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DESIGN AND FIELD TESTING OF A REVERSE OSMOSIS DESALINATION PROTOTYPE COUPLED TO A WINDMILL

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1.0 INTRODUCTION

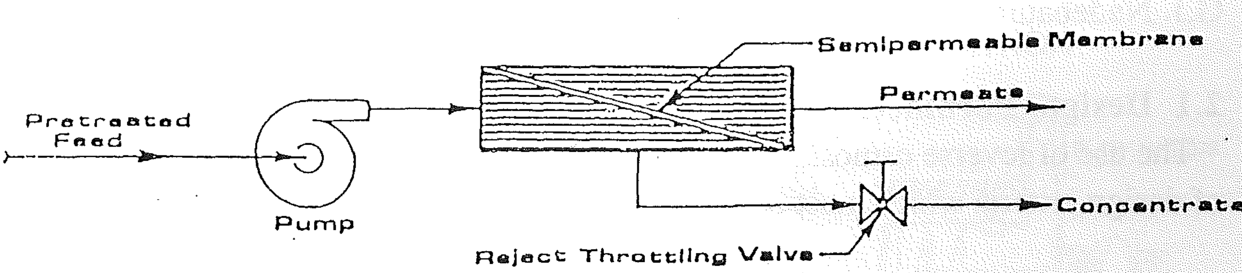
This project is a collaborative venture between a company working with reverse osmosis membrane systems, Memtec Ltd (formerly Osmotron Pty Ltd), a windmill manufacturer, W.D. Moore and Co and the Department of Aboriginal Affairs with matching funding from A.W.R.A.C. It has resulted in the development of a prototype design of a pilot scale windmill pumped reverse osmosis desalination system which is presently undergoing evaluation at Murdoch University. This system has the potential to fulfill the requirements of reliability, small size and low energy input suitable for remote area use.

At the time of this report, the unit has been run from July 1988 for 13 months, yielding 5280 hours windspeed and direction input data, and desalinated water output data. The analysis of the data has commenced and will be completed by approximately November this year.

1.1. Reverse Osmosis Systems

A simplified flow diagram of a typical RO system is shown in Figure 1. Pressure is applied to the feed stream by a pump, producing product water (permeate) and concentrated brine which are continuously rejected.

FIGURE 1- TYPICAL REVERSE OSMOSIS SYSTEM



Permeate flow is proportional to the driving pressure across the membrane. Salt flow is independent of pressure and is a function of the difference in dissolved salts concentration across the membrane. A particular membrane can be assigned a specific 'rejection ratio'- the percentage salt reduction achieved as the solution passes through the membrane. The main components of a reverse osmosis system are:

(i) Pretreatment - generally consists of a cartridge of self-cleaning filters ranging from 1-20 microns depending on input water quality, to remove gross particulate matter, colloidal and polyelectrolyte flocculated material, and organic compounds which may shorten the life of the membrane through fouling. A set of filters should operate for around 6 months before a decline in performance is noted, if the pretreated feed is low in suspended solids (Belfort, 1984). An activated carbon filter may be included to remove organic materials or chlorine to which some membranes are sensitive. With proper pretreatment a membrane should last 2 to 4 years (Fell, 1985).

(ii) Pump- Generally a high pressure positive displacement pump is used to provide constant pressure feed to the system at a pressure specified to give greatest system efficiency.

(iii) Reverse Osmosis membrane- Two types of membrane are commonly available- the cellulose acetate and polyamide membrane. This thin sheet of membrane is attached onto a permable backing and is usually wound into a spiral configuration, ensuring a series of passage stages of the input stream through the membrane. Each has relative merits in terms of longevity, sensitivity to bacterial and oxidant attack, to fouling, pH and temperature variables.

2.0 REVERSE OSMOSIS UNIT FOR REMOTE AREAS

Potential markets exist for small low energy desalination units in remote, unpowered and often unmanned locations. Consultants suggest that up to 60% of the market for desalination systems is located in such areas (Barr, G.J. Nadebaum, P.R. and Camp Scott Furphy Pty Ltd, 1985).

