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WIND ENERGY FOR REVERSE OSMOSIS DESALINATION

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The need for a desalination system for the removal of salts, including nitrates, from groundwaters has been expressed by Aboriginal communities and water supply agencies in remote areas of Australia. This research paper describes the design, construction, field testing and performance analysis of a prototype windpowered reverse osmosis desalination system for these remote areas. Based on the field tests, a performance model is derived which allows for the prediction of the prototype production given the wind and water characteristics of any location. Conclusions are also drawn as to the appropriateness of the technology for remote Aboriginal communities in Australia.

INTRODUCTION

The movement of Aborigines from large communities to their traditional lands in the last decade has prompted the need for small scale, reliable and socially appropriate technologies for the provision of basic services to these 'outstation' communities. Water quality and availability in remote areas of Australia is a generally limiting factor in the development of any community or pastoral station. Table 1 summarises the water quality problems experienced based on data from remote areas in Western Australia, using Australian standards for drinking water quality as the criteria (National Health and Medical Research Council, 1986). This data illustrates general trends in water quality at remote W.A. locations. The predominant problems are the presence of iron and manganese at levels which cause taste, odour and staining problems, as well as causing scaling in pipes, especially in hot water systems in conjunction with hardness. High salinities, hardness, low pH in the Kimberley clay areas, and bacterial contamination all appear to be quality problems. High nitrates and fluoride were found in many areas. Records of sulphates were not available for many bores, but it can be surmised that in the high iron and hardness areas that sulphates and probably hydrogen sulphide would be encountered (Robinson, 1987). Overall, classic highly mineralized waters are typical of most inland semi-arid regions of W.A., ranging from the low pH, high turbidity clay waters of the Kimberley to the hard, high iron content of the Goldfields region. These groundwaters present a particular problem for water supply systems and for human health unless treated effectively with a desalination system.

Table 1- Water Quality Data for all Regions of Western Australia
(Based on quality data from 210 bores in rural W.A., Robinson, 1987)
Average depth to water: 32 m

WATER PARAMETER	NO ; TOTAL NO	PERCENT	STD APPLIED
TURBIDITY (INCL. SILICA)	20 ; 111	18	> 25 NTU
T.D.S.	34 ; 140	24	>1500 ppm
HARDNESS	23 ; 122	19	> 600 ppm (as Ca CO3)
IRON	48 ; 125	38	> 1.5 ppm
MANGANESE	10 ; 125	8	> 0.1 ppm
FLUORIDE	23 ; 125	18	> 1.5
NITRATE	26 ; 125	21	> 45 mg/l (as NO3)
pH TOO LOW	28 ; 126	23	< 6.5
BACTERIOLOGICAL:	19 ; 122	16	(figures not mutually exclusive)
Total coliforms	23 ; 122	20	120 tot. coli./100 ml;
E. coli.	12 ; 122	10	2 E. coli./100 ml;
Faecal streptococci	9 ; 122	7	zero
Salmonella	3 ; 122	2	zero

WINDPOWERED REVERSE OSMOSIS DESALINATION

The application of reverse osmosis (RO) to remote area desalination is not a new concept. Various studies and pilot trials in Australia and overseas have been conducted (Feron, 1985; James, 1985; Commisseriate a' l'Energie Atomique, 1982; Berryman & Frith, 1983; Laing, 1985), and it has generally been concluded that unreliability and high capital costs are the limiting factors in the use of this type of technology. However, recent innovations in membrane design have produced types which can desalinate brackish waters at lower pressures than previously used and at lower capital and running costs. A trade-off of system efficiency for reliability likewise improves the applicability of this technology for remote area use (Swinton, 1985). Thus RO now has the potential to fulfill the requirements of reliability, small size and low energy input suitable for remote area drinking water desalination. By linking RO to the standard windmill pump via a pressure vessel, a prototype has been designed which combines renewable energy with a well-proven pumping technology for the purpose of groundwater desalination.

RO System Design

RO has been made feasible for the removal of ions from water through the development of synthetic membranes which are permeable to water but not to its contaminants. Pressure is applied to the feed stream by a pump, producing product water (permeate) and concentrated brine. 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' with respect to a particular solute under standard conditions. This parameter is usually expressed as the percentage reduction of the solute concentration achieved as the solution passes through the membrane.

