
DEVELOPING COUNTRIES

P.O. BOX 85
3800 AB AMERSFOORT
THE NETHERLANDS

WIND ENERGY FOR WATER PUMPING IN DEVELOPING COUNTRIES

P.T.SMULDERS*, CWD, THE NETHERLANDS

*Technical University Eindhoven, The Netherlands

1. INTRODUCTION

At the United Nation Conference on New and Renewable Sources of Energy in Nairobi in 1981, the Technical Wind Energy Panel "foresaw the possibility of wind energy playing a significant role in pumping water for household needs, animal husbandry, irrigation and drainage in rural areas, especially in developing countries". This statement was made in a period of rising oil prices; at that time price predictions for a barrel of oil in the ninetees ranged between $30 and $45. Those, who after the 1973 oil crisis had jumped into the field of renewable energies, were of necessity optimists and the wind energy enthusiasts among them invoked on willing listeners and, of course, policy makers and donors the image of Lasithi plains in developing countries, lush with green crops irrigated with simple and cheap pumping windmills.

What has become of those expectations? And what are future prospects for waterpumping with windmills in a situation where oil prices have suddenly decreased considerably and might remain low for the coming decade?

Although it is true that many wind energy activities can be traced in many countries of the 3rd world (e.g. India, Sri Lanka, Pakistan, China, Tunesia, Kenya, Tanzania, Mozambique, Brasil, Mexico, Colombia) and a number of western countries, there is no evidence of a breakthrough to really extended wide scale application of wind pumpers. In the author's view, however, the long term prospects for windpumpers are bright as the following will hopefully make clear.

2. THE SCENE [1]

Windpumpers can be used for different applications; for domestic water supply, animal husbandry, irrigation, drainage and salterns. There is a wide variety of requirements: pumping heads from 1-100 m, flow rates from 1 to 1000 m^3/day.
Also wind conditions vary substantially: e.g. average annual wind speeds from 2.5 to 7 m/s.

The hardware - some of it available but most as yet under development - to meet these requirements is equally varied. This is manifest if we look at the different components. Towers: lattice or tubular guyed. Rotors: horizontal or vertical axis, sails or steel plates as rotor blades. Transmission: direct mechanical, pneumatic, hydraulic or electric. Pumps: piston pump, mono pump, centrifugal or axial flow pump, air pump, screw pump. Control and safety: inclined hinge, ecliptic and hinged side vane as passive systems.

The goal of development of wind pumpers is to pump water at minimum costs. This implies a compromise between a. low investment, b. long life, c. cheap maintenance, d. high output. These factors are not independent.

A low investment might imply a shorter life-time. Reliance for maintenance on relatively cheap spare parts which have to be imported may result, owing to import barriers, in low output or loss of crop because the windpumper can't operate for some months.

The most important type of windpumper with a wide range of application available on the market is the classical American multi-blade windmill driving a piston pump (e.g. Dempster, Southern Cross, Aermotor). Its development started around 1850 and was more or less finalised around 1930. Little research was put into its development; the design evolved by a game of trial and error between manufacturer and customer.

The capital investment of imported windmills (including transport, tank and installation) is typically $400 to $500/$m^2$ rotor area. Maintenance and repair, despite the basic reliability of the machines, poses so many problems (availability of spare parts, qualified mechanics, etc.) that the effective water output can be very low, owing to stand still. These mills are heavy and in many countries too complicated for local manufacture and their efficiencies are rather low. Probably, well over half a million of these mills are in use today (USA, Australia, South Africa, Argentina).

---

* P.T.Smulders
Technical University Eindhoven
The Netherlands

3. CURRENT TECHNOLOGICAL DEVELOPMENTS AND FUTURE PROSPECTS

3.1 Windmills driving piston pumps

To design more cost-effective windpumpers driving piston pumps compared to the multiblade machines the following aspects can be considered [2].

Use lighter, lower solidity rotors; use a simpler transmission avoiding gearboxes; avoid specialised parts; aim at high efficiences; design components to be as light as possible; local manufacture in simple workshops (no foundry, no milling).

This strategy is not without pit falls. For example, lower solidity rotors have lower starting torques and they lead to higher pump speeds with all the inherent dynamic problems involved.

A number of organisations has been working along these lines e.g. ORP (India)/TOOL (Netherlands), IT Power (ITDG, U.K.) in close cooperation with a firm in Kenya, CWD (Netherlands), WEU (Sri Lanka in cooperation with CWD), Las Gaviotas (Colombia), Laboratoire d'Energie Solaire in Bamako with Vita (Sahores-windmill) etc.

