# DEVELOPMENT OF A CONTINUOUS FLOW AIRLIFT GROUND WATER PUMP FOR RURAL APPLICATIONS

P Janse van Rensburg · A Brink

WRC Report No. 976/1/02

Water Research Commission

# DEVELOPMENT OF A CONTINUOUS FLOW AIRLIFT GROUND WATER PUMP FOR RURAL APPLICATIONS

Report to the

Water Research Commission

by

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Green Energy Systems

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# EXECUTIVE SUMMARY

## INTRODUCTION

1) It is a well known fact that the earth is running out of its natural energy fuel resources at a rate where it will not have sufficient resources to fulfil the required needs for the Twenty First Century. This means that every possible option to utilize alternative energy sources must be researched as a matter of urgency.

**Wind energy** is, and will always be available as a renewable and sustainable energy source, which has distinguished itself as being reliable in various different applications over many years across the world.

The main applications for wind energy have generally been in the generating of electricity power by grid-connected wind turbines. However, even at the very low production cost of these units, wind generated electricity is not yet fully cost-competitive with coal- or natural-gas-produced electricity for the bulk electricity market. It is because of this cost constraint that Green Energy Systems have approached the wind energy source from a different perspective, where the free wind energy is transformed into a controllable energy source by storing energy as compressed air, which in itself is an expensive and sought after commodity.

The system designed by Green Energy Systems is based on very simple mechanical technology that results in it being a fairly low cost solution to energy needs. This assumption can be made, as we are of the opinion that this method of storing energy is much more cost-effective than other systems that are currently in use, especially if we consider the maintenance cost of the system over the lifespan of the product. The system is virtually maintenance free with all working parts being of a simple, wear free design and available as standard off the shelf items in the market.

2) **Estimate of the Wind Energy Resource in the South Africa region**
It is generally accepted that between 1.5 and 2.5% of the radiant solar energy which reaches the earth is constantly being converted into kinetic energy. Using 2% as the average dissipation rate and a value of 350 $Wm^{-2}$ as the flow average insulation in South Africa, a value of 7 $Wm^{-2}$ is obtained for the total rate of solar input to wind energy. However, since it is possible to extract only that portion of the energy in the boundary layer close to the surface of the earth, this value must be further reduced. Thirty-five percent of the total wind energy dissipation occurs within 1000 m above the earth's surface, hence application of this factor to 7 $Wm^{-2}$ gives 2.5 $Wm^{-2}$. Multiplying by the total land surface area of South Africa (1223803 $km^2$) gives 3.0595075 x 101° W. Assuming that only 10% of this amount can be safely extracted to avoid alteration of global weather patterns, then the upper limit of energy available for capture in South Africa is 3 x 09 W. Integrating this over the year gives a figure of 26280 GWh/yr. Taking a conservative estimate of 30% for the efficiency with which available wind power could be converted to usable power, it is estimated that wind power could supply at least 2.4% of South Africa's electricity requirements in the year 2000 (Diab, 1985).

Full exploitation of the wind would require the use of only a small percentage of the land area, and obviously those areas with greatest potential need to be identified.

A large section of the South African Community lives in areas where power is not easily accessible. This refers to both electrical power supply and to fossil fuel supply such as coal, diesel or petrol. The main development objective of this project was to develop a fairly low cost system that utilizes a renewable energy source to pump water continuously.

## OBJECTIVES

The primary objectives of the project were to:

a) Develop an inexpensive and reliable continuous flow groundwater extraction pump of simple construction and to test the functionality of the equipment.
b) The maintenance of this groundwater pump would have to be of simple design and it should be possible for a non-specialist person, with tools readily available in rural areas, to remove the pump from a borehole and to repair it should this become necessary.
c) The operation of the pump should not be complicated.
d) Any parts that might be required in maintaining and repairing the equipment should be available in most hardware shops, even in remote rural areas.
e) Manufacture of the pump should be possible in rural areas without specialized equipment. Light, non-corrosive material would be preferably used in the construction of the pump.
f) The Wind pack compressor capable of storing wind energy as compressed air should be further developed and tested as a means of providing supplementary power to the groundwater pump.

## ADVANTAGES AND DISADVANTAGES

1) Storage of wind energy as available air pressure in a receiver tank as opposed to direct storage as water in a water tank has the following advantages:

   a) Insects, vandalism or vermin will not affect the quality of water obtained by the community.
   b) Water is not lost from the system by evaporation.
   c) Water is only used as required, thus resulting in more efficient usage of the water available.
   d) Due to the improved sanitary perspective, risk of rural communities contracting diseases through usage of water from open water storage tanks is avoided. The need for boiling water is reduced.
   e) The windmill can be positioned in a location optimal for the capture of wind i.e. on top of a hill, whereas the borehole(s) can be situated at a point most convenient for extracting groundwater. ( See page from Diab insert, hilltop )
   f) This system can power multiple boreholes where water yield is too low for other systems to operate successfully.

2) Primary disadvantages of the system compared to the more conventional systems are:

   a) A new system not known to the rural communities, which still needs to find community acceptance.
   b) Air pressure leaks are more difficult to control than water leaks.
   c) Air pressure tanks are more expensive to manufacture than standard water tanks.
   d) Air pressure tanks needs to be tested and certified at pre-defined intervals through accredited authorities.
   e) Due to the fact that the compressed air used to "push" the water out of the borehole, comes in direct contact with the drinking water itself, a proper filtration system must be installed in the air-line system to remove the hydrocarbons and oil contamination

3) Specific Advantages of the GES Pump System
*(For full detail of these, see section 7.4 in main document)*

- Multifunctional
- Possibility to automate system
- Resistant to normal element damage
- Can serve multi-borehole system
- Only minor maintenance required
- Used in conjunction with submersible pneumatic pump that is basically maintenance free.
- Does not have to be erected on borehole but rather at optimum wind position
- Functional at very moderate wind availability
- Major components available off the shelf
- Power-failures / theft of power cables not a factor
- Individual optimization for specific site variables.

## CONCLUSION AND RECOMMENDATIONS

The following conclusions are reached:

a) The continuous flow groundwater pump developed in the course of this project functions fully satisfactory when installed in boreholes with a water depth of up to 70m.
b) The wind pack compressor allows for sufficient storage of usable energy, which can be used for acquiring groundwater.
c) The maintenance on this system is easy and comprehensible even to unskilled people.

The following recommendations are made:

a) The system operation needs to be fully tested under rural conditions to ensure equipment robustness and potential for wide-spread use.
b) It seems that the system was over-designed to some extent and production cost can be reduced.

## CAPACITY BUILDING

### General

The contemporary view of capacity-building goes beyond the conventional perception of training. The central concerns of environmental management - to manage change, to resolve conflict, to manage institutional pluralism, to enhance coordination, to foster communication, and to ensure that data and information are shared - require a broad and holistic view of capacity development. This definition covers both institutional and community-based capacity-building.
http://nrm.massey.ac.nz/changelinks/capacity.html

The transfer of environmentally sound technologies (EST's) from the industrialized to the developing countries has come to be seen as a major element of global strategies to achieve sustainable development and climate stabilization. It has also been recognized that the effective transfer of such technology will require substantial upgrading of the technological capacities in the developing countries, as well as a deepening of the content of technology transfer. The central technology transfer issue within the context of the United Nations Framework Convention on Climate Change is to provide a direction to the technology cooperation between enterprises in developing and industrialized countries that leads to the greater adoption of EST's in the developing countries.

**Capacity building within the Research Team**
Various ways of capacity building is touched with this development.

- New technology such as is offered with this product, offers new jobs and creates new opportunities. Therefore, as equivalent systems in this product field are very limited, no other employment are directly influenced by this system, as there is now a larger market sector that needs to be serviced.

- Value adding to raw materials.

- Supporting of local industries. Young African artisans whom had no previous knowledge of wind energy or formal training in welding and material strength procedures were trained in these fields over the development period of this project.

- Contracting to rural areas, to create work in these areas. The product require such a basic manufacturing procedure that local artisans and/or businessmen can in future be contracted to perform most of the manufacturing if the product.

- Export opportunities.

- Improvement of living conditions for rural communities.

\# Attached, at the end of this document, please find an extraction from an abridged version of the Book "*Capacity building for technology transfer in the context of climate change.*"

## <u>GENERAL</u>

Successful application of the GES PUMPING SYSTEM allows for use in areas where power generation through the use of diesel, paraffin or electricity is not practical or affordable. It also lends itself to the development of ground water resources in areas where ground water exhibits poor conditions, and where other means of ground water extractions would not be considered as economical. These would account for situations where the ground water yield is poor and a number of boreholes have to be run by a single windmill installation to achieve the desired water delivery capacity, and where other means of extraction, such as electrically driven pumps are too expensive to consider.

Water is a basic necessity to all living, whilst consumption is a reflection of different lifestyles where each person's use varies with habit, culture, climate and the basic availability of this precious product. Third World villages consume as little as 40 litres per person per day because water must be pumped by hand and often carried some distances. Urban dwellers may use three times as much as Third World villagers, because water is often more plentiful. According to field tests by the United Nations the total average water requirement per person is 40 litres for Third World Villagers and 100 litres for Third World Urban residents.

In order to clearly understand the concepts and terminology of wind energy, we have taken the liberty to include the following 7 pages from the "Wind Atlas of South Africa" by Roseanne Diab.

# CHAPTER 3

# DETERMINATION OF WIND ENERGY RESOURCE

## 3.1 Power in the Wind

### 3.1.1 Available Wind Power

The power ($P_a$) available in a cross sectional area (A) perpendicular to the wind flow moving at speed V is the kinetic energy flux, i.e. kinetic energy density x speed x area (Justus, 1978). Hence

$$P_a = (0.5\,\rho\,V^2) \times (V) \times (A) = 0.5\,\rho\,V^3\,A$$

where $\rho$ is air density. The power density, $P_a$ ($Wm^{-2}$) available in a unit cross-sectional area normal to the wind is given by

$$P_a = 0.5\,\rho\,V^3$$

where $\rho$ is air density ($kgm^{-3}$) and V is wind speed ($ms^{-1}$). Standard sea level density (1.225 $kgm^{-3}$) is usually used.

$P_a$ is known as **available wind power** and refers to the theoretical amount of power available, determined by the kinetic energy of the wind. The cubic response of power to the instantaneous wind speed means that a small increase in wind speed results in a substantial increase in power. For example, an increase in wind speed by a factor of 2 results in approximately 8 times as much wind power. In view of this, considerable attention has been devoted to estimating the theoretical or available power in the wind. Traditionally, the method used to obtain estimates of mean annual or mean monthly wind speeds respectively, assumes that available power is proportional to $\overline{V^3}$. This method neglects the contributions of perturbations about the mean value, and usually provides an underestimate of power. Many of the preliminary wind power surveys in the United States (Reed, 1975) and in South Africa (Diab, 1979) have, however, relied upon this method.

Clearly, it is desirable that wherever possible, power calculations be based on the distribution of wind speeds rather than on mean statistics. It is generally considered acceptable to base wind power estimates on hourly averaged wind data. Where these data are not available, attempts have been made to characterise the wind speed frequency distribution by some statistical distribution model, such as the Weibull or Rayleigh model (Hennessey, 1978). Diab (1981) outlines the different techniques used to approximate the wind speed frequency distributions and compares the results thereby obtained.

### 3.1.2 Usable Wind Power

Not all the energy that is available in the wind can be extracted, since this would imply a reduction in wind speed to zero. It has been demonstrated that the upper limit of energy that can be extracted is 0.593 of the total energy in the windstream. Most wind systems do not reach this limit, known as the Betz efficiency limit.

An expression for usable or extractable wind power ($P_u$) is given by

$$P_u = 0.5\,C_p\,\rho\,V^3$$

where $C_p$ is the power coefficient of the wind turbine. By assuming an average value of $C_p$ an approximation of usable energy is obtained. A power coefficient of about 30% is considered to be representative of most modern wind turbines.

To make a more accurate determination of usable power, however, it is necessary to consider the dependence of $C_p$ on wind speed. The turbine does not produce power below and above its cut-in and cut-out speeds respectively. Above the cut-in speed the power increases monotonically until the rated speed is reached, after which the output remains constant. Usable power ($P_u$) is given by

$$P_u = 0.5 \rho \int_0^{\infty} C_p\ (V)\ V^3\ p\ (V)\ dV$$

where p(V) is the probability distribution of wind speed. Figure 3.1 illustrates the comparisons between available power, usable power assuming a constant $C_p$ of 0.4, and usable power with a given $C_p$ (V).

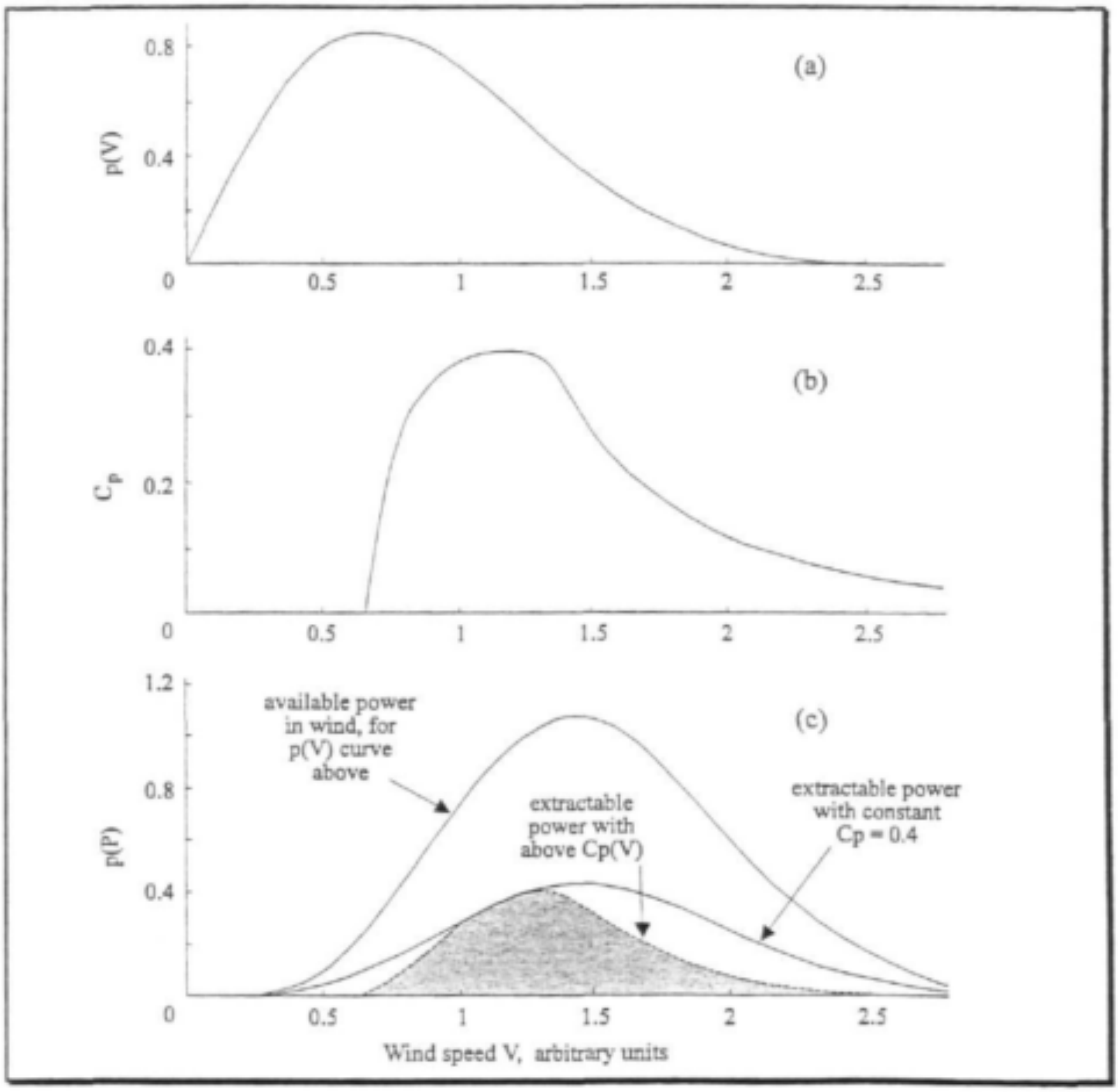


**Figure 3.1. Comparisons between available power, usable power assuming a constant $C_p$ of 0.4 and usable power with a given $C_p$. a) wind speed probability; b) power coefficient; c) wind power probability (after Justus, 1978)**

## 3.2 Wind Statistics

A number of statistics are used to estimate the wind energy resource. Some of the more common ones are listed below.