2.1 Design Parameters

The use of reverse osmosis for remote area water purification generates a set of design criteria which must be catered for. This includes:

- the capacity to produce water of sufficient quality and quantity to satisfy demand. Product water should be less than 1500 mg/l total dissolved solids of which sodium content should not exceed 300 mg/l, fluorides 5 mg/l and nitrates 100 mg/l (as NO_3). Quantities required are in the order of 500-1000 litres/day for a typical remote community of 50 persons (Robinson,1988).

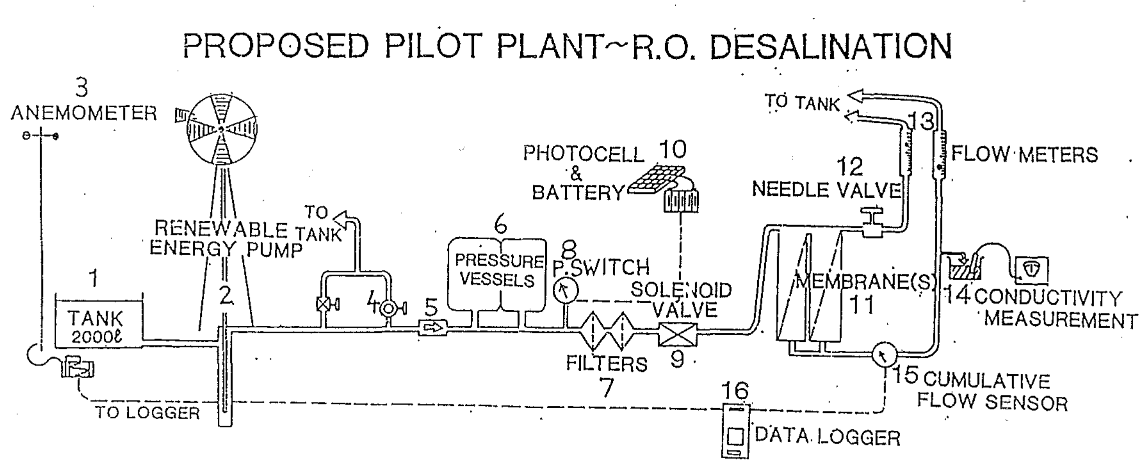
- capital and running cost which is affordable by small communities and comparable with the cost of water supply by alternatives such as water carting.
- both mechanical and electrical maintenance should be low and chemical maintenance must be minimal.
- the system should operate automatically, starting up and shutting down as demand requires. It should be designed to shut down in case of malfunction, thus limiting damage to system components.
- the system should be easy to repair, utilising modular replacement parts which can be installed easily by untrained people if required.
- the system should function with low power requirements, preferably using renewable energy pumping systems, given the lack of available, reliable power on site.

The design of the system fulfilling these criteria depends upon sacrificing high efficiency by using lower input feed pressure with subsequent lower recovery ratio and salt rejection, with the benefits of lower fouling incidence and lower total energy input requirements (Swinton, 1985).

2.2 Prototype Design

A plan for a prototype model was developed jointly with Memtec Ltd, illustrated in Figure 2 and described overleaf.

FIGURE 2- PROTOTYPE LOW ENERGY REVERSE OSMOSIS SYSTEM FOR REMOTE AREAS:



1. **Tank with raw input water-** A 2000 litre tank supplied the pump through an artificial borehole from which the feed pump draws. The input water concentration was 5000 mg/l T.D.S.

2. **Renewable energy pumping system-** The pumping system required would be able to draw water from the required depth and supply this to the pressure vessels within the range of 600-1200 kPa plus line losses. The additional energy requirement of the membrane is in the order of 100 Watt according to previous testing (Robinson, 1988). This pump would operate during periods when energy is available from the appropriate source. During times of low energy input and high demand, a small diesel or portable gasoline pump can be activated to run the system. It is envisaged that the RO unit may be linked in with existing windmill/auxiliary pump systems or M.U.E.R.I remote area power supply systems already in place in some remote communities (James *et al*, 1983).

3. **Anemometer-** Wind speed and direction was measured using a V.D.O. anemometer which was been calibrated and fed data to the datalogger.

4. **Over-pressure valve-** A Delevan pressure-relief valve was incorporated to allow over-pressure to be diverted.