One can discern two ways of tackling the design problem: one more or less aims at a modern, efficient, light, all metal design which can basically be applied in different situations and locations; the other tries to make maximum use of locally available cheap materials (wood, sails) and production is more or less "on site". The latter method usually leads to designs with low efficiencies, not implying that they are not cost-effective. The most well known case is that of the Lasithi plains in Crete (Greece) where the local mills performed well over a period of 40 years (1920-1960). The Sahores windpump promoted in Mali, belongs to the same category. It is unclear, however, what the prospects of this kind of approach will be. It is certainly difficult to engage in general statements, as the approach is so much tied to local conditions.

We will therefore restrict ourselves to the first approach. Substantial progress has been made in the design of light and efficient rotors ($C_p \approx 0.3$-0.4). Reduction in weight has been obtained by using modular welded construction elements. Only recently a start has been made to analyse the behaviour (static and dynamic) of passive control and safety systems. Although most designs incorporate the classic elliptic or hinged main-vane control system, the hinged-side vane concept of Kragten [3] holds good prospects for price reduction and shows that there is still room for innovative concepts. [illegible]

The piston pump is probably the most critical item in a windpump, for three reasons.

- the dynamic loads which they introduce, especially if "back gearing" as used in the classical windmill is left out;
- maintenance and repair, which is difficult and expensive for deepwell pumps (upto 100 m);
- the effect of starting torque on efficiency, including the influence of the pump rod weight.

Although the importance of the first two aspects cannot be overstressed requiring continuous research and feed back from field experience, the third item is particularly interesting because it is the main cause of low efficiencies of existing windpumps.

The efficiency of a windpump driving a piston pump with an average constant torque is shown in fig.1.

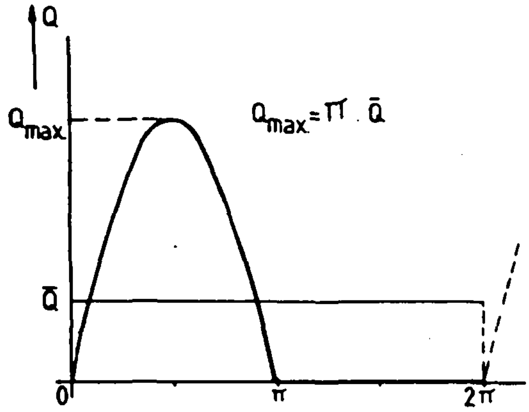


Fig. 1 Torque of piston pump. Once running, rotor inertia smoothes out the fluctuating load. From standstill rotor torque should be high enough to take the bump of the load, Q_{max}

A classical windpump starts at a windspeed $V_{start} \approx 1.5\ V_{design}$. Once it is running it will do so until the wind speed drops below $V = V_{stop}$. The resulting efficiency in the region between V_{stop} and V_{start} will be a dotted line (fig.2), the efficiencies being lower if the probability of low windspeeds is higher. This behaviour has led to the practice of undersizing the pump, resulting in a low overall efficiency of the system.

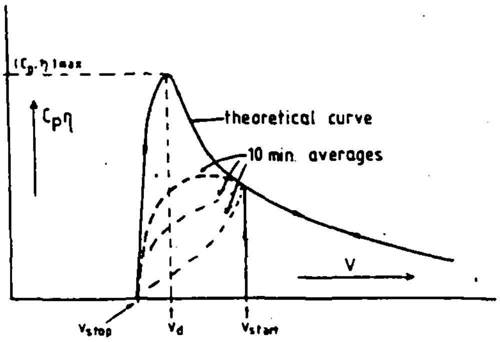


Fig. 2 Effect of starting torque on efficiency of wind pump (dotted lines). Theoretical curve excludes this effect.

This matter has been receiving considerable attention [4,5]: counter balancing by weights or springs, automatic stroke control, the latter being effective but very expensive and complicated for application in developing countries. CWD uses a starting hole in the piston (between pressure and suction head) easing starting. It is currently testing a 2 m. diameter windpump equipped with a piston valve which, controlled by the water flow, remains open at low pump speeds [6].

The importance of the design features described above, lies not only in a potential larger total water output by a factor of 2, but also in an increase in availability, meaning that the water output at low and moderate windspeeds is substantially higher (fig.3).