- **Mean annual wind speed**

The mean annual wind speed, estimated over the full data period, is usually the first indicator of wind power potential of a site. The generally recognised minimum wind speed threshold for wind power viability is 4 $ms^{-1}$. However, the exact mean annual speed at which wind energy utilisation becomes economically feasible depends on the specific application and local terrain enhancement. Mean annual wind speeds at anemometer height and normalised to 10 m (using the one-seventh power law) are given for each station included in Chapter 5.

- **Interannual variation in wind speed**

The year to year variation in mean annual wind speeds (estimated over 12 months) provides an estimate of interannual variability that may result from climatic change. It is usually presented in graphical form.

- **Monthly wind speeds**

A graph or table of monthly mean wind speeds provides an indication of the season in which highest wind speeds occur. When compared with seasonal energy demand, the economic viability of wind power systems can be deduced. A graph of mean monthly wind speed is presented for each station included in Chapter 5.

- **Wind speed frequency distribution**

This is usually a tabular or graphical presentation of the percentage frequency of winds at certain speeds or within certain speed categories. The percentage frequency can be replaced by the number of hours in a year experienced at the various speeds. Because of the cubic response of power to the instantaneous wind speed the distribution of wind speeds is a vital component in the assessment of available wind power.

- **Velocity frequency distribution**

This is a tabulation of the joint frequency of occurrence of certain wind speed and wind direction classes. The dominant wind direction and the direction associated with the highest wind speeds can be ascertained and this information used in the siting of wind turbines. Such a table is presented for each station included in Chapter 5.

- **Weibull parameters**

Knowledge of the probability distribution of wind speed is one of the most important statistics for wind energy resource estimation. The Weibull distribution is usually a good fit to observed wind speed data. The Weibull distribution p(V) is expressed as:

$$p(V) = (k/A)(V/A)^{k-1} \exp[-(V/A)^k]$$ (Justus, 1978)

where A is the scale factor ($ms^{-1}$) and k is the shape factor (dimensionless).

The parameters A and k allow the evaluation of many important properties of the wind distribution. For example, the probability of speeds below some threshold $V_x$ is:

$$p(V \leq V_x) = 1 - \exp[-(V/A)^k]$$ (Justus, 1978)

The mean wind speed $\overline{V}$ is given by:

$$\overline{V} = c\,\Gamma\left(1 + \frac{1}{k}\right)$$

where $\Gamma$ is the gamma function.

Weibull parameters A and k are given for each of 12 direction sectors and for the overall data set for each station included in Chapter 5.

- **Standard deviation of wind speeds**

The standard deviation of wind speed can provide an estimate of the variation about the mean. It can be presented as either a single standard deviation value, as 90 or 95% confidence limits about a mean, or graphically as standard deviation bands about the mean wind speed. The standard deviation could represent variations of daily wind speeds about a monthly mean or variations of monthly mean wind speeds about an annual mean and therefore it is important that this be specified in presentation.

- **Maximum wind speeds**

The maximum wind speed experienced over a specified time period is useful to the engineer engaged in designing a wind turbine. Usually, the maximum is the highest hourly averaged wind speed experienced rather than the maximum gust. Occasionally, with data sets with time resolutions of the order of seconds a detailed analysis of the gust structure or turbulence can be undertaken. The maximum speed, including the time period over which it was measured, is given for each station included in Chapter 5.

- **Run duration analysis**

A tabulation of the number of consecutive hours and the number of total hours above and below certain threshold values is referred to as a run duration analysis. The threshold values may be for example, cut-in speed, rated speed and cut-out speed. An estimate of the number of consecutive hours below cut-in speed has important implications in the provision of storage facilities. An estimate of the number of hours falling within the operating speeds of a particular type of turbine also provides an indicator of the efficiency at which the machine will operate. These statistics are presented in earlier regional wind climatologies (for example Diab, 1990) and are not included in this Atlas.

- **Diurnal cycle of wind speeds**

Mean hourly wind speeds calculated either over a full data period, a season or a month depict the diurnal march in speed. The time of day experiencing the highest wind speed should correspond to the time of day with peak energy load for a cost effective system. Graphs of mean hourly wind speeds for January and July are presented for each station included in Chapter 5.

- **Mean annual power density**

The method of estimation depends on the type of data available. If hourly or better resolution data are to be used

$$\overline{P} = \frac{1}{2n}\sum_{i=1}^{n} \rho_i\, V_i^3$$

where n is the number of observations in the averaging period, $\rho$ is the air density ($kgm^{-3}$) computed from the station pressure and temperature and $V_i$ the wind speed ($ms^{-1}$) at the i th observation time. The allowance for density to vary is not used in practice as usually air density does not vary by more than 10% during the year. However, density may be an important variable when comparing places with vastly different altitudes. Mean annual power density using standard sea level air density is presented for each station included in Chapter 5.

## 3.3 Terrain Effects on Wind

It is well known that wind speeds are affected by local orography. A knowledge of these effects can be used to advantage when siting wind turbines. Wegley *et al.* (1980) provide one of the most comprehensive accounts of terrain effects on wind, which forms the basis of the following summary.

In the case of an isolated hill, the shape of the hill is important. A concave or smooth, rounded hill will show the greatest percentage speedups (Fig. 3.2). Enhancement is greatest at the crest and may be negative in the front and lee of the hill. Under stable atmospheric conditions, air is likely to move around the hill, causing localised acceleration on the sides of the hill.

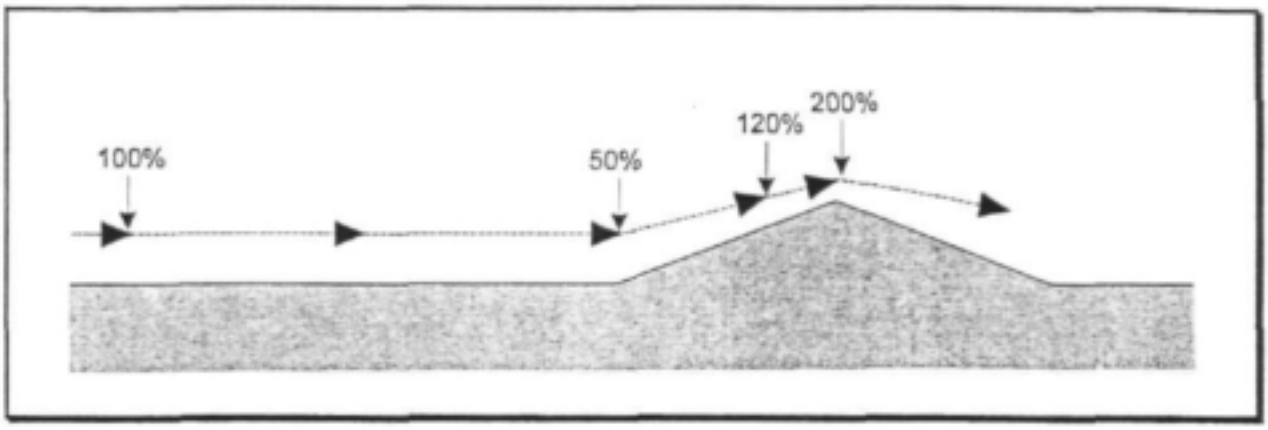


**Figure 3.2. Percentage variation in wind speed over an idealised ridge (after Wegley *et al.*, 1980).**

Elongated ridges are favoured wind turbine sites, particularly when their orientation is perpendicular to the prevailing wind. Concave or smooth rounded ridges show maximum enhancement on their summits and on the shoulders of the ridge. Steep cliffs and flat topped ridges should be avoided because of turbulence, high wind shear and flow separation.

Topographic features such as gaps, gorges, saddles and passes can channel winds and be used to advantage in siting wind turbines. However, increased turbulence in these locations may be a negative factor. Channelling of flow can also occur in valleys, particularly if there are constrictions. Broad valleys, oriented parallel to the prevailing wind, are best. Basins and depressions should usually be avoided. It should be borne in mind that valley locations are likely to show marked diurnal variations in speed.

## 3.4 Roughness Effects on Wind

Surface roughness, which is determined by the size and distribution of roughness elements such as vegetation and buildings, leads to a retardation in wind speed close to the surface. It is characterised by a parameter known as roughness length ($z_0$). Lettau (1969) gives the following empirical relationship:

$$z_0 = 0.5\ hS / A_H$$

where h is the height of the roughness element, S is the cross-section facing the wind and $A_H$ is the average horizontal area of each element. This relationship assumes that the roughness elements are solid. If they are porous then $z_0$ must be reduced by an amount proportional to the porosity.

### 3.5 Shelter Effects on Wind

The presence of obstacles can influence the wind to a height 3 times that of the height of the obstacle and to a distance 30 to 40 times the obstacle height in the downwind direction. The sheltering effect depends on the distance of an obstacle to the site (x); the height of the obstacle (h); the height of the point of interest at the site (H); the length of the obstacle (L) and the porosity of the obstacle (P).

Troen and Petersen (1989) provide a method for estimating the reduction in average wind speed ($R_2$) caused by sheltering, based on the work of Perera (1981).

$$R_2 = \begin{cases} (1 + 0.2\, x / L)^{-1} & \text{for } L / x \geq 0.3 \\ 2\, L / x & \text{for } L / x \leq 0.3 \end{cases}$$

The corrected wind speed ($u_{cor}$) corresponding to sheltered conditions is given by:

$$u_{cor} = u \,.\, [\, 1 - R_2 \,.\, R_1\, (1 - P)\, ]$$

where $R_1 = \Delta u / u$ is the fractional wind speed reduction taken from Figure 3.3.

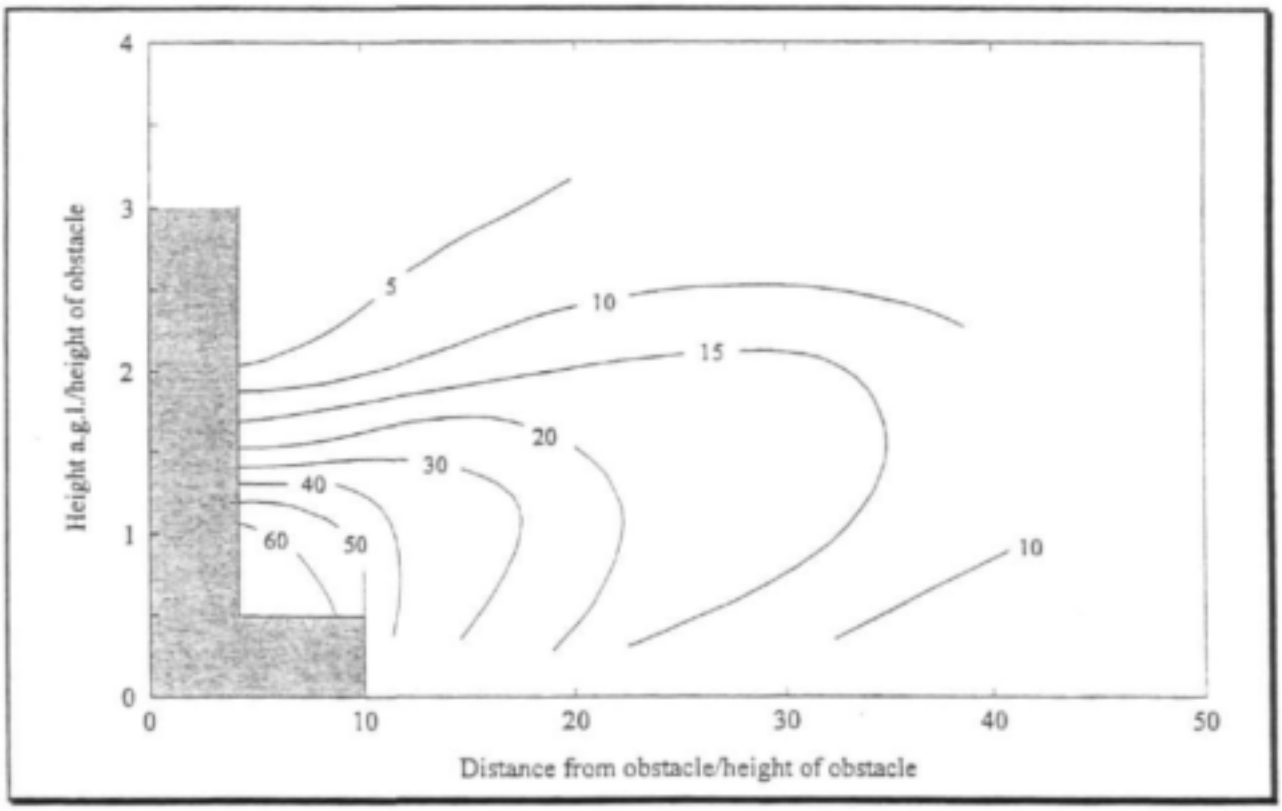


**Figure 3.3. Reduction of wind speed ($R_1$) in per cent due to shelter by a two-dimensional obstacle based on the expressions given by Perera (1981). Sheltering in the shaded area is very dependent on the detailed geometry of the obstacle (after Troen and Petersen, 1989).**

## 3.6 Vertical Extrapolation of Wind

Generally, wind speed measurements are made close to the earth's surface at approximately 10 m, necessitating the extrapolation of wind with height to obtain a wind speed at hub height. Many different methods of vertical extrapolation exist, ranging from those which are theoretically based, and which rely on boundary layer similarity theory to those which are purely empirical and site specific.

One of the most widely used methods of vertical extrapolation is the one-seventh power law. This is given by:

$$u_z = u_{ref} \, ( z / z_{ref} )^p$$

where $u_z$ is the wind speed at height z and $u_{ref}$ the wind speed at a reference height (usually 10 m) and p is known as the power law exponent. Peterson and Hennessey (1978) claim that assuming a value of p = 1/7 yields conservative yet realistic estimates of wind speed. It is well known that the value of p is dependent on stability and roughness and various attempts have been made to account for this. Some workers have favoured different values of the exponents. For example, Justus *et al.* (1976) and Hardy (1977a) have used 0.2 and 0.23 respectively. Justus and Mikhail (1976) derived an empirical value of p based on a least squares regression fit to data from 4 wind tower sites.

Methods based on similarity theory are reviewed by Diab (1986). They are seldom used in practice because they require simultaneous observations of atmospheric stability which are generally not available. Justus (1978) has attempted to take account of the dependence of vertical wind shear on stability by considering the frequency of stability types. Using stability wind rose data and assuming a power law model, speeds are extrapolated to the desired height by an exponent ($p_j$) for each stability and wind speed class ($u_{ij}$). The mean wind is obtained by weighting according to the frequency ($f_{ij}$) of the wind speed class (i) and stability class (j). Garstang *et al.* (1979) adopted an approach whereby p was computed for different synoptic categories and for day and night separately.

The lack of information on vertical wind profiles and stability characteristics hampers the vertical extrapolation of winds. However, in the absence of any alternative there was no option but to use the one-seventh power law in the preparation of this Atlas. There are indications that this is conservative, but is deemed to be the most appropriate under the circumstances. The only vertical extrapolation which was attempted was the normalisation of winds to a common height of 10 m agl.