5. **Non-return valve.**

6. **Pressure vessel(s)-** The ideal characteristic for a RO unit is that a liquid be delivered above a minimum specified flow rate and pressure for a minimum length of time, requiring some system of energy accumulation. Hence a pneumatic pressure vessel, or more than one in parallel, is used to act as an hydraulic accumulator, analogous to the function of batteries in a photovoltaic system. Water is stored under pressure, then released when a pre-set pressure is reached, to generate flow to the membrane within a suitable range of flow and pressure for a suitable period of time. The system then recommences the pump-up phase. The particular pressure vessel under test was the Davey Supercell 8 high pressure model, delivering 38 litres at a maximum pressure of 1100 kPa.

7. **Cartridge Filters-** Suitable cartridge filters in the 5 to 10 micron range are recommended by most manufacturers, depending on the input water characteristics. If organic material is present, an additional activated carbon cartridge filter will be required.

8. **Pressure switch-** To regulate the discharge cycle from the pressure vessel, a valve is required to switch on and off at appropriate pressure settings. The switching mechanism, a Klockner-Mueller pressure switch, was controlled by the pressure within the system itself, and was adjusted to the most suitable range to suit the RO membrane requirements, in this case a switch-on pressure of 1200 kPa and switch-off pressure of 600 kPa.

9. Solenoid valve- The pressure switch activated a solenoid valve, in this case a 12 volt Honeywell stainless steel valve.

10. Photocell and Battery- A Solarex 42 Watt solar panel was connected through a voltage regulator to a deep-cycle 12 volt battery to power the solenoid valve.

11. Reverse Osmosis Membrane- The membrane opted for in this prototype was the Desal 3VLP membrane, which is specified for low pressure, lower salt rejection characteristics. This choice of membrane enabled the comparatively low pressure, low flow delivery of renewable energy systems to be utilized for effective desalination and removal of nitrates and fluorides from bore waters. The lower recovery ratio and salt rejection rates specified, 15% and 91% respectively for 2000 mg/l NaCl, compared with values of 50% and 98% for normal RO desalination membranes. Nitrate and fluoride rejection rates averaged 65% and 78% respectively for a 15% recovery ratio (Robinson, *unpubl. tests*). The use of several membranes in series or parallel can be made to enable tailoring of the RO component to the pressure and flow delivery of the pressure vessel and pumping components.

12. Flow Regulation Valve- This valve, which restricted flow in the reject stream of the RO membrane, determined the system pressure and flow of the permeate and reject stream. This was pre-set, and periodically adjusted to optimize the recovery ratio and minimize fouling potential of the system. Ideally the recovery ratio should be constant; this was not the case as pressure and flow delivery from the pressure vessel was variable.

13. Flow Meters- Visual determinations of the flow rates of permeate and reject streams were taken using Osmotron variable area flow meters.

14. Permeate concentration measurement- Conductivity measurement was taken using an on-line sensor and a Phillips conductivity meter.

15. Cumulative flow sensors- Signet flow meters were linked to both permeate and reject lines, giving both instantaneous and cumulative flow readings for these streams.

16. Data Logger- a Unidata logger stored inputs from wind measurement and flow measurement instruments. This was unloaded and analysed on a computer program at the University.

3.0 TEST SITE SURVEY AND DEVELOPMENT

The choice of the test site was based on the offer by a windmill manufacturer, W.D. Moore and Co. to supply the use of a windmill, anemometer and solar panels on their site near the University. The site had some restrictions in terms of 'clean' wind around the windmill, and the anemometer and monitoring equipment required servicing and in some cases replacement. It was decided that the convenience and cost savings of this offer outweighed the other option of constructing a windmill and monitoring system on a better site at the University.

3.1 Site Survey-

Standard procedure to determine the site characteristics for windpowered apparatus involves a topographic survey and measurement of all natural and constructed obstructions to the wind flow at the site. A plane table and clinometer were used to map the site and height readings corrected to the standard height datum point.

3.2. Determining Usable Wind Sectors

The site features obstructions which caused errors in the wind flow measured by the anemometer and that actually experienced by the windmill. This was due to two factors:

- Turbulence in the air flow;
- Obstruction of the anemometer by the windmill and tower.

