Report of the Commonwealth Workshop on Low-cost Energy for Water Pumping

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REPORT OF THE COMMONWEALTH WORKSHOP

ON

LOW COST ENERGY FOR WATER PUMPING

KANYE, BOTSWANA

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LOW COST ENERGY FOR WATER PUMPING

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CHAPTER 1: INTRODUCTION

Background to the Workshop, Objectives Organisation, Acknowledgements

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1. Introduction

The Regional Workshop on Low Cost Energy for Water Pumping was held at the Rural Industries Innovation Centre in Kanye, Botswana from 24-29 November 1980. It was jointly sponsored by the Food Production and Rural Development Division of the Commonwealth Secretariat and the Commonwealth Science Council (with funds provided by the Commonwealth Fund for Technical Co-operation), and by the Rural Industries Innovation Centre, Botswana. It was attended by 42 participants from Botswana, Ethiopia, Kenya, Lesotho, Malawi, Tanzania, Uganda, Zambia, Zimbabwe and by specialists from Canada, India and the United Kingdom. The objective of the workshop was to enable participants to compare experiences of developing low cost sources of energy for water pumping in the countries of the region, and to agree on measures for promoting the use of such energy sources in place of high cost imported fossil fuels. This report outlines the background and objective of the workshop, summarises the discussions held and the conclusions reached, and points the way to future work on the subject.

2. Background to the Workshop

The 1980s are to be the United Nation's Water Development Decade, by the end of which it is hoped that every family will have ready access to a piped water supply. Currently some 60% of the world's rural population lacks access to such household water supplies.

The scope for improving farm incomes and rural livelihoods through irrigation and improved water supply for livestock is just as striking. But the cost of pumping groundwater for these purposes with the commonly used technologies puts it beyond the reach of most rural families.

Two programmes have been initiated by the Commonwealth Secretariat with the objective of developing and promoting application of low cost technologies for agriculture and rural development: the rural technology programme sponsored by the Food Production and Rural Development Division, and the Africa energy programme sponsored by the Commonwealth Science Council. The Botswana workshop arose directly from proposals made at two regional review meetings held in 1979, and brought together scientists and users of low cost technologies for water pumping involved in both the above programmes.

3. Current Situation

Almost all pumped rural water supplies, for both household and agricultural use, currently rely on imported fossil fuels and high cost technology. The high cost of energy, together with the cost of power units and pumps and the difficulty of managing them efficiently in rural areas, are the main constraints on extension of pumped water supplies.

4. Alternative Energy Sources

Low cost sources of energy available in most developing countries include solar energy, wind energy, biogas, producer gas, wood and charcoal. The two sources which are most appropriate for driving pumping mechanisms in Africa, and the ones on which most research and development work has been done, are wind energy and biogas.

Each has positive and negative features. In many locations wind speeds are inadequate or inconsistent; unit costs of small output windmills tend to be high. Biogas generation requires a continuous supply of substrate and careful management of the plant; the capital cost of many biogas generators is still high, and gas has to be utilised indirectly through a converted combustion engine. Nevertheless, the technical difficulties, and the costs in so far as they are known, are unlikely to be greater than those associated with diesel engine-driven pumping mechanisms.

5. Application of Technology

In the case of both wind energy and biogas, the technology itself is now fairly well known. Windmills and biogas plants are manufactured commercially in many parts of the world, including a number of countries in Africa. Diesel engines have been converted to run off a high proportion of biogas in Botswana and elsewhere. Further basic research and development is unnecessary.

The problem lies in application: first in reducing the capital and recurrent costs to bring the technology within reach of small farmers and rural communities; second to train users in the management and maintenance of the equipment; third to ensure regular supplies of materials and continuous use or storage of the energy generated.

6. Energy Costs in Relation to Water Supplies

The main criterion for developing new wind and biogas technologies is the cost of the energy generated in relation to the supply of water. This in its turn depends on the use to which the water is put. When water is pumped for irrigation purposes, it is required only part of the year. When it is pumped for domestic or livestock consumption, a regular supply throughout the year is required. The capital and recurrent cost of the equipment must be weighed against the 'value' of production. This value is easier to measure when the water is used for directly productive purposes such as irrigation or livestock, than when it is used for domestic purposes, the benefits of which are social as well as economic - reduced time spent in collecting water, increased use of domestic water and better hygiene.

7. Monitoring of Performance

At the moment little information is available on the efficiency of different models of windmills and biogas plants, or on the real cost of water pumped by these means. Such information as is available in different countries is collected using different parameters for measurement. There is thus no comparability between the performance even of similar units in different countries. This is an important gap which needs to be filled.

8. Objectives of the Commonwealth Workshop

The Workshop on Low Cost Energy for Water Pumping brought together research and development workers, manufacturers, appliers and users of windmills and biogas plants from many countries of East and Southern Africa. The purpose was to enable them to review the work done in this field in each country of the region, to learn from each other's experiences, and thus to avoid unnecessarily repetitive research and development in the future.

An important objective was to develop and agree on common procedures for monitoring the performance of windmills and biogas plants, both in technical and in economic terms. This would allow tests carried out in one country or set of conditions to be compared with tests carried out elsewhere, and would considerably enhance the value of such tests.

Where the experience showed that adaptive research and development was needed to iron out problems of application of the wind and biogas technologies, it was hoped that this could be done collaboratively within the region, making the fullest use of the resources that are available. For this pupose a mechanism for exchange of information and continued communication between countries would have to be established.

9. Organisation of the Workshop

Three lead papers were presented summarising the state of development of windmills and biogas plants for water pumping both in Africa and in Asia. Country papers describing the experience of each participating country were then presented and discussed. Participants then divided into two working groups to discuss in detail the potential for applying wind power and biogas for water pumping in the region, and to draw up programmes, both national and regional, for achieving this potential. The programme of the workshop is attached as Appendix 2.

10. Outcome of the Workshop

Participants agreed on a set of guidelines for monitoring wind pump and biogas plant performance, and on a procedure for ensuring continued exchange of information on these subjects in the region. A method of monitoring and presenting wind data, which would allow windmill performance to be compared in different countries, was presented for discussion at a meeting of Directors of Meteorological Services in Africa. A study of the control and performance of biogas systems, including technical, economic, social and cultural evaluations, was proposed.

The detailed Conclusions and Recommendations of the Workshop are presented in Chapters 2 and 3.

11. Acknowledgements

The participants expressed their appreciation to the Commonwealth Secretariat and the Rural Industries Innovation Centre for bringing them together and enabling them to have such productive discussions during their meeting.

The Commonwealth Secretariat thanks the Government of Botswana and the Rural Industries Innovation Centre for hosting the Workshop, and thank Mr Colin F. Beavington for undertaking the editing of this report.

CHAPTER 2: REPORT OF THE WIND POWER PUMPING SUB-GROUP

2.1 Objectives

The Wind Power Pumping Sub-Group began its work by establishing the following objectives:-

(i) To agree on a common way of measuring windmill performance so that information obtained in one country can be used in another.

(ii) To establish a standard way of measuring wind regimes that could provide the necessary information required for the design and/or application of windmills for water pumping.

(iii) To describe and discuss methods for predicting windmill output given existing wind regime data.

(iv) To adopt a technique for comparing different windmill designs, either using a type of 'performance number' (involving factors such as: overall efficiency, operating life, maintenance, number of windmills in operation ....) or by way of an economic analysis.

(v) To examine and explain the procedure for predicting windmill output from wind data.

(vi) To make recommendations on the types of windmill designs that are suitable to different wind regimes.

(vii) To discuss the basic technical problems facing the design and application of wind pumps, including statements of the aims and objectives of each national wind pumping program.

(viii) To discuss the problems related to installation and maintenance of windmills as well as ways and means of ensuring that new innovative designs or concepts can become public material and therefore non-patentable.

(ix) To examine the training implications of wind power pumping.

(x) To establish or strengthen a mechanism for promoting regional collaboration and co-operation (including information sharing).

2.2 Windpump Performance Measurement

A method for determining overall wind pump performance is outlined in the paper entitled "Performance Measurement of a Water Pumping Windmill" (see Annex 1). The group recommended that this method be adopted by all those concerned with wind pump performance in the region.

A complementary procedure for measuring rotor performance only is described in the paper "Performance Measurements on the 6 Meter Diameter Horizontal-Axis Windmill" (Annex II-a) supplemented by the paper "Notes on the Use of Acceleration for Performance Testing", (Annex II-b). It was felt that the information gained from this procedure would be very valuable for those who are actually taking part in the design of wind pumping systems, but that it might be beyond the means of some groups, particularly those interested in the application of existing windmill technologies.

2.3 Wind Monitoring

Standard meteorological recordings of wind speed are carried out at heights of 2m (using cup totalizers) and 10m (using instantaneous wind speed recording anemometers). A 10m height is seen as appropriate for windmill work. There was some concern as to whether this information would be sufficient for windmill design and application purposes. Although there was some disagreement within the group the majority of people felt that a recommendation be made to the respective meteorological departments as follows:

i) Instantaneous windspeed be measured on a continuous basis, or mean windspeed over a very short (nominally 1 second) time interval be recorded.

ii) The resulting data be presented in the form of a windspeed duration curve or a windspeed frequency distribution histogram (or curve).

iii) The band width of wind velocities in the velocity frequency distribution histogram (or curve) be no more than 1 m/s.

iv) Wind records be recorded for as long as possible, preferably on a permanent, on-going basis.

It was realised that it may not be possible to obtain the wind speed information in precisely the way desired and it may be necessary to do the best possible with existing meteorological data.

It will be possible for some wind pumping programs to obtain their own monitoring equipment to enable them to carry out measurements in the preferred manner. A list of manufacturers of wind monitoring equipment appears as Annex III.

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2.4 Use of Existing Wind Data

The statistical methods described in the paper entitled "Wind as an Energy Resource for Water Pumping" (See Annex IV) may be used to estimate the windspeed duration or windspeed frequency distribution curves. The simplest of these methods requires data only on mean windspeed, but the results will not be entirely accurate. The second procedure described would require some detailed measurements to be carried out for the wind region. From these measurements the form of the statistical distribution can be established so that the windspeed distribution curves can be predicted with greater accuracy.

2.5 Windmill Comparison Techniques

The group agreed that windmills should be compared within the 9 sub-groupings shown in the table below:

TABLE I WINDMILL CATEGORIES

Windmill Type	Demand for Water		
	Small	Medium	Large
Borehole (below ground)	1	2	3
High Lift (above ground)	4	5	6
Low Lift	7	8	9

Although it was agreed that a system for comparing windmills across national boundaries, taking account of local economic and financial variables,would be very useful, it was suggested that it would be beyond the scope of the meeting to derive such a procedure immediately. Rather the group recommended that RIIC (Mr Ewens) should continue efforts to establish a Performance Number which would include factors such as: pumping rate in a specific wind speed, pumping head, number of windmills in operation, life-time, maintenance period, rotor area, air density, tower height, start up factor, and perhaps others. Any progress achieved would be circulated to people interested through the information exchange network.

The group then discussed the possibility of using an economic analysis that could provide a means of comparing not only windmill types but also windmills with other pumping systems such as diesel engines, biogas/diesel or solar pumping. One method is described in the paper entitled "An Assessment of Water Pumping Technology Using Locally Available Energy Resources - Botswana (See Annex V-a). It was seen that this technique would present difficulties when applied to comparison of systems across national borders due to varying costs of components.

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A paper entitled "Do Renewable Energy Resources Ever Become Economic?" was presented as a means of standardising the economic calculating procedure to predict present value of future operating costs. This was generally seen as a useful approach: it was referred to an economic sub group for further discussion. The resulting revised paper is included as Annex V-b.

2.6 Predicting Windpump Output

The procedure for predicting windpump output from knowing the wind energy distribution histogram and the overall wind pump performance curve was described and appears as Annex VI.

2.7 Selection of Windmills for Wind Regimes

This topic was handled by describing the characteristics of the windmill designs which are commercially available.

The numbers 1 to 9 refer to the category in which each windmill is classed in Table I.

Table II Windmill Characteristics

Windmill	Category	Characteristics
Kijito	1 - 6	multi-bladed, high lift, high cost, reliable, long life.
ITDG	1, 8, 9	low solidity, 25,000 l/h at 10m, high cost, long life, reliable.
Cretan		low cost, local manufacture, high maintenance, low lift, low efficiency
Savonius		low cost, local manufacture, high maintenance, low lift.
P.I.	1, 7, 8, 9	not yet connected with pump (experimental).
Commercial Fan	1 - 9	high solidity, low maintenance, high reliability.
Vert Axis Sail	7	low efficiency, low cost, high maintenance local manufacture
Lubig	7	low solidity, high efficiency, expensive, reliable, low lift
Aerowatt	7	drives electric pump, low start up speed, remote siting, expensive.
AATP	7	low cost, low/medium lift, higher maintenance
SWD		
Kisumu	7	low lift, lower cost, local manufacture.
Mbita	7	low lift, available on order, few produced.

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The discussion also expanded to include a similar description of pumps.

TABLE III Pump Characteristics

Pump	Suitable with the following windmills	Characteristics of Pump
1. Mono	Filippini, ITDG(rotary drive) Ethiopian (h.a. rotor) - none commercially available	low maintenance, high lift, uniform flow, high starting torque, high rpm.
2. Brass Cylinder Leather Cup	Fan rotors, Kijito, ITDG, Cretan, Mbita, Kisumu, AATP	in widespread use, high lift, relatively low cost.
3. Hydromite	"	remote windmill siting possible, no mass to accelerate, may be used in crooked boreholes, easy to install and remove for maintenance.
4. Polymer Pumps	"	low friction, good wea/characteristics, use PVC or ABS cylinders with high density polyethylene cups or piston rings.
5. Double Acting Pumps	ITDG, Kijito	less starting torque, compressive loading on transmission, more uniform flow,
6. Inertia Flow	Any reciprocating drive, P.I., ITDG.	improved pump/rotor matching, less starting torque, experimental, can place high loads on transmission.
7. Diaphragm	Reciprocating drive	large volume, low lift, available as a hand pump, not for boreholes.
8. Submersible Electric	low solidity, wind generators including P.I.	high lift, good efficiency.
9. Centrifugal	low solidity wind generators	electric drive, low lift, Bosman pump commercially available.
10. Archimedes Screw	fan rotors	large volume, low lift
11. Compressed Air Driven	fan rotors	remote siting possible, experimental, low efficiency.
12. Tyre Pump	unlikely to be matched to a windmill	low efficiency, easily manufactured.
13. Coil Pump	"	" " "

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2.8 Technical Problems

A range of technical problems were discussed and are listed in order of the number of countries interested.

TABLE IV

Technical Topics of Interest, by Country

Rank	Topic	Countries Interested
1	Turntable	Zambia, Zimbabwe, Botswana, Lesotho, Kenya, U.K.
2	Minimum First Cost	Zambia, Malawi, Tanzania, Kenya, Lesotho
3	Polymer Pumps	Malawi, Lesotho, Kenya, U.K.
4	Variable Transmission	Zambia, Malawi, Kenya, Botswana
5	Furling	Ethiopia, Lesotho, Kenya, U.K.
6	Belt Drives	Ethiopia, Zambia, U.K.
7	Blades	Ethiopia, Kenya, U.K.
8	Clutch	Ethiopia, Botswana, U.K.
9	Bearings	Ethiopia, Lesotho
10	Tower Cost	Zambia, Kenya
11	Maintenance	Kenya, Lesotho
12	Pump Testing	Kenya, U.K.
13	Improve Commercial Rotor Designs	Malawi
14	Variable Load	U.K.

2.8.1 Turntable Design:

(i) Zimbabwe has developed a simple turntable for cretan sail type windmills.

(ii) ITDG have used the same system as commercial fan windmills - a tube turning inside two bearings.

(iii) It may be possible to adapt agricultural turntables (trailers) for windmills.

(iv) A large diameter turntable can allow for some simplifications in direct, reciprocating drive transmissions.

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2.8.2 Minimum First Cost

Ways of minimising the capital cost of windmills include:

(i) low solidity (uses less rotor material and transmits less torque).

(ii) rotors can be mounted downwind (Cretan design can release sails for high wind protection),

(iii) reduced tower cost (simple tripods using local materials; octahedral towers are difficult to make),

(iv) reduction of areas where use of skilled labour is required,

(v) wooden material can be used in place of metal,

(vi) simple guyed towers can be very cheap but can require more skill in erection and tensioning of cables,

(vii) the AATP (Tanzania) design seems to be the lowest cost design to reach limited commercial construction,

(viii) generally it was seen that very low cost designs can lead to significant maintenance problems that may lead to failure of such windmills.

2.8.3 Polymer Pumps

These designs can reduce friction and give good wearing characteristics.

Some varieties use piston rings (high density polyethylene is often used) while others use leather cups. Cylinders are of PVC or ABS.

Generally the costs of these materials are lower than when brass cylinders are used.

Constructions using 50 mm diameter (or less) plastic piping can be cemented together by solvent. This allows for easy installation and removal from boreholes as the joints are sufficiently flexible.

Leather cups can be made from good quality cow hide soaked in neat's foot oil and pressed in a simple die.

2.8.4 Variable Transmission

Techniques include (a) the rotary monomore design and (b) the variable stroke reciprocating design. See diagrams a. and b. below. However neither of these are commercially available.

Figure 1a Rotary Monomore Variable Transmission

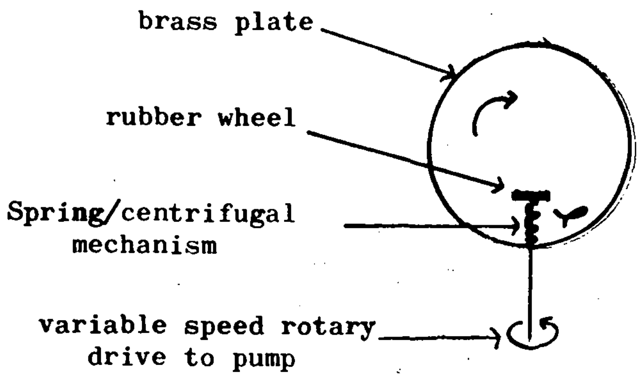
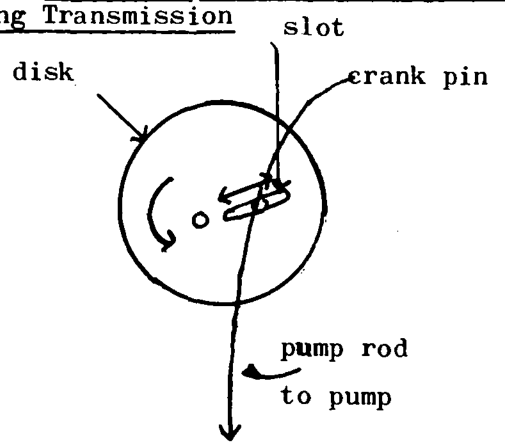


Figure 1b Variable Stroke Reciprocating Transmission



It is recognised that a variable transmission may be the design area where the greatest effect on output could be achieved.

2.8.5 Furling Techniques

Three systems were described from Ethiopia using an angled tail vane, tip flaps and variable pitch angle blades. These were part of the experimental windmill program.

Work in the United Kingdom has shown that the tail vane pivot needs to be angled back and to the side if a weighted tail vane furling system is to be used. These two angles are approximately the same.

2.8.6 Belt Drives

Belt drives may be adaptable for right angle drives although this has not yet been demonstrated with wind pump transmissions.

The Filippini belt drive has not presented problems so far.

2.8.7 Blade Manufacture

Ethiopia is producing non-twisted aerofoil shaped blades from wood (7 man hours per 3½m blade).

There are useful references from SWD (Netherlands) on blade and roto-design.

Twisted blades can be made by cutting blades from a previously formed sheet metal cylinder, or the twist can be achieved by fastening stiff support brackets to the spar. These are offset and therefore force the sheet metal into a twisted shape.

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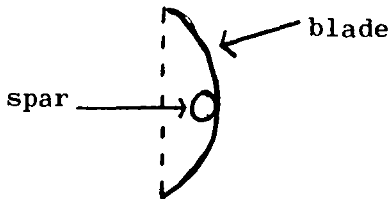
The optimum twist is a source of debate as zero twist is best in starting but over twisting may in fact be the best compromise solution.

Optimum designs have decreasing chord towards the tip but this may complicate manufacturing.

The support spars should be on the concave side of the blade and should not project beyond the chard line, (see diagram below).

Figure 2



Support Spars for Twisted Blade

Two options for blade making have been considered by ITDG for low and high speed rotors.

i) Tip Speed ratios below $2\frac{1}{2}$ - 3.

At these lower speeds a curved plate type is sufficiently aerodynamic. These blades are easily made by rolling a sheet of metal and then twisting it by its attachment to the spar.

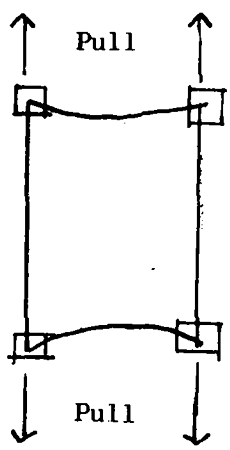
ii) Tip Speed ratios above $2\frac{1}{2}$ - 3.

At higher speeds a full air foil shape and the correct twist are preferable for optimum efficiency.

In essence the twist requires the trailing edge to be longer than the leading edge. This can be achieved by mechanically stretching the outside edges of the sheet the blade is to be made from (Figure 3), or preferably by rolling the sheet lightlv between two slightly tapering rollers to crush both edges (Figure 4). Either way the sheet becomes distorted and will not lie flat. However once it is folded in the middle around a round bar (to form a leading edge) and the two stretched edges are brought together, it assumes a smooth shape. The degree of twist is adjusted by sliding the two edges against each other.

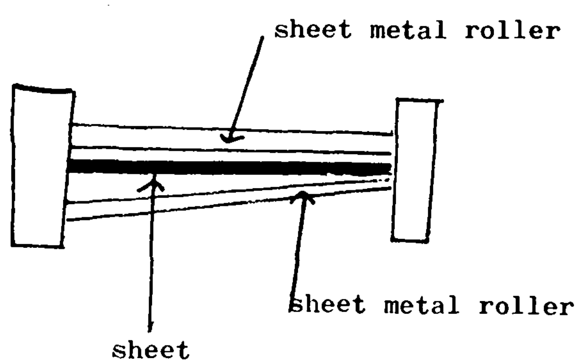
To make curved airfoils the sheet is folded slightly off centre

Figure 3



Stretching Method of Twisting Blade

Figure 4



Rolling Method of Twisting Blade

2.8.8 Clutch

A type of dog clutch has been developed in Botswana to allow the vertical-axis Filippini rotor to be connected to the mono pump. Although the clutch has worked technically, it has suffered continual maintenance problems and this has meant that the design in its present form is not seen to be suitable for production purposes.

A fluid clutch drive can act somewhat as a limited variable transmission and give good, low maintenance, service. But the engaging speed is high although this may still be useful for high speed rotary drives.

Ethiopia has developed a type of friction clutch which will soon be tested on an actual rotor.

So far no commercially available windmill clutches exist.

2.8.9 Bearings

Wooden bearings can be produced from certain types of wood that have been thoroughly soaked in oil. Some experience with wooden bearings has been gained in Zimbabwe and Lesotho (specifically for use in ox-carts). The Mbita windmill in Kenya has also made use of wooden bearings. Ethiopia has used these in hand pumps also.

High density polyethylene can also be used for local production of bearings. This is currently under development in Ethiopia.

It was also pointed out that commercially produced bearings that are locally available will often be comparable in price or cheaper than locally produced, simple bearings and will be of significantly better quality. Also sophisticated commercial bearings may offer advantages and not be much more expensive than simple ones where transport costs are significant.

2.8.10 Tower Cost

See section 2.8.2.

2.8.11 Maintenance

See sections 2.8.3 and Section 2.9 below.

2.8.12 Pump Testing

Some testing of pumps has been carried out by ITDG in U.K. Information about this work can be obtained from ITDG.

2.8.13 Improvement to Existing Commercial Windmill Rotors

See Section 2.8.2.

2.8.14 Inertia Flow Pumps

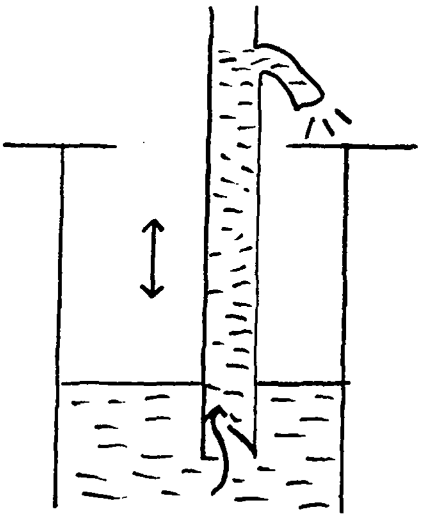


Figure 5: Joggle Pump

A simple Joggle Pump (Figure 5) was described to show the basic principle of the inertia flow pumps.

Detailed work carried out in the U.K has shown this principle can be applied to reciprocating piston pumps to produce a power absorption characteristic which is similar to that for a windmill. Thus much better windmill/pump matching can be achieved over the whole range of operating speeds. The program to match inertia flow pumps to the ITDG rotor is incomplete as a sound mechanical design of the pump was not produced. However details of the work carried out so far are available from ITDG.

2.9 Maintenance and Installation

Problems of improper installation can lead to excessive wear rates in parts of the transmission and excessive tower loading.

Commercial manufacturers supply installation manuals and short courses (at times) but these may not be sufficient to ensure proper installation.

Local manufacture allows for easy access to information on erection, maintenance or other problems.

In cases where towers are badly misaligned it would be possible to correct this at a later stage.

2.10 Training Implications

There will be a need to co-ordinate efforts in applying wind powered pumping with training of maintenance and repair teams. Financial and manpower constraints also need to be considered.

A conference held in Malawi in August 1980, sponsored by IDRC (Canada), dealt entirely with the training component of water supply systems. The proceedings, which should be published shortly, are recommended for reference.

2.11 Patents

To avoid problems of new ideas becoming patented by others an inventor may publish his information in an international journal so that it becomes "public domain" and un-patentable.

Further information can be obtained from

ESARIPO
c/o World Intellectual Property Organisation
U.N.
Geneva, Switzerland

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This agency can also assist in carrying out patent searches to determine whether a design has already been patented. It can also provide information on existing patent designs.

In commercial production a Trademark may be valuable.

2.12 Regional Co-operation/Collaboration

2.12.1 It is recommended that exchange of information on wind power and other renewable energy resources be promoted through the channels established by the Commonwealth Science Council in 1979. The regional co-ordinator for wind is Mr Opondo of the University of Nairobi in Kenya.

It was agreed that detailed technical information gained from national wind energy programs be sent to Mr Opondo. The information available would be circulated along with a periodic newsletter to all seminar participants. Copies of the detailed technical information would be available on request.

2.12.2 It was recommended that each country appoint a national co-ordinator (if not already existing) who would be responsible for disseminating information on all forms of alternative energy resources both within and outside each country.

2.12.3 Several areas of interest common to some or all of the seminar participants have been established and can be followed up.

Applications for funding from the Commonwealth Fund for Technical Co-operation for study tours and other purposes must be forwarded through the local CFTC contact, usually the Ministry of Education or Manpower Development. If funds are not available from this source, other channels can be suggested.

2.13 Bibliography

Preparation of a bibliography of useful technical literature on wind power pumping was proposed by the Group. A draft bibliography is attached as Annex VII.

2.14 Summary of Recommendations

2.14.1 That a common method for determining overall wind pump performance be adopted by all those working on the subject in the region. The procedure outlined in the paper "Performance Measurement of a Water Pumping Windmill" (Annex 1) is recommended as an acceptable method.

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2.14.2 That a common method of monitoring and presenting wind data, which will allow windmill outputs to be predicted, be adopted by all Meteorological Departments in the region. The method outlined in Section 2.3 of the sub-group's report is recommended for consideration by directors of meteorological services at their meeting in Nairobi in February 1981.

2.14.3 That work should continue to enable the performance of windmills to be compared across national boundaries and also to enable windmill pumping to be compared from the point of view of economic analysis with other pumping systems such as diesel engines, biogas/diesel, or solar pumping.

2.14.4 That windmill manufacturers should be encouraged to provide more information on the performance characteristics of their machines, according to the criteria listed above, and that they should provide more guidance on windmill installation and maintenance.

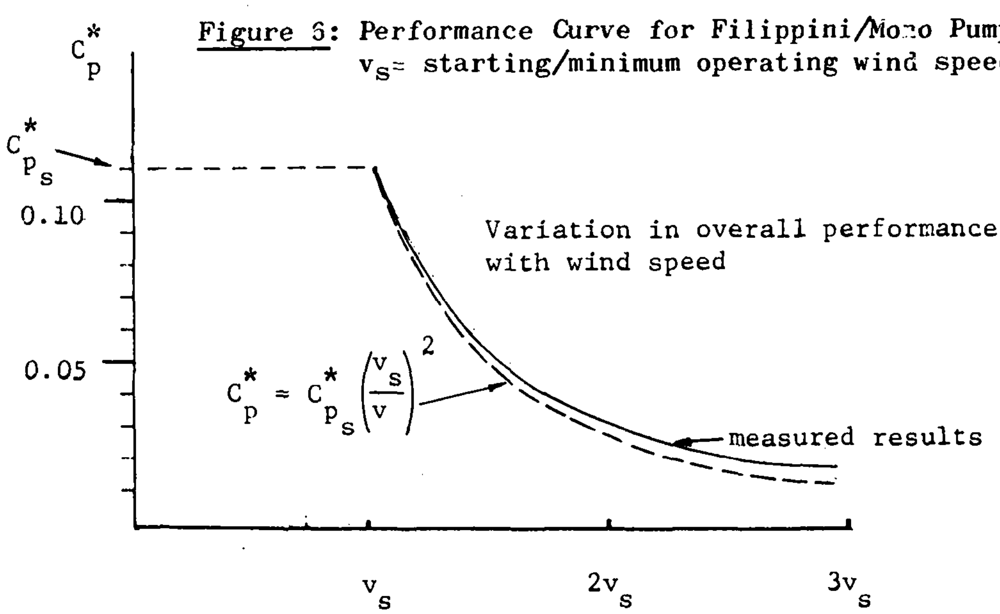
2.14.5 That information on technical and operational aspects of wind power application should be regularly exchanged between countries through the network established by the Commonwealth Secretariat under the University of Nairobi. National co-ordinators for this network should be appointed by countries which do not yet have them, and support for the regional network should be provided from appropriate sources where required.

ANNEX I

Performance Measurement of a Water Pumping Windmill

Most windmill rotors will have an optimum efficiency that is constant over a wide range of wind speeds. But when the rotor is coupled to a water pump the overall system efficiency becomes dependent on wind speed. Figure 1 shows how the overall power coefficient for a particular windmill and pump combination decreases in higher wind speeds. Knowledge of this curve for a water pumping windmill allows the output to be predicted once the wind regime and borehole depth are known.

Figure 6: Performance Curve for Filippini/Mono Pump System, where v_s= starting/minimum operating wind speed



Also the performance curve of Figure 6 can be used to match the windmill/pump system to the local wind regime in a way to maximize the output of water pumped. The following outline suggests a means of measuring the overall performance curve for a windmill/pump system in a way that requires only very basic monitoring equipment.

The measurement procedure begins by establishing the depth through which water is pumped, the diameter of the windmill rotor and the amount of water pumped during one rotor revolution.

The performance curve is established by determining the amount of water pumped (by counting the number of rotor revolutions) in a time interval 'Δt' and the mean wind speed for the interval. To reduce measurement errors the wind speed should remain approximately constant throughout the interval ($\pm$ 2 km/h) and as a result the time interval must be kept reasonably short (nominally 60 seconds). It is suggested that two instantaneous anemometers be located $2\frac{1}{2}$ rotor diameters to each side of the rotor's centre. During readings the wind speed should vary by no more than $\pm$ 15% and wind direction by no more than $\pm$ 10^o. A simple cup totalizer would be mounted with one of the instantaneous probes and this would provide mean windspeed (v) over the time interval.

/.....

The overall power coefficient is calculated from:

$$C_P = \frac{m\ g\ h}{\frac{1}{2}\rho v^3 A \Delta t}$$

where:

m - mass of water pumped (kg)
g - acceleration due to gravity
h - height through which water is pumped (m)
ρ - density of air (kg/m^3)
v - wind speed (m/s)
A - rotor cross sectional (sweep) area (m^2)
Δt - time interval (s)

The measurement of C_P should be carried out over the range of operating wind speeds and the overall performance curve determined. Where this technique has been used in Botswana it was possible to complete the measurements mainly during a single visit to the site (a 2 - 3 hour period). Readings during high winds were taken during a second visit.

While performance tests are carried out it is recommended that starting torque as a function of wind speed also be measured and recorded.

This could be done by fastening a spring balance to one of the blades and simultaneously reading it and an instantaneous anemometer.

Any deviations from the above procedure should be recorded along with the resulting data.

ANNEX II a

Performance Measurements on the Six Metre Diameter Horizontal Axis Windmill

P.D. Dunn and T. Eisa, Department of Engineering, University of Reading; M. Ewens, Intermediate Technology Development Group, London; A. Ibbetson, Department of Meteorology, University of Reading.