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The Steering Committee responsible for this project comprised the following persons:

| | |
|---|---|
| Mr. D.S. van der Merwe | Water Research Commission (Chairman) |
| Mr. J.N. Bhagwan | Water Research Commission |
| Mr. D.J. Marais | Water Research Commission |
| Mr. P.J. van Rensburg | Green Energy Systems |
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| Mr. H.C. Chapman | Cape Metropolitan Council |
| Mr. P. Wagner | Wagner Systems |
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# CONTINUOUS FLOW AIRLIFT GROUND WATER PUMP FOR RURAL APPLICATIONS

## FOREWORD

*New ideas are resisted.... But we must rapidly explore these new technologies, because what is at stake IS LIFE.*

- *Adam Trombly (Astrophysicist)*

There is a fast-growing international effort to completely change the sources of energy on which our world is based. Some of its proponents call it "free energy". Some call it "space energy" or "zero-point energy". By any name, it has the potential to affect the life of every human being on earth.

Because the free energy that surrounds us is such a vast source, so potentially clean and decentralized, some of us believe a revolution is brewing. Afterwards, existing energy sources may be seen as dinosaur nightmares that littered our landscapes and polluted our air. This revolution could open a new paradigm of science and technology that would make the Copernican and Industrial Revolutions appear tame.

Until this day, it is apparent that little true progress has been made to stop our abuse of energy and the environment. We instead reinvent the wheel of vested interests in fossil fuels and internal combustion engines and nuclear energy, and we continue to supply electricity from large central power stations through an ugly grid system that may be a major health hazard (electromagnetic pollution from power lines). So why didn't we do anything about this?

A switch to clean "free energy" could almost totally alleviate air pollution, global warming from carbon dioxide emissions, waste heat, Saddam Hussein's ecocidal fires, black skies, oil spills, acid rain, nitrogen dioxide, sulphur dioxide, hydrocarbon and ozone emissions, unsightly oil production and refining facilities, super tankers, gas stations, power stations, transmission lines, and the rest of it.

Use of "free energy" could also end-out thirst for oil and natural gas. This thirst is draining precious resources from the Earth at alarming rates. The lifeblood, formed over tens to hundreds of millions of years within the Earth's crust, has been greedily extracted as if there were no tomorrow. Oil production and consumption has more than tripled since the onset of the energy crises. Almost half of the world's available oil and more than half of the natural gas have already been skimmed off the top of our best deposits and burned, mostly within one human generation!!

At present rates of consumption, proven U.S. oil reserves will last just ten years, and world oil reserves will last forty years. Even if these reserves were to prove to be twice as abundant as the estimates, we will run out of oil by the middle of the twenty-first century, with inevitable sharp price rises.

The worldwide energy infrastructure that depends primarily on burning oil, coal, and natural gas, and on the use of radioactive elements, consumes about USD 2 trillion each year, a figure so high it is hard to imagine the enormity of its grip on all of us.

We seem to have sunk into a false sense of security, continuing with an abusive energy infrastructure that is destroying the Earth and ourselves. We have created for ourselves an "electric jail", being increasingly boxed in by a grid of unsightly, unhealthy power lines and gas stations, and the endless droning on internal combustion engines and other energy-related facilities that litter the landscapes and the skies and the oceans.

These facts have been ignored by our energy policy-makers. We are indeed borrowing the Earth from our children rather than inheriting it from our parents. An ecological consensus is emerging – ***we must stop this and build a sustainable future.***

- Brian O'Leary, Ph.D
- Physicist and former astronaut

A few extracts from the Book: "The Coming Energy Revolution" by Gene Manning.

# TERMINOLOGY LIST

The following terms in this document will have the meaning as assigned to them below:

| | |
|---|---|
| Wind wheel: | The complete wheel assembly of the Windmill. |
| Wind energy pack: | Complete windmill with air receiver. |
| Windmill: | The windmill system without the air reservoir or underground pump. |
| Groundwater pump: | The underground pump inside the borehole. |
| Airlift pump: | The underground pump inside the borehole operating with air pressure. |
| Receiver tank: | The Pressure vessel in which the energy is stored. |
| Air pressure tank: | As receiver tank. |
| Continuous flow: | A system which allows for continuous flow of water from the underground pump, pending air pressure is available. |
| Automated flow: | Once the air supply to the pump is opened, the pump will continuously keep on pumping water, stroke after stroke. |
| Pressure chamber: | Part of underground pump which is pressurized to obtain water lift. |
| Groundwater extraction: | A method of extracting water from a borehole. |
| Whisper valve: | A very sensitive air valve which was used on one of the experimental switching systems during the development of the automated submersible pump. |
| Siphon outlet: | This type of simple delaying mechanism functions similar to a pipe drawing water from a can. The siphoning effect will only cause water flow, once the water level has reached a certain height. This mechanism was pictured in a simple automated switching mechanism. |
| Base Pressure: | This pressure is the total pumping head pressure plus the driving pressure to overcome the losses in the system. It is the minimum pressure required to pump water in specific applications. The base pressure will differ from installation to installation, depending on parameters of the installation. |
| Base charge: | As Base Pressure. |
| Wind Turbulent: | A sudden "side wind" at 90 degrees against normal wind direction. |

# 1 - INTRODUCTION

1.1 Following the positive results and potential identified under project WRC K5/876 for a "Low Cost Airlift Ground Water Pump for use in Rural Settlements", **Green Energy Systems** was contracted by the Water Research Commission to develop a "Continuous Flow Airlift Ground Water Pump for use in Rural Settlements". The development of the Airlift pump for application in rural applications, under project K5/876 identified the need for improvements to the system, which would allow for automated flow of water.

To achieve this automated flow of water, a switching device had to be developed / implemented which would allow the delivery of the pump to be continuous in nature. By automating the pump, it was envisaged that a number of advantages could be achieved from the system i.e.

# - Ability to supply larger volumes of water than the current hand switch system.

# - Potential to store water, both underground and on the surface, if required.

# - Availability of water resources when required in aiding small farming of vegetable patches.

# - Water on demand can be achieved in both domestic situations as well as township standpipes.

1.2 The development of the automated Airlift pump would be complimented by further developments to the compressed air generator and storage equipment. The original prototype was found to be wanting on a number of issues, such as:

# - Vane shape, size and performance (torque transfer) at low wind speeds, in particular.

# - Actuator arrangement in the compressor system

# - Design and size of the air pressure receiver tanks.

# - Safety improvements on the pressure tank.

# - Design features for protection against high velocity wind and gusty wind conditions.

Successful development of the system would allow for use in areas where power generation through the use of diesel or electricity is not practical or affordable. The system allows water to be extracted in conditions where water levels are low and other means of ground water extractions would not be considered as economical.

These would account for situations where the ground water yield is poor and a number of boreholes can be run from a single windmill.

# 2 - BACKGROUND

## 2.1 General

The prototype development of the ground water extraction system was funded by the WRC during 1997 under project WRC K5/876 and culminated in the WRC report No. 876/1/98. Following the finalization of this project the following conclusions and recommendations were identified:

a) To automate the pumping action of the ground water pump.

b) To design improvement features into the windmill system for protection against high velocity wind and gusty wind conditions.

## 2.2 Practical Considerations

A number of practical considerations were identified. These included the advantages and disadvantages of the concept of storage of wind energy as available air pressure in a receiver tank as opposed to the direct storage as water in a conventional water tank.

***Advantages***

a) Insects, vandalism or vermin will not affect the quality of water obtained by the community.

b) Water is not lost from the system by evaporation.

c) Water is only used as required, thus resulting on more efficient usage of the water available.

d) The risk of rural communities contracting diseases from usage of polluted water is avoided. The need for boiling water is also reduced.

e) The windmill can be positioned in a location optimal for the capture of wind, i.e. on top of a hill, whereas the borehole(s) can be situated at a point most convenient for extraction of the ground water.

***Disadvantages***

a) A new system not known to the rural communities, which still needs to find community acceptance.

b) Air pressure leaks are more difficult to control than water leaks.

c) Air pressure tanks are more expensive to manufacture than standard water tanks.

d) Air pressure tanks need to be tested and certified at pre-defined intervals through accredited authorities.

f) Due to the fact that the compressed air used to "push" the water out comes in direct contact with the drinking water itself, a proper filtration system must be installed in the Air-line system to remove hydrocarbons and oil contamination.

## 3 - OBJECTIVES

The principal objective of the research program was to develop a continuous ground water extraction system, which is based on the efficient and safe capture or storage of wind energy. The use of this energy to power the automated continuous flow pump, lifting ground water from suitably located boreholes, and substantial improvements in the wind pack function and mechanism was the main purpose of the extension of the research.

## 4 - METHODOLOGY

The following basic methodology was used in the development and testing of the various systems discussed in this report:

a) All ideas that were tabled by the research team were discussed at regular project meetings and the most promising proposals were taken to a prototype or small-scale development phase.

b) Proposals were weighed in terms of their potential for success, development cost and lack of complexity.

c) Proposals, which were designed on the principal of air pressure operation, were given priority and water volume based ideas were relegated to secondary positions. This was done, as initially it was believed that the air pressure switching system was more appropriate and easier to develop. Eventually the reverse proved to be the case and water volume based switching systems were given priority for development and testing.

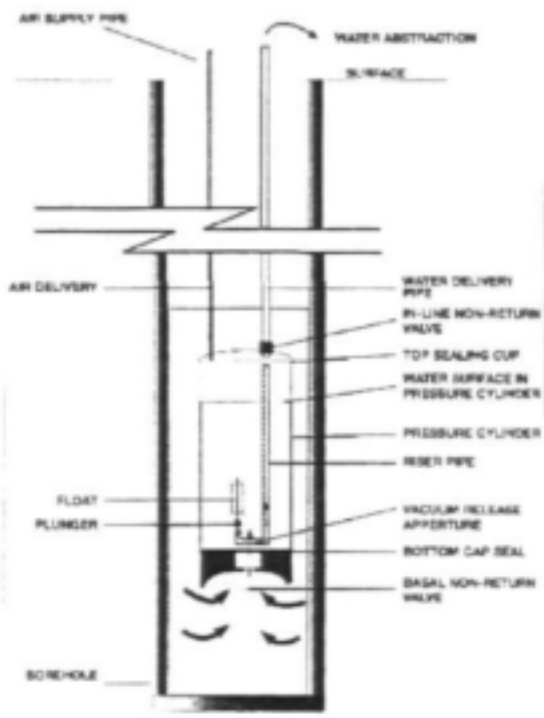
d) The switching systems, which were first developed and tried under laboratory conditions, were installed at a field test facility and tested under controlled conditions. Any changes and/or improvements were recorded for further investigation and comparison with other devices. (See Section 5.2 for more detail on these systems)

## 5 - APPROACH TO THE DEVELOPMENT OF A CONTINUOUS FLOW MECHANISM

### 5.1 Overview of Hand-operated System

The Hand-operated system developed under project K5/876 was of a very simple design, requiring the presence of an underground submerged pressure chamber which was attached to the surface by an air line and a water delivery pipe. The only part visible above the ground level was a three-way operating valve.

The design concept rests basically on the fact that on application of air pressure to the exposed water surface in the cylinder via the air delivery pipe, water is forced out through the water outlet at a rate proportionally equivalent to the applied pressure as per Boyle's Law which states that $P_1 V_1 = P_2 V_2$. Of necessity, this pump is of a two-stroke nature, one to allow water ingress at atmospheric pressure and secondly, on application of air pressure through a hand controlled three-way valve, to extrude the water to the surface




**The detailed operation of this system is documented in WRC Report no. 876/1/98, pages 3 – 10.**

## 5.2 Design Concepts of different continuous flow methods evaluated and / or tested.

A number of methods were conceived and brought to the development and testing stage. The concepts described in this report were chosen as the most potentially feasible from a number of ideas developed at the initial stages of the project.

### 5.2.1. Back Pressure Sensing System

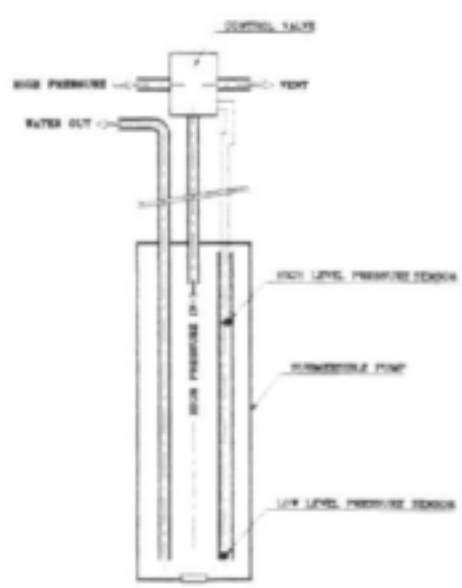


DIAGRAM 5.2.1

The concept behind this configuration was to allow the development of pressure in the air system to the point where the pressure in the air supply pipeline was equivalent to the back pressure created by the full head of water from the base of the submerged pressure chamber.

Theoretically, there is a pressure head difference between the top and bottom of the submerged chamber of approximately 50kPa. The switch function was set to shut off the air supply once this change of air pressure was detected, and then open the supply valve again once all exhaust air had left the submerged chamber signalling that the chamber was once more full of water.

The initial attempts to operate the system failed, because the pressure in the air supply pipeline rose above the switch design pressures in a matter of seconds. This was due to the uncontrolled airflow from the air receiver, which was normally kept at full pressure.

For further tests in this configuration, an in-line needle valve was installed in the air supply line to limit the rate of air pressure delivery, and a standard pneumatic compressor pressure switch was used for the operation of the air valve. The system tended to operate reasonably well, though the rate of water supply was significantly reduced from the expected volumes. The needle-valve tended to "freeze" at the high-pressure settings and thus upset the rate of flow measurements.

Table 1 below presents the volume of water achieved per cycle at a given rate of air supply.

**Table 1:** Airflow reduction versus flow rate with pressure sensing air valve operating switch.

| Air flow setting (as a % of total airflow available) | Water obtained per pump cycle (litres) | Volume of water pumped per hour (litres). (Supplemented by an electrical compressor for air flow on setting 4 & 5) |
|---|---|---|
| Air flow volume 1 (20%) | 55 | 160 |
| Air flow volume 2 (40%) | 50 | 212 |
| Air flow volume 3 (60%) | 15 | 396 |
| Air flow volume 4 (80%) | 10 | 600 |
| Air flow volume 5 (100%) | 5 | 1460 |

This dataset indicates clearly that high flow rates are achievable at the expense of economic air usage. In this case an additional electric compressor was used to achieve these high airflows, and efficiency dropped drastically due to energy losses in the pump. Controlled release of compressed air through a needle valve gave superb performance at the first two settings.

5.2.2. Float Level Control System

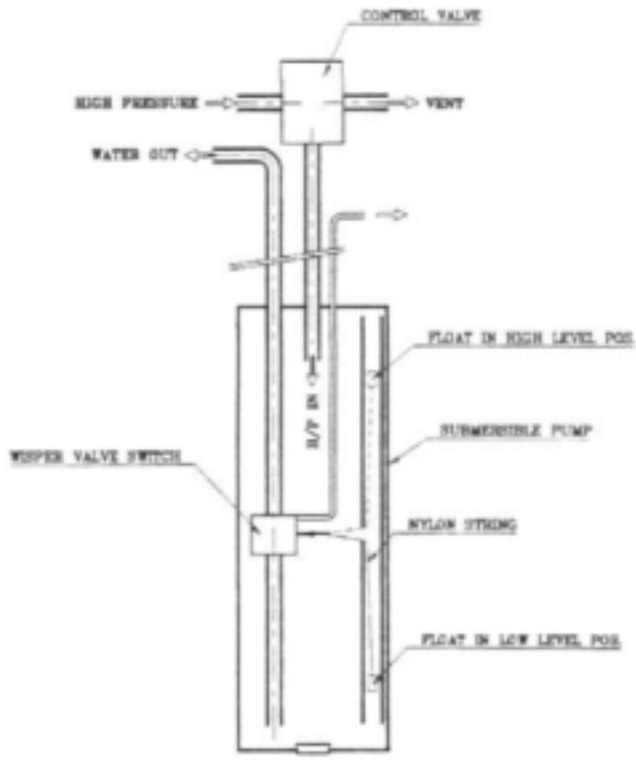



DIAGRAM 5.2.2

A further modification to the automated function of the pressure pump was to introduce a Whisper Air Valve with floats, into the inner body of the air pressure chamber. A Whisper Air Valve is a very sensitive, off the shelf air valve, which reacts on very small force on the leverage arm. This mechanism was never tested fully as the pressure in the chamber caused water to enter into the Whisper Valve resulting in failure of the system.