These factors eliminated certain directional sectors of the wind which were discarded when processing data from the anemometer.

3.3 Storage and Retrieval System

The wind speed and direction and outputs of the prototype have been logged automatically for retrieval and analysis. The data was monitored by meters which were linked to a Unidata storage module. This was unloaded every twenty days on to a VAX 2000 mainframe computer. All values entered into the Datalogger were integrated over ten minute intervals, giving readout files of minimum, maximum and average values for the parameter measured.

3.4. Logsheets

In addition to the information logged, logsheets were filled out, giving information on the total reject flow for a period (usually one week), and instantaneous figures for permeate/reject and overpressure valve flows for a given input pressure. Other information of value includes a totalized number of pump strokes of the windmill, feedwater temperature and wind/weather conditions at the time of reading.

4.0 FIELD TEST RESULTS

The prototype commenced operation on July 18th, 1988 with a launching by the Minister for Aboriginal Affairs and Water Resources, Ernie Bridge. The unit has operated continuously since then until its de-commissioning on the 26th of August, 1989- 13 months operation. During that time some 220 days or 5280 hours of usable data has been logged and stored for analysis. At the time of this report, the analysis of data has begun. The final field trial report will be complete by approximately November this year.

4.1 Prototype Operation

During the period of operation certain faults and difficulties occurred with the system, requiring modifications and/or repair. This is an integral part of the protoype development. Table 1 gives a breakdown of the repair and replacement requirements of the system.

Major problems encountered with the operation of the unit were mainly those of inappropriate component selection. A 24 volt ex-irrigation solenoid valve originally opted for due to its cheapness proved short lived and prone to sticking under test conditions. When replaced with a Honeywell stainless steel solenoid valve, no further problems were encountered. Likewise, cheap tubing for feed and reject lines proved prone to algae blockage and deterioration under sunlight. Black UV-resistant lines will alleviate this problem. A chronic problem encountered with the reject flow meter proved to be due to an ant infestation in the main circuit board of the control box, which appears to have corroded the unit sufficiently to require it be replaced. This problem occurred later with the power supply transformer- a valuable lesson anyone using field testing equipment!

Overall, the prototype appears to have performed reliably over its 13 months of operation, requiring only one change of cartridge pre-filtration, and one R.O. membrane service. Overpressure valves required two services, as did the solar charging setup. The pressure vessel performed without fault or servicing requirements.

TABLE 1-Fault Diagnosis and Repair for the R.O Prototype:

Date	Fault description	Repair
19/9/88	No signal from flow meter	Power board component replaced
4/10/88	Anemometer signals inaccurate	Replaced anemometer cicuit/cable
17/10/88	Datalogger fault	Diagnosed &replaced at Unidata
28/10/88	Leaks around visual flow meter	O-rings replaced
9/11/88	Leak in screen prefilter	Replaced with high pressure model
5/12/88	Overpressure valve stuck	Replaced spring and O-ring
14/12/88	Solenoid valve inoperative	Resoldered wiring connections
9/1/89	Anemometer readings inaccurate	Relubricated bearings,recalibrated
13/1/89	Solenoid valve inoperative	Replaced
9/2/89	Reject meter inoperative	Reconnected wiring, recalibrated
24/2/89	Solenoid valve inoperative	Replaced
	Solar battery charger inoperative	Replaced- fault in curcuit
22/3/89	Solenoid valve inoperative	Replaced with Honeywell solenoid valve
3/4/89	Reject meter inoperative	Recalibrated
10/4/89	Reject meter inoperative,	Readjusted, recalibrated
	Overpressure valve leaking	Replaced O-ring seals and springs
17/4/89	Excess pre-filter resistence	Replaced pre-filter cartridges
3/5/89	Reject meter inoperative	Ants nest in control box ! Cleaned.
	Excess algae in feed/reject lines	Flushed out
	R.O. Membrane cleaned and re-seated.	
30/5/89	Reject meter still inaccurate	Disconnected-suspect damage due to ants
6/6/89	Permeate fitting disconnected	Replaced tubing due to UV deterioration
14/7/89	Battery charge low	Relocated solar panel- obstructed.
22/8/89	Meter power supply failure	Replaced- damage from ant infestation.