Introduction

This work forms part of a general programme on the development of small wind-powered pumps for use in the Third World. Performance measurements are given for the 6M ITDG windmill (1) situated on the Reading University Energy Group site at Shinfield. The windmill characteristics are as follows:-

Rotor diameter	6M
Tower height	6M

Measurements were made using different numbers of curved blades (3, 4 and 6) and in each case several different angles of attack were tested.

The method of measurement adopted was to allow the rotor to accelerate from stationary state up to maximum speed. The rotor speed and acceleration was measured by a tachometer placed on the rotor shaft. Wind speed was obtained by averaging the readings of two anemometers placed in the plane of the rotor and at a distance of 20M from the axis, one on each side. Measurements were taken only when the anemometer readings were approximately equal. The outputs from the tachometer and anemometers were recorded on magnetic tape and processed later. Wind speeds lay in the range 3 m/s to 12 m/s. A measurement of the rotor moment of inertia enabled the power and torque coefficients to be calculated.

Instrumentation

Wind speed: Standard cup anemometers were used.

Rotation speed: This was measured by a tachometer which was separately calibrated. The output signals from the two anemometers and from the tachometer were fed to three channels of a magnetic tape recorder. These analogue signals were later converted to digital form on a punched tape which was then used as input data for the computer programme.

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Moment of inertia of the rotor

The rotor was suspended on three vertical strings to form a torsional pendulum.

The frequency of rotation $f = \frac{1}{2\pi}\sqrt{\frac{mgR^2}{IL}}$

where m = mass of the rotor
g = acceleration due to gravity
R = tip radius, which is also the point of suspension
I = moment of inertia of the rotor about its axis
L = length of the strings

Moment of inertia was also calculated from the blade dimensions. The results are given in Table I.

TABLE I

Number of Blades	Measured I Kg/m^2	Calculated I Kg/m^2
3	65.2	63.2
4	104.7	99.7
6	242.3	228.1
12	-	-

Blade specification

The blades were of arched plate form with centre spar and were constructed from 16 SWG rolled steel plate.

The blade chord, which was constant $c = 0.45m$
length $L = 1.83m$
tip radius $R = 3.0m$
Max offset to chord $\frac{f}{c} = 0.07$
twist $= 25^o$

Table II gives the numbers of blade and the tip angles used in the tests.

TABLE II

Number of Blades	Blade Angle
3	5^o, 0^o
4	7^o
6	9^o

/.....

Results

The measured data of angular velocity $\dot{\theta}$ versus time enabled the angular acceleration $\ddot{\theta}$ to be deduced.

$$\text{Hence Torque} = I\ddot{\theta}$$

$$\text{Power} = T\dot{\theta}$$

$$= I\dot{\theta}\ddot{\theta}$$

The measured characteristics are expressed in terms of the Torque and power coefficients C_T and C_P

$$\text{where } C_T = \frac{I\ddot{\theta}}{\frac{1}{2}\rho . V_\infty^2 \pi R^3}$$

ρ - air density

V_∞ - undisturbed wind velocity

$$C_P = C_T \lambda$$

$$\lambda = \frac{\text{Tip speed}}{\text{Wind speed}} = \frac{\dot{\theta}R}{V_\infty}$$

Theoretical Performance

A computer programme was written using an iterative procedure similar to that described in Griffiths (2). The results of these calculations are plotted in Figs. (7 and 8).

Lift and drag coefficients for the blades were taken from wind tunnel measurements by Buehring (3) Table III.

TABLE III

α	c_L	c_d
0	0.38	0.07
1.98	0.53	0.08
5	1.00	0.082
8	1.16	0.1
10	1.25	0.13
12.7	1.3	0.17
14.5	1.21	0.18
16.5	1.16	0.27
20	1.12	0.345

$$R_c = 2.4 \times 10^5$$

/.....

Conclusions

The measured torque and power coefficients plotted as a function of Tip to wind speed (λ) show generally good agreement with the theoretical predictions.

In taking such measurements care must be taken that the two anemometers do not differ by more than 15%.

Acknowledgements

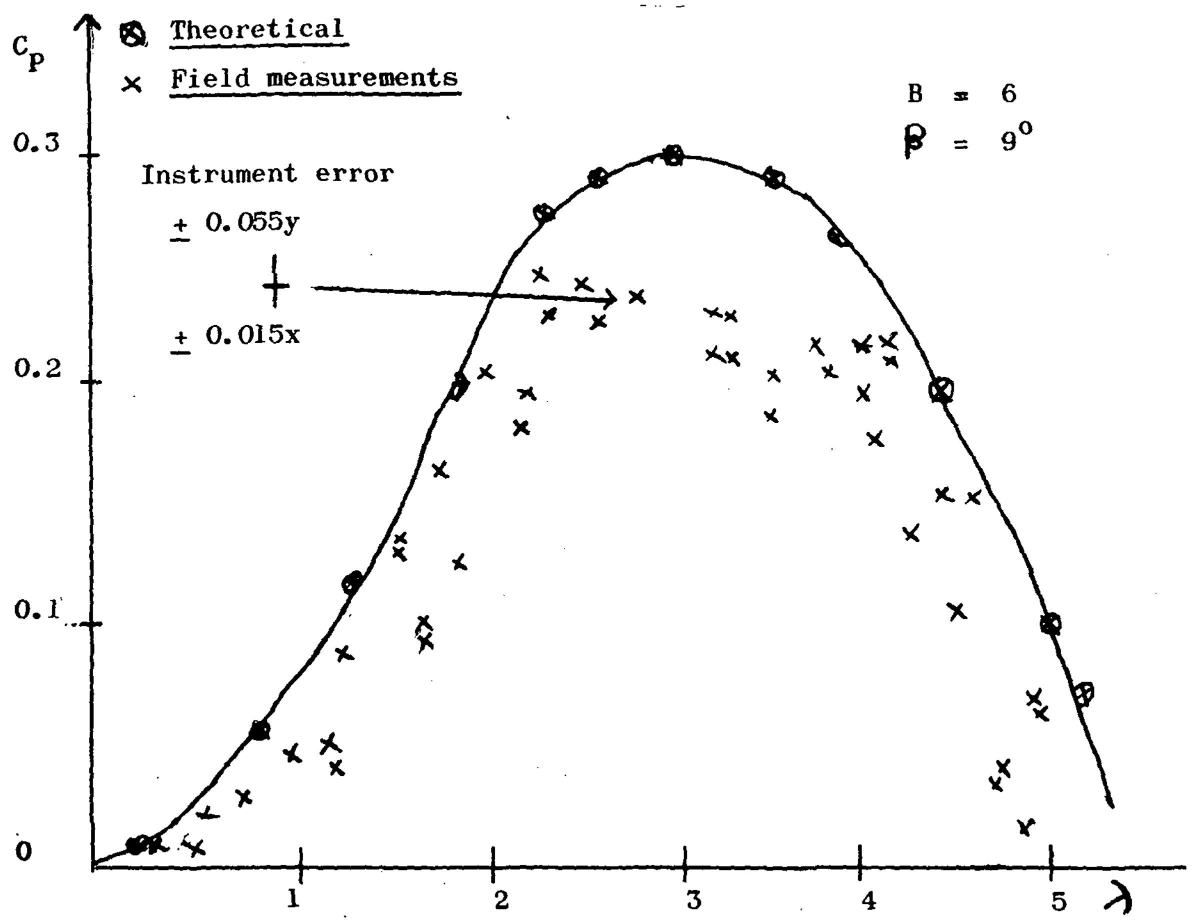
The authors wish to thank ITDG for making available their windmill for these tests.

References

1. Fraenkel, P.L. "An International Development Programme to produce a Wind Powered Water Pumping System suitable for Small-Scale Economic Manufacture". Proceedings of 2nd International Symposium on Wind Energy Systems, Amsterdam, 1978.

2. Griffiths, R.T. and Woolard, M.G. "Performance of the Optimal Wind Turbine". Department of Mechanical Engineering, University College, Singleton Park, Swansea, SA2 8PP.

3. Buehring I. "The Development, Control and Testing of an Aerogenerator", 1980. Department of Electrical Engineering, Imperial College of Science and Technology, London, SW7 2AZ. (Ph.D. Thesis)



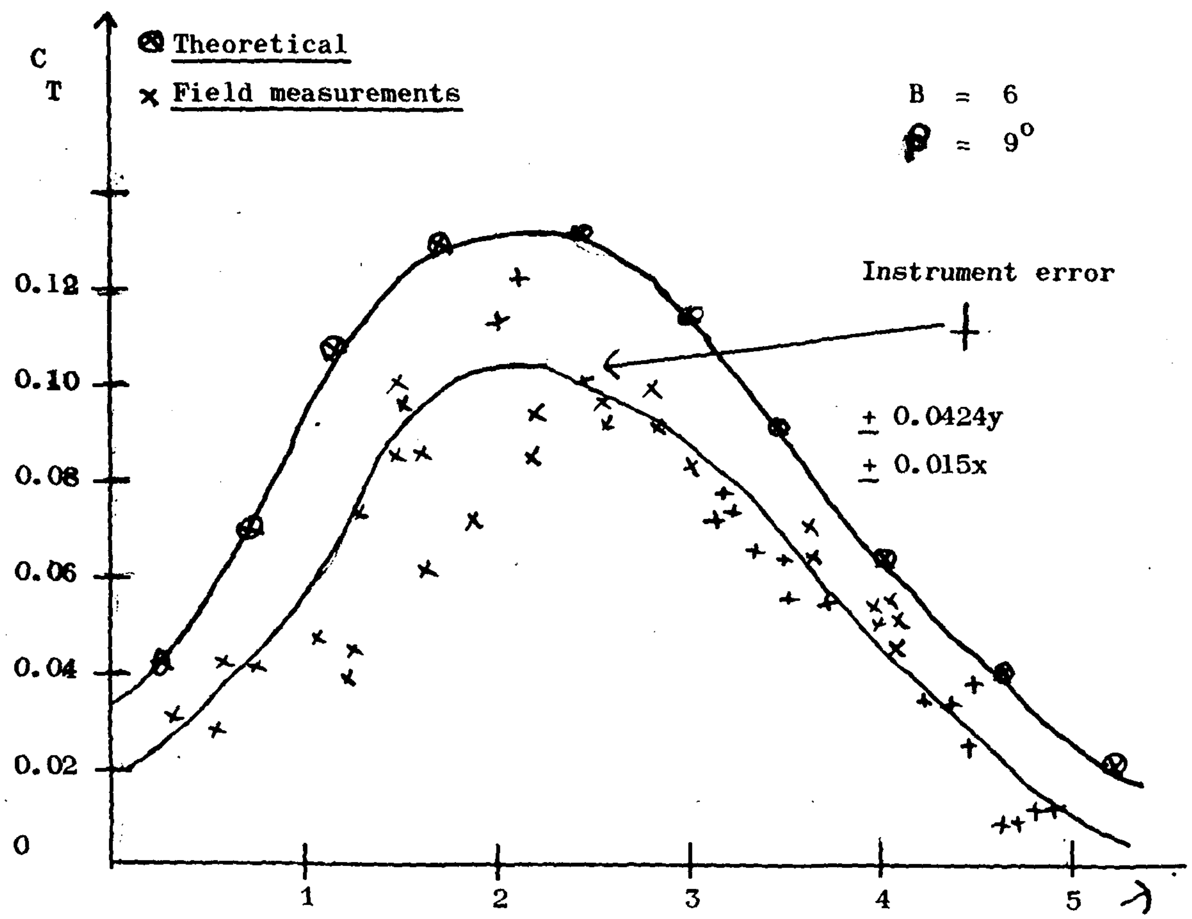
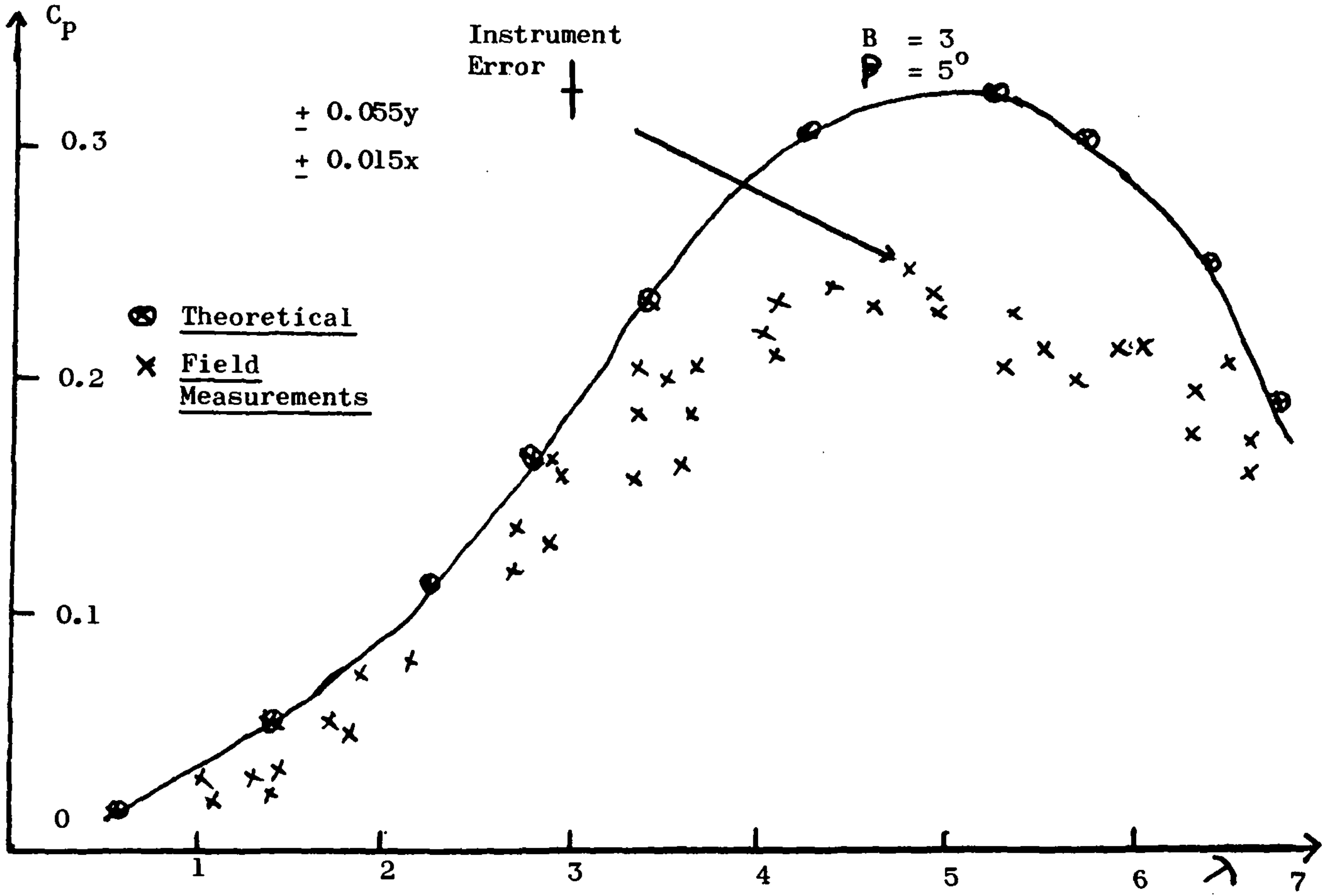


Figure 7: Theoretical Performance Measurements of 6-metre Diameter Horizontal Axis Windmill



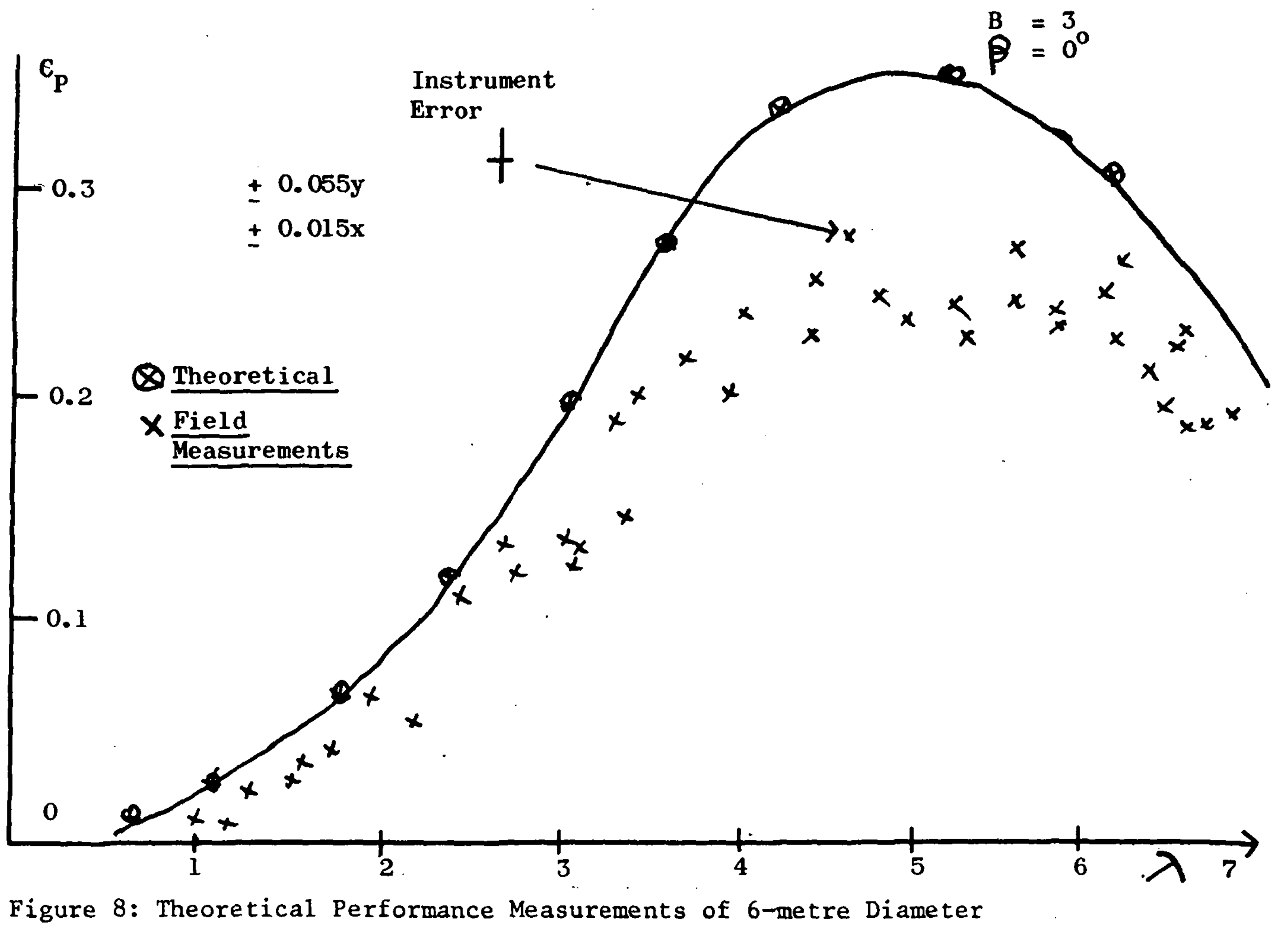


Figure 8: Theoretical Performance Measurements of 6-metre Diameter Horizontal Axis Windmill

Annex II b

Notes on the Use of Acceleration for Performance Testing (Max Ewens)

Background

This paper was presented to a meeting of the British Wind Energy Association in April 1980 by a former colleague, Tayeb Eisa, and describes a system which takes full advantage of the extensive facilities of the University of Reading. As such, the method is unsuitable for most field applications, however, it was developed from a simpler, though more tedious, system pioneered by Dr. Peter Musgrove, also of Reading. The tests carried out by Dr. Musgrove were instrumental in his development of self starting Darrieus machines.

Alternative Methods

Dr. Musgrove's method consisted of marking 1 blade and then using a cine camera to record the rotor's acceleration. Following a successful run the wind speed was recorded on the film before it was removed from the camera and sent for developing. The rotor acceleration was then deduced by counting the number of frames exposed between successive passes of the blade. Although laborious, this system does use a minimum of equipment and is quite inexpensive.

A suggested alternative is the use of a two channel chart recorder connected to the anemometer head and to a switch fitted to the windmill shaft and arranged to briefly close once every revolution. Good runs will be identifiable by a straight velocity trace and acceleration will be deduced by measuring the distance between high points on the shaft position trace.

Procedure

Before erection the rotor and all connected rotating parts, such as main shaft, crank throw, etc., should be hung, with the axis of rotation vertical, on three thin ropes. The ropes should be of equal length and attached vertically to three points on the rotor forming an equilateral triangle centred on the axis. By carefully disturbing the rotor about its axis a torsional pendulum is formed whose period may easily be measured.

An alternative method has been suggested for cases where a horizontal axis windmill is already erected. In this instance a known mass is attached a known distance from the axis and allowed to swing as a pendulum.

A day when the wind is steady in both speed and direction is needed for testing as the anemometer(s) should be erected in the plane of the rotor (perpendicular to the wind) and some two to three diameters from the axis.

The actual wind speed used for the test should not matter but it is best to do runs at a variety of speeds as a check.

From these measurements the rotor's characteristic Cp β curve may be plotted, from which a variety of information may be drawn.

Cautionary Note

For these tests the rotor must be disconnected from its load and repeatedly brought to rest and then allowed to run away. Ensure that an adequate brake is still operational or at least that the rotor may be turned safely out of wind.

ANNEX III

Suppliers of Wind Monitoring Equipment

The following list includes some of the major suppliers of wind monitoring equipment in North America and the United Kingdom. Meterological Departments in each country will be able to advise on local agents for these suppliers.

1. Dwyer Instruments Incorporated
   P.O. Box 373
   Michigan City
   Indiana 46360
   U.S.A.

   (Simple instantaneous wind speed indicators;
   - Dwyer Mark II *)

2. Natural Power Incorporated
   New Boston
   New Hampshire 03070
   U.S.A.

   (Anemometers*; chart recorders*; compilators* and other equipment)

3. C.F. Cassela & Co. Ltd.
   Regent House
   Britannia Walk
   London N1 7ND
   U.K.

   (High quality cup totalizer type anemometers*)

4. Taylor Instruments
   Arden
   North Carolina 28704
   U.S.A.

   (Full range of wind monitoring equipment)

5. R.M. Young Company
   2801 Aero Park Drive
   Traverse City
   Michigan 49684
   U.S.A.

* Equipment used at RIIC, Botswana.

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5. Bendix Environmental Science Division
1400 Taylor Avenue
Baltimore, Maryland, 21204

6. Climet Instruments Co.
1620 West Colton Avenue
P.O. Box 1165
Redland, California, 92373
U.S.A.

7. Texas Electronics Inc.
5529 Redfield Street
P.O. Box 7151 Inwood Station
Dallas, Texas, 75209
U.S.A.

8. Thermax Corporation
Energy Systems Limited
Box 968, Station B
Montreal, Canada
H3B 3K5

(available energy measuring recorders, self powered anemometers)

ANNEX IV

Statistical Methods for Predicting Wind Speed Distribution Curves [1]

Once the wind speed/duration measurements have been determined for a particular region, statistical methods can be used to generalise the results in such a way that measurement of mean wind speed is sufficient to predict the wind speed/duration curve. Figure 1 below shows close agreement between the normalized wind speed/duration curves and a Rayleigh distribution of the form:

$$t = N e^{-1/4 \pi (V/\overline{V})^2}$$

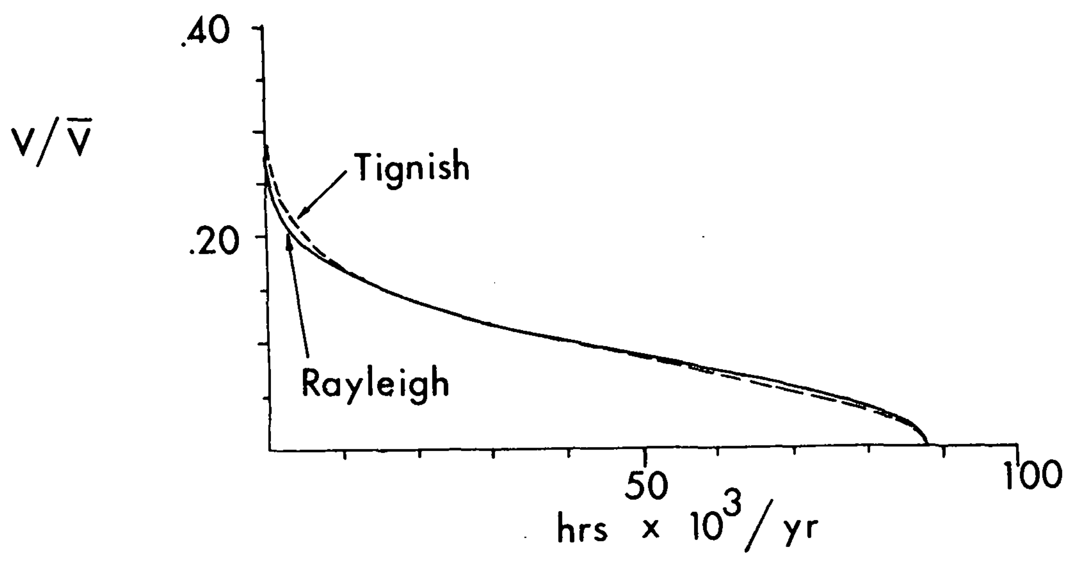
where t - the time in hours that the wind speed is above a given level during one year

N - number of hours in a year

V - instantaneous wind speed

$\overline{V}$ - mean wind speed

Figure 9: Normalized Speed Duration Curve and Rayleigh Distribution



(1) This note is extracted from "Wind as an Energy Source for Water Pumping" by Richard Carothers.
A summary of the paper is reproduced in Chapter 5.

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If the Rayleigh distribution does match the experimental data closely, then this can be used to predict the available energy from knowledge of the mean wind speed only. However the Rayleigh distribution will not match all possible wind speed distributions equally well.

Another and perhaps more common approach is described below. A Weibull distribution is used in the form:

$$f(v) = \frac{k}{c}\left(\frac{v}{c}\right)^{k-1} e^{-\left(\frac{v}{c}\right)^{k}}$$

where $f(v)$ - frequency distribution for wind speed

v - wind speed

k - the shape parameter

c - the scale parameter

This two parameter function can be matched to the frequency distribution curve for a given site. The two parameters 'k' and 'c' allow for matching with a variety of possible wind distributions. Generally 'k' lies in the range between 1.5 and 3.5 while 'c' is approximately equal to the $V / 0.9$ (where $\bar{V}$ is the mean wind speed). Again from the Weibull distribution it is possible to predict the available energy from the mean wind speed. The problem becomes determining the values of the parameters that will match the wind distribution at the site being considered.

Statistical methods can be useful tools in generalising wind monitoring data but cannot entirely replace the actual measurement of wind distributions. Another limitation of the statistical methods is that they are not likely to predict accurately the maximum winds that could be expected.

ANNEX Va

An Assessment of Water Pumping Technologies Using Locally Available Energy Resources - Botswana

(R. Carothers)

Abstract

The paper describes the use of biogas, solar and wind pumping systems, and offers a method for comparing these options, on an economic basis, with existing diesel pumps. Although tests, carried out under conditions in Botswana, suggest that biogas and wind pumping systems may be economically justifiable, these results should be interpreted as tentative rather than final. Much of the information concerning biogas or wind pumping is either new or imprecise and thus less reliable than the detailed, statistical data that is available on diesel pumps. Also the long-term economic analysis will not be the only criterion used in the selection of pumping systems. Such factors as the ability of the pumping system to meet the required water demand, the availability of capital funds, and the frequency and type of maintenance required, would need to be considered.

Where a decision is reached to use biogas or wind pumping systems, there will be a need for the training of manpower in areas such as: energy assessment, biogas digester construction/operation/maintenance, and windmill fabrication and/or maintenance.

Note

This paper was annexed to the provisional report of the Wind Power Pumping Sub-Group. A fuller summary is included in Chapter 5 (section 5.2).

ANNEX Vb

Economic Analysis of Renewable Energy Resources

DO RENEWABLE ENERGY RESOURCES EVER BECOME ECONOMIC? by Derek Medford

Whatever the technical limitations in power density and storage capacity of Renewable Energy Technologies, RET's, it is easy to see that at some level of escalation in oil and mineral energy prices there will be an irrefutable argument for the use of such technologies.

But what annual increment in petro prices makes the decision to change to a RET economic?

Obviously, such a decision is dependent upon capital costs, the recurrent costs, the depreciation in the real value of money, and the escalation in conventional fuel costs; and if one knows how long it will take competing energy systems (conventional and renewable) to wear out one can derive an algebraic formula for deciding which system to use. The derivation of such a formula is given in Figure 10 and is based upon a technique I introduced for survey of energy needs in Fiji: see Siwatibau (1980) "Survey of Domestic Energy Use in Rural Fiji" to be published by IDRC, Ottawa.

Although the formula in Figure 10 is the simplest known to me it can appear messy to non numerate people and it is convenient to think of it in the simpler form:-

PRESENT VALUE OF ENERGY SYSTEM COST = (CAPITAL) + (RECURRENT x NUMBER)

where the number is a function of discount rate, petroleum escalation and inflation rates, and time to obsolescence.

The curve overleaf shows how this number (which is a measure of the relative importance of recurrent cost) varies for a case where the real value of money depreciates at a constant rate of ten percent per annum and the technology wears out after twenty years. Note that, if there is no escalation in petroleum related costs or inflation in recurrent costs, one would simply, in this case, add the capital cost to 8.64 times the annual recurrent costs to obtain the present value of total cost. Whereas, should it be thought that petro costs and inflation will escalate recurrent costs at 30% per annum the present value becomes the capital cost plus 270 times the recurrent costs.

Quite clearly, if the recurrent costs may be split into a non escalating and an escalating part then one multiplies the first part by a number which is the intercept of the curve with the vertical axis and multiplies the second (escalating) part of the recurrent costs by the number read off the graph appropriate to the expected joint effect of escalation in petro price and inflation.

In 1975 terms a diesel installation in Botswana cost 1,100 Pula and used an initial 660 Pula per annum recurrent costs which were almost exclusively petroprice related. Taking a very modest rate of escalation of recurrent costs of 13.9% per annum and using the curve provided one can see, that in 1975 terms, the present value of cost of this diesel system is as follows:-

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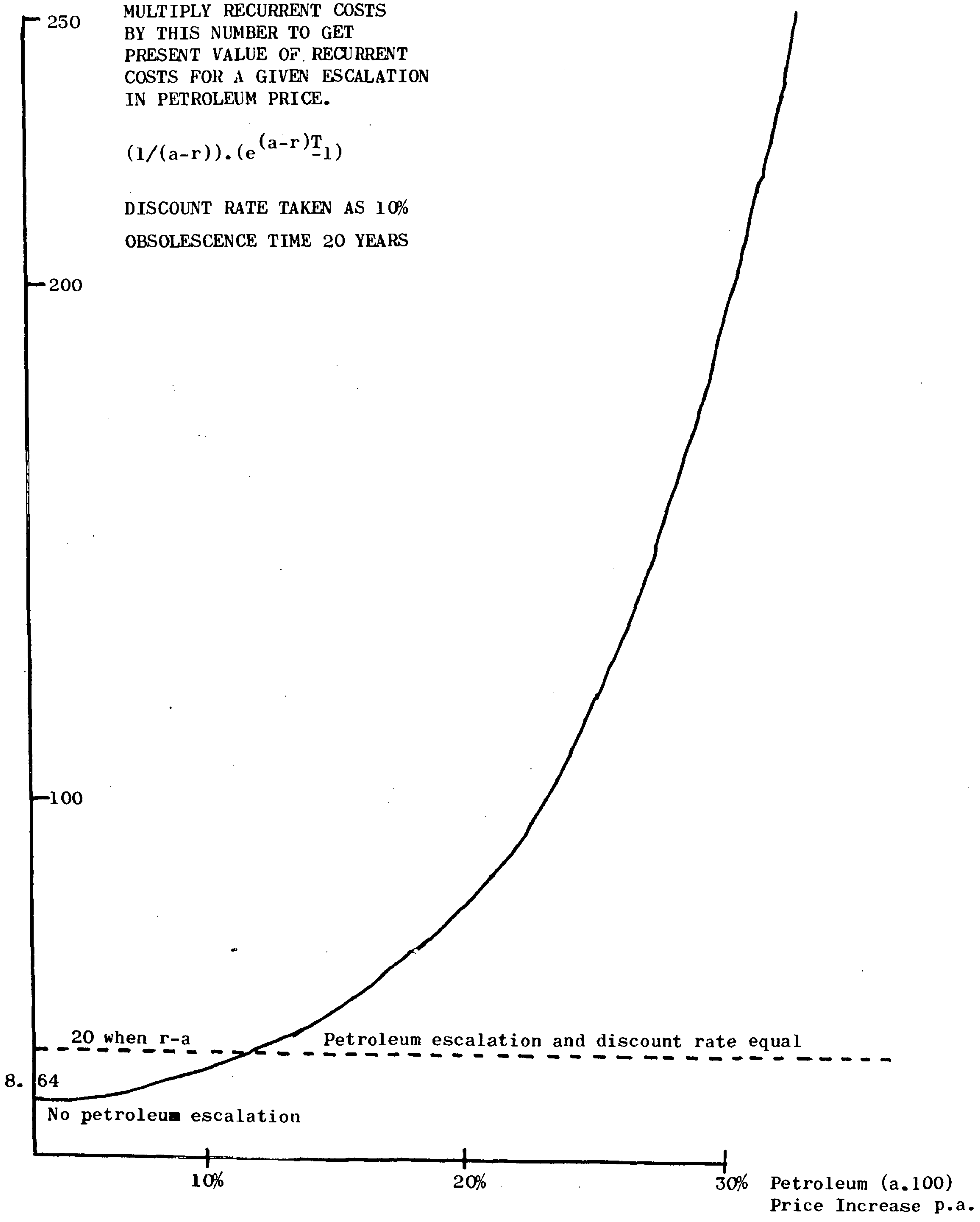


Figure 10: Formula for Economic Analysis of Renewable Energy Resources

1,100 + (660 x 30.15) = 21,100 Pula !!