Basically, the level of the two floats in the pressure chamber were designed to sense the height of the water column and operate the whisper valve on and off accordingly. Problems with the manufacture and composition of the whisper valve for operation in submerged conditions and under constant pressure made these tests impossible. To carry out the tests, the valve would have to have been waterproofed for high-pressure conditions. Its ability to function would then be compromised and not guaranteed.

5.2.3 Magnetic Switch Control on Level Settings

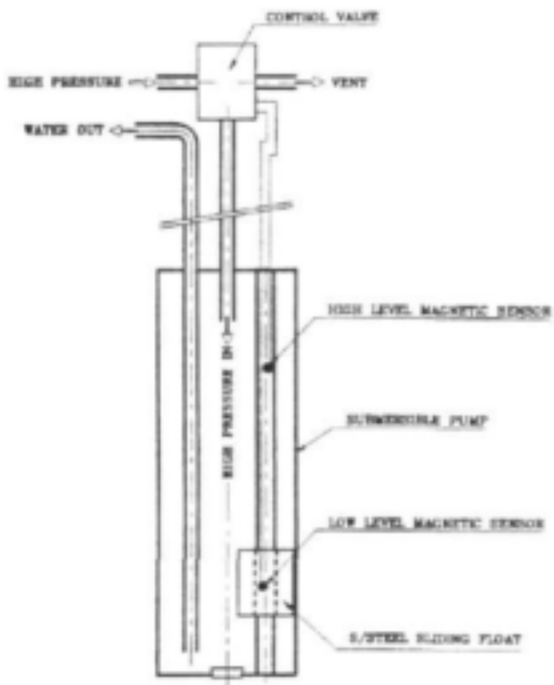



DIAGRAM 5.2.3

This development incorporated a sensing mechanism inside the pressure chamber, which operated a pneumatically operated valve installed on the surface. The sensing mechanism comprised of two magnetic switches installed in fixed positions inside the pump, with a magnet attached to a float acting as the switch mechanism. The switch sends out pneumatic control signals to the surface air valve via small diameter air tubing.

This system initially worked very well. However, the durability was poor, as the magnetic switches situated inside the pressure chamber could not withstand the working pressures inside the chamber and the proto units failed within 2-4 days of operation. This failure was due to water penetrating the inside of the systems through the outer seals which was not designed to work under any outside pressures.

5.2.4 Water Volume Switch "A"

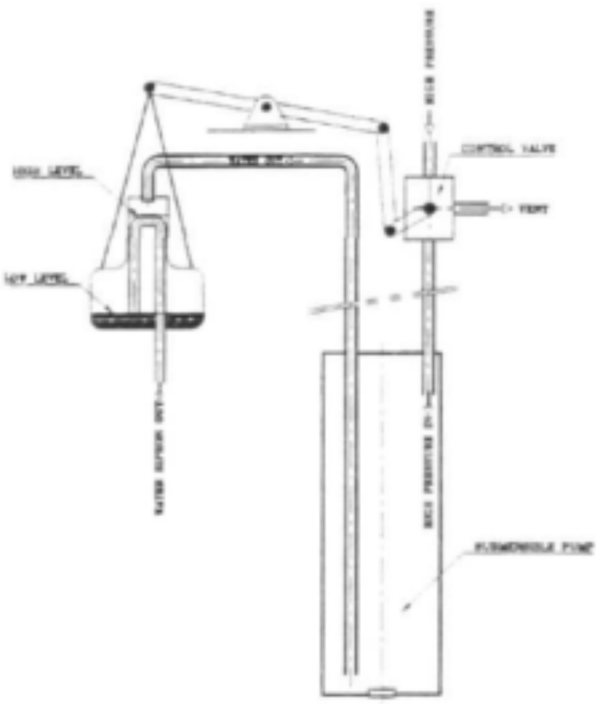



DIAGRAM 5.2.4

This automation configuration is based on the principle of self de-watering of a water container by the action of siphoning from a predetermined water level.

Air supply to the submerged pressure chamber is operated in accordance with the actual volume of water in the water level control tank. In effect the water control tank is the actual sensing and air switching mechanism. The operation of the system is as follows:

1) Water fills the tank up to a predetermined level above the siphon outlet as detailed in the above drawing, and the flow is controlled by float "A" that is attached by a rigid rod to the air valve switch.
2) On achieving the desired water level in the water control tank two goals are met. One, the water level has gone above the siphon activation level, and two, the air valve has moved to the "off" position by the float mechanism. To ensure that these two actions occur, the siphon pipe diameter was designed to be only 50% of the size of the inlet pipe and the top of the water control tank was necked down to allow a fast water level raise at the siphon level.
3) The activation of the siphon action empties the water from the water control tank to the large water storage tank, and activates float "B" mechanism, switching the air valve back to the "on" position, thus repeating the cycle.

The system of siphoning water out of a control tank to operate an air valve worked well when the air supply was at levels high enough to drive water above the siphon level, in the water control tank. In situations when the air pressure decreased (and as such the flow of water) at the point when water was just reaching the siphon level, the system failed. This was due to the inability of water forcing the float to the "off" position as the water leaked out of the siphon pipe faster than the raise in level in the necked portion of the tank, due to the slow rate of flow. Once this occurs, the water level never again rises above siphon level. Eventually, the water in the submerged pressure chamber runs out, the system vents itself and then attempts to fill the tank again.

5.2.5 Water Volume Switch "B"

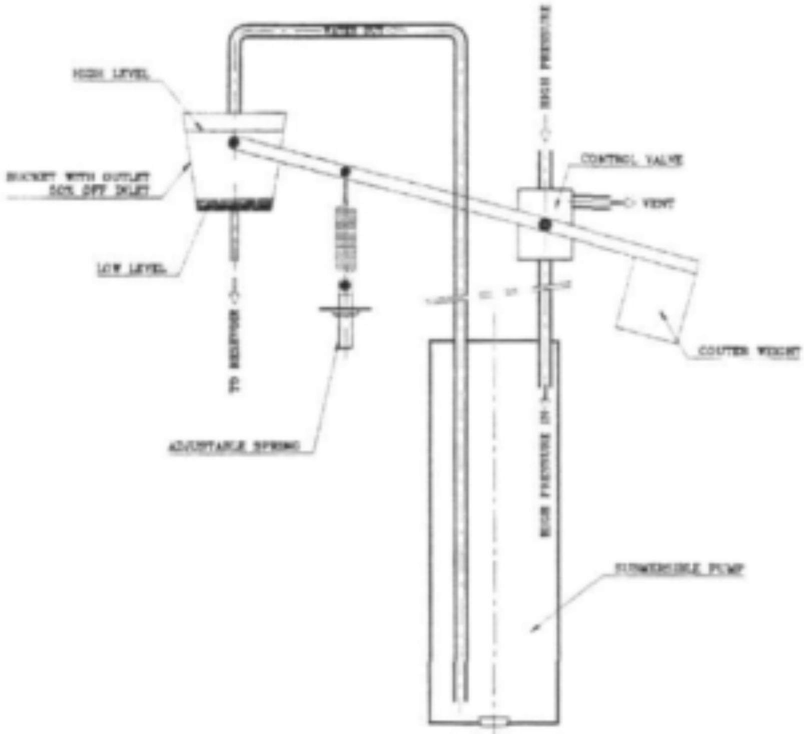


DIAGRAM 5.2.5

A further "water volume control" conceptual automation of the air valve switching device was developed and tested.

This system is based on the overbalancing of a water tank "A", connected via a see-saw arrangement to an air supply valve, "V" and a calibrated weight "W", which in turn has its movement controlled by a spring stopper "S".

This system operated well, in both the high and the low air pressure ranges. The rate of water supplied from this system was a function of air pressure in the air received and the time for the submerged vessel to refill with water. This was a critical function, as the rate of supply of water to the storage tank could exceed the rate of submerged vessel refill, thus reverting to a self-venting situation. Thus, though not detracting from the operation of the pump, as the water tank "A" always returned the air valve to the "on" position by the action of the weight "W", it was not efficient in terms of air pressure losses in the operation of the system.

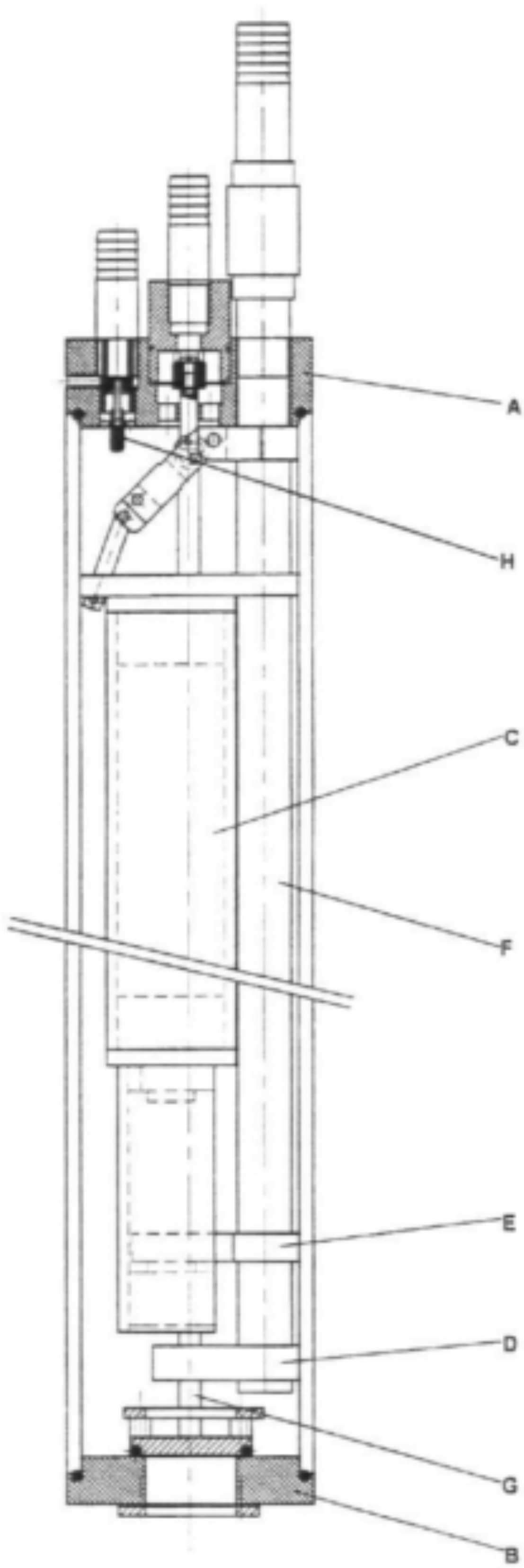
The water extraction process was as follows:

1) Air valve in the "on" position, water tank "A" on the see-saw arrangement fills to a level which exceeds the force exerted by the spring stopper "S" and the weight "W" on the other end of the see-saw.
2) This causes the release of the weight "W" and the fall of tank "A" to the water storage tank. This movement shuts the air valve to the "off" position. Release of water from the tank "A" is enhanced by attachment of a loose cable to the side of the water storage tank, tilting the water tank "A" upside down during its downward travel. This causes the weight "W" to force the seesaw to move in the opposite direction, moving the air valve to the "on" position.

## 5.3 Design of the continuous flow airlift underground pump

### 5.3.1 Pump Design

a) Pump Detail



A - Outlet assembly

B - Inlet assembly

C - Float assembly

D - Magnet holder

E - Outlet pipe support

F - Outlet pipe

G - M10 assembly rod

H - Needle valve assembly

The submersible pump is operated with compressed air. With the needle valve "H" in the "closed" position water is allowed to enter the pump chamber under gravity through the inlet assembly B". Whilst water is filling the chamber, the float assembly "C" rises with the volume of water until it opens needle valve "H" situated in the outlet assembly "A". Once the needle valve is pushed open by the rising float assembly, air pressure enters the pump chamber forcing the column of water to the surface through the outlet pipe "F". During this flow the air pressure closes the bottom valve in the inlet assembly "B". Once the water has been pushed out of the column, the float comes down closing the needle valve which starts the whole operation on a new cycle.

The efficiency factor of this pneumatic driven submersible pump is only 0.455.
Though 300 kPa will lift a head of water 30m high under laboratory conditions, in practice 500 litres of air at 690 kPa will pump approximately 500 litres of water with a 31m lift due to pressure and friction losses in the pump.

Calculation: 690kPa x 500l air x 0,455 = 500l water x 31m lift.

To achieve an automated flow of water, a switching device is used which allows for the water delivery of the pump to be of a continuous nature. By automating the pump, the following advantages are now achieved:

# - The ability to supply larger volumes of water.

# - The potential to store water, both underground and on the surface, if required.

# - Water on demand can be achieved in either domestic water tanks or township standpipes.

The principal of the switching system consists of a mechanical pressure switch situated inside the head of the pump itself. The system releases pressurized airflow into the pressure chamber of the underground pump when the water chamber is filled with water and closes the air pressure inlet port to the pump when the unit is empty of water, allowing the water-head to fill under gravity.

b) Design Criteria

# All parts in the pump are manufactured from either a high composite plastic material or stainless steel. No corroding metal components are used in the pump.

# The positive air valve saves air as it shuts down the air supply as soon as the water inside the pump chamber has been "pushed" out of the system.

# Uses none of the energy source (air) if well pumps dry as the float system will only release the energy once the water chamber is filled.

c) Material used for manufacture

The list of material used in this pump is as follows:

# - **Stainless steel** for the metal parts, such as the valve components, internal outlet pipe, pipe fittings and the threaded-bar clamps.

# - **Teflon and Perspex** used for the fabricated plastic parts such as the valve bodies, supports, activator, o-ring holder.

# - **PVC piping** where standard size piping, such as the float, magnet holders and the body of the pump can be used.

# - **Vesconite** for al the wearing parts in the pump, due to its wear resistance and low friction properties.

# - **Rubber o-rings** for sealing purposes in the pump.

5.3.2 Field data

The best way to record field data was to determine the volume of water pumped from a fully charged pressure tank at a predetermined pressure. The performance of the pump is dependent on the capacity of the air pressure vessel, as well as borehole variables. Expected results for standard size containers were then calculated based on the results from these tests.

| Standard Pressure Vessel sizes (litres) | Water delivered in litres, obtained from standard Pressure Vessels at a Pressure of 700 kPa. | | | |
|---|---|---|---|---|
| | 15m lift | 24m lift | 30m lift | 38m lift |
| 445 | 700 | 500 | 351 | 222 |
| 665 | 1075 | 740 | 536 | 351 |
| 814 | 1221 | 888 | 629 | 444 |
| 1165 (Std Size Vessel) | 1740 | 1277 | 907 | 648 |
| 1850 | 2830 | 2109 | 1517 | 908 |
| 1943 | 2868 | 2127 | 1480 | 1055 |
| 2664 | 4514 | 3182 | 2331 | 1462 |
| 3478 | 5605 | 3960 | 2850 | 1813 |
| 3700 | 5920 | 4181 | 3034 | 1924 |

# The capacity of the pump itself was found to be a max. of 56 litres of water per minute.

5.4 Conclusion

From the results obtained the following trends can be noted:

# - The rate, at which water can be pumped, had an influence on the performance of the pump. It is more energy efficient to pump at slower rates, allowing the driving medium to be used to full capacity.