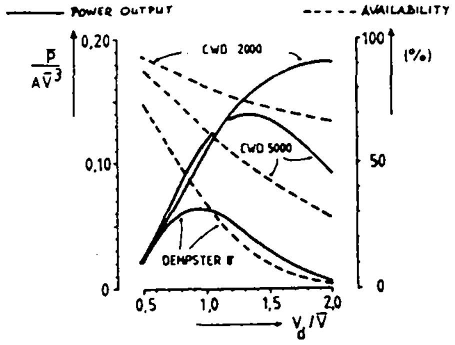


Fig. 3 Effect of starting hole in piston (CWD 5000) and controlled valve (CWD 2000) on power output and availability compared to classical wind pump [7a]; see also [7b].

The results of the developments described above are a potential reduction of weight by a factor of two and a potential increase of water output by a factor of two. This would mean a dramatic reduction of water costs by a factor 3 to 4, if weight is a yardstick for price (fig.4), see also photos. 2 and 3)

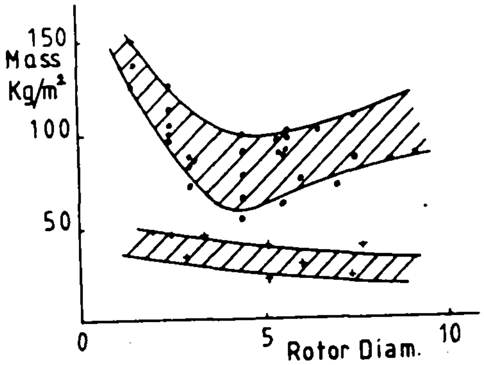


Fig. 4 Trends in specific mass (kg per m^2 rotor area) of classical multiblade and modern design wind pumps.
Note: values have not been corrected for tower height and pumping depth, but the trend seems sufficiently clear.

Production costs of a windmill, however, are dependent on many factors (import taxes, labour costs, production in small series or mass production, etc.) and differ from country to country. In Sri Lanka the WEU (Wind Energy Unit) were able to have 3 m.-windpumps manufactured and installed for $140,-/m^2. In Kenya, because of high material costs in that country, the Kijito windpump costs around $300,-/m^2. It should be borne in mind that these new machines have not had sufficient time to prove to be as reliable as the classical multiblades.

3.2 Other types of windpumps

a. Screwpumps. In China a prototype windpump, driving a screwpump (low lift, high flow rates) has been put into the field for testing (photo 4) after detailed measurements had been performed on the screwpump itself [8]. These measurements showed good efficiencies (70%) over a wide range of rotational speeds. Its starting torque drops to zero at stand still because the water leaks out of the pump to the lower level side.

b. Centrifugal pumps. Thousands of small commercial windmills (3 m diameter) driving centrifugal pumps are in use in the Netherlands for drainage; lifting heights are about 1 meter. The design, however, is specifically adapted to the drainage system in the country and cannot be used without risk of failure in other situations. Although a directly driven centrifugal pump seems a good option for moderate lifting heights (up to 10 m) very little research is being done in this field.

c. Electrical transmission [9,10]. There are many cases in which a system with an electrical transmission between the wind generator and a centrifugal pump can be attractive, for example, if the well is in the valley and the generator can be set on a hill top with high winds. On the Cape Verdian Islands (high wind speeds) electrical deep well pumps (up to 80 m below ground level) are driven by diesel generators or via the utility grid.

In 1984 a Lagerwey 10.6 m diameter wind generator was installed driving a deep well pump, after it had been tested by CWD over a year in the laboratory and in the field (photo 5). It incorporates a synchronous generator driving the asynchronous motor of the pump, implying a more or less fixed transmission ratio between the two, as a mechanical transmission would do. Five more installations are planned for 1987/1988.

Another interesting application of the electrical transmission might be that of a generator autonomously driving a screw pump: synchronous generator, asynchronous motor and reduction gears to drive the pump. Screw pumps can handle enormous amounts of water, up to a few m^3/s, which is very attractive for drainage (power requirements up to tens of kilowatts).

d. Pneumatic transmission. This requires an air compressor driven by the wind rotor; there are different ways to use the air to pump water. The system has a number of advantages:

1. for remote pumping with the windmill set at a location with good winds;
2. the capacity in the piping leveling off the fluctuating output of the rotor;
3. the simplicity of transporting energy from the compressor to the pump, without any components being heavily loaded.