Whereas, had one assumed no petro induced inflation the present value of cost of this diesel system would be a mere 1,100 plus 660 times 8.64; ie 6,800 Pula. Since the diesel system produces some 22 Kilowatt-hours/day the reader is left to ponder the practicality of two calculations: one of which makes no allowance for petro escalation and yields a present value of cost of 309 Pula per KWhr/day; and the other which assumes a very modest escalation of 13.9% per annum and yields a present value of cost of 955 Pula per KWhr/day. Most certainly an advocate of a RET with small recurrent costs would be doing his technology less than justice if he made comparisons with conventional technologies using the former technique.

Comparisons between RET's and conventional technologies do not usually compare technologies with different obsolescence times or, at least, such comparisons assume the same time to obsolescence for the competing technologies. However, should the competing technologies have different times to obsolescence the technique advocated here may still be used with minimum trouble, provided one obsolescence time may be made a multiple of the other. A case in point is a RET, say, which only has ten year life compared to a conventional diesel system with twenty year life: in this case one would proceed as above for both systems but to allow for the replacement of the RET cost multiply by (1 + exp(-10r)): see Appendix 1.

In conclusion, a method has been presented for comparing present values of costs for competing technologies which is intrinsically fair to the RET with potentially high capital cost and low recurrent cost. Such a purely economic yardstick does not, of course, persuade the investor to opt for a RET because the investor may have practical and psychological problems in accepting renewable energy technology. The investor has to be persuaded that it is worth trying to raise the high capital cost of the RET and he might even believe that the future will again see the possibility of cheap petroleum energy.

APPENDIX 1 : PRESENT VALUE FORMULAE

To gain an analytical appreciation of the significance of cash-flows it is generally recognised that continuous discounting techniques are to be preferred: see Medford (1973) "Environmental Harassment or Technology Assessment?", Elsevier, pp 127 to 177.

Using continuous discounting technique the problem is to calculate the present value of cost of a system with a capital cost, C, and recurrent costs which may be split into two parts: one part which is subject to escalation in petro prices and inflation and increases exponentially at a rate 100a% per annum and the other part which is assumed constant with time.

/.....

If the time of system to obsolescence is T years, and the discount rate is taken to be 100r% per annum, then the present value of cost is

$$\int_0^T R_p . e^{at} . e^{-rt}\, dt \quad + \quad \int_0^T R_{\not{p}} . \; e^{-rt}\, dt$$

which equals

$$C + R_p . \; (1/(a-r)).(e^{(a-r)T} - 1) \; + \; R_{\not{p}} .(1/r).(1 - e^{-rT})$$

Quite clearly, if one allows for more than one complete replacement of the system, then the above framed value should be multiplied by

$(1+e^{-rT})$ for replacing it once

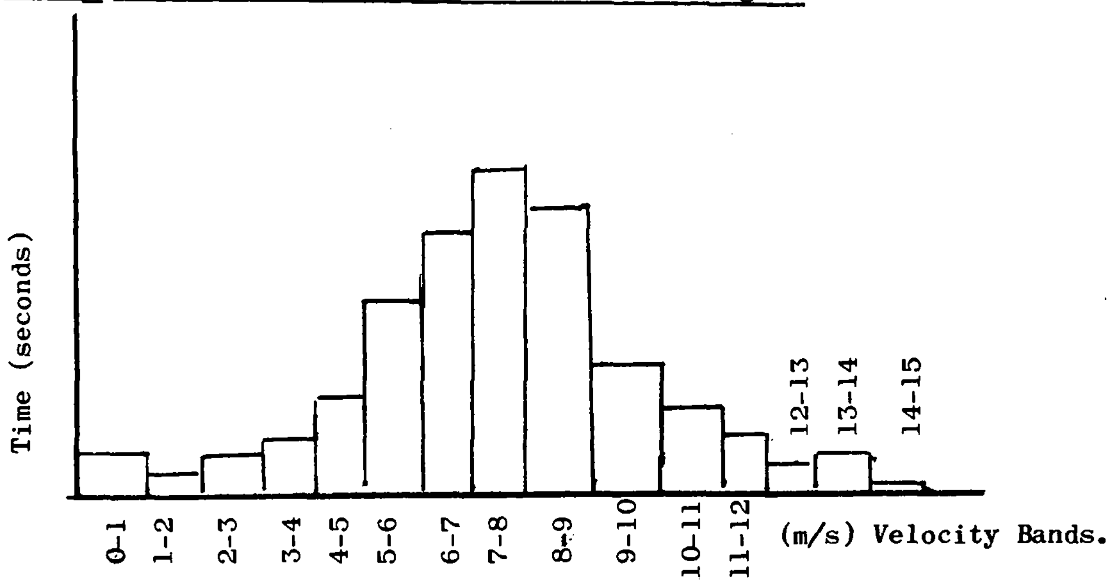
$(1+e^{-rT}+e^{-2rT})$ for replacing it twice, etc.

ANNEX VI

A Method for Predicting Wind-Pump Output

To be able to predict the output of a water pumping windmill it is necessary to know both the wind speed frequency distribution histogram (Figure 1) and the overall performance curve for the wind-pump system as described in Annex 1. Figure 1 shows the times that the wind speed occurs within the range of each velocity band. The total time for monitoring would be normally one year (averaged results for several years may be used) but in some cases it may be necessary or even desirable (if a wind-pump is being matched to certain seasonal wind conditions) to base the analysis on a shorter monitoring interval.

Figure 11 Wind Speed Frequency Distribution Histogram



The mean power density for each velocity band is calculated from

$$\overline{\quad\quad} = \frac{\frac{1}{2}\rho\,(V_1^3 + V_2^3)}{2}$$

where ψ = power density (W/m^2)

ρ = density of air (kg/m^3)

V_1 = wind speed at lower end of the velocity band (m/s)

V_2 = wind speed at upper end of the velocity band (m/s)

A = rotor sweep area (m^2)

Δt = time that wind speed occurs within the velocity band (seconds)

/.....

The available energy resulting from each velocity band is found from:

$$E = \tau \times A \times \Delta t$$

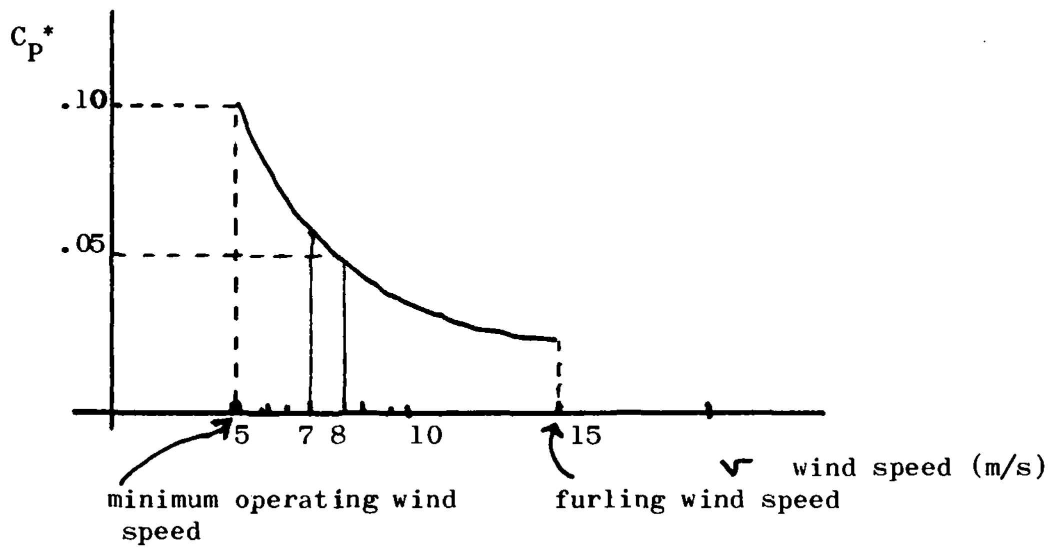
where E = available energy (joules)

A = rotor sweep area (m^2)

Δt = time that wind speed occurs within the velocity band (seconds)

The overall performance curve for the wind pump system (example shown in Figure 2) is now used to determine the fraction of the energy that would be usefully extracted from each velocity band.

Figure 12: Wind Pump System Performance Curve



In the example of Figure 2 we would expect to catch 5% (C_P^* = 0.05) of the available energy occuring in the velocity band 7m/s $\leq v <$ 8 m/s. If the energy available from this velocity band was 10^8 joules during the monitoring period then we would expect to extract 5 x 10^6 joules of useful energy. This would be converted to a water output by:

$$m = \frac{E'_{7.8}}{g\,h}$$

where m = mass of water pumped (kg)

$E'_{7.8}$ = energy extracted from the velocity band 7m/s $< V <$ 8m/s (joules)

g = acceleration due to gravity (m/s)

h = pumping head (m)

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The procedure would be repeated for all velocity bands between the wind-pump's minimum operating speed and furling speed and the total water that would be pumped estimated.

Many wind-pumps will require higher wind speeds to start than to continue operating once already started. As a result the wind pump will operate only for a certain fraction of the time that winds occur between the minimum operating wind speed and the start up wind speed. If these speeds are appreciably different the accuracy of the output predictions will be affected. It is suggested that the prediction procedure be carried out for existing windmill sites and the predicted outputs compared with actual measured outputs so as to establish accuracy limits for the equipment and wind regimes being considered.

Note

This procedure can be repeated for different rotor loadings (i.e. different water outputs per rotor revolution)if the overall performance curves are known. This allows the optimim loading to be selected so as to maximise the amount of water pumped for a given wind regime and wind pump.

ANNEX VII

Bibliography on Wind Energy

The bibliography is divided roughly into references which deal mainly with research and development of wind energy conversion systems, and references that relate more to the application of existing systems. However the distinction is not precise and many items overlap the two categories.

The bibliography is not exhaustive but does indicate the range and emphasis of current work on the use of wind power.

1. RESEARCH AND DEVELOPMENT

1.1.1 International Symposia and Conferences

a) An extensive collection of work being carried out on Wind Energy Conversion Systems appears in the proceedings of two international symposia held in 1976 and 1978. A list of the papers presented in the 'Second International Symposium on Wind Energy Systems' is attached. Copies of the proceedings are available from: BHRA Fluid Engineering, Cranfield, Bedford, U.K.

b) The proceedings of the Wind Energy Conference (1980) sponsored by the American Institute of Aeronautics and Astronautics and the Solar Energy Research Institute provide an up-to-date account of much of the theoretical and other work being carried out in the U.S.A. The list of papers presented is attached. Copies of the proceedings are available through the: AIAA, 1290 Avenue of the Americas, New York, N.Y., U.S.A.

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1.1.3	Bragg G.M. Schmidt W.L.	'Performance Matching of Windmills and Water Pumps', University of Waterloo, Report for IDRC, Ottawa, Canada (1978).
1.1.4	Bragg G.M.	'The Engineering of Small Wind Systems', University of Waterloo, Report to be published - IDRC, Ottawa, Canada (1981).
1.1.5	Calvert N.G.	'Wind Power Principles', Giffin, Crendon Street, High Wycombe, Bucks, U.K.
1.1.6	Jansen W.A.M.	'Horizontal Axis Fast Running Wind Turbines for Developing Countries', SWD Publication SWD 76-3, Amersfoort, The Netherlands (1976).
1.1.7	Van Deven N.	'ORP/TOOL Windmill Project', Werkgroup Ontwikkelings Technieken, T.H. Twente, Enschede, The Netherlands (1979).
1.1.8	Vadot.L.	'Water Pumping by Windmills', La Houille Blanche, No. 4, (1957).
1.1.9	Banas J.F. Sullivan W.N.	'Engineering of Wind Energy Systems', Sand 75-0530, Sandia Labs Report, Albuquerque N.M., U.S.A. (1976).
1.1.10	Shefter, La. I	'Wind Power Machines', NASA TTF-15, 149 NASA, U.S.A. (1972).
1.1.11	Blackwell B.F. Sheldahl R.E. Feltz L.V.	'Wind Tunnel Performance Data for Two and Three Bucket Savonius Rotor', Sandia Labs Report, SAND 76-0131 (1977)
1.1.12	Stam H.	'Adaptation of Windmill Designs with Special Regard to the Needs of Less Industrialised Areas', Paper W/40, New Sources of Energy, Vol.7, U.N. Conference, Rome (1961).
1.1.13	Putnam P.C.	'Power from the Wind', Van Nostram, U.S.A. (1948).

1.2 Periodicals

1.2.1 Wind Digest, 54468 CR31, Bristol, IN46507, U.S.A.

1.2.2 Wind Technology Journal, The American Wind Energy Association, Box 7, Marston Mills, Mass. 02648, U.S.A.

1.2.3 Wind Engineering, Ed. E. Mowforth, University of Surrey, Publisher Multi-Science Publishing Company, U.K. ISSN 0309-524X.

2. Application

2.1 Burton J.D. — 'The Matching of Water Pumps to Windmills for use in Developing Countries', Energy Group, Department of Engineering, University of Reading, U.K. (1978).

2.2 Gingold P.R. — 'The Cost Effectiveness of Water Pumping Windmills', Wind Engineering, Vol.3, No. 4, Multi Science Publishing Company, U.K. (1979).

2.3 Fraenkel P. — 'The Power Guide', Intermediate Technology Development Group Publication, London, U.K. (1979).

2.4 Wegley, H.L., Orgill, M.M., Drake, R.L. — 'A Siting Handbook for Small Wind Energy Conversion Systems', U.S. Department of Energy, Contract EY-76-C-06-1830, U.S.A. (1978).

2.5 Wood A.D. — 'Water Lifters and Pumps for the Developing World', Colorado State University, U.S.A. (1976).

2.6 Best R.W.B. — 'Limits to Wind Power', Organisation for Fundamental Research on Matter, Jutphaas, Netherlands. Energy Conversion; 19: No. 2, 71-72 (1979).

2.7 Nesbit W., DeMeo, E., Goodman F. Jr. — 'Going With the Wind', EPRI Journal, 5: No. 2, 6-17, U.S.A. (1980).

2.8 Krawiec S. — 'Economics of Selected WECS Dispersed Applications', Solar Energy Research Institute, Golden, Colorado, U.S.A.(1980).

2.9 Brace — 'How to Construct a Cheap Wind Machine for Pumping Water', L-5 Brace Research Institute, Ste Anne de Bellevue, Quebec, Canada (1973).

2.10 Karassik, Krutzsch, Fraser, Messina — 'Pump Handbook', McGraw Hill, Canada (1976).

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2.11	Natural Power Inc.	'Operating Manual-Wind Compilator II', NPI, New Boston, New Hampshire, U.S.A. (1977).
2.12	Changery M.J.	'Initial Wind Energy Data Assessment Study', US Department of Commerce, NSF-RA-N75020, U.S.A. (1975).
2.13	Congdon R.J.	'An Introduction to Appropriate Technology', Rochdale Press, Emmaus, PA, U.S.A.
2.14	Watt S.B. Wood W.E.	'Hand Dug Wells and Their Construction', ITDG Publications, 9 King Street, London, U.K.
2.15	DHV Consulting Engineers	'Shallow Wells', Ministry of Water Energy and Minerals, Tanzania and Ministry of Foreign Affairs, The Netherlands.

NOTE

References 2.3 and 2.13 include extensive list of agencies working in the field of Appropriate Technology including wind power.

Papers Presented at

Second International Symposium on Wind Energy Systems

October 3rd-6th, 1978, The Royal Tropical Institute, Amsterdam

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A3	Wind energy developments in the United States L.V. Divone, Department of Energy, U.S.A.	A3-17
A4	The development of wind power plants in Japan I. Ushiyama, Ashikaga, Institute of Technology, Japan	A4-29
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B1	Physical - planning aspects of large-scale wind energy exploitation in the Netherlands A.A. Van Essen, Rijks Planologische Dienst; R. ter Brugge and J.M. van den Berg, N.V. KEMA; G.G. Piepers, Netherlands Energy Research Foundation ECN; and A.L.M. Bongaarts, Ministry of Economic Affairs, Netherlands	B1-1
B2	Program overview for the wind characteristics program element of the United States Federal Wind Energy Program L.L. Wendell and C.E. Elderkin, Pacific Northwest Laboratory, U.S.A.	B2-11
B3	Wind energy prospecting in Prince Edward Island: A program overview and status report M.A. Lodge, Institute of Man and Resources, Canada	B3-21
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E1	Some Canadian experience with the vertical axis wind turbine P. South, R. Rangi and R.J. Templin, National Research Council of Canada	E1-1
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* E7	The cycloturbine and its potential for broad applications H. Meijer Dress, Pinson Energy Corporation, U.S.A.	
* E8	A comparison of aerodynamic analyses for the Darrieus rotor R.E. Wilson and W.R. McKie, Oregon State University, U.S.A.	
* E9	A theoretical and experimental investigation into the variable pitch vertical axis wind turbine W. Grylls, B. Dale and P.-E. Sarre, Department of Chemical Engineering University of Exeter, U.K.	
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CHAPTER 3: REPORT OF THE BIOGAS WORKING GROUP

3.1 Objectives

The first meeting of the group discussed the framework for the discussion and agreed that the following were the major items requiring consideration:-

i) Experiences of Co-operation in the Region: The objective being to analyse past experiences and to help orient programmes of co-operation for the future.

ii) Information Requirements: To discuss the requirements at a regional (and international) level for information transfer, reporting results of research and development, etc.

iii) Methodologies for Testing and Appraisal of Biogas Systems: The discussion would be subdivided into the following areas:

a. Prior evaluation of technical options;

b. Economic evaluation;

c. Technical evaluation and monitoring;

d. Social and cultural evaluation.

iv) Technical areas for research.

v) Management and Support Services.

vi) Training.

This report summarises the discussions, conclusions and recommendations under the above headings.

3.2 Past Experiences and Future Prospects for Collaboration in the Region

The discussion revealed that, apart from co-operation between agricultural machinery testing units in East, Central and Southern Africa, there had been little co-operation in information transfer and R&D in the region.

The disappointing lack of progress in the CSC sponsored regional programme for biogas was discussed, and problems at the CSC level and at local levels - in shortage of manpower, facilities and funds - were noted.

The problem of incorporating people and groups outside the formal network in future efforts was also highlighted.

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For the future, there was agreement on the need for regional collaboration, especially in areas where cross-regional problems could be studied, keeping in mind the fact that local activities must have first claim and the need for local initiatives. It was suggested that a central agency might facilitate some aspects of collaboration - e.g. in information transfer. It was agreed that collaboration should be based on the already existing CSC initiated network, which should be strengthened and extended for the purpose.

3.3 Information Exchange

Discussion on information requirements showed the need for effective mechanisms for exchange of results and information between groups within the region, and between the region and other parts of the world.

3.3.1 Regional Publications:

a) Various possibilities for regionally-based newsletters and publications were explored; it was agreed that a regular (half-yearly?) newsletter covering renewable energy resources would serve a useful role in bringing together news from the region and from abroad.

b) It was recommended to the Commonwealth Secretariat that, as a first step and to assess the potential audience, a short report of this meeting - covering windmills and biogas - be prepared to form the first newsletter.

c) The report would be circulated to the national and regional co-ordinators and participants. Participants are encouraged to inform their national co-ordinators of other likely recipients. Where there is no national co-ordinator, participants should indicate to the Commonwealth Secretariat the number of copies required for their countries.

d) It was recommended that the regional co-ordinator of the African Energy Programme (Professor Githinji, University of Nairobi) should be requested, in consultation with the national and regional project co-ordinators, to investigate the feasibility of a permanent editorial centre in the region. If feasible, the AATP Arusha and RIIC Botswana were mentioned as possible centres.

e) It was recommended that participants identify and obtain the agreement of suitable individuals or groups to act as local correspondents.

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3.3.2 Bibliographic and Library Facilities:

a) The need for easy access to regional and international literature and information was recognised.

b) It was recommended that a regular item in the newsletter be a short review of recent publications, regional and international. It was hoped that a similar review could be included for other renewable energy technologies. A preliminary review of literature on biogas has been prepared by Brian McGarry (Zimbabwe) and Sonya Barrett (Botswana) and is attached as Annex VIII.

c) It was recommended that all reports, papers and publications of collaborating institutions in the region should be listed regularly in the newsletters. These would be referenced by author's name(s), title, source and date and would be made available to enquirers from the institutional source on request.

3.4 Methodologies for Testing and Appraisal of Biogas Systems

Much of the recent experience in the region of developing and applying biogas systems has not proved productive, because information on experience gained elsewhere has not been available, and because many of the likely obstacles have not been anticipated. The Group recommended that, to make future research and development more effective, the following considerations should be kept in mind when planning new programmes of biogas development and application:-

3.4.1 Prior Evaluation of Biogas and Related Technologies: The Group agreed the great importance of prior study and evaluation of the feasibility of the technical options available, before recommending or progressing with any application of biogas systems.

Amongst the factors to be taken into account the group identified the following:-

a) The need to define clearly the objectives and 'target groups' of the technology.

b) The need to involve the local population in defining their needs and future aspirations and the viability of the various options.

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c) The evaluation should consider:

- the available physical resources and their future potential in the locality;

- the needs and future aspirations of the community or project centre;

- the available technical options, including energy conservation and/or the possibilities of changing to different energy systems and different methods of matching the final energy source to the need.

d) Other important considerations would include:

- the ownership of the resource and its implications for community use, project viability, impact on the poorest sections etc.;

- schemes for payment for project inputs and products;

- the infrastructure and support requirements;

- the fundamental constraints imposed by land and cattle ownership.

It was recommended that these factors be kept in mind in evaluating possible projects and that a short bibliography be prepared and publicised. Participants agreed to send suggestions for inclusion in this bibliography to Dr. Pyle.
A preliminary version of the bibliography is attached as Annex IX and further suggestions are invited.

3.4.2 Economic Evaluation: The problems of economic evaluation were discussed on the basis of Derek Medford's paper "Do Renewable Energy Resources ever become Economic?". A number of items were noted and, in particular, the need for all assumptions and numerical values to be made explicit and the need to clarify how non-petroleum-related costs were to be included.

Following discussion with a small group from the windmill working group it was recommended that the extended and amended version of Derek Medford's paper be used as a basis for economic evaluation of projects. This paper is attached as Annex V - b, and detailed comments are sought from all participants before the final version is agreed.

3.4.3 Technical Evaluation and Monitoring: A framework for evaluating and monitoring biogas plants to facilitate regional collaboration and comparisons was discussed. It was emphasised that a relatively simple set of measurements will often suffice for local evaluation of a technology, but that a more detailed methodology is necessary if know-how on the technologies is to be built up.

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a) It was agreed that a finalised version of the methodology would be prepared by the group, Dr. Pyle acting as co-ordinator. A draft methodology is attached for comment (Annex X). Participants are requested to send suggestions or information on locally-prepared methodologies to Dr. Pyle.

b) It was recommended that a short study of the control and performance of biogas systems be commissioned by the Commonwealth Secretariat to indicate the key independent control and measurement variables and their effects, and to assist in developing a common methodology for testing and for treatment of data.

The group commissioned to undertake the study should also act as the centre to receive on a regular basis any country technical studies on biogas units, to check as necessary and to compare the technical evaluations. These results would be communicated to all participating country groups.

c) It was suggested that Professor Githinji be approached with a view to establishing this group and activity at the University of Nairobi. If it proves impossible for the moment for the work to be taken on at the University of Nairobi or in the region, Dr. Pyle's group at Imperial College should be approached to provide this service on an interim basis.

3.4.4 Social and Cultural Acceptability: A number of aspects relevant to this topic are covered by 3.4.1 above. The importance of careful prior and continuing study of acceptability was stressed by the group, and the following points were noted:

a) The key importance of involving those affected by the technology in such a study.

b) It appears likely that there will be problems in handling human excreta and in using gas from human excreta. Some apprehensions may arise from misunderstanding of the technology; others may be the result of deep-seated cultural and religious beliefs which must be respected. A preliminary draft of a bibliography relevant to human excreta, to be included in the final report, is attached as Annex XI.

c) There is little likelihood of human excreta being available in sufficient quantities for pumping applications, although digesters treating excreta may be justified in other situations.

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d) The use of animal and poultry manures does not appear to present significant cultural problems, but there are clear problems in the availability (and ownership rights) of some excreta. It will be necessary to consider each potential application on its own merits.

e) It was stressed that ownership and grazing/penning problems with different animals have significant implications for different social groups.

f) In respect of the consequences of the technology for women and children, it was noted that it offers significant potential for reducing the drudgery of fuelwood and water collection. However the group was concerned that such considerations may not weigh heavily in some areas where the decision makers (e.g. husbands) do not benefit directly from the new technology.

It was recommended that careful study of the social and cultural problems be made, bearing in mind the points above and that a selected bibliography be prepared and circulated. Participants agreed to send suggestions for the bibliography to Dr. Pyle A first draft is attached as Appendix XII.

3.5 Technical Areas for Research: It was agreed that the main objectives of any work on biogas in the region were to bring the technology within reach of the rural poor. Given the resource limitations, basic research would generally have low priority as compared to the solution of immediate engineering problems. However it was felt strongly that each group and country should first try to solve its own problems, and then seek a solution within the region, before going outside for the solution.

3.5.1 A number of problems were identified as needing solution and a preliminary list is given below. Participants agreed to send a listing of any additional problems for inclusion in the final report.

Some technical problems:

i) Design and use of digesters using vegetable residues.

ii) Development of high-solids-loading digesters.

iii) Development of low-cost designs of biogas digesters.

iv) Use of batch digesters.

v) Use of simple heating devices and improving the thermal efficiency of digesters.

vi) Coupling digesters to engines - efficiency, modifications needed, etc.

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3.5.2 It was recommended that the procedure for solving such technical problems should be as follows:

a) group tries own resources and contacts

b) group tries national co-ordinator

c) group tries regional co-ordinator, to seek help within or outside the region.

To make the procedure workable, participants should send names of possible outside agencies and individuals which might assist in problem-solving (e.g. KVIC, ITDG, VITA) to the national and regional co-ordinators.

The newsletter would also act as a means of communicating particular problems.

3.6 Management and Support Services: The key role of management and other support services was recognised by the group. Some country experiences were discussed and the need to use existing agencies, ministries and extension services was stressed.

The high initial cost of such support services - up to 20% of recurrent budgets - was also recognised. There is a clear need for further information on country experiences and for allocation of more skilled staff and funds for overcoming management difficulties.

3.7 Training: The role and importance of training programmes was discussed and agreed, and the following conclusions/recommendations were made:

3.7.1 Technician Level Training

(i) It was recommended that the feasibility of short-term interchange of technicians working on biogas projects in different countries be explored and encouraged.

(ii) The need for programmes for training in construction and operation of biogas plants was recognised. It was noted that a UNIDO-funded scheme would shortly be started in Arusha, Tanzania. Moreover it was agreed that, for the moment, the only likely sites for training programmes were RIIC Botswana and AATP Arusha (collaborating with the UNIDO programme), where training programmes have already started. It was recommended that the feasibility and costs of such a scheme be explored.

3.7.2 Higher Level Training

There was not felt to be a need for formal higher level training programmes, but the need for occasional regional seminars to discuss progress and improvements in the technology was endorsed. It was recommended that interchange of active workers be encouraged and that future regional seminars be considered and planned.

3.8 Summary of Recommendations

3.8.1 That the network for regional collaboration on biogas programmes initiated by the Commonwealth Science Council be strengthened and expanded.

3.8.2 That information exchange on biogas development and application be promoted through a regional newsletter, and through establishment of an editorial centre with bibliographic and library facilities.

3.8.3 That the regional co-ordinator of the Africa Energy Programme be requested to investigate the feasibility of a permanent editorial/information centre in the region.

3.8.4 That a common methodology for testing and appraisal of biogas systems be adopted by all research and development institutions in the region. This methodology should include prior evaluation of biogas and related technologies, and economic, technical, social and cultural evaluations.

3.8.5 That a short study be commissioned by the Commonwealth Secretariat of the control and performance of biogas systems, as a necessary precursor for developing an acceptable common methodology for comprehensive testing and appraisal.

3.8.6 That a preliminary list of technical areas for research be compiled, and that information on such research be regularly exchanged between research and development institutions in the region.

3.8.7 That exchange visits by technicians and others working on biogas programmes be arranged as a means of exchanging information on management issues, and of upgrading technical and managerial skills.

ANNEX VIII

Some Contributions to a Biogas Bibliography

(B. McGarry)

This preliminary draft lists several papers which give a good introduction to biogas technology with sufficient practical detail of its application. Additional suggestions would be welcomed.

1. Bertrand R. Saubolle sj and Andreas Bachmann -

   Fuel Gas from Cowdung. 2nd edition, published by Sahayogi Press, Tripureshwar, Kathmandu, Nepal, 1980.

   Compares domestic Chinese and Indian designs, both of which are used in Nepal, and some local Nepali variations. These two authors are also leading contributors to the Nepal Biogas Newsletter.

2. Nepal Biogas Newsletter. Published quarterly (P.O. Box 1309, Kathmandu, Nepal).

   This is a mine of useful information on biogas and, sometimes, on other technologies for saving energy in the home, such as wood-burning stoves. The newsletter is published in and primarily for Asia, but until something as good is produced on the African continent, I recommend it very highly.

3. L. John Fry -

   Methane Digesters for Fuel Gas and Fertiliser, 1973 and The Practical Building of Methane Power Plants, 1974

   Both are published from his address, 1223 Nopal Street, Santa Barbara, California, USA and the first one is also published as New Alchemy Institute's Newsletter no. 3 (Woods Hole, Mass, 02543, USA) 1973.

   Both books contain a lot of useful data, though how far this is Fry's own or collated from other sources is hard to determine. He does not answer postal enquiries. The second book is more concerned with building large plug-flow digesters.

4. Khadi & Village Industries Commission -

   Biogas Newsletter

   A regular newsletter on biogas information in India, published by the Director of Gobar Gas (Biogas) Scheme, KVIC, Bombay 400 056, India, in collaboration with the Department of Science and Technology, Government of India, New Delhi.

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5. Ram Bux Singh -

   Biogas Plant (1971). Gobar Gas Research Station, Ajitmal, Etawah, U.P., India.

   He is one of the pioneers of Gobar Gas in India.

6. Michael Crook & Ariane van Buren -

   A Chinese Biogas Manual (1979). ITDG, 9 King Street, London, WC2E 8HN, U.K. - translation of an original of 1976 by the Sichuan Biogas Promotion Leading Group.

   Its main virtue is that it is the first such information available all in one place in English.

7. Chengdu Seminar (1979). Biogas Technology and Utilisation, Sichuan Provincial Office of Biogas Development.

   This report of a UN sponsored seminar is a somewhat more technical and much more thorough book on Chinese biogas techniques. Detailed instructions on the building of domed digesters, in Chinese, were prepared for that seminar. A translation into English is being prepared; the energy project of the Institute for Environment and Development, 10 Percy Street, London WIP ODR, is involved in this. It is worth checking whether the UNIDO collection of 30 Chinese digester plans is a translation of this book or something else.

8. United Mission Development Agency -

   Several reports commissioned by the UMDA in Nepal are among the better sources of information on biogas available. They are in a file in the RIIC library and give good references to original measurements when giving numerical data. (e.g. the one on Economics of Gobar Gas by Robert L. Berger (1976) refers to an Indian Council for Agricultural Research Technical Bulletin on N content of fresh dung and digested slurry).

9. Arusha Appropriate Technology Project -

   Report on test running Kirloskar and Lister 6-1 engines on biogas in Tanzania, 1979. One of the very few reports of actual measurements on gas consumption, the other good one being in the Chengdu seminar report. Much Indian writing on this subject quotes the same set of figures over and over without indicating a source, which is probably one of Fry's books, but it is not clear whether his figures are based on his own measurements or not.

10. Chung Po and Associates -

The Joint Commission for Rural Construction, Nan-Hai Road, Taipeh, Taiwan, has done some very thorough work, using mainly a variant of the KVIC floating drum design. They have also developed a rubber bag digester. The papers containing their results are well worth consulting, e.g.:

a) Production of Methane Gas from Manure, in Proceedings of the International Biomass Energy Conference, Winnipeg, Canada, 1973.

b) Small Methane Generator for Waste Disposal, in Proceedings of 3rd International Symposium on Livestock Wastes, 1974:

published by American Society of Agricultural Engineers, P.O. Box 410, St. Joseph, MI 49085, USA.

11. Andrew Barnett, Leo Pyle & S.K. Subramanian -

Biogas Technology in the Third World: a multidisciplinary review

IDRC, Ottawa, 1978. IDRC-103e

A very thorough review including analysis of technical feasibility, social and economic factors, and a survey of work in several countries, with plenty of experimental data, and a very full bibliography.