Prototype Design

The prototype windpowered reverse osmosis plant consists of the following components (Figure 1):

Figure 1 - Prototype Windpowered Desalination System

The system operates by charging up a pressure vessel (6) using low volume input from a windmill pump (2) under varying windspeed conditions. The water accumulates until it reaches a critical pressure, triggering the pressure switch (8) which closes the circuit to a 12V solenoid valve(9), opening to send a 'plug' of water to the reverse osmosis membrane (11) at the required flow and pressure. When the pressure falls below a minimum value, the switch opens the circuit, recommencing the pump-up phase. In this way the low, variable flow from the wind can be effectively matched with the constant flow/pressure requirements of a RO membrane. It has been shown that the system is capable of producing from 130 litres/day to over 1000 litres/day of desalinated water depending upon wind conditions. The RO membrane removes on average 96% of sodium chloride, the predominant contributing ions to salinity, and nitrate and fluoride rejection rates averaged 65% and 78% respectively (Robinson, 1987).

Field testing of the prototype consisted of hooking up the unit to a 3 metre diameter Aeromotor windmill pump near the University, and running through samples of simulated groundwater feed of various salinities. The prototype commenced operation on July 18th, 1988 and operated continuously since then until its de-commissioning on the 16th of August, 1989, a 13 month operation. During that time some 220 days or 5280 hours of raw data was logged and stored for analysis. Elimination of irrelevant data yielded 3348 hours of usable windspeed, direction input data, and desalinated water output data which was subsequently analysed by the author (Robinson, 1990). An application of the results is given below.

PRODUCTION SPREADSHEET

It is useful to translate the test performance curves into production curves. This is achieved by combining wind profile data characterised by the site frequency distribution curve with the performance curve of the prototype derived from the field trials. A spreadsheet software spreadsheet package "VP Planner" was used to allow the prediction of system performance given the groundwater characteristics from groundwater characteristics and average windspeed using wind distribution patterns determined for the W.A. Wind Atlas Project presently being prepared by Murdoch University's Institute of Environmental Science.

Two examples of production prediction using the spreadsheet are shown in Tables 2 and 3. The input variables and output estimates for the spreadsheet model are described, in order of presentation on the spreadsheet model. The effects of the input variables on overall system performance is assessed with reference to the two sites being examined.

(i) Feed/permeate salinity: The osmotic pressure required for reverse osmosis is directly proportional to the feed salinity- hence higher feed salinity produces a greater power requirement per unit production of permeate. The product salinity limit of 1500 p.p.m. is the limiting factor in the feed salinity which can be processed. Up to 9,500 p.p.m. is the feed salinity value limit for the RO system to produce permeate of under 1500 p.p.m. for most circumstances. This product limit is not exceeded for either test example.

(ii) RO membrane age: With increasing age the overall tendency of the RO membrane is for a decline in both the salt rejection and permeate flux. An equation for performance decline is entered into the spreadsheet programme, based on field and other research results. Fouling of the membrane is almost always detrimental to the system performance, so replacement of the membrane will bring about benefits which must be offset against the replacement costs of $300 to $ 500 per membrane.

(iii) Recovery Ratio: The recovery ratio is the most influential of the operator-controlled input variables, and is best maximized. Permeate salinity is improved under a higher recovery ratio, as salt flux is constant, but permeate flow improved. Thus increasing recovery ratio is a common strategy for improving the salt rejection. The ceiling to recovery ratio increase is the maximum allowable concentration of salts in the reject stream. Once ionic concentrations exceed scaling values, the increased cost and complexity of pretreatment must be offset against the increased efficiency and product quality due to a higher recovery ratio. Examples shown here specify recovery ratios based on minimal pretreatment options for low maintenance requirements.

(iv) Weibull parameters: The wind characteristics of a site can be resolved into two factors describing the frequency versus windspeed curve given by the equation:

$$f(V) = (K/C)(V/C)^{K-1} \exp[-(V/C)^{K}]$$

where V is the windspeed (m/s);
K is a dimensionless shape parameter and
C a scaling parameter (Lyons et al., 1989).