# - The depth of the borehole has a direct relation with the "base charge" of the container. The deeper the borehole the higher base charge is required.

# - The energy available relates to the difference between the maximum vessel pressure and the base charge required for the specific borehole.

# - System and friction losses due to different pipe configurations also vary, and thus have an effect on the pump performance.

## 6 - OVERVIEW OF INITIAL WINDMILL SYSTEM

### 6.1 INTRODUCTION

The original unit under project K5/876 used a standard rear axle, to bear the load of the wind wheel. The initial motivation for this was that it was a proven design and the parts were available all over the world. Though this axle is not used any more, the criteria to use components that will be available internationally still apply.

One of the safety features that needed attention on this unit was the way to safeguard it against extreme wind conditions, as none was in place in the first units. This had to be addressed in the new design. The rotating table that was used in the first proto-units did not operate as well as was anticipated and therefore the new units now operate with standard commercial units, which turned out to be cheaper than the initial units used.

### 6.2 VANE SHAPE AND SIZE

The system used initially had only three aerofoil type vanes on the wind wheel, and was quite large with a 6m diameter in order to be able to drive the compressor system. The system also had to use a four-cylinder compressor to distribute the load, due to less torque and less momentum from this configuration of wind wheel, especially at low wind speed. A further concern was the speed at which this aerofoil type wind wheel operates, as the system was limited to a maximum rotational speed of 330 rpm. This limitation was due to restrictions on the linear speeds of the components used in the compressor assembly.

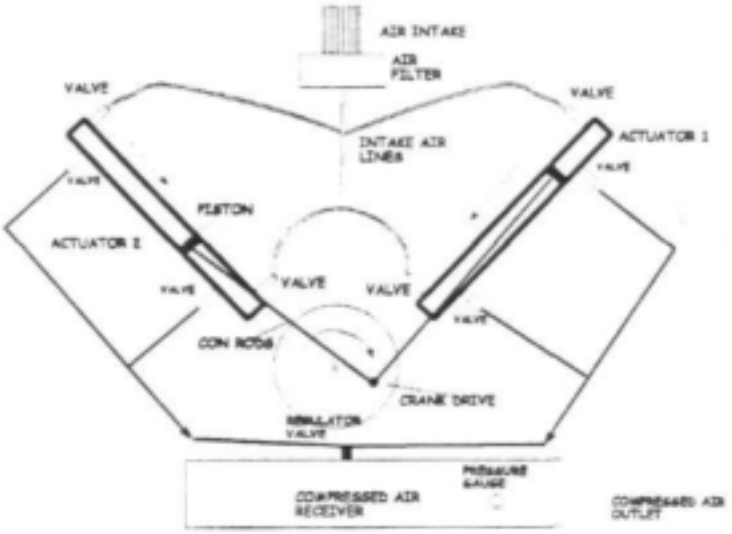
The initial vanes were manufactured from standard pipe, metal plate and wood, which were profiled to the specifications of the NASA and European Wind Association designs for the "new generation" wind wheels. The speed at which this wheel operates was of great concern and other possible solutions were considered. At this point in time it came to the attention of the project team that some research on wind power and especially on the design of wind wheels was done at the PE Technicon. Dr van der Linde was contacted in his personal capacity to clarify whether there were any other developments in the field that could be applied in this regard.

A set of this newly developed wind blades was obtained from the Technicon and tested on the windmill system. Unfortunately the torque transfer at low to moderate wind speeds was insufficient whilst the rotating speed at higher wind speeds was much higher than what the compressor system was designed to operate at.

It is important to realize that most of the available wind energy inland comes in the form of low to moderate winds, and we therefore have to use this most frequently available wind strength to it's full potential. In view of this it was only logical to make use of the well-known and proven multi-blade wind wheel system.

## 6.3 ACTUATOR POSITION AND FUNCTIONALITY

SCHEMATIC OF COMPRESSOR DESIGN



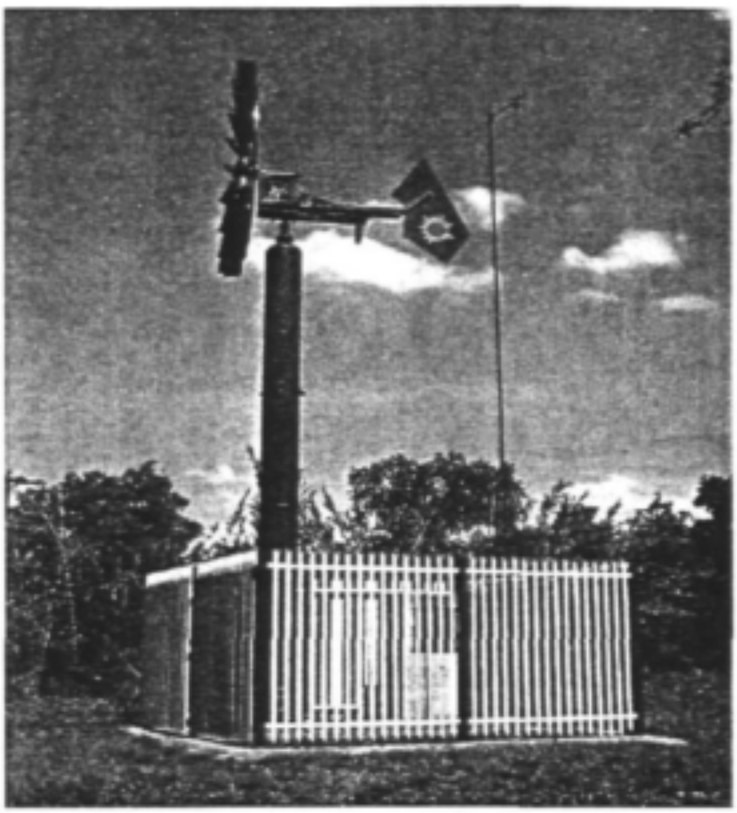

With the wind wheel used not transferring sufficient torque, the double-action actuators used in this compressor were at right angles to get best performance and smooth operation. The idea was to have the power strokes at 90° intervals, and equally distributed in one revolution. It was during this phase and with this wheel not producing the torque needed, that we came upon the idea to provide for a range of actuators with different stroke-lengths and diameters to utilize the wind energy for any given location to its maximum.

## 6.4 SIZE, DESIGN AND APPLICATION IMPROVEMENTS TO THE RECEIVER TANK

The initial pressure tank used was not manufactured and certified through the appropriate authorities, which meant that some of the design parameters were not on specifications. These had to be corrected, and the tank was then re-designed to withstand winds up to 140 km/h, the maximum wind speed recorded in South Africa. With the installation not in a high wind prone area, an acceptable safety margin is acquired. The system was designed so that the pressure vessel forms the mass of the system as can be seen in the picture under section 7 on the following page. The size of the air reservoir was also increased from 1.60 $m^3$ to 3.09 $m^3$. The new tank was constructed to fit onto a single foundation-base, and the three separate foundations of the initial tank were replaced with a single larger foundation. The initial tank had a manual moisture release valve that had to be operated by hand from time to time. This was replaced with an automatic moisture release unit on the new tank.

# 7 - THE FINAL SYSTEM

## 7.1 DESCRIPTION OF THE COMPLETE SYSTEM



The system can be described in two different categories i.e. the Wind Energy Pack and the Submersible Pump system.

### 7.1.1 Wind Energy Pack

a) Main Body.

One of the design criteria identified was that the final design configuration of this energy pack must be very simple mechanical technology and easily maintainable as many of these units will be constructed in rural areas. Therefore the design and construction is based on very simple mechanical technology, with all maintenance components already available nationwide. The basic design consists of a wind wheel, which is mounted on top of a pressure vessel via a rotating table, i.e. the pressure vessel now acts as the mast for the wind wheel. The rotating wind wheel drives the open plan compressor system as is described under section 6.3, which in turn forces compressed air into the pressure vessel, acting as the manageable energy source. A one-way valve situated at the inlet to the pressure vessel allows for maintenance / repairs to be performed on the compressor system without losing any of the already stored energy. (For the purpose of this report the compressor system will be referred to as an "open plan" compressor.

To assure continued ease of maintenance and safety on the pressure vessel system an automatic moisture release-unit has been introduced into the system. This valve allows the system to release water build up inside the pressure vessel on a continuous basis. The compressed air (energy) can be released as and when required from a separate "air-tap". As a standard safety feature a pressure release valve is installed to eliminate the possibility of creating an over – pressure situation.

The compressor system, compressor bed and wind wheel assembly are located on a turntable which rotates on Vesconite bushing that is able to accommodate the lateral pressure forces created. This material is used due to its proven life expectancy in similar applications. The compressed air is channelled through the centre of the turntable into the pressure vessel with sealing obtained through a pneumatic rotation-seal.

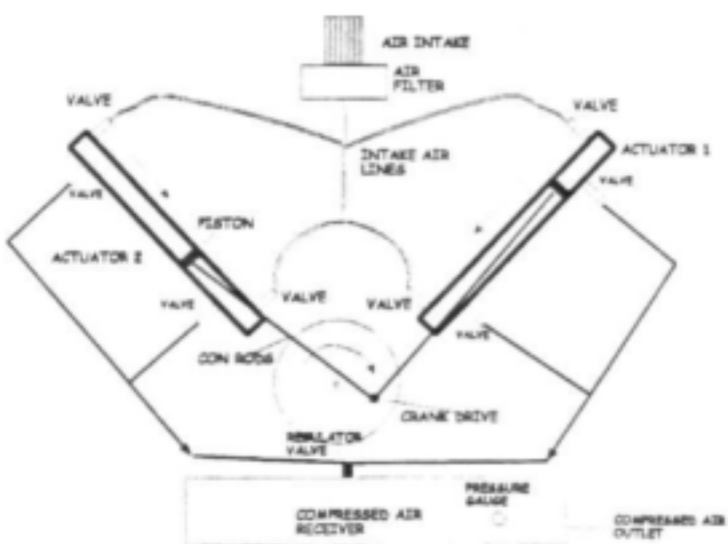
b) Wind wheel

Results obtained from continuous data capture of wind conditions, i.e. wind speed, direction, maximum during gusts etc. by means of an electronic weather station, showed that more free wind energy can be stored under continuous lower wind speeds (>4-6m/s) than those stored under higher wind gusts.

The vane configuration that allows for the most effective torque transfer at low to medium wind conditions is the well known multi-blade system as is found on the standard traditional "American" type wheel arrangement. This system also proves to be a more cost-effective system than the "high speed Aerofoil" systems that are generally used on other products in the 20[th] century wind energy scenario where high revolutions are required for maximum performance such as in electricity generating systems.

a) Compressor System

SCHEMATIC OF COMPRESSOR DESIGN




The compressor system is designed from a double action actuator, which effectively results in two compressor strokes per actuator for each completed turn on the wind wheel. Thus, if two actuators are used it will effectively result in four compression strokes per each completed turn of the wind wheel. This open plan compressor system lends itself to easy and relatively cheap maintenance and repairs. Should one of the actuators fail, the second unit will still be fully functional assuring continued operation of the compressor system.

This unique compressor system has been opted for as different piston diameters and compression stroke lengths allow for an optimum compressor system per wind region.

Specifying the individual parts will assure maximum functionality under different wind conditions.

An in-line oil vapour lubricator, on the intake of the compressor unit, achieves effective lubrication of the moving parts.

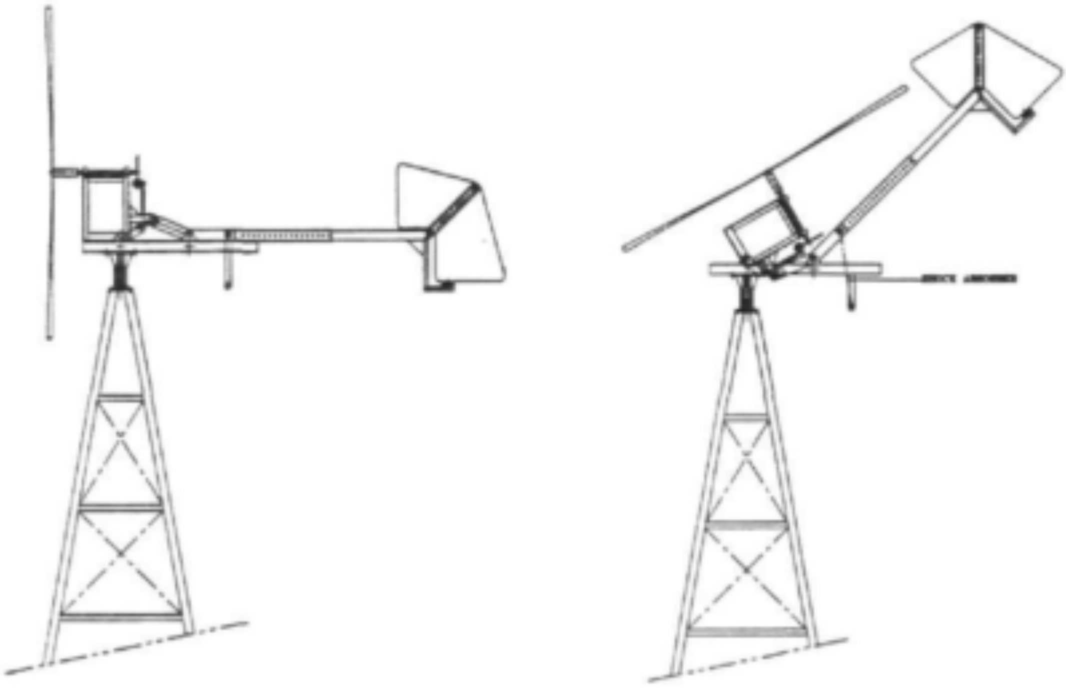
b) Reservoir / Mast

Two systems are identified:

# System 1 is where the reservoir acts as the mast for the complete system. This configuration is mainly used for applications where access to the installation site is possible with a vehicle fitted with a crane.

# System 2 is used for terrain where access is restricted. Here a system is used where the windmill stand is of a four-legged design, similar to the current traditional type windmill stand. In this format loose modules can be applied to the system, allowing for a serial build up to a capacity energy source as required per application.

e) Protection against high speed winds and sudden gusts.



Low wind speed High wind speed

A wind turbulence protection system allows the system to move out of the wind direction in a vertical plane, when high wind speeds or sudden turbulence are experienced. This approach uses a smaller protected sweeping area as the governing action, and with a lifting tail and resultant flagpole mime feature, the "gyroscopic-effect" - which is the main reason for wheel failure on this type of wind wheel, is eliminated due to the ability of the complete system to adapt to these severe conditions.

This self-protection system acts as a second line of precaution as the wind wheel used has been designed to reach a maximum revolution of max 120 rpm, whilst the compressor unit can operate comfortable up to 330 rpm.

f) Safety features

The following safety features have been designed into the system:

- A one-way valve situated in the inlet section of the reservoir allows for maintenance and repairs to be performed on the compressor system or wind wheel without losing any of the already stored energy.
- A pressure release valve, set at 8 – 12 bar max, is installed in the air line between the compressor and the one-way valve which eliminates all possibility of a potentially dangerous over-pressure.
- A water-trap or water bleeding point is installed at the lowest point in the air tank in order to drain all moisture that accumulates due to the compression of the air. This water-trap is also designed to blow a release point should the system at any stage over-pressurize.
- A blow plug that blows out, releasing the pressure safely, if the pressure exceeds the set pressure due to any unforeseen reasons.
- The moisture release and the main air supply valve are situated at the bottom of the reservoir inside the stand where it can be locked up.