12. Michael G. McGarry & Jill Stainforth - (eds) & Lee Thim Loy (tr.) -

Compost, Fertiliser and Biogas Production from Human and Farm Wastes in the People's Republic of China IDRC, Ottawa 1978, IDRC-TS8e.

Includes useful data for kill rates of a number of pathogens in anaerobic fermentation.

13. German Appropriate Technology Exchange (GATE) -

Module on biogas plants building instructions. Produced by BORDA Biogas Team, Bremen, published by German Appropriate Technology Exchange and the German Agency for Technical Co-operation (GTZ), PO Box 5180, Eschborn 1. West Germany.

A handy summary and comparison for both "Indian" and "Chinese" designs, with a method of calculating feed amounts, construction costs, etc.

14. Alan Poole and Arjun Makhijani -

Energy and Agriculture in the Third World. (Published Ballinger, Cambridge, Mass. USA 1975).

An interesting study of the economics of communal biogas plants, concluding that the best way to use them would be to run an electric generator on the gas to supply households with electricity.

15. Felix D. Maramba -

Biogas and Waste Recycling - the Philippine Experience Maya Farm Division, Liberty Flour Mills Inc., Metro Manila, Philippines.

A summary of his very successful large-scale operations.

16. Canadian Hunger Foundation -

Handbook on Appropriate Technology

The section on biogas gives some more references.

17. Appropriate Technology. ITDG, 9 King Street, London.

This periodical includes interesting articles on biogas work in different parts of the world, e.g. vol.6 no. 3 (Thailand), vol.7 no. 1 (brief but critical look at India), vol.7 no.2 (Java).

ANNEX IX

Draft Bibliography on Factors influencing Project Selection

World Bank	World Development Report (1980)
Hughart D.	Prospects for traditional and non-conventional energy sources in developing countries. World Bank Working Report No. 346 (1979)
Barnett A.	in Barnett, Pyle and Subramanian, 'Biogas Technology in the Third World' (IDRC, 1978).

ANNEX X

Draft Methodology for Biogas Digester System Testing and Monitoring

1. Objective

This note summarises the proposed procedure for measuring, recording and evaluating biogas digester system performance. The procedure has been developed to allow intra-regional transfer and comparison of results. A simpler form may be sufficient for routine monitoring and control of digester behaviour.

2. Monitoring Procedure

2.1 Length and Scheduling of Digester Tests (continuous digesters).

The test procedure and results are only meaningful if the digester conditions are held constant during the period of the test, and for a period prior to the test. Any variations in key parameters (temperature, gas rate, pH, etc) during the test must be recorded.

For convenience the time scale adopted is the retention time of the digester (= V/Flow rate of substrate).

a) No test should commence within $\frac{1}{2}$ retention time of significant changes in flow rate, loading rate, substrate material (composition, temperature). Preferably retention time should be left between tests but this will often be impractical.

b) A test should preferably be carried out over several retention times; again this will normally be impractical. It is suggested that each test be carried out over a minimum of $\frac{1}{2}$ x retention time with daily (or more frequent) monitoring of key parameters and variables (see below). Averaged values over this test period should be used.

2.2 Key Independent Variables

The following variables affect digester performance and should, where possible, be measured. They should, where at all feasible, be held steady during the course of a test:

/.....

a) Feed:

(i) Substrate: Composition

Quantity and frequency of feeding
Dry matter

Size (if vegetable matter included)

plus: (if practicable)

volatile solids

elemental composition (C,H,N)

B.O.D. and C.O.D.

(ii) Water: Quantity

Temperature at(inlet)

b) Operating Conditions:

Temperature

Retention time

Loading rate

Mixing

2.3 Dependent (measured) variables

The following variables should be mentioned in order to evaluate digester performance:

Gas production rate

Gas composition (when practicable)

Solids content of slurry

plus (when practicable):

volatile solids

B.O.D.

C.O.D.

pH

Elemental composition

/.....

2.4 <u>Engine conditions</u> (where practicable):

Gas feed rate	)	Hold steady under test conditions.
Diesel (liquid fuel) feed rate	)	
Air rate	)	
Load	)	

Rating

Length of test

Operating temperature

Cooling rate

ANNEX XI

Preliminary Bibliography on Use of Human Excreta for Biogas Production

Barnett, Pyle & Subramanian	'Biogas Technology in the Third World' IDRC (pp 25, 59)
Van Buren A (Ed)	A Chinese Biogas Manual ITDG London (1979)
Rybczynski *et al*	Disposal and Treatment of Human Wastes: an annotated bibliography IDRC (1979)
National Academy of Sciences	Methane Generation from human, animal and agricultural wastes. N.A.S., U.S.A. (1979).

ANNEX XII

Draft Bibliography on Social and Cultural Aspects of Biogas Use

Makhijani A.	Economics and sociology of alternative energy sources. UNEP/ESCAP Conference on Environment and Development, Bangkok (August 1979)
Reddy A.K.N.	Alternative and traditional energy sources for the rural areas of the Third World. Royal Institution, London and A.S.T.R.A., Bangalore (1979)
Prasad, Prasad & Reddy	Biogas Plants: prospects, problems and tasks. Economical & Political Weekly (Bombay) 1347 (1974)
Subramanian	*in* Barnett, Pyle and Subramanian.

CHAPTER 4: SUMMARY AND DISCUSSION OF LEAD PAPER

4.1 WIND AS AN ENERGY SOURCE FOR WATER PUMPING-Richard Carothers

The need for clean, safe water is basic to human health and life itself, yet many ofthe world's people have to fetch water from supplies that are remote and often polluted (Figure 13). Governments, faced with this fact, are attempting to find solutions to the variety of problems affecting water supplies. One particular problem area, that is increasingly demanding attention, is the rising costs of energy consumed in pumping water. Until recently, these costs were acceptable and imported fossil fuels were in adequate supply, but, with the rapid escalation in fuel prices since 1973-74 and with the realisation that such resources are finite, there has been a resurgence of interest in alternative energy resources such as solar, wind and biomass. Of the alternative forms of energy that may be applied to water pumping, wind has the oldest history.

A History of Wind Power

The earliest recorded use of wind power is from North Africa, where a 500 year old drawing shows a Nile River craft that used wind energy for motive power. Later,sails were attached to either vertical or horizontal shafts which were used to drive rotating devices for milling grain, pumping water, etc. By 1000 AD, wind power was in use in China, Persia and Europe. Largely by trial and error, several technical advances were made, particularly during the 1600s and 1700s, until, during the 19th century, the multibladed fan or American farm windmill (Figure 14) was developed. However, by 1900, with the rise of other more convenient forms of power, the use of wind had declined generally, although the multibladed windmill did in fact increased in popularity during the early part of the 20th century, especially in the agricultural areas of North America, parts of Africa and Australia. By the 1920s and 1930s, wind power had become popular for generating electricity in rural areas, particularly in North America and, during and just after World War II, the emphasis was on large-scale units that would feed directly into the power grids. Unfortunately, with the advent of low-priced oil, these attempts were followed, during the late 1940s, by a decline in interest in wind-powered electrical generators.

Wind power had lost out to other forms of energy for a combination of technical and economic reasons. For instance, windmills have to depend on an uncontrollable and fluctuating energy resource which, technically, presents many more difficulties than one which can be controlled. Also, to provide the same power output, a windmill must be much larger than other motors or engines and, therefore, the initial costs are higher. Another problem is that the costs in building the structure are determined by the highest winds it must withstand, while the economic benefits are determined by the usual, comparatively low, operating winds. The decline of wind power came about because of the greater attractiveness of other options. In considering a resurgence, it would be wise to maintain an economic and technical comparison with both existing and alternative (solar, biomass) energy forms.

Fig. 13 Water from pools, bacteriologically unsafe.

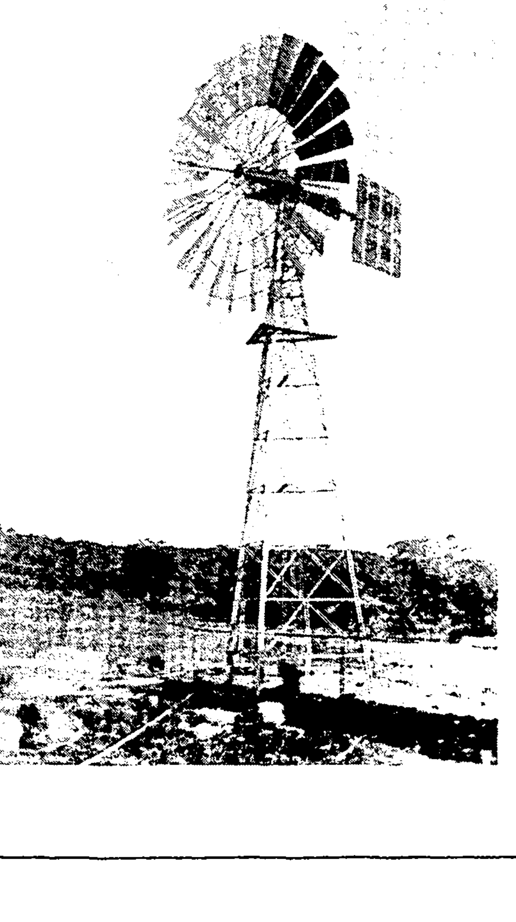


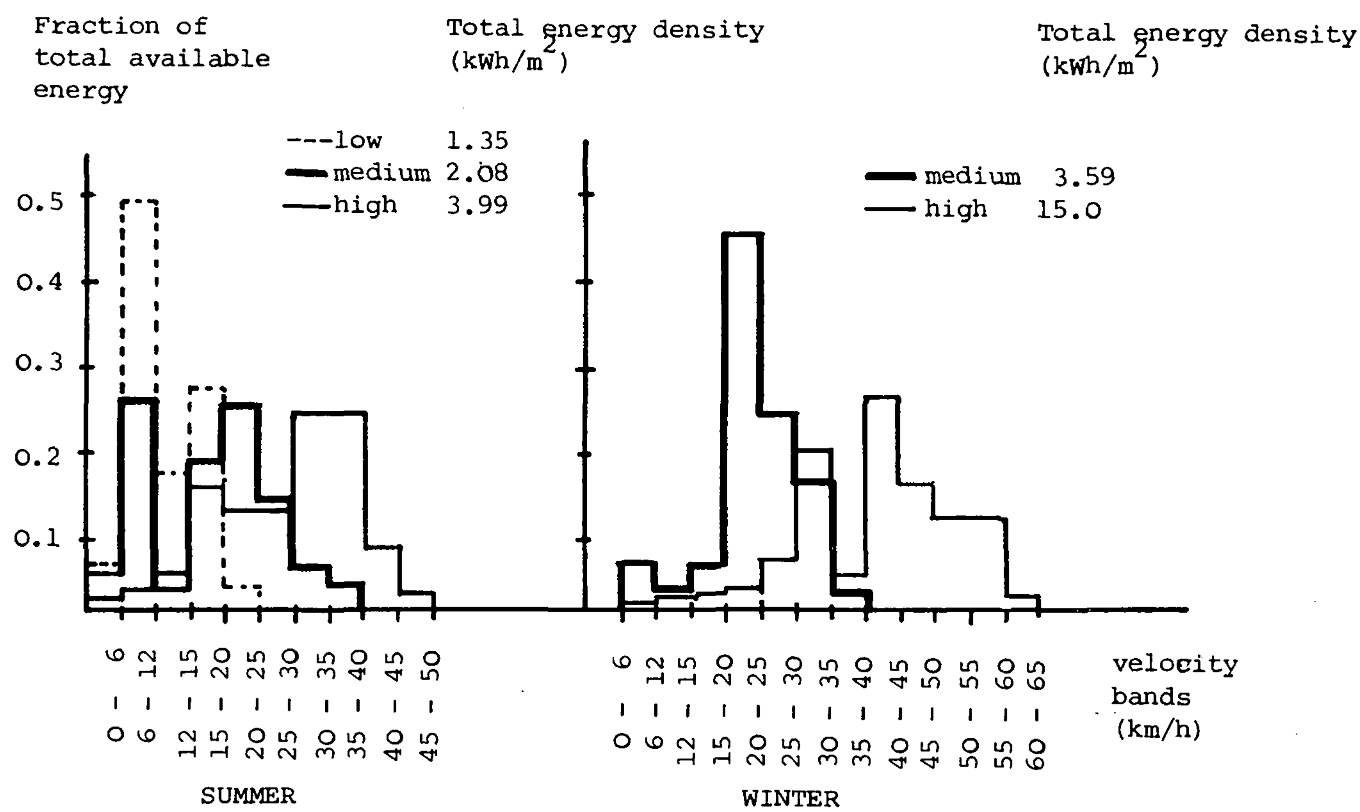
Fig. 14 Multi-bladed fan or
American farm windmill

Wind as a Potential Source

Considerable effort can be applied to the development of cost effective wind energy conversion systems, but the economic viability of any such system will be strongly dependent on the local wind regime. Most meteorological data consists of measurements of wind run taken over intervals of one hour or more using the cup counter type of equipment. The information gathered can be used to compile wind speed/duration curves, from which the available energy can be estimated, and to indicate the comparative windiness of different sites. Most of Africa receives relatively moderate winds and so wind power systems for use in this region will have to be more thoroughly optimised to be cost effective than systems intended for use in higher wind regions.

Apart from the determination of available energy, it is important to know the maximum wind loading that the windmill structure will have to withstand. Due to the very high structural loading that can occur, most windmills include furling, feathering or other mechanisms to slow or stop the windmill rotors during periods of high winds thereby reducing the loading. The energy/duration histogram (Figure 15)

Figure 15: Energy/duration histograms



can be used to determine the wind speed at which such protective mechanisms should come into effect. Too little wind also presents problems in that the length of the calm periods affects the size of storage capacity that is required. Monitoring equipment, which can provide records of energy/duration and wind history, can be very useful in designing or selecting wind power systems, but such equipement tends to be expensive, requires careful handling and must be returned to the manufacturers when in need of repair. The ability to predict available energy using a simple cup counter can be improved by reducing the time interval between successive readings, say to 10 minutes, but such approximate techniques lack the ability to predict maximum winds, as these often occur in very short duration gusts lasting for only one second. Once the wind speed/duration measurements have been determined for a particular region, statistical methods can be used to generalise the results in such a way that the measurement of mean wind speed is sufficient to predict the wind speed/duration curve (see Figure 9). However, although they can be useful tools in generalising and monitoring data, statistical methods cannot entirely replace the actual measurement of wind distributions and are not likely to predict accurately the maximum winds that could be expected.

Current Wind Rotor Designs

The many horizontal and vertical axis devices shown in Figure 16 and 17 reflect the fact that any configuration that produces an asymmetric force in the wind can be made to convert wind energy to some other usable form. The value in a reliable theoretical model comes in allowing the designer to predict how new rotor designs are likely to perform. While simple, theoretical models have been developed which predict the performance of idealised rotors, actual windmills will always perform less efficiently. Aerodynamic drag, tip losses, unsteady flow conditions and other effects combine to decrease the effectiveness of the rotors in extracting energy from the wind. In the analysis of low-solidity (projected blade area/rotor sweep area), high tip speed ratio rotors, that are frequently used in wind generator applications, several simplifications are possible with the result that close agreement has been obtained between the performance curves predicted by such models and those determined by experimental measurement. For high-solidarity, low tip speed ratio type windmills, often found at water pump installations, it has not been easy to establish accurate theoretical models as the flow conditions through the rotor tend to be more complex.

Performance curves bear out the theoretical predictions that the lower tip speed ratio machines are less efficient. The drop in performance of all rotor types as they move to lower tip speed ratios is a result of a change in angular momentum, while aerodynamic drag accounts largely for a similar decline in performance at high tip speed ratios. An important consequence of the shape of the performance characteristics common to all rotors is that there exists a single tip speed ratio where the rotor will deliver its optimum output. To maintain the rotor at this position over a range of wind speeds would require it to be connected to a device that absorbs power in the same way it is produced by the rotor. This is not possible with simple generators or wind pumps, if directly coupled, so the rotor will overspeed in high winds and perform at less than optimum efficiency. The optimum tip speed ratios for most windmills range from just below 1 to about 6, and as a result rotors usually operate in the order of some tens to a few hundreds of rpm. Loads that require high rpm, such as certain generators and rotary pumps, need step-up transmissions to be connected to the rotor and these can further reduce efficiency while increasing cost.

The efforts of the industrialised nations in wind power development have been concentrated on the study of large-scale wind generators (Figure 16) that would feed power directly into existing electricity grids. Recently, there has been a renewed interest in the

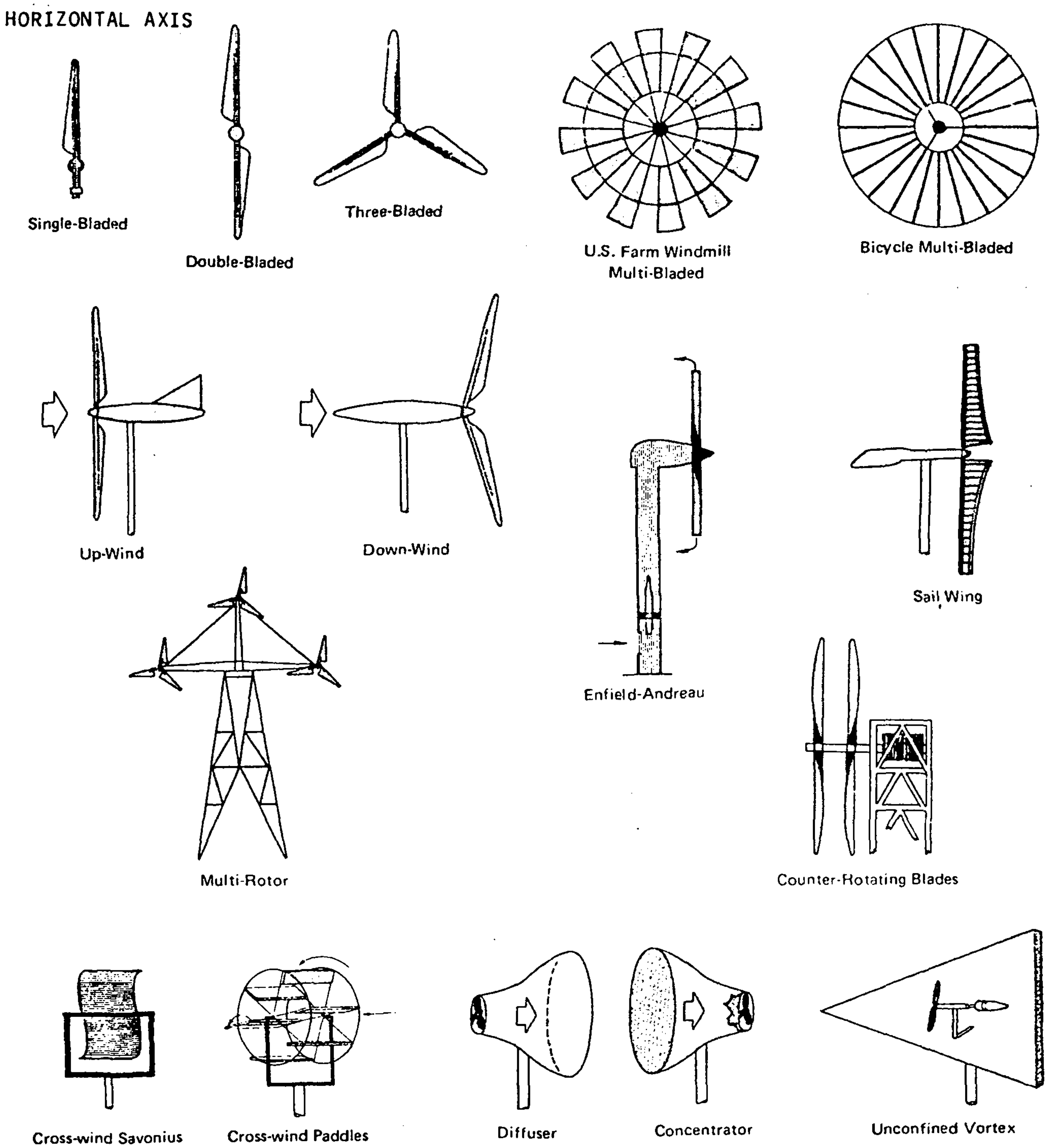


Fig. 16 Types of Horizontal Axis Windmills

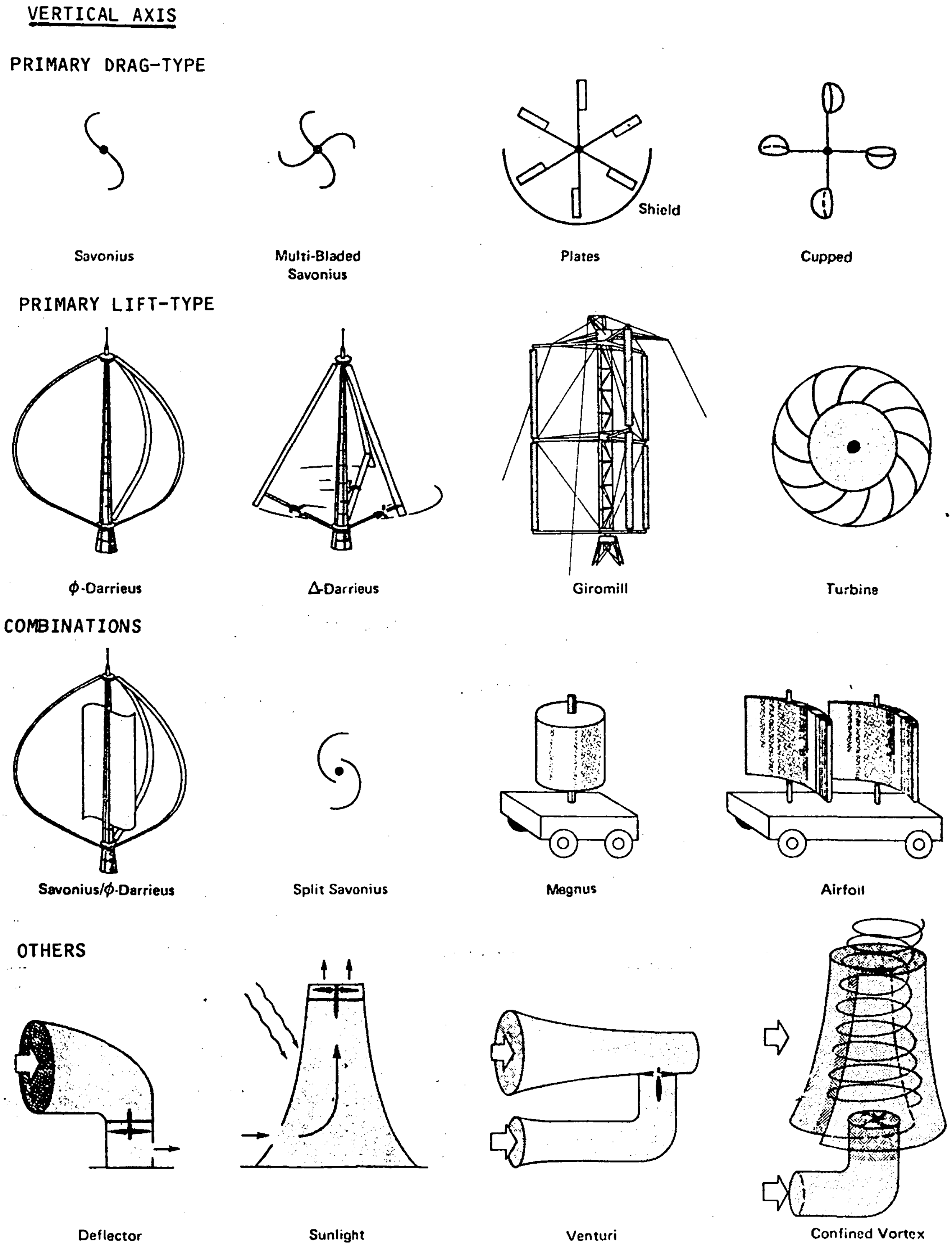


Fig. 17 Types of Vertical Axis Windmills

smaller wind generators and such established manufacturers as Aerowatt (France), Dunlite (USA) and Electro (Switzerland) are finding that sales are increasing and there are many new manufacturers entering the market. However, these smaller units require separate storage facilities (typically in the form of storage batteries) that add to the system costs, although their energy output/system weight ratio is not as far below that of the larger rotors as might be expected.

Water Pumping Windmills

Historically, water pumping windmills have found their greatest use in sparsely populated areas, where water and energy are in limited supply. It is in such situations, common to most rural areas of Africa, that renewed interest in these windmills will be most strongly focussed. In 1979, 18 commercial manufacturers of water pumping windmills were operating, some of which had been in business since the latter part the 19th century and still using the same basic design. Most of these machines are of the multibladed, high solidity, low tip speed ratio type, with high wind protection normally afforded either by furling the rotor (turning it edge on into the wind), or by using a small vane mounted in the place of the rotor (Figure 12).

The scale of commercial production and the technical infrastructure, on which many of the windmill manufacturers have been able to draw, has enabled the designs to evolve in the way that they have. Foundries are required to produce the large housings and many other components, but investment in facilities, such as galvanising equipment, can be justified only for a reasonably large rate of production. One manufacturer quotes a minimum (break even) production rate of 1000 units/year. Performance data are available from most manufacturers, although they should be taken as very approximate. A point strongly in favour of the older windmills, however, is their proven reliability over long periods of time. Many manufacturers specify operating lifetimes of 20 years and, indeed, it is possible to find machines older than this still in operation. Although problems can occur, these are more often related to the pump rather than the rotor or tower and, generally, maintenance and repairs are required far less frequently than in other pumping options (viz. diesel or hand pumps).

Recent developments in water pumping windmills have followed a variety of routes in seeking improvements over the time-tested multibladed fan design. Although approaches differ, they all attempt to devise a windmill that will provide a reliable supply of water at the minimum possible loss. None of the newer machines can point to the century-old experience of some of the present commercial designs and, in fact, many of the new units are still at an experimental stage. Yet progress is being made and some new commercial ventures are underway in Africa.

Problems affecting the development of water pumping windmills, particularly in the African context, fall closely under three headings. 1. Windmill <u>design</u> involves the optimisation of several interrelated factors. This interrelationship extends not only to the physical parameters governing airflow, structural integrity, etc, but also includes constraints arising from manufacturing and application concerns, such as the level of industrial infrastructure and local maintenance skills. 2. The local <u>manufacture</u> of water pumping windmills

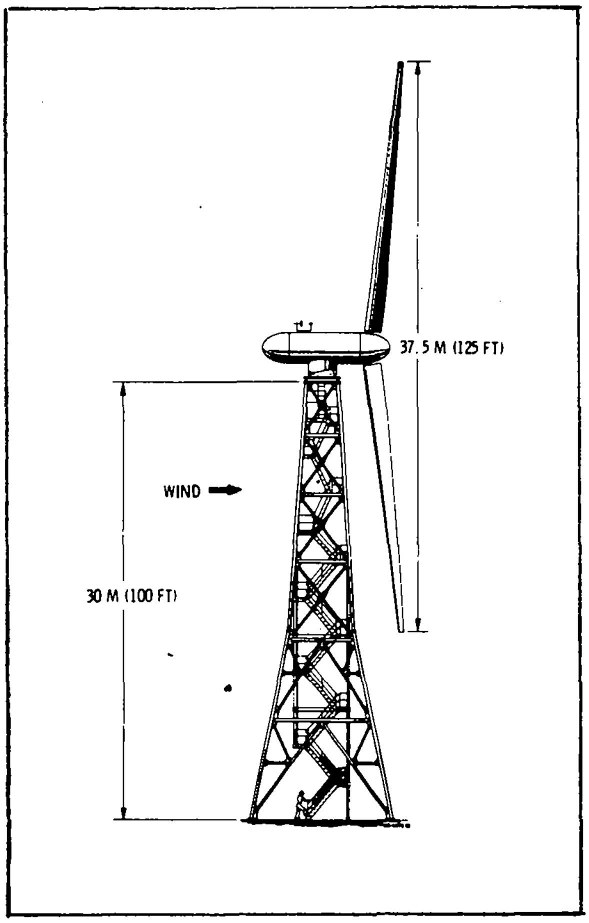


Fig 18 Large Horizontal Axis Rotor

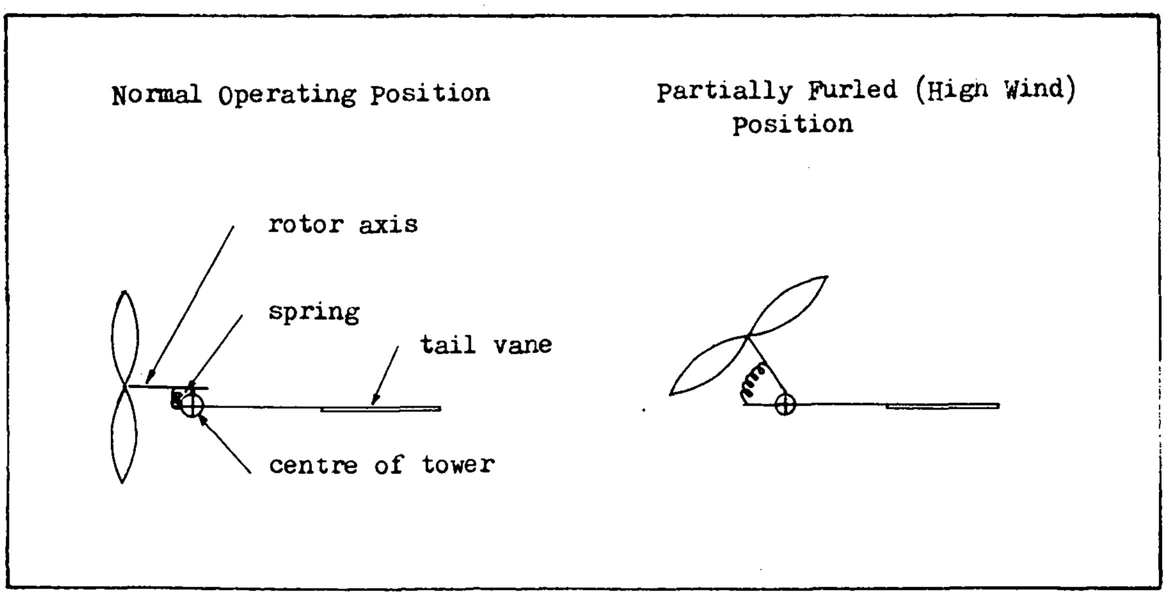


Fig. 19 Furling the Rotor

has obvious advantages, but there are associated problems involving such factors as scale of production size of the local market, lack of skilled manpower and the attitude of local governments. 3. Application problems affect both new and locally-produced windmills as well as existing commercial machines. The selection of windmill sites can greatly affect performance as can the height ofthe windmill tower. A windmill must be matched to local wind regimes and sized so as not to exceed the rate of water supply. Also, apart from the straight technical problems facing the application of water pumping windmills, there are those related to manpower. The need for training in the installation, maintenance and repair of windmills points to the need for a consultative approach among those who design and produce windmills and those who will use them.

In Africa, many programmes are already underway to harness wind energy for the purpose of pumping water. More detailed information about ongoing programmes in Botswana, Ethiopia, Kenya, Tanzania is available from the relevant country papers. In Botswana, the windmill programme has worked with both vertical-axis (Filippini) and horizontal-axis (ITDG design) rotors in an attempt to develop a system that would be able to operate successfully the commonly-used monopumps. Apart from the Filippini rotor, Ethiopia has developed a low solidity rotor for water pumping. This design has introduced small starting blades that aid in increasing the starting torque.

In Kenya, there are a number of windmill designs at or near the commercial production stage. The ITDG with a reciprocating pump has been produced in a somewhat modified form as the Kijito windmill. Another design is the KIE (Kisumu) windmill, which is based on the design originating from the SWD group in the Netherlands. A third manufacturer produces the Mbita windmill representing a compromise in rotor solidity. In Tanzania, some preliminary studies have been carried out through the national university and the Government has arranged to import several Australian windmills to supplement units already operating. Two programmes, one under the Government water department and the other at the Arusha Appropriate Technology Project, are underway in an attempt to develop a locally-manufactured windmill. Some work has also been carried out concerning the use of wind for electrical power generation that could serve rural areas.

The SWD group in the Netherlands has carried out considerable theoretical and practical work. It has developed a horizontal-axis windmill, originally designed to supply water in the rural areas of India which allows for the use of local materials and simple construction methods. Several programmes relating to water pumping wind power have also been undertaken in the UK. The ITDG has devoted considerable effort to the design and testing of a reliable horizontal-axis windmill. This rotor is well engineered with considerable attention having been given to its reliability. Two versions have ben designed - one for low lift and one for high lift. Manufacture of the machine can be carried out with limited production facilities, although the sophistication of the design is more complex than most other windmills that can be produced under these conditions. A new type of variable geometry, vertical-axis windmill has also been developed in the UK. Although originally intended as a wind generator, it is now being adapted for use in water pumping.

Conclusions

In comparing the economics of water pumping windmills with that of other pumping options, it is necessary to refer all costs to some unit measure of delivered energy. The same windmill, involving the same costs, will deliver different amounts of energy in different wind regimes, for the matching of the windmill to local conditions will affect its cost per unit of delivered energy. In Africa, governments are having to spend increasing proportions of limited foreign exchange on fossil fuel imports and, although wind regimes are generally moderate or low, several countries have found that wind power for water pumping can be practical. However, at present, links between the various wind energy groups in Africa are tenuous or non-existent; closer co-operative efforts would be to the benefit of all concerned.