A problem is the efficiency of the whole system. Research is being done at the "Universidade Federal de Pernambuco" Recife, Brasil; 150 wind pumpers, using compressed air, have already been manufactured in Brasil [11]. In the USA a pumper using compressed air is manufactured under the name Bowjon. At present this windmill is being tested on the Almere testfield of CWD.

4. ECONOMICS

If there is one item on which it is impossible to make generally valid statements, it is that concerning the economics of different waterpumping systems. Interest rates, labour and material costs, subsidies, import duties, availability of skilled labour, fuel prices, these are just a few of the many factors that determine the economic viability of a system. Also the economic value of pumped water depends on the application: live stock, domestic use, irrigation. The first two require a constant output over large periods of time; for irrigation the requirements may only extend over shorter periods but are very critical.

An estimate of water costs resulting from the pumping system alone (excluding well and storage tank) is given by [12].

$$0.114 * \frac{(\alpha + \mu)\ (SI)}{\beta\ \overline{V}_{cr}^{3}} * \frac{\overline{E}_{cr}}{\overline{E}_{an}} \qquad \$/kWh_h$$

in which:

SI is the specific investment per m^2 rotor area,
α is annuity factor on investment
μ is fraction of investment for annual maintenance and repair
$\overline{E}_{cr}$ is average daily hydraulic energy requirement in the critical month
$\overline{E}_{an}$ is annual average daily hydraulic energy requirement
β is a quality factor indicating the efficiency of energy conversion
$\overline{V}_{cr}$ is the average windspeed in the critical month

In the critical month the ratio hydraulic energy requirement/windpotential is maximum.

Note: 1 kWh_h is equivalent to pumping 367 m^3 over 1 m height or 36.7 over 10 m or 3.67 over 100 m height.

For domestic use the demand over a year is constant, so the critical demand factor $E_{cr}/E_{an} \approx 1$. For irrigation this factor might be 3 to 4, showing that a careful analysis on its economic viability is necessary, especially as the added value owing to irrigation in terms of crop production is small. Typically prices should be below $0.10/$m^3$. The added value is much higher for animal husbandry which has been the main application for windpumpers in the past (USA, Australia). The value of drinking water depends strongly on the economy and policy of the country.

Assuming $\beta = 0.08$ and SI (including installment) = $400/$m^2$ for a "classical windpump", $\alpha = 0.132$ (interest 10%, lifetime 15 years), $\mu = 0.02$ (conservative) and a constant water demand the water costs are:

$$\frac{85}{\overline{V}_{cr}^{3}} \qquad \$/kWh_h$$

At $\overline{V} = 3$ m/s that would be $3/$kWh_h$. For a solar pump at a specific investment level of $18 per watt peak, water costs are approx. $4/$kWh_h$. Fuel costs at $0.4 per liter for diesel pumps are at least $0.4/$kWh_h$ and for kerosene pumps $0.8/$kWh_h$. However problems with maintenance and repair, and availability of fuel can escalate the total costs per kWh_h, but this will depend on the local situation.

Future prospects are that $\beta = 0.15$ and SI = $200.-/$m^2$. In that case water costs become $23/\overline{V}_{cr}^3$ $/$kWh_h$. Even including the costs of a tank it is seen that water costs at $\overline{V}_{cr} = 3$ m/s reduce to approx $1.-/$kWh_h$, which puts windpumps, especially if locally produced in a very competitive position. If in the case of irrigation the lifting head is 10 m and the critical demand factor is 3, the costs of water would be $3.-/$kWh_h$, which is equivalent $3/367 m^4 or less than $0.10 per m^3.

At $\overline{V}_{cr} = 4$ m/s the values of water costs given above are more than halved and wind energy is probably less expensive than any other option.