## 7.2 EXPERIMENTAL RESULTS AND CAPACITIES OF PUMPING SYSTEM

In order to perform controlled tests on the wind wheel performance, a controllable wind supply was required. This was achieved by constructing a mobile laboratory on the back of an open truck, with the wind wheel itself situated in front of the cab of the truck.

With this installation the wind speed could be controlled and subsequent comparisons between the wind speed and wind wheel rotation could be logged. This test was performed by driving the vehicle at a speed where the rotation speed on the wind wheel was logged against the specific ground speed of the truck.

Furthermore, by charging the pressure vessel manually, the backpressure on the compressor piston could be simulated to obtain different data points against fixed backpressure conditions.

The raw data from these tests are as follows:

7.2.1 Equipment used:

a) Data Logger: Davis Weather Wizard III

b) RPM Logger: Smith ATH4

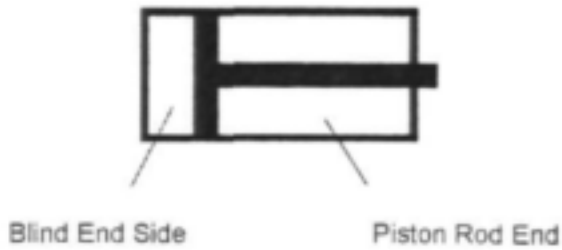
c) Compressor detail: Double acting with diameter 32mm and stroke 200mm

7.2.2 Data Recorded

| Back Pressure from Vessel | Wind Speed at which Wheel Rotation commences (m/s) | RPM of Wind Wheel at different Wind Speeds (m/s) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2 m/s | 3 m/s | 4 m/s | 5 m/s | 6 m/s | 7 m/s | 8 m/s | 9 m/s | 10m/s | 11m/s |
| | | | | | | | | | | | |
| 0 kPa | 0,9 | 21,0 | 29,1 | 43,7 | 58,2 | 72,8 | 76,0 | 88,9 | 97,0 | 113,2 | 129,4 |
| 200 kPa | 1,6 | 17,8 | 27,5 | 38,8 | 46,9 | 63,1 | 72,8 | 88,9 | 97,0 | 113,2 | 129,4 |
| 300 kPa | 1,8 | 14,5 | 30,7 | 42,0 | 53,9 | 67,9 | 80,9 | 85,7 | 97,0 | 113,2 | 129,4 |
| 400 kPa | 2,0 | 16,2 | 25,9 | 38,8 | 54,9 | 67,9 | 80,9 | 88,9 | 92,2 | 113,2 | 129,4 |
| 500 kPa | 2,2 | 0,0 | 32,3 | 45,3 | 58,2 | 71,2 | 80,9 | 97,0 | 97,0 | 113,2 | 129,4 |
| | | | | | | | | | | | |

In order to calculate the true performance of the pump, we calculated the volumes of the free-air displaced by the actuator for one turn of the Wind wheel.

Results as follows:




a) Volumetric displacement of the actuator at Blind End Side:

$V_1 = a_1 \times l$ where d = actuator diameter and l = stroke length

$= \pi / 4 \times d^2 \times l$

$= \pi / 4 \times 0.032^2 \times 0.2$

$= 0.161 \times 10^{-3}\ m^3$

b) Volumetric displacement of the actuator at Piston Rod end:

$V_2 = a_2 \times l$ where $d_1$ = actuator diameter and $d_2$ = shaft diameter

$= \pi / 4 \times (d_1^2 - d_2^2) \times l$

$= \pi / 4 \times (0.032^2 - 0.012^2) \times 0.2$

$= 0.138 \times 10^{-3}\ m^3$

c) Total volumetric displacement for one revolution of the Wind wheel:

$Vpump = V_1 + V_2$ ( V pump depends on actuator size)

$= 0.161 \times 10^{-3} + 0.138 \times 10^{-3}$

$= 0.299 \times 10^{-3}\ m^3$

This results in to 0.299 litres of free air per rotation.

d.) Formula for water delivery at different depths.

According to Boyle's law ($P_1 V_1 = P_2 V_2$), there is a direct relationship between pressure and volume.

The height of the water column (pumping head height) in the piping of the borehole induces a pressure (Ppumphead) on the pressure chamber.

Assuming that the total head to lift the water is 35 m, the pressure induced will be 3.5 atmospheres. To overcome friction, spring loads in valves and other energy losses, we need to add another 0.7 atmospheres (Pdrive) for driving the water out of the pump and along the pipes. A pressure of 4.2 atmospheres is required for the pump to start delivering water above ground as Pdelivery = Ppumphead + Pdrive.

The delivery rate can be increased by inducing more driving pressure (Pdrive).

*If this is applied to Boyle's law, the water delivery for each turn of the wind wheel is:*

$$V_2 = (P_1 V_1) / P_2$$

Vwater = (Pfree x Vpump) / Pdeliver

e.) Water delivery for every turn of the wind wheel.

Vwater = (Pfree x Vpump) / Pdeliver

$= (1 \times 0.299 \times 10^{-3}) / 4.2 \quad m^3$

$= 0.071 \times 10^{-3} \ m^3$

This means that every rotation of the wind wheel will pump 71 ml of water under these conditions, when connected directly to the pump.

f.) Formula for water delivery by the pressure vessel system.

This whole scenario changes when the pressure vessel is incorporated into the system. Energy can then be stored in a manageable way, and this works very similar to making use of a battery, as the battery also has to be charged. However, all the compressed air that was stored cannot be used to extract water from the borehole. Only the available air above 4.2 atmospheres can be used as this is minimum pressure required to pump water.

Therefore:

Pworking Vtotal = Ptotal Vtotal - Pdeliver Vtotal where Vtotal = constant

Thus $< P$ = Ptotal - Pdeliver

and the water that can be pumped from the stored compressed air is:

V water = (< P x V total ) / Pdeliver

Where < P depends on the maximum system pressure,

V total depends on the total storage volume of the installation,

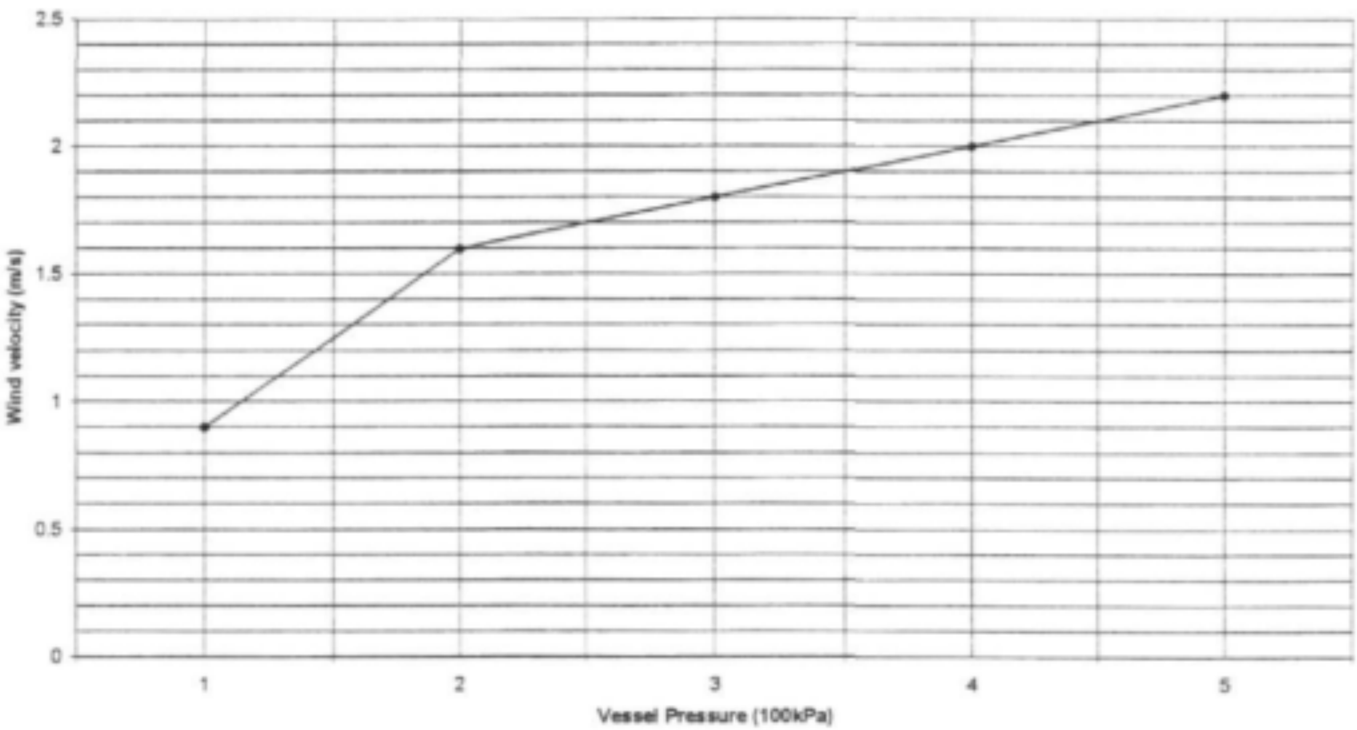
Pdeliver depends on the borehole parameters and installation conditions.

From the data presented under section 7.2.3, it can be seen that the influence of the backpressure is minimal, and that a mean value can be derived to work from at different wind speeds. For illustration purposes, the values at thirty kPA backpressure are used.

7.2.3 Data calculated:

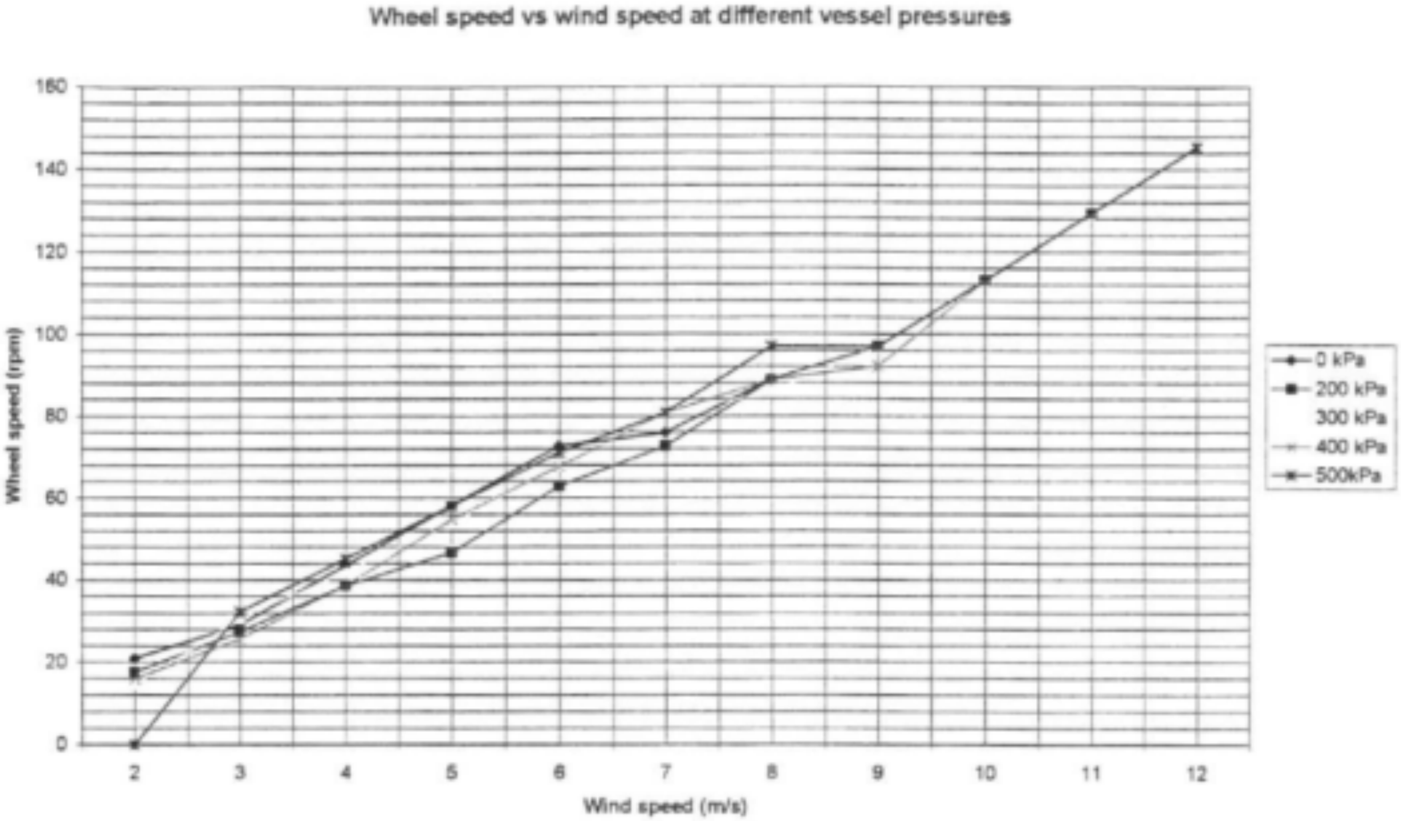
a) Influence of backpressure on start-up speed.

**Influence of vessel pressure on start-up speed.**




As can be seen on the graph, a drastic increase in wind speed for start up is required due to the low energy density at low wind speeds. Subsequent to this, it only requires 0,2m/s to overcome another 100kPa in vessel pressure.

b) Wheel speed vs. wind speed at different vessel pressures.

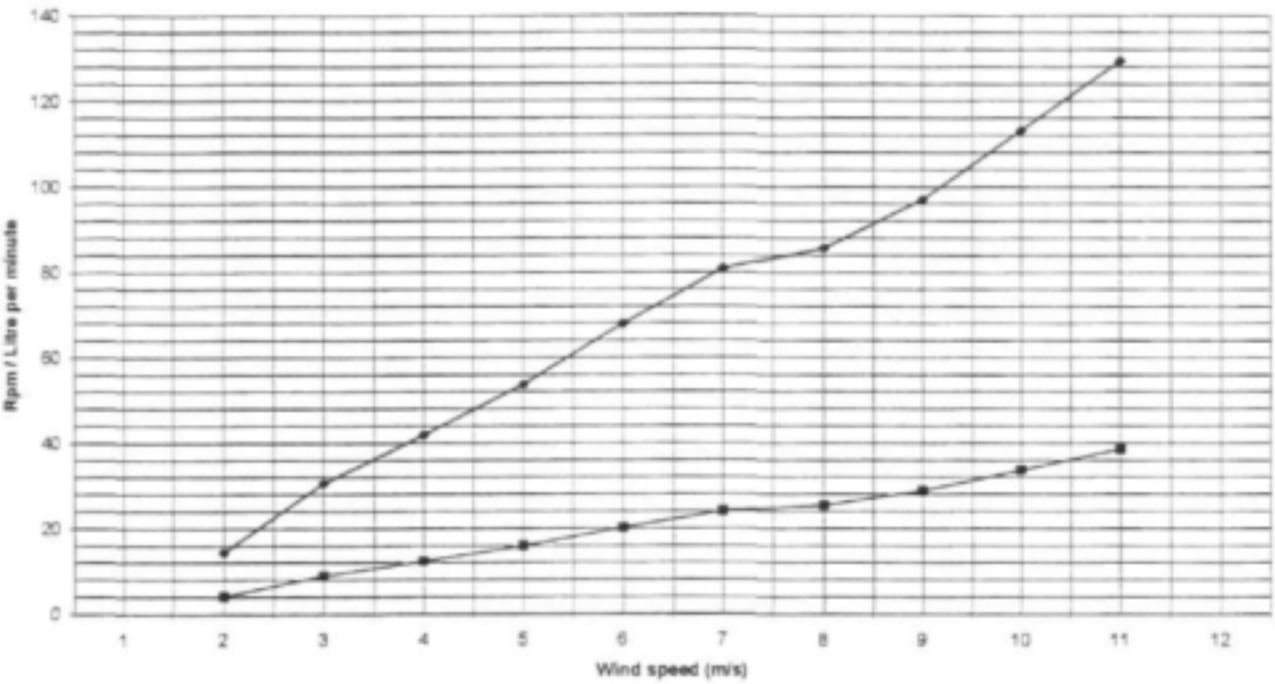



The linear tendencies of the graphs indicate that vessel pressure has no major effect on the relationship between wheel speed and attributed wind speed. The unstable area between 8 and 9 m/s could be contributed to a number of conditions. These could be the inner diameter of the pipe used in the compressor system, the turbulence created in the turning pane of the wind wheel or the thickening flow pattern of the air stream over the truck cab.