Discussion

In choosing a suitable windmill design, there are a number of constraints that may have to be considered. For instance, in Botswana the Filippini design from Ethiopia was adopted because it suited the needs of the mono pump, which the Government is presently committed to using. The rotor has a high solidity, which leads to heavy structural loading during high winds, but, unlike other vertical axis windmills, the Ethiopian machine has a higher starting torque and fewer starting problems. Another reason for adopting the Filippini design is that it can be built in Botswana and more easily maintained and repaired there. Sixteen imported windmills are now being tested in the country along with four Filippini rotors and one ITDG windmill. The Fillipini rotors were not provided with a high speed protection system, as techniques suggested by IDRC in Canada were found to be unsatisfactory. As a result, the rotor has been designed to continue running in high winds. Further, because of the widespread use of the mono pump in Botswana, new experimental windmills have not been designed to operate piston pumps, even though these may be more easily driven by windmills.

Meteorological stations usually measure windspeed at two metres above ground level and this is important, for these measurements do not take into account how wind velocity varies with height. There are theoretical methods of predicting the way wind speed changes with height, but these were found to be quite inaccurate for several Botswana sites where actual measurements were taken. Although countries with low wind regimes may be wasting their time as far as windmill research is concerned, there is evidence to suggest that insufficient information in at least two areas is a problem. A lack of accurate wind regime data is one area of concern and normal measuring techniques can underestimate wind speeds by as much as 100% in some cases. The other area concerns a lack of accurate information from the manufacturer. Insufficient accurate data on wind pump performance is another part of the problem. With respect to windmill maintenance, Botswana is not concerning herself with windmills that require a high degree of maintenance, because there are not the necessary technical skills available in rural areas. A low-maintenance machine that could be built and repaired by rural users is therefore desirable.

Unfortunately, there is as yet no training programme which can teach the rural people how to install and maintain the windmills, because Botswana has still to reach the stage of commercial productioHowever, at RIIC, there are short courses which are designed to meet the present needs of the users of windmills in the country.

4.2 REVIEW OF BIOGAS TECHNOLOGY - Leo Pyle

Energy Needs and Alternative Technologies

There are several dimensions to the energy problem faced by the developing countries: there is a set of problems and issues relating to the availability and cost of 'conventional' fuel and energy sources; there is a related set of issues concerned with the effects and distribution of such energy sources and their technologies within developing countries; and there is a set of problems to do with the use of traditional sources of fuel - fuelwood, charcoal, crop and animal residues, It is a complex problem with social, economic and technical issues woven together and, because of the inter-relationship of the different issues, it is necessary, whilst considering particular technologies and their application to particular locations and problems, to keep in mind and if necessary develop an appropriate policy towards the wider dimensions of the problem.

A good deal of effort into the diffusion of biogas technology has presupposed that, because the technology is relatively simple and produces a convenient fuel, etc, its benefits for the rural poor would be positive. Paradoxically, however, there is evidence to show that, under particular sets of circumstances, it may benefit the rich rather than the poor or, worse, benefit the rich at the cost of the poor. Further, because of the relative inefficiency of many traditional technologies (lights, stoves, etc), traditional fuels may in fact be more expensive per unit of useful output realised than conventional fuels, such as kerosene or electricity. It is essential, therefore, that technical solutions are sought which will ease the overall economic burden and direct more efficient sources of fuel and energy towards those sections of the community and economy that are currently deprived.

One reason for considering alternative technologies is that they offer the hope of mobilising local skills, local manufacturing and construction capabilities and the local community, in a positive drive towards better living standards and quality of life. The question is whether, and to what extent, biogas technology is an appropriate component of the solution to this complex problem.

Biogas as a Fuel and Energy Source

The technology has three important characteristics: it provides energy in the form of gas; it can be used and valued as a waste treatment device for handling human, animal, agricultural and degraded industrial waste streams and byproducts; and the slurry product can be valued for its fertiliser value. However, despite the simplicity of the technology, its application is not cheap, mainly because of the limitations imposed by the kinetics of the fermentation. Moreover, there are quite strong scale economies associated with the process and the effects of capital cost and scale tend to favour larger rather than smaller scale technologies. Further, it is easy to underestimate the resource requirements, such as the available energy from the feedstock, the demand for water, the need of materials for construction and maintenance and the requirements in human, managerial and technical skills. Finally, one issue, particularly relevant to this Workshop, lies in the flexibility of the process and in its ability to follow changes in demand; if a plant is being considered for irrigation purposes, then this will be a most important consideration.

Biogas Technology: Some reflections on the State of the Art

There are a few programmes or activities presently ongoing in the African region. In Kenya, Hutchinson at Fort Ternam had developed a number of designs which range in scale from about 1 centimetre upwards. The construction materials include corrugated metal, water tanks and concrete, and both continuous and batch plants are available.However, although over 50 plants are known to exist in the country, it is reported that only very few are functioning. In the Sudan and Egypt, where water hyacinth is a serious problem on the Nile, various types of biogas plant are being investigated, such as some modified Chinese designs and standard versions or simple adaptations of the well-known KVIC Indian design. a trial programme in Egypt also involves the use of biogas to power a Humphrey pump for water pumping and irrigation. (Information concerning biogas programmes in Botswana, Tanzania and other African countries can be found in the summaries of the relevant country papers). A general lesson to be learnt is the importance of analysing the most important elements in the economies of the process and directing R&D and design efforts to reducing those elements, rather than setting up a rather aimless and generally broadly-directed programme of work.

Biogas Plant Designs

The principles of biogas technology are, in outline, well-known: substrate in the presence of nutrients, water and the necessary population of micro-organisms is fermented under anaerobic conditions via various intermediates to methane and carbon dioxide. Such processes can be classified according to their modus operandi, namely batchwise (Figure 20), semi-continuous or continuous, or according to their mixing modes, that is unmixed, partially mixed and mixed. Most simple low-cost digesters fall into the unmixed and partially mixed categories, and most are best described as semi-continuous with intermittent loading at around daily intervals. Many continuous or semi-continuous designs have been proposed - some depend on the movement of materials and rather crude mixing devices for any mixing that does occur; others have more sophisticated (and expensive) mixing systems. However, in some designs mixings is deliberately suppressed as in the horizontal 'plug flow' digester (Figure 21).

On the question of efficiency of gas production, there is little solid evidence to suggest that continuous processes are particularly superior to batch processes. Similarly, there is little to choose between mixed and plug flow digesters, although there is evidence to indicate that well-mixed frequently-loaded digesters can achieve much higher production rates than poorly mixed units; but only at some expense. As far as the operational aspects of digesters are concerned, the batch unit suffers from the cyclic nature of its gas output but it does offer some other significant advantages. One is that operation is much easier and less demanding than a well-managed continuous system. Another is that they can more easily handle vegetable matter. Plug flow digesters also offer some operational advantage in that no mixing is required and running costs and trouble are thereby reduced. Temperature control is perhaps more difficult for batch and plug flow units.

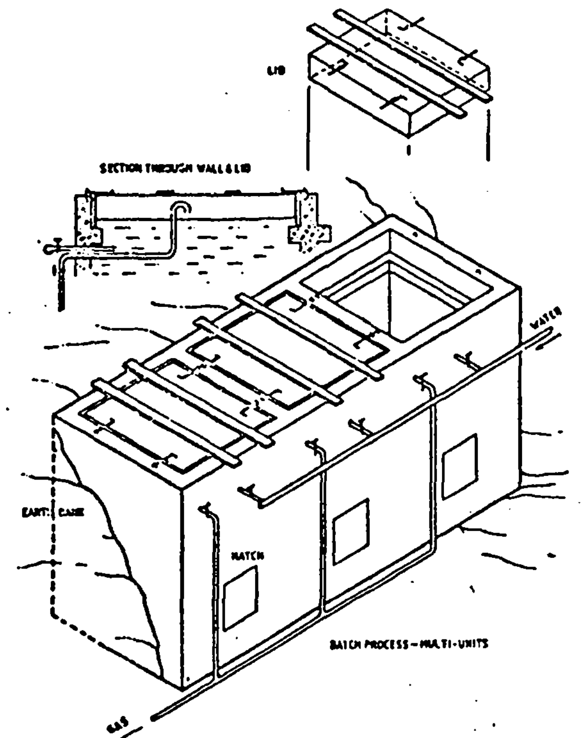
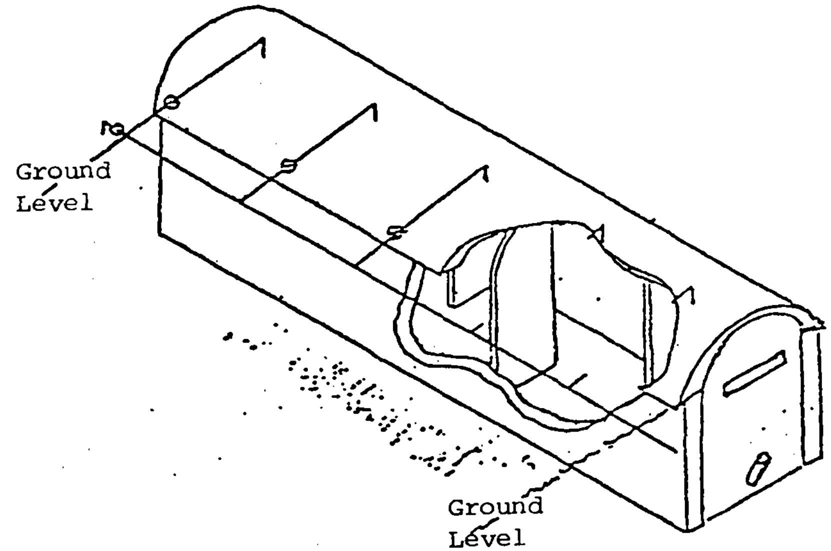


Fig 20. BATCH DIGESTER (MANN)



COMMUNAL DIGESTER MODULE (Mexico) MARTINEZ (1980)

Fig 21. A HORIZONTAL (PLUG FLOW) DIGESTER

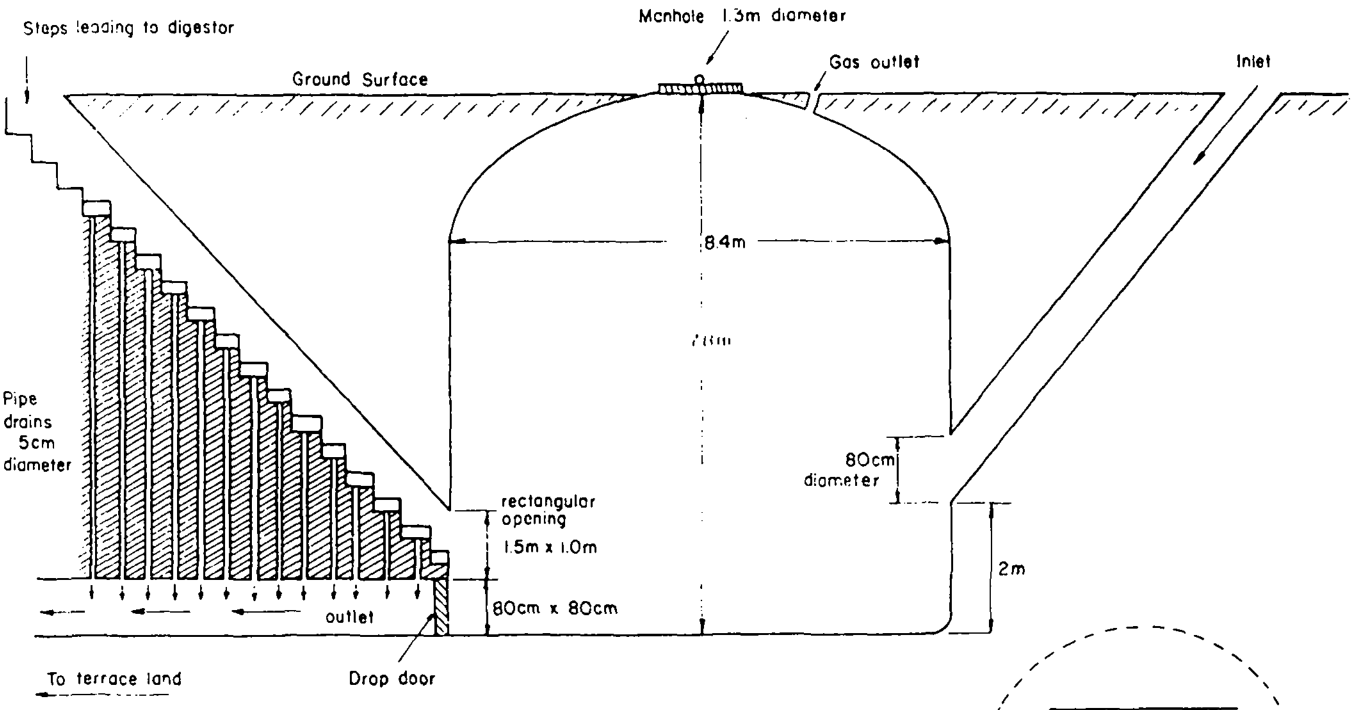
In addition to the above, some basic design differences exist that stem from considering the effects of composition. Most rural digesters will operate with solid or semi-solid feedstocks, although most digesters operate with less than 10% dry solids concentration in the input. Higher concentrations give rise to operational and production problems, but there are considerable potential advantages in operating at high solids loading rates, providing these can be supported, since this would imply reduced digester volumes (and thus capital investments) for a given substrate feed rate. Also, increased concentrations of the right micro-organisms in proximity to the reacting species should increa se production rates. A number of different process configurations, whose efficiency depends on manipulating the environment to be more suited to micro-organism functioning, can be distinguished. These include multistage processes and process technologies depending on microbiological effects. Temperature is another factor that must be considered, for changes in operating temperature probably cause rather fundamental changes in the whole process, its efficiency and economics. The vast majority of low cost plants operate at mesophilic or low temperatures, but the smaller the scale of production the less likely is the possibility of good temperature control. There is accumulating evidence to indicate the benefits of operation at higher temperatures, but as yet insufficient data preclude the study of the costs and benefits of operating in the thermophilic range.

Detailed local engineering, which translates a basic design into a locally appropriate technology is vital to the successful opertion of biogas plants. Most familiar designs are in fact local variations of a very few basic designs, the most common of which is the semi-mixed, semi-continuous variety of the type shown in Figures 22 and 23. It would be surprising to find significant differences in operating efficiency between variations, but local adaptation is absolutely crucial to successful design and implementation and one should not understimate the potentially enormous range of locally-adapted designs. For any successful adaptation, there are two major prerequisites, assuming a basic knowledge of the technology: a clear understanding of local conditions and needs; and access to information on designs and experiences from other regions.

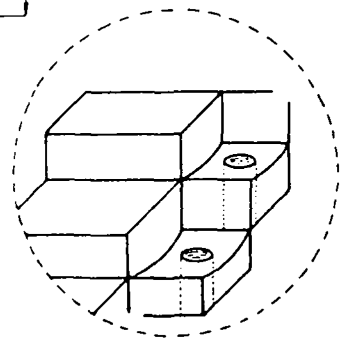
Applications of Biogas

In considering the uses of biogas plants and potential applications, it is useful to recognise that invariably the value of the slurry <u>and</u> the gas will be important considerations. The slurry treatment/disposal part of the process has a dual function: to reduce pollution load, kill parasites, etc, and to recycle nutrients to the land. There is also evidence to indicate that, as a plant feed, the slurry is rather better than compost and certainly better than raw excreta. So, as well as increasing the organic nutrient supply, the quality of supply is slightly improved and, in an economic evaluation of biogas projects, the output slurry can probably be assigned a value of around 10-15% higher than the feed. Two additional points about slurry disposal: if the slurry contains pathogens, from human excreta for example, it is clearly important to complete treatment before disposal to the land; care must also be taken in storing the slurry before disposal to ensure that volatile nutrients are not evaporated.

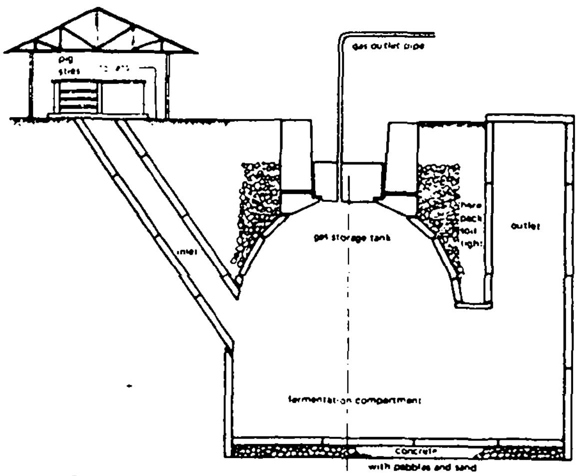
The main uses of biogas, or the methane if it proves advisable to separate out the carbon dioxide, are for cooking, lighting, heating



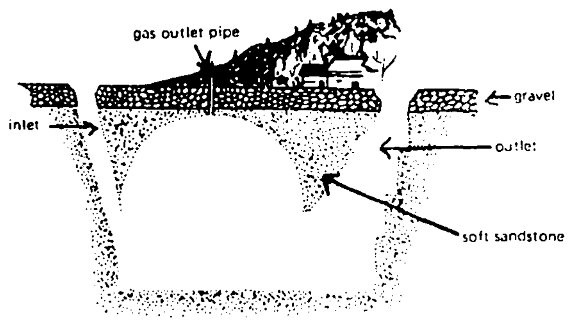
A 268m^3 biogas plant under construction at the Weicheng People's Commune, Sichuan Province



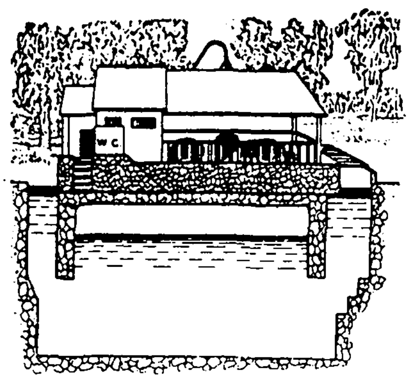
Detail of drain pipes through steps



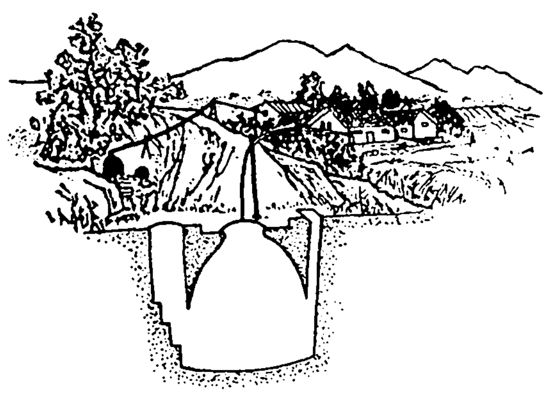
Design of a circular pit made from stone slabs.



Biogas pit carved out of soft sandstone.

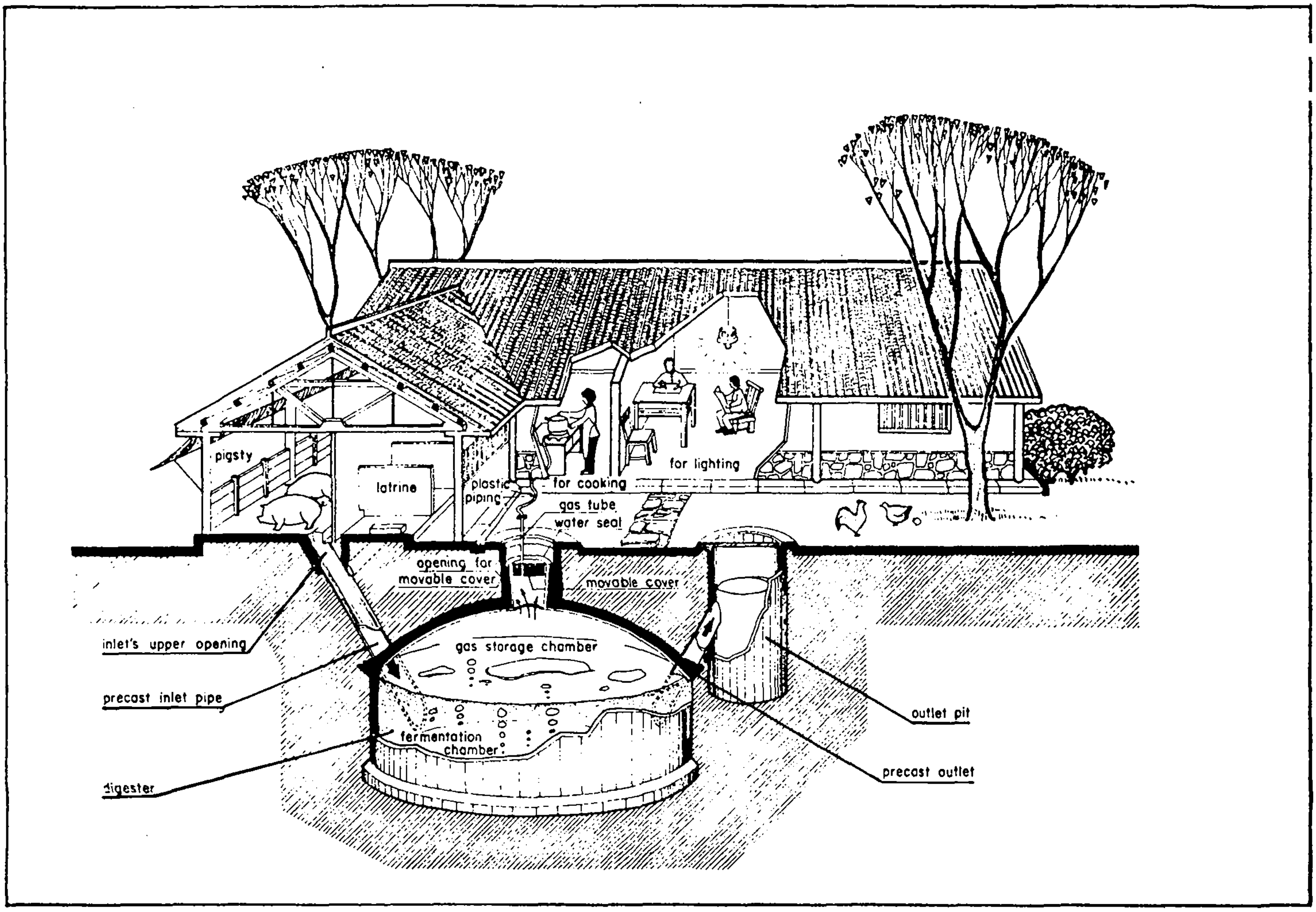


Toilets and pigsties built above a biogas pit.

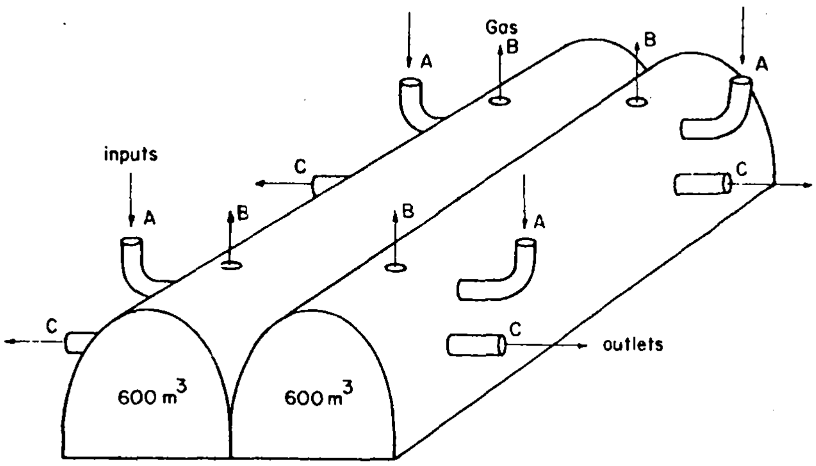


A pit in sheer rock.

Fig. 22 Chinese Design of Biogas Digester



The placement of a typical 'three-in-one' biogas unit in a Chinese household.



Design of inter-connected large-scale biogas digesters of 600m^3 each at Pin Niu People's Commune, Jiangsu Province.

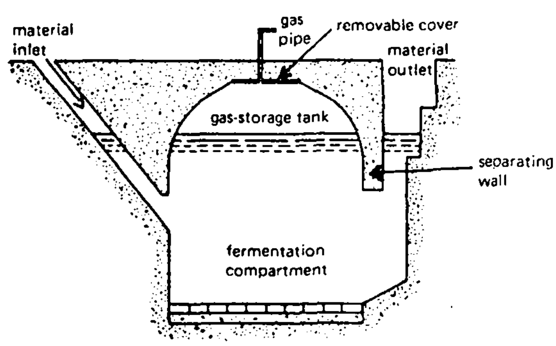


Diagram of a circular biogas pit.

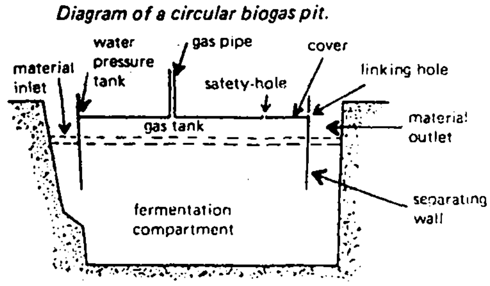


Diagram of a rectangular biogas pit.

Fig. 23 Chinese Designs of Biogas Digesters and power. In areas and social groups hitherto dependent on traditional fuels or to whom commercial fuels are increasingly expensive, it seems likely that the main priority should be given to replacing fuelwood and charcoal for cooking, since these dominate both the end uses of traditional fuels and are the main source of the appalling burdens falling on women and children as fuel collectors. The efficiency of a gas cooker is considerably higher than traditional cookstoves and a range of designs for simple gas burners is available. The potential for local manufacture is high in most parts of Africa. A range of designs for simple gaslights is also available, although the luminous intensity of biogas is much lower than for liquid propane or electric lighting and it might be preferable to generate electricity from the gas rather than use the gas directly. Heating appliances are also available and may be useful in cold areas or for such uses as heating poultry and animal 'nurseries'.

Methane can only be liquified below -82.5°C and is not so attractive a motor vehicle fuel as gasoline, diesel, LPG. Most power uses of biogas are thus onsite, for raising heat in boilers or for power and electricity in internal combustion or dual-fuel diesel engines. The use of gas engines (e.g. the Humphrey pump) may also be atttractive. A petrol engine adapted for use with biogas and having a compression of 8:1 is about 20-25% efficient; the presence of carbon dioxide in the biogas seriously affects engine efficiency at high compression ratios. Dual-fuel engines are modified so as to induce a combustible gas/air mixture and, because of their higher compression ratios, the power output and thermal efficiency are increased; at a ratio of 12:1, a diesel engine is about 30-35% efficient. In practice, this means that 1m of biogas (at STP) will give an output of around 2Hph. The engine may be either coupled directly to a drive or used for electricity generation. The balance of the energy is converted into heat (about 3.5 kWh equivalent per m^3 of gas), which in sewage works is often used to heat the digestion tanks. Another option, which is being studied seriously in various parts of eastern and northern Africa, is to use the Humphrey pump for irrigation and water pumping purposes. However, it has been suggested that the efficiency is low and, moreoever, there is no apparent method of improving the cycle performance by heat recovery.

Insofar as priorities between the various biogas applications are concerned, it is obviously necessary to understand the local situation. If water collection and provision is a pressing human problem, as it often is, then the possibility of biogas-powered lifting and distribution should be explored. Irrigation is, of course, a pressing need in many areas, but this need is very seasonal and adequate supplies of substrate must be assured for meeting peak demand. There is also the question of how to use the digester output, if at all, during periods of low zero demand.

The Cost and Benefits of Biogas Production

As with any process technology, it is impossible to make useful generalisations about the economic feasibility of biogas. However, a study of the potential for biogas plants in Kenya does provide a basis for discussion. It illustrates, for instance the extreme sensitivity of the result to the evaluation placed on the slurry and demonstrates the sensitivity to scale. The study also shows how very sensitive the economics are to the use of local materials and to the development of designs which are adapted to local conditions. Further, the result indicates the importance of labour costs and the valuation of output energy in the financial analysis of such projects. One other input to the process is the water used. There may well be many situations where the availability of water is a serious constraint on the practicality of biogas production; this seems likely to be particularly true in semi-arid and arid parts of Africa, where it also acts as a brake on agricultural production. The cost of water could also be a constraint and, even if this is not the case, a design objective should be to attempt to minimise the water demand.

In addition to a purely financial analysis, there are other economic considerations that should be taken into account in the final assessment. One is the increasing time spent by rural people, especially women and children, in the search for firewood. Another concerns the conservation of the physical environment and the tendency for fuelwood to enter the monetary economy; moreoever, as the price of conventional fuels, kerosene, etc rises, there are increasing pressures from the urban communities to move back towards the use of charcoal and firewood as fuels. The central objectives in the search for alternative energy sources will include, therefore, the reduction in time and money spent by the poorest sections of the community on obtaining fuel and energy and the conservation and recovery of the physical environment, in particular the forest stock. Whatever the quantitative argument and conclusions, it is important to consider these social objectives and the attendant costs and benefits associated with the particular technology.

Implementation Aspects of Biogas Programmes

There is little information available on the progress of problems of national biogas programmes in Africa, but it is noteworthy how little has happened since the work of Boshoff in the early 1960s and the even earlier work related to FAO by Mann. However, there is enough evidence to point to the more significant and likely problems to be overcome. On the technical side, the crucial need for careful and reliable engineering of biogas plants cannot be overstressed. The evidence from Kenya suggests that many plants are not working because of poor construction, maintenance, control, technical support, etc. There is also evidence that too much has been claimed for biogas plants and that operational difficulties due to climate or substrate have been treated too lightly. In principle, there is no reason at all why the technology should cause insurmountable problems, but no technology will function adequately without careful attention to engineering detail, without professional skills and without adequate technical support and management services. In developing countries, the 'match' between technology and local skills and technical traditions is a very important factor in determining whether successful implementation and diffusion is possible.

The need to improve the economics of biogas plants has already been stressed. The economies of scale associated with biogas plants and the relatively large investments called for have often, in the absence of clearly articulated credit and community-based actions, led to the more or less successful implementation of biogas plants by the richer farmers with the poor untouched or even impoverished, due to the secondary effects of the technology. As far as social aspects are concerned, it is of primary importance to understand the patterns of demand and need, of users' preferences, of the influence of location and, especially, of cultural traditions and preferences. In some societies, the cultural and social problems raised by the use of biogas plants, particularly when using human excreta as substrate, are of overwhelming importance. There is also a need for carefully established managerial and technical support systems for biogas programmes and commercialisation as attested to by the experience in Kenya. In China, comprehensive training programmes have been vital to the diffusion and improvement, through local initiative, of the technology. No country or region should simply attempt to translate a particular management structure to its own situation without careful consideration of its feasibility and of the need for local adaptation, but, that said, in the absence of managerial support, biogas programmes will falter and, at worst, fail.

Some Conclusions and Suggestions

In conclusion, here are a few suggestions on where problems still await solution and the work involved in overcoming them. Energy policy: there are glaring gaps in understanding and in data available on energy needs, present costs, patterns of consumption and the possibilities and consequences of technical innovations. There is need for locally-focussed studies on energy possibilities, with special attention being paid to resource demand and mobilisation, the beneficiaries of technical change, etc.
Technical issues relating to biogas: it is strongly recommended that clear distinctions be made and objectives defined appropriately between basic scientific, basic process technology and detailed engineering. There are problems requiring R&D in each category, but it is plainly important to have clear and realistic objectives.

Information requirements: despite the amount of work that has been carried out, there is surprisingly little reliable, technical and economic data available on the operation of different designs under different and controlled conditions. The Workshop might like to consider the need for mechanisms for information exchange, the development of agreed methodologies for monitoring and testing biogas plants and the development of country and regional programmes for such testing and analysis. Managment, technical support, marketing, etc: as already stressed, management and support services for biogas implementation are absolutely crucial. The Workshop may like to consider these requirements and to assess critically experience in the region and in other parts of the world. Finance and credit: social considerations suggest that significant credit and subsidy arrangements may be worthwhile under certain circumstances. The implications of this suggestion should be developed further.

Two appendices were presented as part of this paper but are not reproduced here: 1. Anaerobic digester designs in the Third World. 2. The environmental and social costs of fuelwood.

Discussion

Biogas technology is being used in various parts of the world for waste disposal, energy supply and nutrient recycling. Problems arise both with engineering and with technical support systems. In a centralised management system such as China, biogas plants seem to have been most successful. This may be because the users are involved in choosing and developing the technology, and therefore understand how to operate it. It is significant that most biogas plants in China are relatively small-scale.

The efficiency of a biogas plant should be measured as the volume of gas produced per day in proportion to the volume of the digester. Typically this proportioin is 1/5 to 1/3, but it can be increased by a factor of 4 or more. If the performance of biogas plants were carefully monitored, 3/4 of the models currently used would disappear. The extravagent claims made for many of the existing models need to be examined carefully.

The economic evaluation of biogas is difficult to undertake. It is not clear how to value the labour saved, the environmental benefit in terms of firewood saved, the value of the fertiliser applied as slurry, or the cost of the inputs.