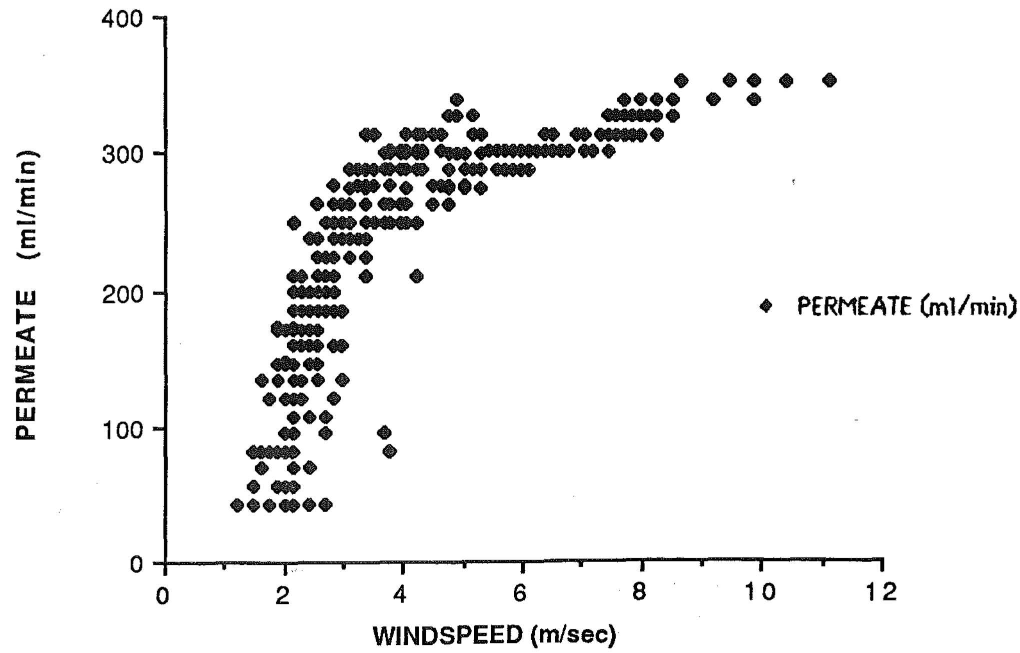
4.2 Data Retrieval and Analysis

Once data is gathered on the inputs and outputs of the system, statistical analysis of the data files should provide a range of production rates and quality of desalinated water for each average velocity of windspeed at each level of feedwater salinity. These values will be used to predict the production and quality of desalinated water given the groundwater characteristics and average windspeed at various potential locations in W.A. using wind distribution patterns determined by the W.A. Wind Atlas Project presently being prepared at Murdoch University's Environmental Science School (due for release 1990).

4.3. Data Analysis

Initial analysis of one of the 26 data files logged from the field unit gives some estimate of the system performance under one set of performance conditions. This data was summarized from 345 logs of 10 minute integrated readings, taken after data from inaccurate sectors was discarded. Data was calibrated following the logging period for the flow meter and windspeed readings.See Figure 3.below.

FIGURE 3- PERMEATE PRODUCTION at various WINDSPEEDS for the PROTOTYPE RO SYSTEM*:



*Preliminary data for protoype performance at a feed salinity of 6000 ppm total dissolved solids, at an operating temperature of 16-18 deg. C, for a year-old membrane and windmill pump.

The analysis of the data is not extensive enough to draw more than tentative conclusions on the system performance. It indicates that there is a positive relationship between windspeed and permeate production, and that for an average windspeed 2-4 m/sec, typical of W.A. coastal sites, roughly 100-300ml/min (approx. 150-450 litres/day) of permeate would be produced at 6000 mg/l TDS. Water quality for this permeate should fall roughly between 900-1150 mg/l according to log sheets.

5.0 CONCLUSIONS AND FURTHER RESEARCH

Interpretation of data should have provided conclusive evidence of the effectiveness of the prototype under field test conditions. Conclusions will be drawn as to whether further testing, design changes and/or placement of a unit at a remote community should be undertaken as the next step in the timetable for the development of a desalination unit for remote area communities.

6.0 REFERENCES

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