5. TESTING

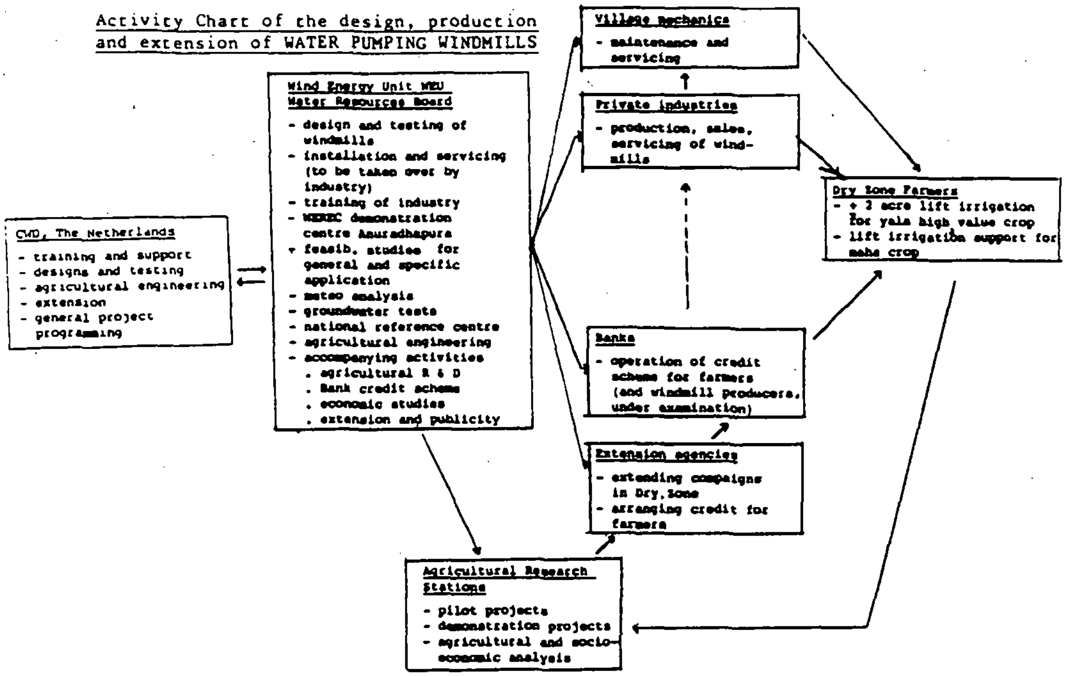
There is a lack of reliable field data on waterpumpers. The last years a number of institutes have set up test fields, e.g. USA (Texas) [4], Canada (Lethbridge), Netherlands (CWD), besides testing in pilot projects e.g. in Kenya (IT Power) [13], Sri Lanka (WEU), Cabo Verde (DER/CWD). As yet comprehensive testing and evaluation methodologies are still in the stage of development. The IEA-recommendations for wind generators are insufficient for waterpumps showing a hysteresis loop (fig. 2). The power curve in this case is not independent of the wind regime; that means that methods will have to be developed to correct the measured data to a standardised wind regime [7]. For demonstration projects simple testing methods rendering reproducible results in different locations need to be agreed upon internationally.

6. FIELD EXPERIENCE AND DISSEMINATION

Although it is true that many wind energy activities can be traced in many countries of the 3rd world (e.g. India, Sri Lanka, Pakistan, China, Tunesia, Kenya, Tanzania, Mozambique, Brasil, Mexico, Colombia) there is no evidence of a breakthrough to really extended wide scale application of wind pumpers. Why? There are many reasons.

1. The technology has shown to be more difficult than was anticipated. In the late seventies under the banner of appropriate technology many believed in an "old rubber tyre-bent nail" approach. Though the bent nail may serve many purposes, it doesn't work with windmills which have to operate under extremely difficult conditions.
2. Those countries wishing to absorb the technology, lack the infrastructure: e.g. availability of basic data,

Activity Chart of the design, production and extension of WATER PUMPING WINDMILLS



expertise and man power, industrial capacity, maintenance potential, experience with irrigation, capital, financing: etc. These are difficult circumstances for a technology to take off. In the swell of wind energy application in wind farms in California these factors were available: because of the tax-credits there was an abundance of capital. This triggered an inflow of expertise, consultants, management, companies. In the beginning the whole system was not even sensitive to failure. New capital came rushing in, which would otherwise have drained away as tax anyway. The technology gradually improved from the field experience of hundreds of wind generators. These are conditions not normally encountered in developing countries.

3. Wind pumpers are as yet more expensive than suggested a number of years ago.
4. Political instability in some countries has hampered the extension of the technology.
5. Lack of validated information on real performance in the field, especially for donors, decision makers, extension agencies.

In such circumstances it can be appreciated that the large scale implementation cannot be wrought overnight.

The wind energy project in Sri Lanka is a good example, showing the complexity of the process of introducing a new technology. The chart below summarizes the many aspects involved. In total 150 windmills (3m. diameter) locally manufactured were installed at farms, most of them private. When the project started, there was no wind energy expertise in the country [14]. The farmers - who in this case had experience with irrigation - had to learn to adapt their cropping patterns to the typical water provision by the windmill. After the technology had been developed, a demonstration centre was set up. Arrangements had to be made with banks for providing loans. A design was made for an inexpensive ferro-cement water storage tank. Winddata were analysed in detail. Small industries had to be involved for the production of a product hitherto unknown to them etc., etc.