The cost per unit of gas is greater for a small family digester than for a large community digester. However, community digesters have to run at low pressure to avoid the danger of explosion. The possibility of compressing gas into bottles or piping it over some distance needs to be investigated.

The use of chemical catalysts in the process of digestion have shown variable results. The output of gas is not necessarily increased. Not much is known about the microbiology of the digestion process; research needs to be done on this topic.

4.3 BIOGAS DEVELOPMENT AND APPLICATION IN INDIA- Y N Sharma

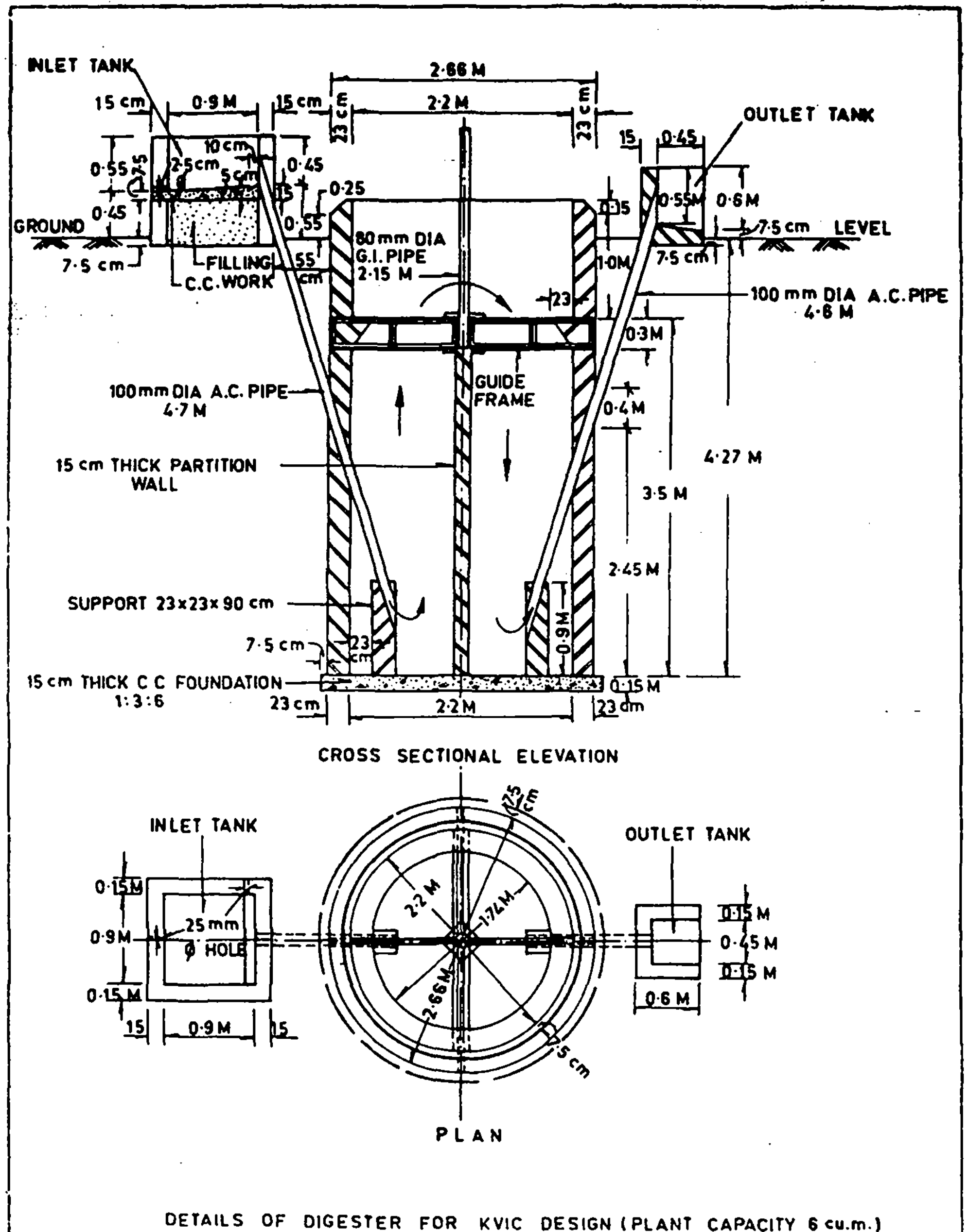
India has a huge cattle population and it has been estimated that 980m tonnes of cattle dung are produced in the country every year. However, nearly 30% of this dung is burnt as fuel in the form of cattle dung cakes and the amount of dung thus wasted is equivalent to a third of the chemical fertilizer used in India. If all of the cattle dung was processed through a biogas plant, this could result in the production of 36,260 x 10^6 m^3 of fuel gas, which is enough to meet the domestic needs of 87.45m families, and the amount of organic manure produced would be of the order of 368m tonnes. In addition, not only is the burning of dung cakes highly pollutive, but the thermal efficiency is only 11% as against 60% for biogas.

The potential of biogas as a source of energy was identified in India as far back as 1937-8 and efforts by several organisations finally led to the development in 1954 of a continuous type of digester coupled with a centrally-guided floating type of gas holder (Figure 24). This design was adopted by the Khadi and Village Industries Commission (KVIC) in 1962. Gas production per kilogramme of fresh cattle dung under tropical conditions is taken for these biogas plants as 0.036m^3/day and they have been designed to suit the needs of individual farmers and institutions. There are 14 different plant sizes depending upon the availability of dung and the amount of gas required.

KVIC has also developed appliances which can run efficiently on the gas, such as gas burners and a special lamp, and in 1964 it undertook the conversion of petrol and diesel engines. In the case of petrol engines, it was found that if their compression ratio was raised from 7:1 to 12:1 they could run satisfactory on gas although they deliver less HP than their rated capacity. Further studies are underway, which will look into the possibility of running engines on gas mixed with 10-15% petrol. More successful has been the conversion of diesel engines to operate on biogas and a number of different types is available. All of them have been designed so that they can switch back to diesel should the supply of biogas become exhausted. By using a mixture of 20% diesel and 80% biogas the engines perform most satisfactorily and produce 20% more power than those run solely on diesel. While they can be used for generating electricity, most engines are used only as water pumps.

Gas engines are installed where biogas plants having a capacity of 15 to 20m^3/day capacity have been set up and the net savings in fuel costs can pay for the total cost of the gas plant and engine within 4½ years. A 5HP diesel engine while running a pump for an hour can lift 200 gallons of water to a height of 50 feet and uses one litre of diesel costing Rs.2.60. When the same engine is used with gas, the hourly cost of diesel is reduced to Rs.0.52. At the moment over 80,000 gas plants are in operation in India, most of which are owned by farmers in rural areas. Bigger capacity plants are run by co-operative societies educational institutions, Goshalas and big farmers. The gas is used mainly for domestic fuel, lighting and in engines for running water pumps; at present more than 500 engines are in use, mostly for the purpose of lifting water for farm irrigation.

The possibility of reducing the costs of biogas plants is being studied under the research and development programmes. For instance, using cement rings in the construction of digesters will



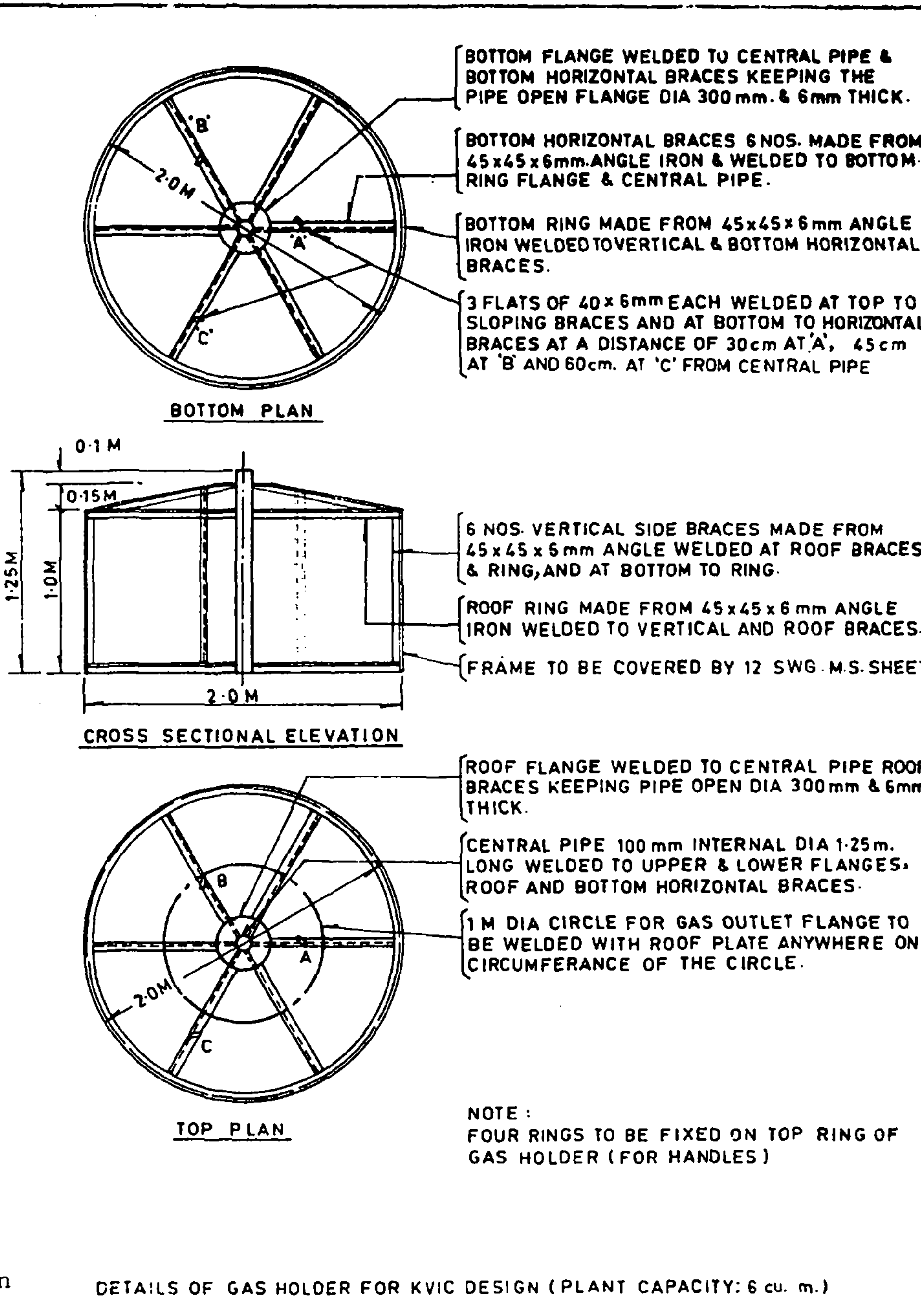


Fig. 24 Details of Digester and Gasholder for KVIC Design

reduce the cost by upto 20% and the ever increasing rise in the cost of steel means that alternative materials will have to be found for the manufacture of gas holders. Microbiological fermentation slows down during the winter season in some parts of India and the possibility of utilising solar power to overcome this problem is also being looked into. Efforts are meanwhile underway to develop more efficient gas burners as well as the engine which runs wholly on gas. To cater for farmers who have little or no cattle, community biogas plants are being installed; 20 such plants will be ready shortly and will operate on alternative types of organic waste to cattle dung, such as night soil and agricultural waste.

Discussion

During the discussion the question of digester was raised. If a digester is going to be used say for an entire day, a larger storage tank is necessary so that some of the gas can be retained for future use. The centre wall has been known to break under pressure but Mr Sharma said that this only occurs during the intitial filling of the digester if the slurry is not added through the inlet and outlet pipes simultaneously. In a small digester the wall is not so essential, but must be used in the large ones. The wall helps the circulation of the slurry and its eventual removal from the digester. Sludge does not appear to be a problem in small plants which are not opened, but, in larger plants if sludge builds up, it must be removed and the digester replastered.

Until recently, only the richer 10-15% of the people have benefited from biogas. Now the poorer people, those who have only a few head of cattle, may benefit from community gas plants. People will be encouraged to bring five buckets of dung a day to the plants and in exchange will receive five buckets of slurry with which to fertilise their crops. An extensive training programme will show them the advantages of slurry over composted dung and a demonstration plant will be used to teach the people about biogas technology. In addition, the Indian Government is subsidising the capital costs of plants by upto 75% for poor farmers, 50% for underdeveloped areas and 25% for small and marginal farmers. This raises questions of how widely government can afford to promote the adoption of biogas units.

Questions were also raised about the comparative combustion efficiency of dung cakes and biogas produced from the same amount of dung. The questioners felt that dung was as efficient as biogas, but Mr Sharma once again stressed that biogas was the more efficient. And the use of biogas has overcome the problem of smoke, the cause of some serious eye ailments suffered by housewives. Because of this and through education and training programmes, the people of India have readily accepted the biogas technology.

CHAPTER 5: DISCUSSION AND SUMMARY OF COUNTRY PAPERS

5.1 BIOGAS FOR WATER PUMPING IN BOTSWANA - B McGarry

Botswana needs to find alternatives to petroleum as a source of power; biogas is the obvious substitute for diesel fuel now used to pump water for cattle, which are kept in large herds in many remote, arid areas of the country. At the Rural Industries Innovation Centre (RIIC), several digesters have been built, their performance monitored and the running of diesel engines on a mixture of biogas and diesel studied. Work has now begun on establishing a pilot biogas plant at a borehole near Kanye which will provide gas to drive the diesel engine installed there. Meanwhile, preparations are already underway for a larger-scale implementation programme.

RIIC had built two small digesters and run one of them ($0.6m^3$ digester) for three years, before constructing a $10m^3$ Chinese type digester. Since then, two $3m^3$ digesters have been built as part of toilet systems which resulted in an improvement in construction methods and the ability to make the digesters leakproof. In contrast with the earlier $0.6m^3$ above-ground digester, the $10m^3$ "Chinese type" maintained an appreciable level of gas production throughout the winter months, the minimum being $1.0m^3$/day, ie. 10% of its volume, and this could rise to as much as $3.0m^3$/day during the summer. The temperature of the $0.6m^3$ digester fluctuates during a 24 hour period by as much as that of the atomsphere, while that of the underground digester varies by no more than 2°C in this time. The digester is fed on slurry made exclusively from fresh cowdung and the biogas that is produced contains approximately 60% CH_4, 39% CO_2 and 76mg total S/m^3. The digesters fed with cowdung perform better than the toilet digesters, the biogas from which has a higher sulphur content; there is also a greater amount of accumulated sludge with the latter.

RIIC now favours a more recent design of $50m^3$ digester from China, which has a curved floor and ensures less contact between the slurry and atomsphere. Satisfactory tests have also been carried out on Chinese techniques for rendering a concrete digester gas-tight by plastering with a mixture of very fine-grained sand and a little lime. The problem of leaks increase with digester capacity because the larger the digester the greater the gas pressure; there are also increasing problems in constructing large unreinforced domes. In China, digesters are not built above a $50m^3$ capacity. RIIC is planning three digesters, each of $30m^3$ capacity, for a pilot biogas-powered borehole; UNIDO has been asked to provide expert consultants to assist in the construction.

Diesel engines can easily be adapted to operate in biogas, but a pure biogas/air mixture will not ignite in a diesel engine, so a certain amount of diesel fuel is needed in the mixture. In comparing the performances of a Kirloskar AVI engine and a Lister STI engine it was seen that the Lister provides a greater reduction in diesel consumption (87% as against 82%), uses less biogas to replace a litre of diesel ($3.8m^3$ compared with $4.3m^3$) and gives a more consistent performance than the Kirloskar. An average Botswana borehole is 115m deep and supplies water for 600 cattle. An STI engine pumping this water would use $33m^3$ biogas/day calling for 0.55 tons dung/day; 13% of the dung of the 600 cattle that use the borehole.

This would require at least $300m^3$ of digesters capacity. A digester assembly providing a winter minimum of $30m^3$ biogas/day would cost an estimated P9000-16000, giving a unit installation cost of P300-540/m^3 gas/day and a cost per unit pumping capacity of 1.0-1.2 thebe/ℓ/m/day for a complete digester, dual-fuel engine and pump assembly or 0.3-0.5 thebe/ℓ/m/day for a biogas digester added to an existing diesel-driven borehole. The range of uncertainity in these figures is due to the need to use different digester designs when making projections for large scale biogas production from the Chinese type which was used for testing. The installation cost could be recovered, as a saving on fuel purchases, in 7.2-12.9 years at constant prices. However, with an 11% inflation rate and petroleum prices rising at 10% year above this, the time taken to recover the cost of installation will be shorter than this. At current inflation rates, this remains true even if digester construction is financed by a soft loan at 6%/year, which the Botswana Enterprises Development Unit is prepared to consider offering.

In the inflationary situation that seems certain to prevail for some years, the biogas/diesel operation of borehole engines offers a saving over pure diesel operation, although it is not so clear whether biogas becomes as cheap as wind pumping or not. However, the larger cost of biogas installations per unit pumping capacity decreases with size, which is not the case with windmills. Biogas is also better able than wind power to satisfy a steady high demand for pumping power.

It is concern that both of the RIIC engines use biogas less efficiently than diesel and this concern is accentuated when reports from workers in other countries show that they can achieve a considerably higher efficiency with their engines. If Botswana could improve the efficiency of her use of biogas, her demand for gas could be cut by nearly half thereby making the economies of biogas pumping much more favourable. However, even at the present efficiency, dual-fuel operation does offer real cash savings.

Discussion

Questions relating to use of the technology dominated discussion of this paper. The regulation of gas pressure can best be achieved by using a floating gas holder rather than using the gas directly from the digester, which would cause the problem of variable pressure in the digester itself. Temperature control for the optimum production of gas is another problem. Cooler weather results in a lower level of gas production and, as a way of retaining the heat, digesters have been painted black. Suggestions were made concerning the possibility of utilising solar heat to control the temperature. It was also suggested that heat from the engine exhaust, or heat from water used to cool the engine, could be channelled in order to raise the temperature in the digester. This problem is very complex and should be discussed thoroughly in the working groups.

The efficiency of the digesters used in Africa seems to be about 25-30%. It is difficult to see why these digesters work less efficiently than those in other parts of the world. Perhaps the organic matter is not mixed in the same way or maybe there is a significant temperature change. Biogas containing water is less efficient, and an attempt at RIIC to fit a condenser on the line of a digester did not work. In addition, condensation forming in pipes and causing blockages could pose problems. Equally worrying is the question of leakage. Leaks occurred at RIIC when adapting Chinese biogas digesters, although the $3m^3$ digesters of Chinese design installed there did not leak. In order to control leaking, the floor of the digester must be reinforced and, if possible, curved, although some leakage still takes place through the masonry and around the manhole.

The question of which digester feed produces the most gas was discussed. Dung from one cow can produce sufficient gas to satisfy the needs of a small family for one day. It would require the total excreta of 35 people to produce the same amount of gas. It was suggested that the quantity of gas produced from various feeds be studied and measured. It was also suggested that the meeting should avoid becoming too concerned with biogas technology per se or its applications other than for pumping water and remember the importance of solving the original water supply problem. This would reduce some of the social problems that can arise from many biogas applications.

In the light of the many technical points raised, discussion of research and development focussed on ways of overcoming the problems that can occur as a result of using and analysing existing literature with a view to building prototypes for study. But such research is expensive and very slow and one is in danger of losing touch with the practical realities of developing the technology. So perhaps Africa should continue to concentrate on production and maybe the working groups could evolve a mechanism for filtering and analysing the literature so that the people who need practical information don't have to waste valuable time. Also, one model could serve as a prototype for all those in the region who are interested in biogas. Then, as a result of experience gained from research, requests for analytical assistance could be more specific.

The use of human excreta as a feed can also give rise to social problems. Digesters producing biogas from human excreta are used in some parts of the world, but in Botswana they are not socially acceptable. A programme of education could perhaps alleviate this problem, although at present Botswana is considering using only cowdung and then only for borehole applications. If countries without cowdung wish to undertake a biogas programme, education in the use of human excreta may be necessary. A positive way of educating the people may be to show them what can be achieved from the technology. For example, a young schoolgirl, aged twelve, seeing wild vegetables growing in the vicinity of a public latrine, many more easily understand that recycled excreta from a biogas digester is helping the crops to grow. There are a number of ways to tackle the education issue and they must be carefully examined; but, at the same time, social taboos must be respected.

When dealing with the village water supply, the conversion of diesel engines to operate on a mixture of diesel and biogas may pose another problem. For instance, the villagers may find the converted engines more difficult to handle. Also, organising the people to be responsible for collecting the dung, starting the engines and maintaining the equipment may prove complicated, although, if the people can be involved in the development of the technology in their own areas, they may be more ready to take responsibility for the maintenance and operation of the equipment. After all, the people of India were initially prejudiced against using biogas, but have been successfully taught to work with it. However, one should beware of trying to 'push' the new technology in the rural areas; this again can create social problems.

5.2 AN ASSESSMENT OF WATER PUMPING TECHNOLOGIES USING LOCALLY AVAILABLE ENERGY RESOURCES, BOTSWANA - Richard Carothers

Botswana is a dry, semi-arid country with little or no surface water throughout most of the year. About 75% of the people and livestock rely on goundwater and, in most cases, this requires the drilling of boreholes. Because of the depths and demands placed upon these boreholes, power sources beyond hand pumps often become necessary. Original pumping systems installed throughout Botswana used reciprocating pumps driven by diesel engines. Recently, however, the Government and many private borehole operators have changed to using mono pumps. Further, the recent rise in petroleum prices has prompted the search for alternative, low-cost, low-maintenance pumping systems. This has led the RIIC to investigate the use of local energy resources such as biogas, solar radiation and wind energy.

As a means of comparison, an attempt was made to determine the present day value of all costs for a standard diesel engine on a per unit pumping capacity basis. A study, carried out on behalf of the Government of Botswana, detailed a cost breakdown for the installation and operation of a diesel engine over a 20-year period and showed that present day costs per kWh/day pumping capacity would be £1060, using 1980 fuel prices, but would increase to £1520, if the cost of diesel fuel prices rises at a rate of 5% in real terms over the 20-year period. An Alternative to this could be biogas /diesel pumping. Biogas can be fed to a diesel engine, which would require only minor modification, and thereby replace 85% of the diesel fuel. For a borehole of 100m depth, it is estimated that dung collected from 15% of a herd could supply enough fuel to meet the water demands of that herd.

There are, however, technical problems in supplying sufficient biogas to the engine throughout the year, since the rate of gas production decreases during the coldest winter months. To maintain production would require larger digesters and, hence, higher investment costs. The problems can be overcome and the economic outlook improved if smaller digesters are used and, during the winter months, the engine runs on the biogas/diesel mixture for only half of the time and wholly on diesel fuel for the rest of the time. The costs per kWh/day pumping capacity would be £1040 or £1170 with 5% inflation. Other economic benefits of dual systems include savings on foreign exchange, while costs involved in establishing digesters involve mainly labour and therefore contribute positively to the national economy. Moreover, the biogas/diesel pumping option can be designed to supply energy for large diesel engines where required.

Botswana is fortunate in having abundant solar radiation, lying within one of the world's few areas that receive more than 3200 hours of sunshine annually. Also, the intensity of the radiation is high, ranging from 0.7kW/m^2 in winter to 1.2kW/m^2 in summer. Incident solar variation ranges from about 3.90kWh/m^2/day in June to 6.8kWh/m^2/day in January, with a mean at about 5.4. At this rate, the solar energy falling on 4m^2 would be equivalent to that delivered by a 4.5kW (6hp) engine running for eight hours. Unfortunately, the technologies for capturing this considerable energy resource have been expensive and are generally felt to be uneconomic at present for water pumping applications. An estimate of the costs for two types of pumps has been made using published data. This ranged from £2000 - £3000 per

Fig. 25
Filippini Rotor

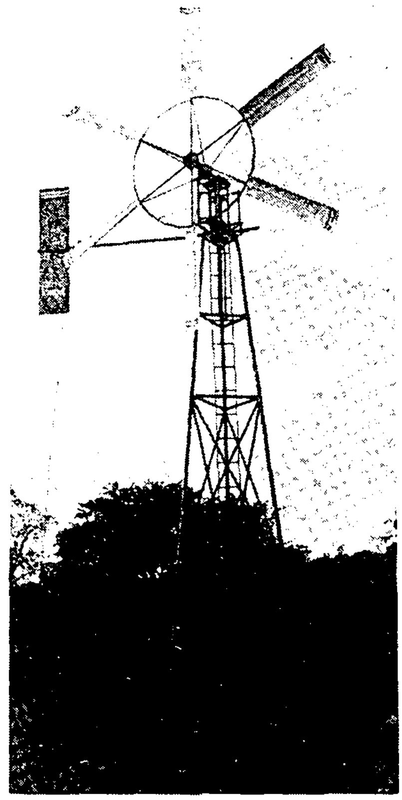


Fig. 26
ITDG Rotor

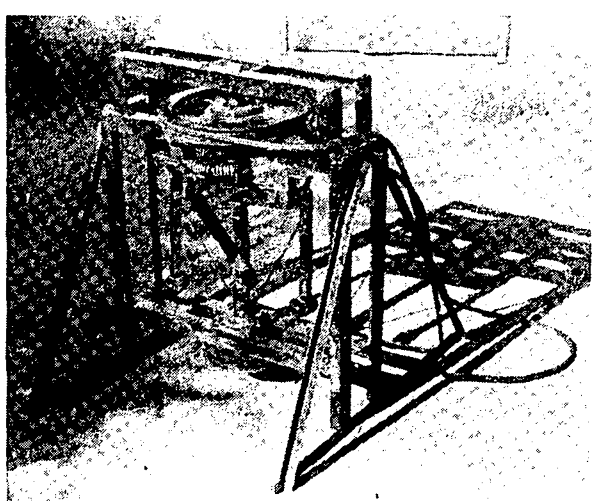


Fig. 27
Centrifugally-operated
Clutch Mechanism

kWh/day pumping capacity for a photovoltaic system, upto £8000 for a solar thermal pump and, although the photovoltaic system will almost certainly reduce considerably in price as the technology improves, the high costs of the solar pump are likely to discourage its use, even though it is more rugged and, therefore, requires less frequent maintenance.

As with solar pumping, the consideration of wind pumps as a means of providing water requires a knowledge of both the energy resource that is available and the performance characteristics of the pumps being considered. In practice, however, there are complexities in determining both the available energy and in evaluating different wind pumps and, although approximate methods exist to predict the performance of a wind pump at a given site, these methods are not sufficiently accurate to carry out comparisions of various machines with each other or with other pumping systems. Thus, work at RIIC has included detailed wind energy monitoring as well as performance tests for two experimental wind pumps. These tests have been completed for the vertical-axis Fillippini rotor (Figure 25), connected to a monopump, but have yet to be done for the horizontal-axis ITDG rotor (Figure 26).

The energy available from the wind depends on the wind cubed, i.e. a doubling of the wind speed means that the available energy increases by a factor of eight (2^3). As a result, the use of the average wind speed to predict available energy can introduce large errors. Equipment called a "compilator" has recently been developed for measuring available energy from the wind, particularly for windmill testing. A frequency distribution of wind speeds can be produced and histograms drawn (Figure 15) to indicate the value of the wind energy resource that is available. To determine the costs per unit pumping capacity, however, the performance characteristics of the windpump must also be known.

The mono pump presents some serious technical difficulties, if operated by wind. Its high starting torque and high operating rpm require that the windpump's transmission be specially designed to overcome these problems. The choice of the Filippini rotor as a means of driving the mono pump has eased one additional problem. The mono pump requires a rotary drive while most conventional (horizontal axis) rotors operate reciprocating pumps. A three-stage transmission has been used to achieve the high rpm required and a clutch mechanism (Figure 27) designed to overcome starting problems. The efficiency of the Filippini/mono pump system was measured at a variety of wind speeds and the performance curve of Figure 6 determined. From this and the available energy histogram, it is possible to maximise the output from the system and minimise the operating costs. For instance, if the unit is set so that it operates in winds above 14Km/h, the costs per kWh/day pumping capacity are about £1100. In winds above 20Km/h, the amount of water pumped increased and costs drop to about £700. Although the Filippini rotor has been successfully matched with a mono pump, the unit must still be classed as experimental. Further work is to be carried out in attempting to develop a high wind protection system for the rotor and some refinements of the clutch mechanism will be necessary before production could begin.

The horizontal-axis windpump, originally designed by ITDG is currently being field tested in several countries. In Kenya, the ITDG design is well made, but expensive when compared with other models. Part of the high costs, however, result from the use of moulded fibreglass blades, which are peculiar to the Kenyan rotor. In Botswana, the ITDG design incorporates all metal blades as in the original concept, but, since the transmission is intended to drive reciprocating pumps, major modifications are required to run the rotary-drive mono pump. As with the Filippini rotor, a clutch will be necessary to overcome starting problems and will enable the rotor to start without a load, with the result that fewer blades (six only) will be needed, as the normal 24 blades are required only in starting. The ITDG rotor already has a self-protection system for high winds which is a considerable advantage. At present, the performance curve and costs per KWh/day pumping capacity are not available.

Costs have been estimated for such wind pumps as Climax and Southern Cross, although manufacturer's claims may be inaccurate, because, while published data would suggest on overall efficiency of 31%, independent tests indicate an efficiency of 28% for the rotor only. Further losses would be expected in both the transmission and the pump.

Cost per kWh/day pumping capacity under idealised conditions	
Southern Cross	£175 - £348
Climax - No.12	£366 - £371
Filippini Rotor	£380

As a summary comparison of power sources (in economic terms), that make use of locally available energy resources, with existing diesel energies, it appears that both the biogas and wind pumping options are practical alternatives. Solar pumps would be impractical at present, but would become the least expensive option in the future, if prices of photovoltaic equipment continue to fall as predicted. Biogas and wind systems will involve local costs and contribute to the domestic economy, but require a higher initial investment than the diesel engine. Technically, the biogas system and the diesel engine offer similar benefits. Both can pump water when required, do not require large storage facilities and can also meet large pumping demands where these occur. However, they have similar maintenance problems and the biogas system while providing considerable fuel savings does introduce the necessity of operating the biogas digester and ensuring collection of dung. On the other hand, wind pumps require less frequent and less sophisticated maintenance. They are useful for meeting small to medium demands and locally-produced wind pumps can be matched more effectively to domestic wind regimes and preferred pumps. However, they require large storage facilities or back-up systems that allow for extended calm periods.

As imported energy costs continue to rise, it seems inevitable that Botswana will turn increasingly to locally-available energy resources for the pumping of water. High-level manpower will be required to maintain an up-to-date assessment of available energy resources and technologies. Manpower at the skilled and semi-skilled level would also be required to design, manufacture and maintain biogas or wind-powered pumping system. Progress towards meeting some training needs has been made as new windmills have been manufactured at Kanye and Gabane with work also starting at Serowe. Biogas pumping systems have also been developed and tested at the RIIC site in Kanye. The Government evaluation programme of commercial windmills will be a means whereby high-level skills in the ability to assess available wind energy resources could be developed. This programme, along with the tests of experimental wind pumps and biogas systems could be used to develop future training materials and programmes. These, in turn, could then be used to equip extension staff with the knowledge and support materials necessary to play an essential role in advising local groups or individuals as to the most suitable pumping system for their needs.

5.3 MEASUREMENT OF A WATER PUMPING WINDMILL - Richard Carothers

Most windmill rotors will have an optimum efficiency that is constant over a wide range of wind speeds, but when the rotor is coupled to a water pump the overall system efficiency becomes dependent upon wind speed. The overall power coefficient (C_p) for a particular windmill and pump combination decreases in higher wind speeds and a performance curve has been determined, which will allow the output to be predicted once the wind regime and borehole depth are known. It can also be used to match the windmill/pump system to the local wind regime in such a way as to maximise the output of the water pumped.

There is a way of measuring the performance curve that requires only basic monitoring equipment. The procedure begins by establishing the depth through which the water is pumped, the diameter of the windmill rotor and the amount of water pumped during one rotor revolution. The curve is produced by determining the amount of water pumped (by counting the number of rotor revolutions) in a time interval, Δt, and the mean wind velocity for the interval. To reduce measurement errors the wind speed should remain approximately constant throughout the interval ($\pm$2 km/h and, as a result, the time interval should be kept reasonably short (normally 60 seconds).

The overall power coefficient is calculated from:

$$Cp = \frac{mgh}{\frac{1}{2}p\ v^3\ A\,\Delta t}$$

where:
- m - mass of water pumped
- g - acceleration due to gravity
- h - height through which water is pumped (m)
- p - density of air (kg/m^3)
- v - wind speed (m/s)
- A - rotor cross sectional (sweep) area (m^2)
- Δt time interval(s)

C_p will reach a maximum at the minimum operating wind speed and will decline as the wind strengthens. Thus the measurement of C_p is carried out over the range of operating wind speeds and the overall performance curve determined.

Where this technique has been used in Botswana, it was possible to complete the measurements mainly during a single visit to the site (ie. during a 2-3 hour period). High wind readings were taken during a second visit.

5.4 FUTURE WIND-RELATED WORK AT RIIC - Max Ewens

IDRC had a contract with RIIC to work on a Fillipini windmill. The termination of this agreement meant that RIIC was left without a machine capable of being put into production. However, work by Dr Peter Musgrove at Reading University has resulted in a start being made on the commercial manufacture of a self-starting Darrieus-type windmill with automatic gale protection. In addition, considerable progress has been made in the development of ITDG's horizontal axis machine, notably in Kenya where commercial manufacture is underway.