The K value determines the 'skewness' of the frequency distribution curve in relation to the y-axis. Thus a K value of 2 describes a 'Raleigh" distribution curve; that of 3 a normal distribution curve. The C parameter scales the value with respect to the x-axis. A value of C above 5 gives higher wind frequency values for a given windspeed category. The effects of changes in wind characteristics are large and understandable since this is the power source for driving the desalination process. The production at windspeeds below approximately 2.5 m/sec are negligible, hence a windpattern having a higher K value translates windspeed into production more effectively. This effect is noticable when comparing example 1, with a distribution of wind frequencies grouped in the lower windspeed categories, compared with example 2, with higher C and K values. Overall production, however, is higher in example 1 due to its higher recovery ratio.

(v) Modelled performance flow: The base factor Qm is derived from performance curve for the RO prototype calculated for time= 0 (new membrane), salinity= 0 p.p.m. and recovery ratio= 100% (Robinson 1990). For a particular site, water quality and design parameters, the values of recovery ratio (Qr), salinity (Qs) and age of membrane (Qt), in that order, are calculated to derive the performance under those particular conditions. This value (Qt) is then multiplied with the particular windspeed frequency value, to derive the final performance estimate, Projected Flow in litres per year, which is converted to an average litres per day estimate.

APPROPRIATE DESALINATION TECHNOLOGY

Most forms of desalination technology have potential technically for use in remote Aboriginal communities but require development to be made 'appropriate' in terms of design criteria established for appropriate technology (Walker, 1982; Swinton 1985). Results found from research into windpowered desalination are examined in the light of these criteria. Recommendations are made as to whether further testing, design changes and/or placement of a unit at a remote community should be undertaken.

Robustness and reliability of design: The field prototype trials have proved that the basic components are reliable or indicate where improvements are required. Performance monitoring equipment proved unreliable, a problem not anticipated in community-based facilites. The translation of the field results from this study to the remote community setting involves a number of additional variables which have not been fully tested. The field trial was conducted using a basically pure sodium chloride source of salinity, which was recycled. The use of groundwater involves a number of additional factors of hardness, insoluble compounds and bacteria which could change the performance markedly. Although fouling trials helped establish the causes and remedies of fouling, there is no adequate means of estimating the fouling potential of a feedwater without actually trialling that water in the system (Hubbard, 1986; Desal, 1986). Likewise, the additional hardware such as dosing pumps and chemical required for this groundwater treatment adds complexity and potential unreliability to the system. The harsh environmental conditions including extremes of heat and cold, dust, wind droughts and cyclones add further to reliability problems. It is recommended that the RO system be field tested in a remote Aboriginal community context, using a groundwater feed which is tested and treated with the required pretreatment system. It is important that the RO unit be sufficiently 'proved' at this stage to minimise the chances of failure due to these untested environmental conditions, before such a system could be recommended for general community use.

Reliability of supply: Where depended on as a sole source of drinking water, the pumping system should be linked to a backup source of pumping energy, such as the dual diesel/windmill setup favoured by the servicing authority (Public Works Department of W.A., 1982). Alternative pumping systems such as a treadmill system using a vehicle rear wheel drive, and wind/solar pumping is worth investigation. The RO desalination system is best implemented as the drinking water supply to a community using dual-supply of drinking and secondary water use, where quality water is limited. This system is used in a number of communities (Australian Water Resources Council, 1989). More detailed analysis of wind patterns for areas for which the system is required is needed, as wind drought limits the reliability of the windpowered RO system as a water supply.

Water quality and quantity: The quantity of water produced obviously depends upon the wind characteristics of the site, the other operating parameters such as feed salinity and recovery ratio. The tradeoff between cost, complexity and efficiency will have to be determined for each community site in turn. The spreadsheet model can be used for predicting the permeate production levels and quality Ultimately the delivery rate of 10 litres per person per day and T.D.S. of 1500 p.p.m. can be considered the absolute minimum for drinking uses (Robinson, 1987), so requiring a system sizing to reflect the expected population size of the community given the prevailing wind conditions of the site. If this requirement cannot be met, the system is inadequate for the community's needs and alternatives should be investigated.

Mechanical, electrical and chemical maintenance: It is unreasonable to expect that a RO system can operate reliably without periodic servicing, although the system design endeavours to minimise these service requirements. The transitory nature of the Aboriginal community populations makes it unlikely that a community member can perform routine servicing requirements, although every effort should be made to train members in this task. It is recommended that a service 'round' be instigated by the relevant servicing agency, such that a visit is made, say, every 2 to 3 months. During this service, a standard method of system testing will be initiated, as well as backflushing, cleaning and disinfection cycle using chemical treatments as recommended (Desal 1986), depending on the performance problem encountered. Parts requiring replacement can be replaced using standard replacement components supplied.