The Sri Lanka project was evaluated in 1984/85 by Greeley [15]. His enlightening report reflects the many complexities involved. In his analysis, based on limited interviews with 30 farmers, he concludes: "the limited evidence that is available suggests that windmill farmers cultivate smaller areas and on average achieve lower net returns per acre than kerosene pumpset farmers. The main explanation advanced for this difference is the adoption of a different cropping pattern by a substantial minority of pumpset farmers, i.e., early planting of high value vegetable crops. Windmill farmers are not able to provide suitable quantities of water for early planting because of low wind speeds at the beginning of the year. This explanation is still tentative but does suggest that a shift to windmills involves a critical loss of flexibility in choice of cropping patterns" and further: "It is absolutely clear that if oil prices had continued to rise, as they were universally expected to do at the time of project inception, the economic viability of windmill irrigation would have been assured.

The "loss of flexibility", mentioned by Greeley is partly due to the low efficiencies of the windmills at the lower wind speeds owing to the starting problems, mentioned earlier in paragraph 3.1.

A reverse situation is reported in [1]. On the Kenya-Sudan border a windmill was installed for drinking water. With the surplus water the semi-nomadic people on their own initiative planted a hectare of crops. In this case the combined use of water as drinking and irrigation water has a favourable effect on the economics of the system.

7. CONCLUSIONS

1. The technological development of water pumpers is still in its beginning; considerable reduction in water costs can still be achieved.
2. The economic competitiveness of wind pumps to other pumping options depends on many factors, that need to be carefully analysed before embarking on a dissemination programme. At wind speeds ($\bar{V}_{cr}$ > 3.5 m/s) wind energy is certainly one of the best options.
3. The introduction and dissemination of a new technology is a very complex process; it will take many years for dissemination processes to become self supporting.
4. Training is a vital aspect in any project.
5. To avoid expensive learning by trial and error in far away places, an extension of field testing at laboratory field-sites is imperative.

REFERENCES

[1] "Wind Technology Assessment Study" Vol. I and II - ITP 82041 - Febr. 1983 - IT Power - U.K.

[2] P.T.Smulders, R.Schermerhorn "The design of fastrunning waterpumping windmills" Proceedings AWEA Conference - Pasadena - USA - (1984)

[3] P.T.Smulders, e.a. "Innovative control and safety systems for waterpumpers" Proceedings EWEC - Hamburg - 1984

[4] Dan W.McKensie "Range waterpumping systems" State-of-the-art-review - Forest Service Equipment Development Center - San Dimas - CA - USA - July 1984

[5] J.A.C.Kentfield "The case for wind-turbine driven waterpumps with adaptive load characteristics" 19th Inter Society Energy Conversion Engng Conf. (IECEC) - San Francisco - USA - Aug. 1984

[6] H.Cleijne, P.Smulders, F.Verhey "Pump Research by CWD: the influence of starting torque of single acting piston pumps on waterpumping windmills" see session 2-E this conference

[7a] H.Oldenkamp, N.Pieterse "Field measurements on CWD-2000" - Report R 765 D - Wind Energy Group - Dept. of Physics - University of Technology Eindhoven - Netherlands - (1985)

[7b] J.v.Meel, e.a. "Field testing of waterpumping windmills by CWD" (This conference session 3F)

[8] D.Shen, e.a. "The national research programme about wind power - screw pump unit" (This conference)

[9] F.Goezinne "Performance of wind electric pumping systems" (This conference)

[10] L.M.Semedo, e.a. "Matching an electrical centrifugal pump to a variable wind speed turbine" (This conference)

[11] E.Feitosa "Compressed air water pumping systems driven by wind turbines - progress and potential" See session 2-E this conference

[12] P.T.Smulders "Costs of water (in preparation)" Technical University Eindhoven

[13] J.P.Kenna "The field performance of Kijoto windpumps in Kenya" (This conference)

[14] N.W.M.Pieterse, G.C.J.J.Stevens "Manpower profiles in energy sub-sectors Vol. VII Wind Energy - Bangkok 1985 - published by UNDP/ESCAP/ILO

[15] M.Greeley "Rural energy technology assessment: a Sri Lankan case study" Inst. of Development Studies - University of Sussex - Brighton - U.K. 1986