The future emphasis at RIIC will be on developing a commercially-viable wind pumping system, as quickly as possible, that is suitable for rural Botswana and could be maintained by Botswana. It is expected that as much of the system as is commercially possible would be made in Botswana and, in the process of bringing a reliable water supply to rural areas, it is hoped that the skills associated with Commercial manufacture will be further developed.

Two major windmill activities presently taking place in Botswana are likely to have an effect on RIIC's programme. Already underway is a scheme by the Ministry of Mineral Resources and Water Affairs to buy, install and monitor 16 South African-made windmills. The objective of this is to increase the awareness in Botswana of the potential of wind energy and to acquire valuable information concerning potential windmill performances. A second activity stems from a major USAID RET programme (see paper 5.8) about to start under the auspices of the Botswana Technology Centre. As part of this programme, there will be renewed extension activity in the field of wind pumping and eight wind/hand operated pumps are to be installed.

Policy decisions taken at RIIC will mean, first and foremost, the avoidance, wherever possible, of original research and a shift of emphasis to the development of existing ideas to suit the Botswana situation. Thus work on the Filippini rotor will be suspended and a self-starting Darrieus will be installed at one of the sites occupied by a Filippini machine. A comprehensive review of wind potential will be undertaken and RIIC will advise on the installation and monitoring of the 16 windmills ordered by the Botswana Government.

Development of a slow solidity, rotary transmission version of the ITDG rotor will be a component in RIIC's plan of action and this will be used to drive mono-pumps by using belt step-ups and a centrifugal clutch. The components are available and considerable information exists concerning their use. It will also allow a simple adaptation to reciprocating pumping should this prove desirable.

The step away from innovation and towards the practical solution of a pressing need, ie. small water supplies for rural areas, would not be possible without previous innovative work carried out by so many people and further progress will not be made unless those institutions best suited to research continue their efforts. It is to be hoped that conferences, such as this, will continue to bring together researchers and developers for vital exchanges of information.

5.5. WIND PUMP COMPARISON - Max Ewens

Although there has been a amazing growth in recent years in the number of windmill development projects aimed at small-scale water pumping in developing countries, there is no objective means of comparing these windmills that is intelligible to the uninitiated. What is proposed here is a classification system designed by windmill engineers but for the use of managers.

It is suggested that the wind pumps under consideration fall into nine categories:

	Small Village	Village, Stock or Garden	Town or Irrigation, Ranching
Borehole			
High lift			
Low lift			

Small Village - Under 200 people, less than 20,000 L/day.

Village, stock or garden - Around 400 people, a small herd or market gardening. Around 40,000 L/day

Town, irrigation or ranching - Over 800 people, commercial farming or Over 80,000 L/day.

Borehole - Water from a small diameter well, usually deep.

High Lift - Pump pressures high enough to need strong values and good fits. Over 20 metres total head.

Low Lift - Single pumps. Less than 20 metres total head

However, although a prospective purchaser or project initiator would find his task much easier with such a table to guide his selection, he may still be left with a choice between a number of machines in the same category. For this the Performance Number (N_p) is proposed, which presents all things affecting the price per litre metre without going into monetary terms:

$$\frac{\text{(litres in 20km/hr wind)} \times \text{(head)} \times \text{(life - in years)}}{\text{(rotor area)} \times \text{(air density)} \times \text{(height to rotor centre)} \times \text{(start up speed factor)*}}$$

*- factor to allow for variation in wind speed with height.

Or it could be modified to allow for the state of knowledge by multiplying by:

$$\frac{(\text{number standing})^{y} \times (\text{years first standing})^{z}}{(\text{maintenance period})^{a}}$$

y - a symptotic factor to enhance the value of the one NOT including prototypes.

z - a symptotic factor to enhance the early years.

a - value factor.

The information from which the performance number is calculated should be readily available for all machines and, thus, allow their immediate comparison.

5.6 PERFORMANCE MEASUREMENT ON THE SIX METRE DIAMETER HORIZONTAL AXIS WINDMILL - P D Dunn, T Eisa, M Ewens, A Ibbetson

Performance measurements were carried out on the 6m ITDG windmill situated on the Reading University Energy Group site at Shinfield. The diameter of the rotor and height of the tower are both 6m and measurements were made using different numbers of curved blades (3,4 and 6); in each case several different angles of attack were tested.

The rotor was allowed to accelerate from stationery up to maximum speed and the speed and acceleration were measured by a tachometer placed on the rotor shaft. Wind speed was obtained by averaging the readings of two standard cup anemometers placed in the plane of the rotor and at a distance of 20m from the axis, one on each side. The output signals from the anemometers and the tachometer were fed to three channels of a magnetic tape recorder and later converted into digital form on punched tape, which was then used as input data for a computer program. Wind speeds lay in the range 3m/s to 12m/s and a measurement of the rotor moment of inertia enabled the power and torque coefficients to be calculated.

The rotor was suspended on three vertical strings and, by carefully disturbing the rotor about its axis of rotation, a torsional pendulum was formed.

The frequency of rotation $f = \frac{1}{2}\pi\sqrt{\frac{mgR^2}{IL}}$

m = mass of the rotor
g = acceleration due to gravity
R = tip radius, which is also the point of suspension
I = moment of inertia of the rotor about its axis
L = length of the strings

The measured date of angular velocity ($\dot{\theta}$) versus time enabled the angular acceleration ($\ddot{\theta}$) to be deduced.

Hence Torque T = I
Power P = T
= I

The measured characteristics are expressed in terms of the torque and power coefficients C_T and C_P :

Where $C_T = \frac{I\theta}{\frac{1}{2}LV_\infty^2\pi R^3}$

L = air density
V∞= undisturbed wind velocity

$C_p = C\lambda$

$\lambda = \frac{\text{Trip Speed}}{\text{Wind Speed}} = \frac{\theta R}{V_\infty}$

The theoretical performance was determined with the aid of a computer programs. The measured torque and power coefficients, plotted as a function of tip to wind speed (λ), show generally good agreement with the theoretical predictions.

This method takes full advantage of the extensive facilities available at the University of Reading, but is unsuitable for most field applications. However, Dr Peter Musgrove, from Reading University, has developed a simpler, though more tedious, method whereby the rotor's acceleration is recorded with the aid of a cine camera. Following a successful run, the wind speed is recorded on film and the rotor acceleration deduced by counting the number of frames exposed between successive passes of the blade. A suggested alternative is to use a two-channel recorder connected to the anemometer head and to a switch fitted to the windmill shaft, which closes briefly once very revolution.

From these measurements, the rotor's characteristic $Cp\beta$curve can be plotted from which a variety of information may be derived.

5.7. DO RENEWABLE ENERGY RESOURCES EVER BECOME ECONOMIC? - D Medford

As the costs of conventional energy continue to rise, at some stage we will be faced with an irrefutable argument for using a renewable energy system. It is simply a matter of recouping capital costs, which may be high, out of savings accumulated from using a cheaper form of energy. The question is, what annual increment in oil, or mineral fuel, prices makes the decision to change to renewable energy technology economic?

Such a decision is dependent upon capital costs, recurrent costs, depreciation in the real value of money and the escalation in conventional fuel costs; and, if we know the life of competing systems, we can derive a simple formula for deciding which system is the most economic:

Present Value of energy system Cost =
Capital Cost + Recurrent Cost (I/a-r).(e(a-r)T-I)

where T is the time to obsolesence; r is the discount rate divided by 100; a is the annual escalation rate in petroleum related costs divided by 100; and e is the base of natural logarithms.

Or put more simply:

Present Value of Energy System Cost = (Capital) + (recurrent cost x a number)

where the number is a function of discount rate, petroleum escalation rate and time to obsolescence.

Pure economic reasoning alone will not, of course, persuade the prospective investor to opt for a renewable energy system, because he will be faced with a number of practical and psychological problems against accepting renewable energy technology. He may not have the means of raising the high capital costs. He may not believe that this technology will be technically satisfactory, or he may think that the days of cheap petroleum fuel will return someday.

5.8. USAID RENEWABLE ENERGY TECHNOLOGY PROJECT

The purpose of this project is to improve the economic welfare of lower-to-middle income Botswana through the introduction or rural energy technology (RET), which is easily reproduced and derived from locally-available resources that are cheap and abundant. It also aims to research, develop and put into use RET, which will minimise Botswana's dependence on vulnerable supplies of expensive mineral fuels and reduce the growing demand for firewood.

Among its various achievements, the project has: collected information on energy use in three districts; created an awareness in the villages and identified energy needs; installed many domestic village technology units; installed eight small wind/hand pump systems; trained RET project personnel; codemonstrating RET potential; installed solar water heaters in schools and other institutions; and installed two solar photovoltaic water pumps at village water supplies. In addition, pedal-powered sorghum dehullers/grinders will be installed by village enrepreneurs; two pilot wood lot sites will be used as demonstration sites for a fuel wood lot management programme; energy studies will be commissioned; and R&D technologies will be developed, including advanced wind-powered water pumping systems, and an ethanol fuel feasibility study undertaken.

Discussion of Papers by Carothers, Medford and Ewens

The discussion recognised that problems exist in the manufacture of windmills in this part of Africa. There are patent and licensing problems as well as industrial difficulties. Theoretically, it should be possible to stick with proven designs, such as the Southern Cross. However, although this machine originated in Australia, it is manufactured in South Africa. This presents us with the problem of purchasing from south Africa with all the attendant political constraints. One way round this predicament could be to import Southern Cross windmills from Australia and this possibility should be investigated.

Under Botswana's evaluation programme, both proven and new designs are studied, with Southern Cross and an ITDG machine both being tested and used and trials are underway on new rotor designs and a vertical-axis PI machine. This programme will determine which type of windmill is best suited to meeting Botswana's water pumping needs.

Another problem arises out of the high cost of research and development resulting in manufacturers having little interest in the R&D aspect of wind energy; as long as their machines continue to sell, that is. So we are faced with the question of who will undertake appropriate research and development and how it will be funded. To this there is no ready answer.

On to alternatives to wind pumping, a point was raised about the suitability of wind pumping in an area such as Botswana, which has only moderate to low velocity winds. Would it not be more feasible to use solar power? After all, it is realistic to assume that the cost of solar voltaic cells will come down in the future. However, more investigation needs to be done on the sun as a potential source of energy in Botswana and testing programmes will soon begin. It is important to maintain an up-to-date assessment of the various pumping options, as these (particularly solar pumping) are developing quite rapidly.

It is also important that Botswna seeks an alternative to diesel fuel for water pumping, because she presently gets her supplies from South Africa. Depending on the political situation in that country, Botswana's supply of diesel oil could be affected at any time. Should the supplies stop altogether, 40% of the cattle in Botswana would die within three weeks. The implications of this are perfectly clear -Botswana urgently needs an alternative to diesel fuel.

The question was raised concerning the practicalities of wind energy storage. This is easier with water pumping applications than with electricity generators, because the storage facility in the former is simply a water tank. However, even a water tank, because the need is usually for several days' storage capacity, can make up a significant part of the total cost of a windmill installation.

Finally, someone wished to know about the number of windmills manufactured worldwide each year. An estimate of the number of windmills produced could be based on an annual production rate, from 18 large commercial manufacturers in operation (as listed in ITDG's 'Power Guide'), of something in the region of 20,000 units/year.

5.9 LOW-COST ENERGY SOURCES FOR WATER PUMPING IN ETHIOPIA -Teferi Taye

Ethiopia is in dire need of alternative energy sources to satisfy her growing energy requirements. Unfortunately, the rural areas are scantily populated which makes it difficult to supply the rural communities with electricity and potable water, and the traditional sources of domestic water are, in the main, unhygienic. However, in an attempt to overcome these problems, the villagers have organised themselves into producer associations and resettlement areas have been established. Also, during 1974-75, the 'Development through Co-operation' programme was launched throughout the country and this formed the basis of a project co-sponsored by IDRC, UNIDO and UNDP. This project's activities are concerned with the testing and developing of various types of hand pumps, three types of locally-manufacture rotors, a Filippini rotor and, lately, engine-driven pumps.

Although Ethiopia has yet to set up a definite policy towards low-cost renewable energy, research into wind, solar and biogas energy is very much encouraged by the Government. for instance, under the 'Food from Wind' project, which started in 1973, a series of windmills were developed for irrigating small plots of land on the banks of the Omo River using river water and, by August 1975, it had installed four Dempster windmills, five Savonious rotors, 16 sail windmills and three windmills of various experimental designs.

Under the present project, three types of windmill are being studied. The Type DW windmill is a six-metres diameter, three bladed horizontal-axis rotor of $28.3m^2$ swept area. The design was engineered to use locally-available non-twisted Zigba wooden blades and the mill is a high speed runner with a tip speed ratio of 5:1. The cut-in and cut-off wind speeds are 3 m/s and 8 m/s respectively, although the blades and the structure are designed for a maximum wind speed of 40 m/s, when the machine is at standstill. The advantage of the design is that the blade remains unaffected by flexual stress at the design wind speed.

The type BW windmill is a seven-metres diameter, six-blade rotor and is a moderate speed runner having a tip speed ratio of 2:8. Like the DW prototype, this machine was designed for community water supply at 30 metres pumping heads. The rotor employs untwisted wooden blades, although the design is that of a classical horizontal axis windmill using tail vane orientation and control. Due to the lack of suitable sites, the installation of the DW and BW prototypes has yet to begin.

The Type EW windmill is a nine-metre diameter wind turbine, employing three fixed main blades and three swivelling control blades. The swivelling blades, actuated by contrifugal force and torsion bars serve as overspeed control gear and act as starter blades. The blades are calculated to produce a starting torque of about the same magnitude as the rated running torque of a rotor in a 3 m/s wind. As in Type DW, the orientation of this rotor is down-stream of the tower. From the outset, the project's programme was to test the smaller wind turbines first and, from the field experience gained from these rotors, the project was to continue experiments on the bigger units. However, because of difficulties in finding suitable locations for the smaller turbines, it was forced to install the nine metre machine which is now the project's only experimental wind unit and is presently being tested at Zadai. Also, for economic reasons, the project's trend is towards wind turbines of a low solidity ratio. Such rotors have inherently very low starting torques. The EW turbine is therefore coupled to the mono pump through a centrifugal clutch and a friction type clutch is under development. Following a dynamometer test, the performance of this machine in general is considered to be satisfactory. A maximum power factor of 0.38 has been attained at a tip speed ratio of 6:5.

During the course of the 1974/75 programme, a small biogas generation plant (Gobar gas) was constructed. The object of the exercise was to test the performance of the plant and to determine possible applications for the Ethiopian farmers. The volume of the pit was $12.2m^3$ and $1.5-2m^3$ of gas at 10cm water column was produced daily at 17-19°C. The total cost of this plant was about US$400; too much for the rural farmer. Other biogas research is underway at the Awassa Junior Agricultural College and at Debre Zeit Agricultural Research Institute. The Ethiopian Science and Technology Commission is also planning to conduct tests at 12 different sites during 1980/81.

Discussion

Many participants observed that high-speed rotors such as the EW type often were prone to problems of cavitation and vibration and may fall apart if the blades are hit by an object at high speed. During field testing of the EW type machine, it was found the leather crips used in the pumps distintegrated within three to four months. The reason for this has not as yet been determined, although it is thought to have something to do with the river water; strainers have not been used. New cups are being designed from high density polyethylene and have so far been tested at depths of 100 metres. The machine has been designed for use with a mono pump and the windmill blades are untwisted making them easier to carve; carving of the blades is done locally. At this point in time, the windmill has been in the field for one month only.

5.10 WATER PUMPING BY WIND ENERGY IN KENYA - M N Opondo

A survey, carried out in Kenya in May 1980 and designed to collect information on the present use of wind energy for pumping water, showed that well-designed, durable windmills had been around for almost 100 years in Kenya but had been largely superceded by more efficient diesel engines. However, since the fuel crisis of 1973, wind energy generally has taken on a new lease of life. The industrialised countries have concentrated on the developoment of large-scale windmills, while in developing countries, due to inadequate research facilities, limited manpower and the fact that such technology was new to many scientists, the emphasis has been mainly on the production of smaller scale machines for the purpose of pumping water and generating electricity in the 1 to 10kw range.

All countries are trying to reduce their foreign expenditure on energy and the aim of research is to discover ways of achieving self-sufficiency and of producing energy from sources which will conserve the nation's foreign exchange. This means that windmills should be constructed from locally-available materials. The criteria for identifying a good windmill are: it should have at least 30% conversion efficiency (Cp = 0.3); it should be durable, with a lifetime of at least 20 years; it should be affordable by low income communities; it should be effective in conserving foreign exchange. Several types of windmill have been designed all of which are at the research and development stage.

The Kijito windmill (Figure 28) evolved from an ITDG prototype design. Its Cp value could reach 30%, it has a swivel head rotor which always turns the wind, and its blades are moulded from fibre-glass giving them a good aerodynamic profile and improving overall efficiency. Maintenance requirements are considered minimal. However, despite its good performance, some experts feel that the Kijito windmill does not, as yet, satisfy the essential requirements necessary for the widespread use of windmills in the rural sector: the prices are high for low income users (they range from US$500 for the smallest machine up to US$13,700 for the largest); they are constructed with a high proportion of imported materials; and weathering can cause the fibreglass blades to break. However, this is still a new product and these limitations could be overcome through extensive improvement programmes.

The Mbita windmill is an excellent development with blades constructed from galvanised sheet metal of good aerodynamic efficiency and most of the components are made from locally available materials. A six-metre diameter rotor machine for deep well pumping would cost US$2,300. After operating successfully in stormy conditions along the shores of Lake Victoria for about two years, further improvements are being made to design as ideas develop from field tests.

The production of the CITC Cretan Sail rotor (Figure 29) has been abandoned because of poor aerodynamic properties. The only remarkable achievement has been the construction of a tower costing US$370. It is envisaged that a Mbita wind rotor and a CITC windmill tower could be åssembled together to produce a very cheap water pump.

The KIE (Kisumu) windmill is another very impressive and efficient machine comparable to the Mbita windmill. It is manufactured by Plough and Allied Products and costs approximately US$2,300. This

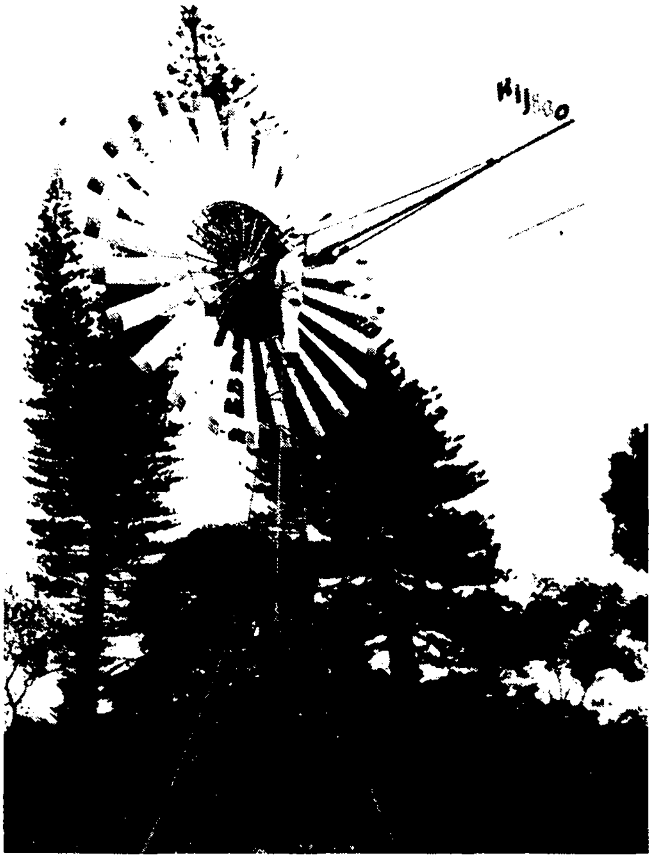


Fig. 28
The Kijito Windmill

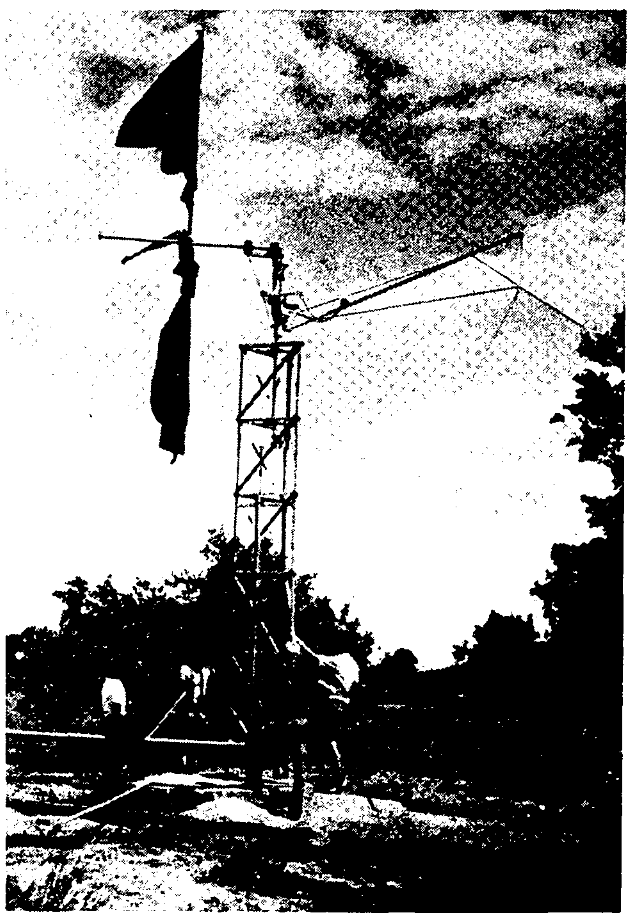


Fig. 29
CITC Cretan Sail Rotor

organisation is willing to participate in training prospective users and in collaborating with academic institutions in attempting to find ways of reducing production costs.

However, scientists are not yet satisfied with the Cp values currently available, even from the best windmills in existence, and many attempts are underway to increase the Cp values towards 0.5. Unfortunately, the higher the Cp the more sophisticated the windmills become. In developing countries, while high efficiency is paramount, greater priority is given to machines that are durable and not dependent on imported materials for their construction. There is an inevitable need to go on with research and development in order to achieve these requirements and, in Kenya, prototypes for R&D work can be constructed at establishments already manufacturing windmills, such as KIE(Kisumu) and CITC (Nairobi). Training of technical manpower will also be carried out at university or by attaching trainees to Mbita, KIE and CITC.

Very few rural people can afford to buy windmills and this is a major limitation to their widespread use. Methods should be found to promote the use of these machines in rural areas by offering reasonable financial support to the users. Funds will also have to be found for the training of farm techniques to install and maintain the windmills, as well as for financing well-planned research programmes. Financial limitations for research have meant that at the moment there are only a few development projects ongoing in Kenya.

In order to realise a successful expansion in the use of wind energy in rural areas, an extension scheme should be implemented which ought to include: the establishment of pilot projects in small centralised communities; the holding of frequent seminars; the setting up of a wind energy fund; and the monitoring of these schemes so that training programmes can be improved and better teaching methods suitable for rural people can be developed and implemented. After all, the training needs are directly linked to the state of the art and to possible extension programmes.

Financial requirements of the training programmes for the next two years have been estimated at US$175,700 for the first and US$46,100 for the second; external funding may be required. The most suitable establishment in Kenya at the moment for developing the training programmes is the CITC in Nairobi. It is expected that the programmes will achieve their objectives within the two years, thereby making further financing easier to obtain.

The use of wind energy for pumping water has reached a stage where it can be exploited on a large scale in Kenya and ways of assisting manufacturers to install machines on a large scale should be outlined and put into practice. In addition, R&D support should be provided where needed along with any necessary technical and advisory assistance.

Discussion

The discussion reflected upon the use of both biogas and wind energy in Kenya. Firewood and charcoal fill 95% of rural energy needs and biogas is seen as an alternative in order to conserve the forests. Socio-economic analyses would be necessary to determine the viability of small-scale digesters which could be used for cooking and lighting purposes. Seminars and demonstrations have been held at provincial levels and guidelines for building the digesters are available to interested parties. A comparability study between small and large scale digesters is also underway. Improvements have been made to Hutchinson's (1958) original design and a big investigation is being undertaken into the possibility of using biogas in the milling of animal feeds. The present cost of a small-scale (6' x 6') digester is Ksh5,800 rising to Ksh11,625 for one measuring 12' x 12'. Perhaps the Government could find some way of subsidising the use of biogas digesters in Kenya.

As far as windmills are concerned, comparison of costs of different models can be very misleading. There is evidence that some locally made windmills are cheaper than the imported equivalent in terms of cost per gallon of water pumped. Local manufacture also has advantage in employment generation, etc. It is important to develop common monitoring and reporting procedures including presentation of cost data, for the accurate comparison of manufacturing performance data and for the potential exchange of information. Meanwhile, a twisted blade, belt-driven windmill is about to be produced in Kenya. A variable stroke transmission will be used to improve the overall rotor-pump matching through the range of operating wind speeds. The cut-in speed of this windmill will be 3m/sec and it is hoped that high wind speeds can be effectively utilised.

In order to keep down the costs of windmill construction, it is important that commercially-available components are used that have been tested and are cheap. The efficiency of design is also important to the calculation of costs. Efficiency of windmill multi-bladed fan rotors is fixed at about 30% and it is very difficult to improve upon this without changing to low solidity rotors. However, transmission and pump efficiencies are areas where great improvements could be achieved.

Even so, it was strongly suggested that the costs of the windmills described in the paper would far exceeed the rural farmer's ability to purchase them. The windmills could be bought through co-operative schemes, but would still require subsidies from the Government.

5.11 RURAL TECHNOLOGY UNIT - THABA TSEKA PROJECT, MASERU, LESOTHO

The long-term aims and general working philosophy of the Rural Technology Unit are to develop implements and techniques in the areas of agricultural production and transportation, education and village environment, in order to improve the quality and standard of living of the people in the rural areas through increased self-reliance at the individual, community and district levels.

The Rural Technology Unit has been designed to get more government services out to the people and has identified technology that is designed to improve life in the mountains. The unit is subdivided into four sections: a) agricultural technology; b) village technology -emphasising energy, water supply and sanitation; c) production -providing technical assistance to sections a and b; d) external consultants - undertaking work and providing facilities to the RTU as required.

During 1979, in the energy sector, some work was done on solar technology. For instance, modifications were made to some solar water heater units and a watt-hour meter was repaired for Linakeng Clinic, which receives its electricity through the aid of solar panels. In addition two lorena-type mud stoves are almost complete and experiments are presently underway concerning the existing size and shape of solar ovens at the RTU. Despite some recent problems in the production of solar technology, extension work has resulted in its acceptance by the rural people of Lesotho.

However, not much has been accomplished with respect to water supply. Progress on the irrigation project at Mohlakeng was stopped in early October 1979 and work on the experimental village water system at Thabana' Mahlanya was halted with only some parts completed. In fact, the history of water pumping in Lesothc has been bleak. In the lowlands, diesel pumps have been used and there are about 60 commercial windmills at present in various states of repair in the country. The windmills, however, come from South Africa and have been installed in places where there is little wind. In the mountains, some hydraulic rams are being used to pump water.

Cost is an important factor when deciding on the type of pump to use. Presently, there is one type of low-cost windmill design, which has a two-level Savonius rotor, but does not really give value for money. However, an attempt is now being made to develop a low-cost horizontal axis windmill that would be a hybrid, drawing on techniques used in a variety of other machines. Hydraulic rams (Blake), as used in the mountains, can be purchased for less than 100 Rand. They seem suited to use in the mountains and require a drop of 5-7 metres. They are imported from England and can be designed and built in a workshop in Lesotho. It was suggested during the discussion that a hydram, which is made in Tanzania, could be four times as efficient as the Blake design and a Tanzanian delegate introduced a paper by Protzen, which explained the development of this new ram.

Finally, a Renewable Energy Programme funded by USAID was explained whereby local people are trained to develop, build, install and test new technologies and demonstrate them to the villagers. Experiments are underway with mud stoves, cold frames and biogas.

Diesel fuel is expensive and is imported from South Africa, which means that it is important for Lesotho to develop wind power. Some hydromite (hydraulic drive) pumps have been tested, but have encountered maintenance problems.

5.12 BIOGAS PRODUCTION AND USE IN MALAWI - M L Mwinjilo

Malawi has a population of about 5½ million people of which more than 90% live in the rural areas where firewood and crop residue are used for cooking and paraffin (kerosene) is used for lighting. In the urban areas, some of the people use electricity for both lighting and cooking and some use electricity for lighting and paraffin or charcoal for cooking. Others use paraffin for lighting and paraffin or charcoal for cooking or use paraffin for lighting and firewood for cooking.

As yet, the Malawi Government has no policy concerning biogas, although an Energy Unit has been established during the past year in the Ministry of Agriculture and Natural Resources. The objectives of the Unit are to look at possible sources of energy and their applicability to Malawi, to test and/or construct prototype energy plants and systems, improve thermal efficiency of existing systems and set up and run a demonstration centre for different systems.

The only biogas plant operating in Malawi is found at Bunda College Farm. It is of Indian (Gobar Gas) design with a gas capacity of $11m^3$/day and a digester volume of $36m^3$. It was installed in 1977 and the gas produced is used to cook meals for farm labourers, thereby saving on firewood which was previously used. Biogas research has been done at both Chancellor and Bunda Colleges of the University of Malawi. At Chancellor College, the research was to find the percentage composition of gases contained in biogas while, at Bunda College, the research was concerned with reducing the installation cost of a biogas plant by using cheap and locally available materials. Research is proposed into the construction of a Chinese biogas plant, in order to evaluate cost and gas yield and to appraise material other than cattle dung for feeding the digester, for instance vegetable waste.

Only in rural areas is it feasible to use biogas, not in urban areas, and the most commonly-used source material is cattle dung mixed with large amounts of water. However, installing biogas plants in rural Malawi does have its limitations. Malawi has the highest population density in this part of Africa and the population is unevenly distributed. In addition, the ratio of livestock to human population is the lowest of any country in the region.

Another problem in some areas is that during the dry season, people can travel up to 3km to draw water which is needed for the efficent running of a biogas plant. The high cost of biogas plants again limits the widespread use of biogas as does the fact that some smallholder farmers would have to transport the biogas slurry as much as 3 to 5 kilometres to spead on their fields.

So, all in all, only the large farms with large numbers of livestock and an abundant water supply are in a position to install biogas plants and then only if the gas replaces expensive and/or scarce fuels. Research needs to be done on designing low cost plants.

Discussion

Malawi has recently experienced a serious shortage of fuel and her people rely heavily on wood for cooking and heating. Because of this, biogas research has been undertaken at universities in Malawi and a reafforestation programme has been mounted. The Government is supporting the research and both Indian and Chinese plant designs are being used. The digesters are made of galvanised iron sheets soldered together and there is a circular pit with a floating gas-holder. A rectangular construction was tried but was found to leak. Polythene plastic sheeting was then used in the construction of the digesters, but serious leakage of water and gas still occurred at the joints. Biogas will be used for fuel in Malawi provided a design can be developed that is cheap enough for rural farmers. So far, biogas has been used only for cooking, but there are no plans at present to use it for pumping water.

It was suggested that in high population density areas (eg in the south where there are 470 people per square mile and where the people: livestock ratio is 18:1) biogas digesters might use human excreta as feed, thereby solving the problems of both fuel and sanitation. However, the people will be very reluctant to use human excreta for making gas and, even if this was not the case, the cost of biogas is much too great to be borne solely by individuals. As yet, no clear Government policy has emerged which favours either biogas or windmills, but it is expected that some decision will be made after the completion of the RET survey.

5.13 WINDMILLS IN MALAWI- K Jellema

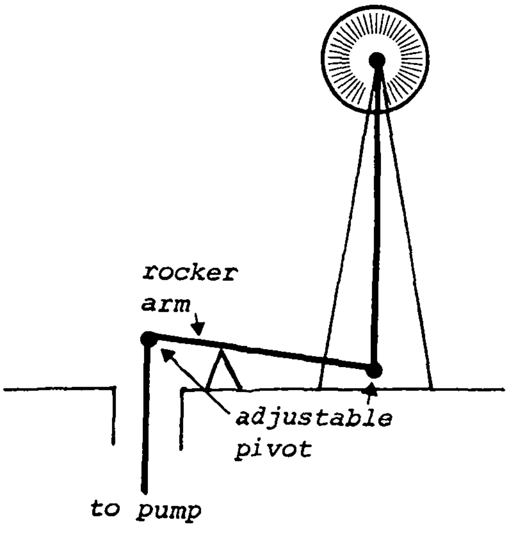
Wind power in Malawi has been considered with new interest in recent years. In 1976, a study was undertaken in the northern most windy part of the country, although the hydrologist assisting with the work underestimated the amount of water that could be lifted by a windmill. From his readings, he calculated the average wind speed and to this he added a factor of 15% so as to estimate the available wind energy. This factor should have been higher.