Capital and running costs: The costing of the system, based upon equipment, labour and transport costs for installation in a remote community, can be estimated at $12,000. Running costs are low, ranging from $250 to $490 per year depending on the frequency of membrane and filter replacement (3 yrs/4 monthly or 1 yr/2 monthly respectively appears to be a realistic range). This does not include the servicing agents labour costs for service rounds. Based on these figures, an amortisation of the capital cost of the system over a 15 year lifespan plus running costs results in a production cost shown in table 4.

Table 4. Unit Cost Comparison of Various Sources of Drinking Water:

Source	cents/tonne/km	$/tonne	Comments
10 km carting	20.10	2.01	from James (1988)
20 km carting	19.05	3.81	"
30 km carting	18.47	5.54	"
40 km carting	18.35	7.35	"
100 km carting	14.25	14.25	"
Diesel/mechanical		6.53	"
Diesel/ electric		7.80	"
Photovoltaic RO desalination		9.53	"
R.O Desalination		0.76-14.00	Smith and Swinton (1988)
Windpowered RO		25.10-31.80	100 litres/day production
"		6.36-5.02	500 litres/day production
"		2.51-3.18	1000 litres/day production

This cost comparison shows that the windpowered RO system is economically viable in comparison to similar technologies of drinking water production at production levels averaging 500 litres per day or more. This costing ignores the additional costing of a backup pumping system, as these are usually already supplied at communities by servicing agencies. However, the cost comparison with water carting shows that it is still more economical to cart water around 30-40 kilometers than to desalinate using RO technologies and pumping using diesel equipment.

Low power requirements for renewable energy efficiency: The use of renewable energy has been a central design criteria for the system. The wind is, by its nature a highly variable energy source, requiring an energy accumulation system such as that developed with the pressure vessel. However, the system operates at low recovery ratios, necessitating the loss of a great deal of energy in the reject stream (over 90% at 10% recovery ratio). The development of energy recovery systems using the reject stream energy, such as that used for yachts (Swinton, 1985) can reduce this energy loss dramatically [see paper by Harrison et al. in this publication].

Automatic shutoff/fail-safe operation: The variability of pumping inputs, and of demand, combined with a lack of personnel to attend to the system creates the need for a system which is self-regulating and which can shut off and re-start as demand requires. The incorporation of a circuit-breaker in the solenoid-valve circuit can allow the system to stop production when the permeate tank is full. Likewise, the use of a differential pressure switch across the filter and RO membrane can allow this circuit to be broken if the pressure drop is too great, an indication of excessive fouling. In these circumstances, any further pumping by the windmill will be diverted through the overpressure valves back to the feed tank. The service round will then replace the parts at fault, and the system will start up automatically when demand requires.

Acceptability in community lifestyle: The technological 'hardware' for service provision to communities is only one part of the equation of sucessful technology transfer; the human factor or 'software' is equally relevant and often ignored, with the ultimate result being failure of the technology to provide for community needs (Walker, 1985). This includes the need for community consultation from the start, familiarisation and training of community members in the correct use of the technology and ensuring that the technology is compatible with their lifestyle and resource usage patterns. It is difficult to assess the ultimate degree of acceptance of the technology in the community, other than to propose the general principle that if it enhances their quality of life, it will be used fully and if not, rejected. It is recommended that the consultation with the community through their representatives be made, explaining the design, construction and servicing requirements and potential usefulness to the community. Full opportunity, including paid training for installation and/or servicing of the system, should be made available to community members who may wish to take on a 'custodianship' role It is then the prerogative of the community to accept, reject or recommend changes to the technology as they perceive it may benefit or reduce their quality of life, at any stage of the installation and use of the system.

CONCLUSIONS

The research conducted as summarised in this paper has contributed to the understanding of the use of reverse osmosis desalination using windpower for remote Aboriginal communities. The field testing of the prototype system has yielded information which allows the prediction of the performance of a similar system in a remote area, given specific wind, groundwater quality and RO operating parameters. Subsequent testing in a remote community setting should determine the feasibility of the system, provided that the performance and appropriateness criteria above are fulfilled. If a technology for desalination can be developed which fits these criteria, a very real contribution will be made to the needs of Aboriginal people returning to their traditional lands.

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