It can also be seen on the graph that the highest vessel pressure needs a start of speed of higher than 2m/s.

c) Volumetric air displacement at 300 kPa backpressure

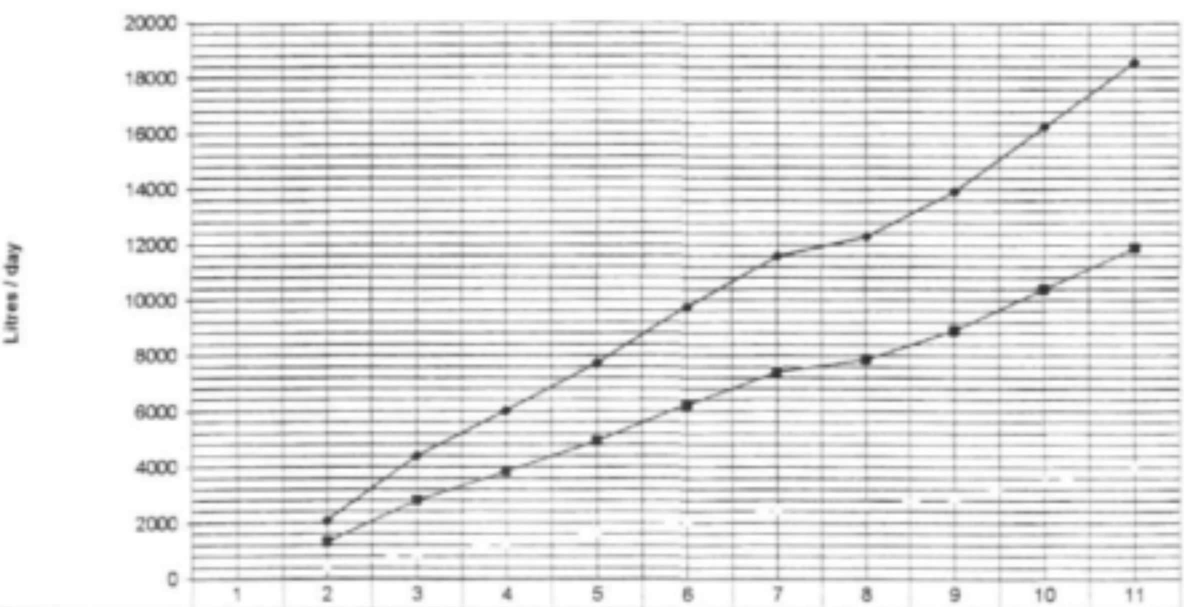
Volumetric air displacement at 300 kPa vessel pressure




This graph indicates the irregular effect of 300kPa backpressure on the volumetric displacement of the compressor at different wind speeds. The netto effect is not very large but is still indicated.

d) Water displacement at wind availability

Water displacement at wind availability



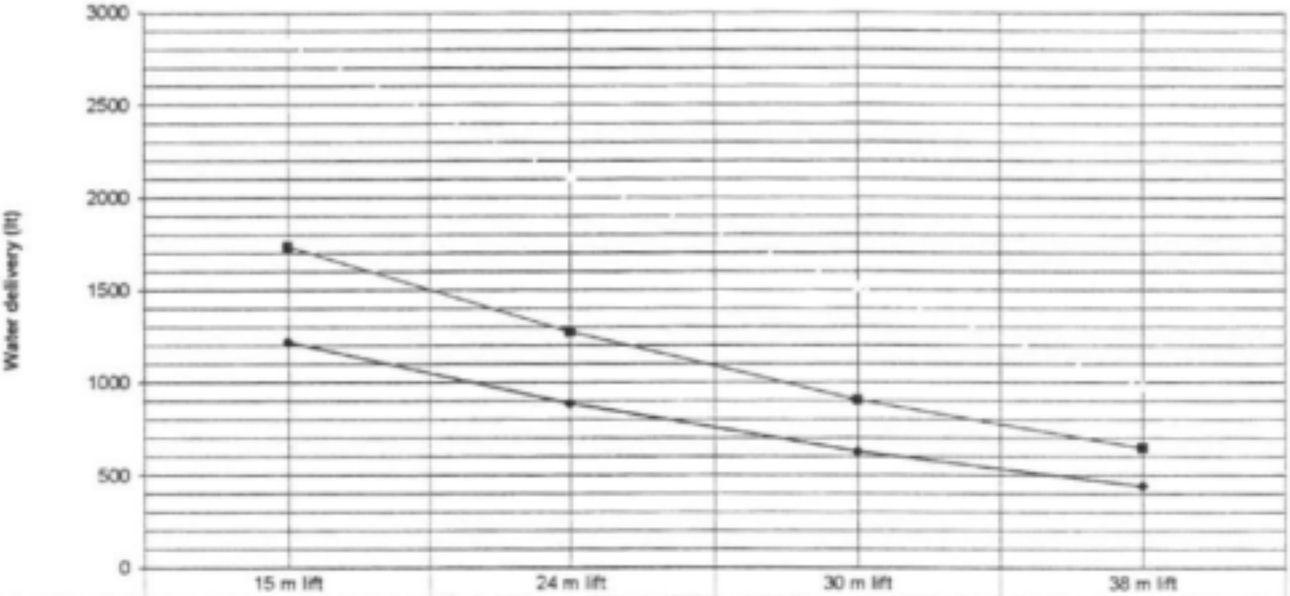

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Daily air volume(lt) at 3 bar | | 2088.914 | 4410.409 | 6035.599 | 7731.137 | 9749.703 | 11607.47 | 12303.78 | 13928.97 | 16250.46 | 18571.96 |
| Daily waterdischarge at 15 m lift | | 1337.11 | 2823.094 | 3863.375 | 4948.686 | 6240.766 | 7429.921 | 7875.625 | 8915.906 | 10401.89 | 11887.87 |
| Daily waterdischarge at 30 m lift | | 446.1406 | 941.9546 | 1289.055 | 1651.18 | 2082.296 | 2479.07 | 2627.784 | 2974.884 | 3470.698 | 3966.512 |

Wind velocity (m/s)

This graph indicates the effect of different borehole depths on water displacements as mentioned in section 5.3.2. The effect of the unstable area found on previous graphs is still visible in this data set.

e) Capacity of the submersible pump at 700 kPa charge

**Capacity of the submersible pump at 700 kPa charge**




| | 15 m lift | 24 m lift | 30 m lift | 38 m lift |
|---|---|---|---|---|
| 814lt vessel | 1221 | 888 | 629 | 444 |
| 1165 lt vessel | 1740 | 1277 | 907 | 648 |
| 1850 lt vessel | 2830 | 2109 | 1517 | 980 |

Ground water level (m)

This graph indicates the effect of vessel size and base pressure on water delivery, the base pressure being the minimum pressure required in the pressure vessel to pump water. Pumping capacity is the difference between the maximum working pressure in the vessel and the base pressure required to pump water from a specific borehole depth.

## 7.3 ADVANTAGES OVER OTHER SYSTEMS

Wind energy was first utilized through the use of the well-known water-pumping windmill system as it is generally known throughout the world. This design had been left unchanged and unchallenged for centuries where it is generally accepted as the ultimate free energy water pumping system. However, this design is mainly a one-function system that can only be utilized for the pumping of water from a borehole situated directly below the wind-driven system. Maintenance of this system is an expensive drawback where repairs usually result in a time consuming exercise with rigid piping being pulled to the surface before the main pump element can be reached. This task might be required when performing minor repairs or when replacing pump seals etc. which subsequently results in maintenance being a costly, time-consuming and labour intensive exercise.

To date, the main development in the field of power generation by means of wind energy, was dominated by generating direct current, which is then stored in deep cycle batteries. This power is converted into alternating current by means of an electronic converter, and fed into a utility grid.

These batteries need to be replaced at regular intervals, and repairs on the electronic systems can only be done by skilled personnel. All these drawbacks add up to very high operating - and maintenance cost over the lifespan of such a system.

It is because of all these drawbacks of the existing systems that we have come to the conclusion that, although wind-energy in general is relatively cheap compared to other energy forms, there is a definite need for improvement of the current systems in operation.

## 7.4 SPECIFIC ADVANTAGES OF THE GES-PUMP SYSTEM

For the benefit of the reader, the advantages of the system are summarized as follows:

### 7.4.1 Multifunctional

The wind pack can be used to pump water, but can also be used for other applications. With the pressure vessel at pressure one really has a "raw" energy source which can be utilized as required.

### 7.4.2 Possibility to automate the system

System can accommodate a setting sequence where it can either pump a specific volume of water at a specific time-setting or alternatively pump for a pre-set duration at a predetermined set time.

### 7.4.3 Resistant to normal element damage

The safety features incorporated in the pump are such that the pump will become inactive when the wind conditions are not favourable. This will prevent the pump from over-speeding as well as protect the system from excessive forces due to the gyro-effect. This is possible because the wind acting on the front of the wheel pushes the wheel into an almost horizontal position when the wind force becomes too great. The wheel moves back into the original position as soon as conditions become favourable, as a result of the gravity forces acting on it.

### 7.4.4 Can serve multi-borehole system

The wind-pack can be constructed on an advantage point where wind volume is maximum. From here the single energy system is able to supply up to three different boreholes in the adjacent vicinity. With the principle of the pump being activated through a float control, a "slow yielding" borehole, which under normal circumstances is not usable can now once again be utilized to capacity, since "slow" boreholes improve over time when pumped continuously.

### 7.4.5 Only minor maintenance required

This system is designed in such a way that it is basically maintenance free. The only standard maintenance function is the filling of the oil vapour reservoir and greasing of the rotating parts. All these functions are scheduled during the routine inspection of the pressure vessel.

7.4.6 Used in conjunction with submersible pneumatic pump that is basically maintenance free

The submersible pump only has a few o-rings that make up the wearing parts of the pump. The rest of the system parts are made up of various plastics and stainless steel components. The gliding guide in the pump itself is manufactured from poly-propylene, gliding on a stainless steel riser pipe. This pump is very close to being maintenance free.

7.4.7 Does not have to be erected on borehole but rather at optimum wind position

It is well known that wind speeds are affected by the local topography of any terrain. A good knowledge of these effects can be used to ones advantage when placing wind turbines. The system's ability to be located away from the borehole to take advantage of these features enhances the performance of this system. (See insert from Diab.)

7.4.8 Functional at very moderate wind availability

The adaptability of the system regarding the optimization for every wind region and site, is a major improvement on the performance of the system. This means that the system can utilize the maximum amount of wind available in a region, even though it might be of moderate strength. Energy that might have been lost in cases where the pump is in a safe position can now also be captured due to the systems ability to store the energy in the form of compressed air.

7.4.9 Major components available off the shelf

This system was designed with the consumer in mind, so that the wearing parts are available as part of the existing international product range of a leading supplier.

7.4.10 Power failures / Theft of power cables not a factor

The theft of copper wire is a problem facing at the authorities on a national scale. This leads to the interruption of many services at huge costs, annually. As high density polyethylene piping is used to transfer the energy in the form of compressed air to the pumps, theft is not such a huge factor in this case.

7.4.11 Individual optimization for specific site variables.

One of the strongest claims for this system is the individual optimization for every wind area. This means that the system can be optimized for every individual installation to utilize maximum available wind, whilst other site conditions such as the topography allows for optimum performances. This is possible due to the various actuators with different diameters and stroke-lengths that can be fitted to the compressor. The rate, at which water is pumped, can also be pre-set, so that water yield can be set to what is optimally required.

# 8 - DISCUSSION OF RESULTS

## 8.1 Production cost

The production cost for a standard size unit with a 1000 litre air reservoir will be in the region of R 35 000,00. Every additional borehole supplied from the same Windmill System will be at an on-cost of approximately R 5 000,00. (This cost is based on year 2001 prices).

If we consider a system with one borehole-pump delivering an average capacity of 1800 Kl per month at an approx. market value of 50c/ Kl, then the system will pay itself off in 38 months. If a second borehole is serviced from the same Windmill the system will be able to pay itself off in as little as 22 months.

Please note that these calculations assume that enough wind is available to keep the system fully charged up for 75% of the time.

## 8.2 Efficiency

To calculate the exact efficiency for a specific application can be treated in a number of ways. It can be a simple calculation when seen as an isolated system, or it can be an elaborate exercise when all the parameters are taken into account. A holistic approach would be the safest option, measured against what other systems would require to do the same work. This would mean that an electric motor turning the same shaft than the wind wheel, would use the coal that was burnt to create the energy to turn the motor, together with all the energy losses down the line in the system, in the efficiency calculation. It happens so often that these losses are overlooked, and we then indicate working solutions to be inferior options.

This same holistic approach brings us to the point where we have to decide where efficiency ends and mechanical dependability begins. The view that these two factors are interrelated makes good sense. A system cannot be efficient if it is not dependable and a system that could be maintained by the people who use it, sounds a lot more efficient than a dependable one that runs out of fuel from time to time. Down-time and expensive repairs are part and parcel of this efficiency-equation, and potable water is the result.

Various energy losses between the components of the system are usually a point of discussion under this heading, but it would be appropriate to mention the counter actions instead, which minimize these inefficiencies:

# - This system can make use of topographic advantages, to utilize the available wind-energy to the full

# - This system can be optimized to utilize the mean annual wind speeds where other windmills cannot operate at. In other words, this system can be optimized to use the available wind most effectively. This means that very low wind speeds that could not be used previously can now be applied effectively.

# - The system has the capability of storing the wind's energy, and pump water when it is needed.

# - This system can pump slow yielding boreholes that could under normal conditions not be used before.

# - Unlike other systems, this system can pump from more than one borehole at a time

When the available energy in the wind is logged, it is clear that most of the energy is available at very low wind speeds, and the system was designed to utilize this low speed energy. By doing this, the system can harvest more of the winds energy than other systems on the market. This in turn allows the system to pump more water over a period of time than what other machines are capable of. To express this utilization of low speed wind-energy as a percentage is possible, but it is also relative because every installation would have its own percentage utilization of the available wind conditions. The same installation can also utilize both the topographic advantages as well as the best water position in the area.

There are other systems on the market which will work more effectively under certain conditions, just as this system will function more effectively under a variety of conditions.

## 9 - CONCLUSIONS AND RECOMMENDATIONS

The following conclusions are reached:

a) The continuous flow groundwater pump developed in the course of this project functions fully satisfactory when installed in boreholes at water depth up to 70m.
b) The wind pack compressor allows for sufficient storage of usable energy, which can be used for acquiring groundwater.
c) The maintenance on this system is easy and comprehensive even to unskilled people.

The following recommendations are made:

a) The system operation needs to be fully tested under rural conditions to ensure equipment robustness and potential for wide spread use.
b) It seems that the system was over-designed to some extent and production costs can be reduced.

Successful application of the GES PUMPING SYSTEM allows for use in areas where power generation through the use of diesel, paraffin or electricity is not practical or affordable. It also lends itself to the development of ground water resources in areas where ground water exhibits poor conditions, and where other means of ground water extractions would not be considered economical. These would account for situations where the ground water yield is poor and a number of boreholes have to be run by a single windmill installation to achieve the desired water delivery capacity, and where other means of extraction, such as electrically driven pumps, are too expensive to consider.