Again the problem arises of designing a wind pump which is not too costly and which can be used by the small farmer. A simple model that is being used in Malawi with some success is of the type that is fixed to a pole which, in order to maximise the machine's output, can be turned manually into the wind. At the moment, there are some 20 Southern Cross windmills of 10ft diameter in the country, but only half of them work and trees have grown up in areas where the machines are located and are now catching the wind. In addition, the pumps leak excessively and at certain times of the year the water yield is too low. Groundwater is scarce in Malawi and there is the added problem of borehole siting. Pump loading is too great for the size of the rotors with the results that the windmills cannot start except in quite high winds. The poor matching of windmills to local wind regimes lead to low water outputs. It would be better to design an inverted pump, on which the work stroke could be the down stroke, in order that the rods and the water would not have to be lifted at the same time. This would reduce the initial loading and allow the windmill to start at lower wind speeds.

The overall windmill output might be improved by using a manually-operated, variable-stroke system. This would require off setting the windmill from the borehole (not possible with existing commercial designs) and driving the pump as shown.

The position of the pivot could be set differently during high and low winds. Although it could be possible to add weights to the rocker arm to counter the pump rods, where this was tried in Kenya the windmill transmission was damaged. Also, if the windmill is designed to pump on the down stroke, the compressive loading on the pump rod will limit the pumping head to 30-40 metres.

In conclusion, the people of Malawi have experienced a 250% rise in fuel costs during the last year and a half. There is, therefore, increasing pressure to find alternative sources of energy.



5.14 BIOGAS PRODUCTION IN MAURITIUS - J Baguant and S Callikan

Although Mauritius was not represented at the Workshop, this paper was prepared for the meeting and a summary of it is provided here to complete the record.

Foreign exchange spent on imports of fossil fuel represented 2 to 3% of Mauritius GNP at the beginning of the last decade. This has now risen to almost 8% due to the three-fold increase in the volume of imports and to the drastic incease in the price of oil during the past few years. There is a strong functional relationship between economic growth and energy consumation and in order to maintain the country's annual economic growth rate of 4-6%, assumed to be the basic need for sustaining the welfare of the nation, it has been estimated that the annual growth rate in energy supply should be maintained at around 5-8%.

The role of the sugar industry, the most important industry in Mauritius, in meeting energy needs through the production of electricity from bagasse and ethanol from molasses, cannot be ignored. If the sugar industry was further improved and its byproducts used more efficiently, as much as 50% of the country's commercial energy needs could be obtained from this source by the year 2010. Nevertheless, in order to further decrease the dependency on imported fuel, other locally available energy sources need to be studied. Reneweable sources of energy, such as hydro-electricity, wave, wind and solar power are currently under investigation at the University of Mauritius. This paper focusses its attentioin on the production and utilisation of biogas from cow dung and other materials.

Preliminary experiments concerning the aproduction of biogas from cow dung were carried out during 1976-77 using a simple drum-type digester and inverted gasholder. Following these initial experiments a small-scale digester and gas collector were designed for studing different operating parameters and raw materials. Further, a medium-scale digester (1500 litre capacity) and a separate flexible leak-proof gasholder were designed and constructed locally for pilot experiments. Unfortunately, the project was interrupted in June 1977, but is now being resumed with a broader perspective.

Looking to the future the development of biogas production from cow dung in Mauritius has to take into account the followingfactors: the total cattle population is very low (about 8000 head), representing at most some 3.0×10^{10} BTU, a negligible fraction of Mauritius' total energy demand (9.0×10^{12}BTU in 1979); more than 50% of the cattle are found on a few centralised breeding stations, making access to cow dung for small-scale biogas users difficult. Thus, future research plans will have to identify and evaluate other locally available raw materials for biogas production: e.g. pig, goat and poultry wastes, farmyard residues, industrial byproducts and the water lily. Of the potential uses of biogas, the running of water pumps appears to be the most attractive. In this cintext, the modification of already-existing internal combustion engines would become an important aspect of future activities. It is also proposed that the various characteristics of slurry, such as pH, total and available NPK, the effect of storage and the actual fertiliser value, will be studied.

5.15 SOME NOTES ON BIOGAS RESEARCH IN SEYCHELLES - P Shilton

Seychelles was not represented at the Workshop and no paper was prepared. However, Mr Peter Shilton, Research and Development Officer at the Department of Works, has provided some information about activities in biogas research presently ongoing in the country.

The first biogas pit has just been completed. It is of the Khadi Village Industries Commission design with a dividing wall up to the level of the drum between the inlet and outlet pipes. The capacity of the pit is some $9m^3$, but it has yet to be commissioned due to feedstock problems. It is designed to run on chicken faeces which are currently only available combined with around 50% weight of a mixture of sawdust and wood shavings used as litter in hen houses. Some attempt has been made to separate out the wood by sieving. This has resulted in a small degree of beneficiation of the feedstock, but it is felt that the degradation period of the residual sawdust will be considerably longer than that of the faeces, resulting ultimately in a pit of sawdust which would have to be dug out rather than pumped.

However, it is possible that this problem may be of only secondary importance. Laboratory-scale tests have been undertaken in 2-4 litre glass jars with a variety of feedstock preparations ranging from complete stock through sieved fractions to coarse filtered liquor. A number of these stocks rapidly began to evolve gas without recourse to a starter, even from bone dry material of a dubious age from an outside stockpile; but all ceased to function within 3-6 days. It was soon discovered that the chicken feed stock, which was imported, contained antibiotics and attempts are presently underway to establish whether these additions are responsible. If it is so proved, it is possible that the pit may have been constructed in the wrong place because the farmer will naturally be extremely reluctant to use feed without antibiotics.

In addition, if attempts at laboratory fermentation using cow dung are successful, then proportions of chicken faeces will be added as "seed" to see if the reaction ceases, compared to the controls without addition.

5.16 BIOGAS AND WIND IN TANZANIA - M Khatibu

Biogas

In Tanzania, many villages are faced with a shortage of fuel for cooking and the depletion of the forests is making this problem more acute. 75% of the land in Tanzania supports at least some farm animals and their effluent could provide the source material for producing biogas.

The Arusha Appropriate Technology Project has developed two designs of biogas digesters. The first is the 7-barrel digester, designed particularly to suit villagers on low incomes and lacking in technical skills. The whole thing, with its simple stove and gas carrier system, costs about US$150.00 (as at November 1980). There are about 10 of these units in use and some have been operating trouble free for about one and half years, while others have experienced only minor problems. In many cases, these digesters require feeding only twice a week and have produced enough gas for cooking three times a day.

While the technology is cheap and proven, villagers are reluctant to adopt it, probably because they have more pressing problems and because of the lack of information on the advantages of biogas generation. Some of these advantages are as follows - the gas can be used for lighting and cooking; it can drive electricity generators; the effluent and slurry from the biogas pit can be used as fertilizer; biogas can also save on deforestation; it is smokeless, whereas the use of dried cowdung for cooking produces smoke that can cause tuberculosis; it saves on time spent collecting fire wood; it reduces the consumption of other fuels, such as kerosene, natural gas and charcoal.

The second design developed by AATP is a modification of the Indian Gobargas Digester, costs US$500 compared to US$1,500 for the Indian design and produces the same quantity of gas.

One final point, biogas technology needs regular checks and proper maintenance and it is important that training in its use and maintenance accompanies its introduction into rural areas.

Arusha Windmill

The Arusha windmill is a 16'6" diameter horizontal axis motor design with six blades and was originally designed to pump water in rural areas of the Arusha region and elsewhere in Tanzania. The first prototype was completed in 1976 and cost approximately $500 at that time.

However, through a series of field tests, several weak points were discovered and consequently major modifications were made by the Arusha Appropriate Technology Project. The Ujuzi Leo Co-operative Industry will mass produce this modified design and currently the price is $3000 per windmill. The co-operative has also been involved with AATP in developing the jig for standardisation of spare parts.

At the moment, the windmill has these features: self-governing by the use of a camber pivotal tail vane; one motion pull out/brake mechanism which unloads wind stresses before engaging the hand brake; easy field installation by the use of a pivoting tower, which enables the assembly on the ground of major heavy components; all moving parts are either in sealed bearings, such as the crankshaft and connecting rod bearing, or equipped with machined easily-replaced brushes; it is easily transported to the site; and is convertible to hand pump at times of no wind. Because of the problems of understanding and lack of skills in rural areas, AATP has been developing an instruction manual. Also provided are a 30-day guarantee and two days training on operation and maintenance.

Although no wind data is available for areas in which the windmill could be used, it has been designed to understand any extreme situation. Today, there are 15 windmills pumping water in various parts of Tanzania.

Wind is a major potential energy source, although much more than theoretical technical knowledge is required for the success of any windmill development programme in rural areas. In this respect, AATP are offering to share their experience with anybody who is starting a wind energy programme in their country.

Discussion

There are 86 digesters of the Indian design in Tanzania. Sixty per cent are presently in working order and are producing from $2m^3$ to $20m^3$ of gas each day. Lister engines have been adapted to run on biogas and have been operating for 3 years. A UNIDO survey has shown that it takes $100m^3$ of biogas to produce 5kw of electricity and, in Arusha, two big digesters are used to feed a 5kw generator; a 100m digester is envisaged. In addition, Oxfam has set up a community biogas digester that seems to be working efficiently. The success of the biogas programme in Tanzania, thus far, is due to the organisation and training of people in rural communities to operate and use this technology. In addition, the Government is subsidising the cost of biogas plants in rural areas through a rural development bank.

Average rural earnings are only 3,000Tsh per year and so costs must be kept down. A biogas digester has therefore been developed using seven oil drums bound together by wire to form the digester top and gas-holder. The villagers are taught to dig and plaster the pit, tie the drums together and pipe the gas to the kitchen. The cost of the oil drums is less than US$100 and they are easily available in Tanzania making this design both inexpensive and practicable.

Slurry is normally fed into the digesters twice a week and the units will serve the cooking needs of a family of five when operating at 16-18°C. At 20-28°C there is enough gas for cooking five times a day as well as for lighting. One problem with the digesters is that scum forms, no matter what material is used as feed. The digesters have been fitted with special fork-like devices for stirring the slurry to prrvent the build up of the scum, which hampers the efficency of the digesters.

Slides were shown of the building and erection of a windmill in Tanzania. Currugated iron was used for the blades and the pump was designed and constructed from scrap material. The pumps can be assembled and maintained in the villages. In the case of one windmill, the tower was not set deeply enough into the concrete with the result that it blew down. However, the tower itself is not weak and, if properly installed, should work very well.

Only four windmills have been produced in Tanzania for generating electricity in homes. Imported windmills are very expensive and have been used solely for pumping water and grinding maize. Danish designed solar thermal pumps have been tested for pumping water from boreholes and a faculty energy group at the University College of Dar es Salaam has been woeking on the development of a hydraulic ram. The Small Industries Development Organistion has also been experimenting on gasification by partial combustion of maize cobs (pyrolysis). This is one area that should be examined more closely, because there is a general unawareness of the potential of gasification. In fact, the whole range of thermochemical processes for cellulosic waste should be studied. The technological argument against these processes is the high moisture content of the feed, but it seems that the energy produced could be used to get rid of the water. Where the feed has a high moisture content, it is better to produce biogas, but for feeds with little moisture thermochemical methods are preferable.

Shell is now conducting a survey of sources of energy in developing countries, particularly in Eastern and Southern Africa, and is developing some wood-based processes. The Commonwealth Science Council has a project on gasification in India and producer gas, based on coal, is being used in bakeries in Zimbabwe.

5.17 STUDIES ON THE BIOGAS TECHNOLOGIES FOR RURAL ENERGY NEEDS IN AFRICA - H L Uppal

Biogas was produced in Africa as far back as World War II when the supply of petroleum was scarce. Some of the commonly-available organic waste materials were crop residue, woodchips or charcoal, which were used in the production of producer gas, and air-dried cattle manure and other agricultural waste materials, from which fuel gas was manufactured. After the war, the petrol situation improved with the result that the use of waste materials for fuel energy received no serious attention. However, with petroleum again in short supply, scientists today are once more turning their attention to the use of organic waste for producing biogas. In Uganda, there is abundant hydro-electric power, but high transmission costs and the fact that all electrical appliances have to be imported mean that electricity is in fact very expensive and in the rural areas, where 90% of the population lives, alternative sources of energy must be considered.

The anaerobic digestion of waste materials is a biological process which, with the aid of living micro-organisms, converts the complex organic matter into methane, carbon dioxide, hydrogen sulphide, some stabilised effluent and bacteria. The main factors that influence the digestion are pH, temperature, toxicity, nutrient ratio and conversion efficiency. There are three steps involved in anaerobic fermentation - acid fermentation, acid regression and alkaline fermentation. The bacteria present in steps one and two are collectively called acidogens or acid formers and the bacteria responsible for step three are called methanogens or methane formers. The methanogens are more sensitive to pH, temperature, etc, than the acidogens.

The fermentation is carried out in a container, in order to isolate the waste from the air. There are two main groups of container, namely: the batch type, where the digester is loaded once and sealed until fermentation is complete; and the continuous flow digester, which is loaded at frequent intervals. The continuous digester also comes in two types - completely mixed and plug flow. The rate at which the volatile solids (VS) may be loaded into the digester can range from as low as 0.1 - 0.4 lbs VS/ft^3 up to 0.7 - 1.2 lbs VS/ft^3 per day and the volatile solids content is maintained at somewhere between 4% and 12%. The time that the wastes are allowed to remain in the digester (detention time) is closely associated with the loading rate:

$$\text{Detention Time} = \frac{\text{VS Concentration x Slurry Density}}{\text{Loading Rate}}$$

Low loading rates imply a detention time of 10-14 days, medium rates 6-10 days, and high loading rates 3-6 days. The digester volume is determined by the loading rate and the amount of material to be digested:

$$\text{Digester Volume} = \frac{\text{Amount of VS Per Day}}{\text{Loading Rate}}$$

The digesters can be operated at temperatures of either 130-137°F (thermophillic) or 90-97°F (mesophillic). Thermophillic digestion has many advantages, such as satisfactory loading and waste material, higher loading rate, improved gas production, etc, over mesophillic digestion.

During the three months prior to this Workshop, a study of existing literature on biogas production was carried out in Uganda and the availability of different types of waste material was investigated. Of the three main types - agricultural waste, cow dung and decayed plant matter, only the lattter is available in abundance and is well-scattered throughout the country. Unfortunately, the carbon: nitrogen ratio of plant weed waste is much too high (C/N = 72) and will produce only CO_2 and H_2; consequently it is of no practical use to biogas production. For the manufacture of biogas, C/N = 30 is required although variations within the range 15 to 45 have proved satisfactory. An alternative waste, such as cow dung, human excreta, chicken manure, etc, with low C/N ratios, will have to be mixed with the plant material in order to reduce the C/N ratio to around 30.

The future programme of work in Uganda will be to: work out the optimum mixture of plant waste and other organic waste material so as to attain a C/N ratio of 30; design and develop a digester suitable for different laboratories attached to the various departments of Makerere University; store and distribute gas on a commercial scale.

Discussion

The discussion of this paper focussed upon some material, which Dr Uppal had brought from a Ugandan river bed and at present is clogging rivers and streams throughout Uganda. The substance is somewhat like peat with a high carbon content and could perhaps be used as a feed for biogas digesters, although it would require a supplement of nitrogen. Research needs to be carried out on this substance and on its potential as a source of energy.

5.18 THE DEVELOPMENT OF BIOGAS IN ZAMBIA - G M S Manyando

At present, Zambia depends largely on local resources for her energy: wood, dung or straw for burning; hydro power for water wheels and for generating electricity; and coal, the only fossil fuel so far locally available. She is reportedly self sufficient in most forms of energy, but her oil bill (about K100 million is 1978) consumes about 40% of her foreign exchange. Consideration of alternative sources of energy is, therefore, very necessary and, in Zambia, nuclear power, solar and wind energy and biogas are being studied.

The lack of cheap and adequate energy hampers rural development plans and retards improvements in the quality of rural life. There is a need therefore, to develop an alternative source of energy suitable for use in a rural environment. Ideally, it should be local in origin, depend only on local materials and labour and invove a fuel that can be used for different kinds of work. With large supplies of agricultural residue and animal wastes available in rural areas, biogas is thought to have the greatest immediate potential and, under the Third National Development Plan, approximately K100,000 has been set aside for research into this resource.

To date, two biogas plants have been successfully established in Zambia. The first was built on a private farm in the Nega Nega area of Mazabuka district late in 1973 by Mr Larry Hills and the other by Chadiza Secondary School pupils under the guidance of the missionaries who run the school. Between 1973 and 1976, Mr Hills did most of his cooking using piped gas from his digester and the Chadiza pupils have managed to use the gas in their science laboratories for some time now with minimal problems. The main difference between the two plants is that the former uses a separate gas holder and hence uses two units, while the latter uses only one combined unit. A similar design to that of Mr Hills was adopted by a student of mechanical engineering at the University of Zambia in 1978. This plant, however, did not produce any gas probably because the incorrect water/dung mix was used. An experimental biogas plant is also being built by the Zambian National Council for Scientific Research (NCSR) at their farms in Chalimbana and will be completed by year end 1980. The estimated relative unit costs of these plants are as follows: the Chadiza and University of Zambia plants -K30 to K50 per unit; Larry Hills' plants - around K200; and the NCSR plant - K1000.

Being a new technology, the major problems encountered in the production of biogas are mainly due to a lack of relevant background information among the local population. For instance, in the use of human excreta as feed, the social and cultural inhibitions of the people could be overcome by adequate education programmes. Other problems which have arisen include the question of storing the gas for future use and the difficult choice that must be made to select the type of digester most suitable for a particular locality.

With respect to ongoing research and development programmes, once NCSR's plant at Chalimbana is complete, qualitative and quantitative analyses of the gas will be undertaken until an optimal slurry mix is achieved which produces the best comparative results. The main requirements at the moment to facilitate this are funds and equipment. It is also hoped that a continuous feed digester made out of drums will be studied as all the laboratory models are of the batch type.

Should the experimental plant at the Chalimbana farms succeed, it is planned that two or three other plants will be set up in places where NCSR can easily monitor them. the local people in these places will be exposed to the new technology and, depending upon their response, the technology can then be taken into the rural areas. It is further planned that research personnel be allowed to visit other countries which have done a great deal of work on biogas technology.

5.19 THE USE OF WINDMILLS FOR WATER PUMPING IN ZAMBIA - J P Van Paassen

Research into the wind energy potential of Zambia was begun by the Wind Energy Group of the University of Zambia. When the Group disbanded in July 1980, the Technology Development and Advisory Unit (TDAU) carried on the work and plans to develop a windmill for water pumping that can be produced locally. Under Zambia's Third National Development Plan, 1979 - 1983, however, the emphasis with respect to wind power is strictly on its use for electricity generation and, because the use of wind power for water pumping is already established in many areas, no further attention is being paid to this application.

Although some wind pumps, such as the Arusha and Cretan types, have been erected in Zambia out of locally-available materials, no information is forthcoming on their performance. So only the commercially-available windmills can be discussed here with the most commonly used machine being the traditional American or Australian multi-bladed fan mill type. At the moment, wind pumps are available from three companies in Lusaka and the Copperbelt, with the prices of available models ranging from K2500 (£1350) to K5200 (£2800). About 35 windmills were sold during 1980 and the two main user categories were commercial farmers and the Zambian Department of Water Affairs.

A study of the cost effectiveness of commercially-available windmills in Zambia is presented in a report of the Cranfield Institute of Technology. For this study regime data were obtained from the Zambian Meteorological Department, the Zambian Geographical Association and the World Survey of Climatology, the viability of a wind pump depending on the relationship of its performance to a particular wind regime. From the records of 11 stations in Zambia, it can be seen that Lusaka has the highest wind speeds with a mean of over 3.0 m/s. Mongu and Choma have average speeds of around 3.0 m/s, Kasama and Chipata of around 2.5 m/s and other stations of less than 2.0 m/s. At Lusaka airport, therefore where average wind speeds are 3.5 m/s, the largest commercial wind pump is significantly more cost effective than diesel pumps at an oil price of 15p/litre. As the oil price increases to 25 p litre (44 N/litre), the smaller machines, down to a diameter of 3m, become competitive. The match of wind energy and rainfall in Zambia is ideal from a water pumping point of view with the wind speeds reaching their maximum before the rains, when the water tables are likely to be at their lowest.

Under the co-ordination of the TDAU, an investigation has been started into the use of windmills for water pumping in Zambia. Some preliminary conclusions can be drawn from this: there is no local manufacture of windmills and imports are heavily restricted by limited foreign exchange; there is a growing demand for windmills for water pumping, particularly from commercial farmers, and the availability of water to less fortunate farmers through wind pumping could have an enormous impact on Zambia's agricultural development; although in recent years no windmills have been installed in Zambia, the Department of Water Affairs is still interested in them, especially with respect to rural cattle watering places.

With reference to ongoing and proposed activities in windmill development at the TDAU: at the request of the Ministry of Agriculture, a study is being planned into the feasibility of wind-driven water pumps for a dairy settlement scheme, near Lusaka; in Kitwe, the Forest

Products Division recently undertook the development of a combined windmill-water tank in co-operation with the Ndola Water Affairs Department - the TDAU is assisting in this project and has offered to look into the possibility of developing a head construction, in order that a complete windmill could eventually be manufacture locally.

Discussion

In Zambia, the Meteoological Department conducted a climatology survey in order to examine the relationship between wind speed and the output specified by the windmill manufacturers. It has been found that the manufacturers often make large errors when assessing the performance of their machines. The UK Cranfield Institute of Technology has developed a method for measuring wind speed and water output from windmills. This method has been used in Kenya and Botswana, but according to staff working on windmill technology at ITDT it may have some limitations. However, Cranfield has recently devised some new wind-measuring techniques and it was suggested, therefore, that the research workers might return and re-evaluate the situation in these countries.

5.20 LOW-COST WINDMILLS AND BIOGAS PLANTS IN ZIMBABWE - Stuart Spence

Even though the price of electricity in Zimbabwe is one of the lowest in the world at 3 cents per kWh, the small, low income farmer still relies on wood as his basic fuel. So alternative forms of energy are being studied, such as direct solar, wind and biogas systems, which would be appropriate to rural needs. In the past, the Government has supported alternative energy projects with the aid of small grants issued to innovators in the various fields and now the Ministry of Water Development is investigating various methods for solving the problem of water supply in rural areas.

Three types of low-cost windmill have been built in Zimbabwe: the Cretan sail, the Savonius rotor vertical axis and the multibladed. Of these, only the multibladed windmill has operated with any degree of success. The relative costs of the machines, including pump, piping and fittings are: Z$400 for the Cretan sail windmill; $200 for the Savonius rotor; and $250 for the multibladed windmill. Only the latter machine has been used to pump water on a regular basis and, during September and October 1980 when the average wind velocity was between 7 and 9 knots, output rose to about 3000 litres/day. The main difficulty in Zimbabwe is the low average wind speeds and, during certain times of the year, there is virtually no wind at all. However, low-cost windmills might still have a role to play provided they could be made reliable and further research is to be undertaken into the three types of machine already available in the country.

Two types of biogas plant have been set up in Zimbabwe. The most popular is of the Indian Gobar gas design and there are four such units in operation in the country. The capital cost of each unit is approximately $500 and the estimated cost per 100 litres of gas works out at about 24 cents. The second type is the tube digester which is of local origin and is at present at the experimental stage. The cost of the digester is $100 and the estimated cost per 1000 litres of gas is 27 cents. Only one of these units is in use with the biogas units is the capital cost and investigations are underway to find alternative materials and methods of construction. Oil drums are not as plentiful as they used to be and are certainly not readily available in the rural areas any more. However, ferrocement looks promising at this stage.

So far, little work has been done with respect to using low-cost windmills or biogas units for pumping water in Zimbabwe. Only superficial investigations have been carried out, mainly by research organisations. There is, therefore, an urgent need to examine the possibility of utilising low-cost sources of energy, particularly in the rural areas where the emphasis is on development.

Discussion

A biogas digester has been developed which is based on an Arusha design and uses a coiled neoprene hose. Unfortunately, however, there is a problem with the joint and leakage has occurred. The digester is fed with horse manure and the gas has been used for cooking. The principal draw-backs are the high price of the neoprene tubing and the fact that it deteriorates in the sun.

In addition to some windmill work, a simple coil pump has been developed. This pump can be self powering if mounted in a flowing stream and can provide a form of water pumping at very low cost. Some leakage has occurred at the rotary joint in the centre of the pump, but this has not prevented the unit from working.

APPENDIX 1: OPENING ADDRESSES

SPEECH BY THE MINISTER OF MINERAL RESOURCES AND WATER AFFAIRS, DR G. CHIEPE, ON OPENING THE COMMONWEALTH WORKSHOP ON LOW COST ENERGY FOR WATER PUMPING NOVEMBER 24 1980

It gives me great pleasure to welcome you all to this workshop; it is a privileged opportunity to step aside from the day to day pressures of work and concentrate on a challenge which must be met by all of us who are working to supply water to all our people, especially those living in remote areas.

Many of our water supplies depend on diesel engines to pump water from boreholes, to supply our villages. Diesel engines are becoming increasingly expensive to run as oil prices everywhere continue to rise. I am sure this problem affects each one of us to a greater or lesser extent. But it is not the only problem. Although diesel engines give many hours of good service, they do require regular maintenance and skilled attention backed up by expensive spare parts when they break down. With the shortage of skilled manpower faced by most of the developing world, it is often difficult and sometimes impossible to provide an adequate maintenance and repair service to cover all the remote areas.

These, then, are the two main problems with which we turn to you for alternative technical solutions. We need water pumping systems which are cheap to install and run, very reliable, and simple to maintain. And they must be large enough to supply the volume of water required. The economists will of course point out that other things being equal they should cost less, over their working life, than the conventional systems they replace. These criteria are hard to meet, but unless they are met most of our efforts will be wasted. This is a sobering thought, but I hope that you will keep it at the front of your minds during this week.

There are of course a number of alternative technical systems to consider: these include windmills, solar power, biogas, and perhaps others of which I am not aware. Each needs to be weighed carefully against the criteria of suitability for the job and choices made. There are of course other things to consider: for example it is desirable to manufacture systems or components locally, but the system must meet the basic requirements first.

As Botswana is hosting this workshop I should say something about the work which this country is doing now and our plans for the future. We are of course participating in the Drinking Water and Sanitation Decade which the United Nations launched recently, though our own targets had been set by ourselves well in advance. We are aiming to provide safe water to all villages by the middle of the 1980s; we have prepared most of the projects and now await the finance to implement them. During the last development plan we completed water supplies to the 15 major villages (of which Kanye is one), 40 intermediate sized villages and 14 smaller villages with a population of below 500 (in 1971). We have about 250 villages still to cover, many of them with small populations.

Many of our supplies depend on boreholes which are on average 100 metres deep. This poses a major technical challenge to the designers of alternative pumping systems but I believe there are some hopeful signs that solutions have been found, at least for low daily volumes of water. The pressing need is of course to increase the pumping output; as each borehole requires 100 metres of drilling, and only two thirds of the boreholes yield any water at all, it is generally too expensive to have two boreholes where one would suffice, if it had an efficient pump, even if this is diesel powered.

Botswana has already invested a good deal of time and money in the research and development of pumps which use renewable energy. One of the more promising fields is with windmills and you will be hearing from Richard Carrothers about his work here at Kanye. There has of course been a good deal of research into the use of biogas and I understand that this now needs to be tested in the field.

My Ministry's Department of Water Affairs has its own programme to install windmills which use existing technology and are commercially available. Many of these are feeding into existing village water supplies and we will be assessing their performance and collecting wind data over the next year or two. There is in addition a pilot programme to test hand pumps; we have recently received a number of petrol pumps through SIDA, two of which are now here at Kanye.

For the future we plan to start work on a P3.5 million project to develop renewable energy technologies, starting in mid 1981. USAID have assisted in the preparation work and will be providing a large part of the financing. The project has provision for further development work on windmills and hand pumps and the testing of solar electric cells to drive electric water pumps. These solar cells are at present far too expensive for us to contemplate their introduction now, on a large scale. However we are advised that they may come down in price, as other silicon devices already have. If this happens, our pilot projects should leave us in a position to apply solar technology as soon as it becomes available at low cost.

I very much hope that your work here will lead to developments in time for us to influence the design of our village water supplies, which we hope to complete by the mid 1980s. There will of course be some scope for replacing diesel engines once better alternatives become available, but it would be a pity if we had to duplicate installation work.

(b) OPENING REMARKS BY MR ANTONY ELLMAN, ASSISTANT DIRECTOR, FOOD PRODUCTION & RURAL DEVELOPMENT DIVISION, COMMONWEALTH SECRETARIAT

Mr Chairman, Honourable Minister, friends and colleagues.

On behalf of the Commonwealth Secretariat which is jointly sponsoring this Workshop with the Rural Industries Innovation Centre, I am happy to welcome you to this opening session. I want particularly to thank Dr Chiepe for taking the time to be with us today. This indicates the importance which her Ministry attaches to the subject of the Workshop. I want also to thank the staff of the Rural Industries Innovation Centre and the Botswana Technology Centre for making such excellent arrangements. I am sure we have the makings of a most valuable conference.

I should like to take a few minutes to explain the background and purpose of the meeting. The Commonwealth Secretariat, as you will know, is an international organisation based in London, which specialises in promoting exchanges of experience and people between Commonwealth countries. We are not so exclusive as to leave out non-Commonwealth countries which have contributions to make or lessons to learn. And I am very happy to see representatives from Ethiopia and USA among us.

Two divisions of the Commonwealth Secretariat, the Food Production and Rural Development Division and the Commonwealth Science Council, are engaged in programmes for rural technology development in Africa. The Science Division brings together scientists and researchers who are developing new technologies, and the Food Production and Rural Development Division works with appliers and users of the new technologies in the field. At regional meetings held in Tanzania and Zambia in 1979, the need of many countries for technologies to tap low cost sources of energy for water pumping became very clear. A regional project for collaboration in work on biogas and windmills for water pumping was proposed.

This meeting aims to bring together scientists and users of biogas and wind energy for water pumping, so that they can pool their skills and move ahead together. The meeting is necessary to ensure that engineers in different parts of Africa know of the work that is going on in other countries, and do not embark on expensive and unnecessary programmes of research and development which simply duplicate work that has already been done elsewhere.

For the real problems with windmills and biogas are not basically technical (though such problems no doubt exist). They are rather the problems of application:- the problem of bringing down the capital cost of windmills and biogas plants to put them within reach of the small family; the problem of management, ensuring that the plant is properly maintained and that people know how to use it; the problem of ensuring that the energy generated is productively used, and that the power mechanism is efficiently linked to an appropriate pump for lifting water.

I believe that countries can learn a lot from each other in these respects. Botswana has made good progress both on windmills and on biogas, Kenya manufactures windmills which are now commercially available, India has long and valuable experience of biogas schemes. The other countries represented here have their own experiences to contribute.

I hope that several things will come out of this workshop:

- that innovations which have been proved successful in one country will be immediately applied in other countries;

- that research workers will design their programmes in the light of experience elsewhere, aiming to adapt known technologies to local needs rather than to develop new technologies from scratch;

- that this meeting of research workers and users of biogas and wind technologies will give the appliers the opportunity to specify the problems they encounter in practice, and that the research workers will then formulate appropriate research and development programmes to solve these problems;

- that uniform criteria for measuring the performance of both windmills and biogas plants will be agreed to;

- and finally that collaborative development programmes will be formulated, as a way of sharing experience and reducing the costs inherent in individual national programmes.

Whatever proposals are formulated at this workshop, the Commonwealth Secretariat will be ready to help countries to implement them as far as resources permit. If the needs put these programmes beyond our reach, we will help countries to locate funds from other sources. For what happens after the Workshop is the key: we will have done something useful here only if, as a result of our work, more windmills and biogas plants are installed, more water is pumped at lower cost, and better livelihoods are assured for the rural populations of Botswana, Kenya, Zimbabwe, and all countries of the region.

APPENDIX 2: COMMONWEALTH WORKSHOP ON LOW-COST ENERGY FOR WATER PUMPING - RIIC 1980

PROGRAMME

	MORNING	AFTERNOON	EVENING
Monday 24 November	10.30 a.m. Opening Session - Introduction by Chairman, Mr Felix Mokobo - Official Opening by Hon Dr Chiepe, Minister of Mineral Resources & Water Affairs - Introductory Remarks by Commonwealth Secretariat	2.30 - 4.00 p.m. Lead Paper No 2 Review of Biogas Technology Dr Leo Pyle	7.00 p.m. Welcoming Party Rural Industries Innovation Centre
	11.30-1.00 p.m. Lead Paper No 1 Wind as an Energy Source for Water Pumping - Mr Richard Carothers	4.15-5.45 p.m. Lead Paper No 3 Biogas Technology in India Dr Y N Sharma	
	Presentation of Country Papers		
Tuesday 25 November	8.00-9.15 : Biogas Pumping, Botswana Fr. Brian McGarry 9.15-10.00 Ethiopia 10.30-12.00: Kenya, Lesotho	2.00-3.30: Malawi, Mauritius 4.00-5.30: Tanzania, Uganda	7.30-900: Zambia, Zimbabwe
Wednesday 26 November	Working Group Session a) Windmills b) Biogas	Field Visits Rural Industries Innovation Centre	Free
Thursday 27 November	Working Group Sessions	Field Visits Windmill Sites	Film Show
Friday 28 November	Working Group Session	Reports of Working Groups	7.00 p.m. Farewell Party Commonwealth Secretariat
Saturday 29 November	Concluding Session	Depart for Gaborone	-

APPENDIX 3: LIST OF PARTICIPANTS

WORKSHOP ON LOW-COST ENERGY FOR WATER PUMPING
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24 - 29 NOVEMBER 1980

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