Water is a basic necessity to all living organisms, whilst consumption is a reflection of different lifestyles where each person's use varies with habit, culture, climate and the basic availability of this precious product. Third World villages consume as little as 40 litres per person per day because water must be pumped by hand and often carried some distances. Urban dwellers may use three times as much as Third World villagers, because water is often more plentiful. According to field tests by the United Nations the total average water requirement per person is 40 litres for Third World Villagers and 100 litres for Third World Urban residents.

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Annexure

COPIES FROM THE BOOK

"CAPACITY BUILDING FOR TECHNOLOGY TRANSFER"

AS

SUPPLIED WITH THE DRAFT-FINAL REPORT

# 8

# Capacity building for technology transfer[1]

*Ajay Mathur*

## Scope and context

The transfer of environmentally-sound technologies (ESTs) from the industrialized to the developing countries has come to be seen as a major element of global strategies to achieve sustainable development (UN 1992) and climate stabilization (FCCC Secretariat 1992). It is also recognized that the effective transfer of such technology will require substantial upgradation of the technological capacities in the developing countries, as well as a deepening of the content of technology transfer (UN 1992). The central technology transfer issue within the context of the United Nations Framework Convention on Climate Change (UN FCCC) is to provide a direction to the technology cooperation between enterprises in developing and industrialized countries that leads to the greater adoption of ESTs in the developing countries. This paper seeks to provide the conceptual framework and to suggest strategies for moving in that direction.

## Constraints to the effectiveness of technology transfer

The empirical evidence relating to the effectiveness of technology transfer suggests that the considerable trade in capital goods between the industrialized and the developing countries has not resulted in

[1]This is an abridged version of the book *Capacity building for technology transfer in the context of climate change*, brought out by TERI, New Delhi for the Third Session of the Conference of the Parties (COP-3), at Kyoto.

concomitant increases in productivity or in corporate and research capacities for technology management. In the context of climate change, this shortcoming could become a major constraint; if newly-transferred low or zero greenhouse gas (GHG) technologies fail to perform adequately, the anticipated GHG emissions reduction would not be achieved.

This possible inadequacy necessitates an examination of the reasons for this shortcoming, and addressing interventions that can upgrade the quality of the technology transfer process. Our emphasis here is on highlighting institutional processes and capabilities that need to be strengthened in order to make the most effective use of the technology transfer process, which is, at the core, still seen as a private transaction between two enterprises – one, a technology developer (the majority of whom are located in the industrialized countries) and the other, a technology user (of whom those in the developing countries are of central interest in this paper). An evaluation of the accumulated technology transfer experience indicates two major lessons.

> First, that developing-country enterprises are unable to effectively exploit the diversity of available technological options and services.

In most enterprises in developing countries, technological change decisions occur when the current technology approaches the end of its productive life. The immediate objective in decision-making is to seek a replacement technology, which, it is hoped, is more productive than the dated vintage being retired. In most cases, enterprises again approach their previous technology partners; active market research for identifying new technologies, and for evaluating them, is generally limited because of the high transaction costs involved.[2]

> Second, the transferred technologies seldom reach the designed operational efficiencies, and often deteriorate significantly over their productive life.

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[2] In a major review of technology transfer, Hoffman, Garvin (1990) conclude that much of the responsibility for the lack of effective technology transfer lies with recipient governments and enterprises which failed to demand the transfer of specific skills at the managerial and higher technical levels.

The inadequacies of the technology selection and adaptation processes lead to sub-optimal performance. Often, the technologies are not designed or optimized for the raw material available, for the quality of power, or for the product quality required by the market. There may also be a mismatch between the maintenance requirements and capabilities, and between the financing requirements and revenue flow patterns over the economic life of the technology.[3] Technological adaptation and troubleshooting is limited, since repeated access to the technology supplier is expensive in terms of time and effort (though not necessarily in terms of its direct costs).

To a large extent, both these problems stem from the high transaction costs associated with the development of human capabilities to manage and generate technological change.[4] The lack of these capabilities imply that technology assessments and negotiations are, every time, a one-off affair. Consequently, the lessons learned from the evaluation of options, the continuous assessment of technological development, the internalization of performance results of new technologies at various locations around the world, etc. are infrequently available when the next round of technological choice decision-making is in progress.

Similarly, the lack of an interface between operators (who are at the technology performance forefront) and the technology suppliers (who have the capability to address and resolve the operational problems) leads to inefficient performance and gradual deterioration. At the same time, the lack of adequate and appropriate indigenous research, design, and development capabilities imply that the enterprise has to depend on the (high-cost) technology supplier for troubleshooting and upgradation needs.

[3] For example, a comparison of the performance of new classes of thermal-power generation units in India and in Britain indicates that average availability initially increases in both countries, and stabilizes about 10 years after the installation of the first units. However, the stabilized values were about 10% less in India than in Britain (Mathur, Bhandari 1993).

[4] This concept has been developed in a particularly powerful manner in Bell (1990) and Bell, Pavitt (1992).

> The need for local technology adaptation is crucial. Its absence would dilute and dissipate strategic interventions for controlling GHG emissions. The immediate imperative is to enable the development of local capacity for the management and generation of technological change. We believe that the international institutional and financial mechanisms associated with the climate change process need to internalize this imperative.

## Strategic interventions for capacity building

The effectiveness and sustainability of technology transfer requires the strengthening of two crucial elements of the process. These call for the provision of support to user-enterprises to:

- facilitate the evaluation of technological options in the context of their own identified needs; and
- access knowledge-based skills to address local adaptation and upgradation needs.

## Assessment of technological options

The conventional approach to this information gap has been the creation of databases listing available energy-efficient ESTs. Typically, such databases contain information about the approximate costs and efficiencies of these technologies. However, the utility of such a database to an enterprise is rather limited. In its early years, Technology Information Forecasting and Assessment Council (TIFAC) functioned as a technology and expertise database, but experience indicated that such a technology information clearing house had limited demand.

> Consequently, the facilitation of the evaluation of technology requires Technology Assessment Support (TAS) services that develop expertise in specific sectors of industry.

On interacting with a client enterprise from a new industrial sector, TIFAC initially learns from the enterprise; this knowledge is, in turn, utilized to access more information based on their contacts and networks. In the assessment of options, TIFAC again works with the enterprise; the objective is to evaluate the technological fit between the available options and the needs of the enterprise, as well as the technological development/adaptation needs associated with each technological option.

This reflects the importance of a continuing interaction between TAS services and the enterprise during the evaluation of options. We believe that to be effective, TAS has to be able to provide an evaluation that meets the specific needs of the enterprise. This necessitates that TAS should be available as a user-based service, rather than a technological information database.

Over a period of time, as TIFAC's expertise in certain sectors has grown, it has sought to proactively influence all enterprises in that sector. These activities, under the rubric of technology missions, seek enterprises as partners to demonstrate new technologies (which have been previously adapted by, may be, one enterprise in the sector), and then to seek its active dissemination through technology suppliers and developers. Within these missions, TIFAC has also sought to engineer innovative financial mechanisms. These mechanisms unbundled the risks associated with new technologies; one approach is for TIFAC to initially fund technology development and demonstration, with the enterprise repaying this investment as the benefits of the new technology start flowing in.

Within this model, a financial corpus for the TAS, therefore, becomes necessary, if it is to be proactive. This corpus would provide the initial support to the activities of the TAS itself as it enters new areas, and spends much more time and effort on learning than can be recovered through user-charges from its clients. In the climate change context, with the broad array of user sectors, and the rapid technological advancements in each sector, the learning phases in the activities of TAS would be significantly high. This can place a large demand on the corpus. The corpus could also provide capital for technology adaptation and troubleshooting support in activities related to the demonstration of new technologies.

The TIFAC example illustrates one institutional model for TAS where the same organization provides assessment and demonstration support. Within the Climate Convention perspective, a formal TAS component could accompany Global Environment Facility (GEF) or Activities Implemented Jointly (AIJ)/Joint Implementation (JI) projects. This component would aim at ensuring that adequate and appropriate support for the adaptation and adoption of the EST transfer is provided.

## Provision of knowledge-based skills for effective technology adaptation and upgradation

The absorption of new technologies in developing-country enterprises is often constrained by the lack of indigenous skills to adapt the technology to local conditions. The small-scale enterprises such as foundry and glass sectors urgently need technological upgradation, primarily to address local environmental concerns, as well as to enhance energy efficiency (which would lead to GHG emissions reductions as well). Internationally, the state-of-the-art technologies available in these sectors cannot be utilized by these enterprises because they are inappropriate in terms of size and operating needs. This lack of technological packages implies a need to engineer appropriate packages.

The Tata Energy Research Institute (TERI)-Swiss Agency for Development and Cooperation (SDC) projects have sought to develop appropriate packages through the utilization of state-of-the-art knowledge. International experts in these sectors have worked with local small-scale enterprises, fabricators, and engineers for adapting current design and operating practices to meet local needs. Demonstration units, installed in enterprises identified by local industry associations, are being utilized to enable state-of-the-art knowledge transfer to these sectors.

In the current TERI-SDC model, the beneficiary enterprises will repay the cost of the demonstration units as they gain viability. However, the costs associated with knowledge-transfer and programme development processes are supported by the SDC. In the Climate Convention context, the TERI-SDC knowledge-transfer model provides an institutional option for addressing the technology-transfer needs of smaller enterprises that have limited engineering capabilities. The large numbers of such enterprises across all non-Annex I countries implies a large potential for this model to be effective in mitigating GHG emissions.

The TERI-SDC knowledge-transfer model can be utilized both for multilateral (GEF) and bilateral programmes for GHG mitigation. It could be effectively combined with a line of credit for the dissemination of the technological package developed through the knowledge-transfer process. It also builds up linkages between engineering and research organizations across countries, which can then collaborate in the third world countries as well.

The Ecofrig project illustrates technology adaptation in the large industry. The refrigerator manufacturers in India are currently faced with technological choice decision-making in the context of the globalization of the Indian economy, as well as the requirement for the ozone depleting substances (ODS) phase out. The industry has been evaluating non-ODS alternatives, both for foaming and for refrigerants. In both cases, the industry faces a choice between a (better developed) technology based on a chemical substitute, and a (developing) technology based on a hydrocarbon substitute (which has a much lower Global Warming Potential than the chemical substitute).

The Ecofrig project has built a partnership between the Governments of India, Switzerland, and Germany to provide a framework for collaboration between private and public enterprises and organizations in these countries. The project's explicit goal is to facilitate the development and adaptation of hydrocarbon refrigeration technologies in India. However, because of the public-private partnerships, it has helped in the creation of capacity to assess, evaluate, adapt, and monitor technological change within the sector. This has occurred because of linkages both between private enterprises in India and Germany (through which detailed information on technology characteristics and performance has been transferred), as well as between research organizations in these two countries (which has helped in building up the capabilities to design and test the new technology). These linkages have enabled Indian research organizations to provide support to Indian private enterprises in optimization and troubleshooting as they adapt the new technologies.

Experience indicates that the capacity building to manage and generate technological change requires a broad-based structure that brings stakeholders together, as well as creates new stakeholders (e.g., research organizations) who have a vested interest in continued technology development.

> The addition of the knowledge transfer component (to the traditional technology transfer component) ensures the short-term adaptation of the technology; but more importantly, in the long term, it creates the partnerships (and the vested interests) for continuous incremental innovations.

This partnership, beyond the short term, is based on mutual benefits. However, in the short term, the creation of infrastructure for adaptive research and for initiating knowledge transfer, requires a structured programme and financial support.

At the sectoral level, such interventions lead to a deepening of the industrial structure. We measure this depth by the capacity, ability, and opportunity for enterprises to access skills and expertise for technological adaptation and upgradation from other specialized organizations, rather than having to build them all up themselves. Such depth promotes both productivity and quality, thereby providing a strong incentive for individual enterprises to invest in continuously ongoing innovation.[5]

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[5]Athreye (1996) concludes that the lack of industrial deepening, along with the regional fragmentation of markets, has reduced both the scope and the need for technological learning in the Indian mini steel industry.

## Conclusions

The effectiveness of technology transfer is essential for the stabilization of global climate change. The major constraints to effectiveness today lie in the high transaction costs associated with the development of capacities and capabilities to manage and generate technological change. Due to these high costs, developing country enterprises tend to ineffectively exploit available technology options, as well as to inefficiently utilize the transferred technologies.

This paper identifies two kinds of interventions to promote the creation of these capacities and capabilities. The first is the establishment of Technology Assessment Support services which would respond to technological-change needs within developing-country enterprises, and, later, initiate such changes in other enterprises in that sector. The second is to establish public-private partnerships across countries to promote knowledge transfer (in addition to traditional technology transfer), thereby addressing the short-term need for technological adaptation and troubleshooting, and providing the long-term capacity for technology innovation. This would provide the much needed support to the developing country enterprises to participate in technological partnerships on a more equal basis.[6]

It must be emphasized, however, that we see both these interventions as being need-driven, and incremental in nature. They do not seek to either supplant the traditional technology transfer processes (which should, for economic efficiency reasons, continue to be private transactions between two enterprises), or to establish open-ended support mechanisms.

Within each intervention, the operationalization would be initiated by the involvement of currently interested parties. The partnership would be later expanded to bring in new organizations (from both the developing and the industrialized countries) that can enhance the technology absorption process. In this expansion, due attention is to be paid

[6]The need for more equal partnerships is effectively made by Barnett (1993).

to ensure that adequate and appropriate interests are created so that the technology upgradation process can continue beyond the life of the intervention.

The diversity of capabilities within developing-country enterprises would imply that different enterprises would require different kinds of support from these interventions.[7] This also necessitates that the interventions must be flexible enough to accommodate differing needs. It has been brought out earlier that we view high transaction costs as the major constraint to capacity building in developing-country enterprises. We believe that within the existing GEF and AIJ/JI processes, strategically-configured and need-driven interventions are essential for overcoming this constraint. The inclusion of key stakeholders in the interventions presents a major challenge to institutionalizing the adoption of ESTs. These stakeholders include investors, corporate managers and entrepreneurs, engineering designers, and technology consultants. Each of these stakeholders is already in the energy-technology business. The design of the GEF and AIJ/JI projects has to ensure that the interests of each stakeholder increase as they support the adoption of climate-friendly technologies.

The interventions broadly include three components: a motivational push – largely through public policies and regulations; an information assessment support system; and a pull provided by knowledge-based experts, who seek opportunities to exploit their skills. Typically, international agreements or national energy-environment considerations drive governments to establish the necessary rules that provide the motivational push. However, bilateral/multilateral interventions explicitly need to recognize the two latter components.

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[7]During the implementation of the Montreal Protocol ODS phase out, it was found that the large refrigerator manufacturers did not need help in identifying or assessing new technologies. Their main need was for knowledge-based support to carry out technological evaluation (including pilot-plant operation) before they decided on new technological choices. On the other hand, in the fragmented commercial refrigeration sector, with many small-scale enterprises, the greater need has been for basic operating information (including design rules, servicing practices, equipment needs, etc.).

A mix of national, bilateral, and multilateral financing is required to support these interventions. This financial support would be used for:

- initiating dialogue and establishing partnerships between private enterprises and research organizations in developing and industrialized countries;
- enabling knowledge transfer to the developing-country enterprise;
- provision of troubleshooting support to technology demonstration projects; and
- providing lines of credit for the large-scale deployment of new technologies.

Finally, such interventions have to ensure that they meet an explicit need (which may, at times, be unvoiced, but should be distinctly identifiable); involve the appropriate stakeholders; create adequate physical and human infrastructure within the enterprise and in supporting organizations to address technology development and adaptation needs; and most importantly, enable the institutionalization of the technological upgradation process within the enterprise and the host of supporting organizations.

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