The Economics of Desalination and It's Potential Application to Australia

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Abstract

Future concerns about the quality and quantity of Australia's fresh water supplies from salinisation has necessitated the need for action. Several options exist to secure fresh water supplies for the future, including revegetation, engineering methods, and desalination. Revegetation and engineering options can be very expensive when applied on the scale needed. Desalination has considerable potential as it gives immediate benefits and can be applied anywhere saline water exists, subject to it being suitably cost-effective. This paper shows that, in Australia, based on current prices charged for water, desalination is currently only competitive with traditional water sources in remote locations. There are two ways that this might change. There may be a continuation of advances in technology for desalination, or alternatively the true cost of traditional fresh water sources may rise. Even if the former does not occur, the latter appears certain.

Key Words: Desalination, salinity, water supply.

Introduction

There are concerns about the future quality and quantity of Australia's fresh water supplies, particularly because of salinisation. Several options exist to secure fresh water supplies for the future, including revegetation of catchments with perennial plants, engineering methods to manage saline groundwaters (for example pumping saline groundwaters into evaporation basins before they discharge into waterways), and desalination of saline water. Revegetation approaches are attractive in that they address the underlying causes of salinity, but they can be very expensive when applied on the scale needed to prevent saline discharges into waterways (Pannell, 2001), and in many cases they will be slow to be effective (Hatton and Salama, 1999). Engineering options are effective more quickly but can also be expensive. Desalination seems to be an alternative with considerable potential as it gives immediate benefits and can be applied to nearly any situation or location where saline water exists, subject to it being suitably cost-effective. This paper provides a summary of a more detailed review of the economics of different desalination technologies, the environmental impacts of desalination and its potential application in Australia.

Desalination processes

Desalination processes are divided into (i) thermal methods, which involve heating water to its boiling point to produce water vapour, and (ii) membrane processes, which use a relatively permeable membrane to move either water or salt to induce two zones of differing concentrations to produce fresh water. The main thermal method employed is distillation, where saline water is progressively heated in subsequent vessels at lower pressures. Brief descriptions of the main desalination processes are provided below.

1. Distillation Processes

Multistage Flash Distillation is the most widely used desalination method worldwide. The process involves heating saline water to high temperatures and passing it though vessels (stages) of decreasing pressures to produce the maximum amount of water vapour (fresh water). The plant can contain from 15 to 25 stages, which increases the total surface area. They are generally built with capacities of about 4,000 to 57,000 kL/d and operate up to top temperatures of 90 to 110°C (Buros, 1999).

Multi-Effect Distillation operates at lower temperatures but uses the same principles as multistage flash distillation. The plants are built with capacities of 2,000 to 20,000 kL/d and operate at a top temperature of $70^{o}C$ (Buros, 1999).

Vapour Compression Distillation is generally used in combination with other processes, where the heat for evaporating water comes from the compression of vapour, rather than the direct exchange of heat.

2. Membrane Processes

Reverse Osmosis is a pressure driven process which forces saline water through a membrane, leaving salts behind.

Electrodialysis is a voltage driven process and uses an electric potential to move salts selectively through a membrane, leaving fresh water behind.

Current usage of desalination

Desalination processes are used commercially to provide fresh water for many communities and industrial sectors around the world. The Middle East region has the majority of the desalting capacity, whereas Australia has only one percent of the total world capacity (Gleick, 1998; Buros, 1999). The installed world capacity consists mainly of multistage flash distillation and reverse osmosis processes, with the remainder made up of multi-effect distillation, electrodialysis and vapour compression. The installed capacity of membrane and thermal processes is about equal, but most older plants are distillation units which are facing retirement, so it is probable that the total operating capacity of membrane units will increasingly exceed that of thermal units (Buros, 1999). Reverse osmosis desalination for brackish water is the most utilised method in Australia. The Water Corporation in Western Australia is investigating the feasibility of developing several desalination facilities for industrial and urban application.

Determinants of costs of desalination

Theoretically, all desalination processes, including those yet to be invented, have certain minimum requirements for energy. However, inefficiencies arise in all desalination processes

due to the transport of energy in the process, or transport of matter at phase boundaries (National Academy of Sciences, 1962; Water Corporation, 2000). These inefficiencies increase the energy requirements of desalination methods, thus raising unit water costs.

Since all desalination processes can use some combination of energy sources and can be designed for different levels of energy efficiency, simple economic comparisons are difficult to make. However, it is clear that the cost of desalting is determined by a number of technical and economic factors. The major categories are capital costs, and operating and maintenance costs. These two categories are interdependent; that is, if one component is increased the other component usually decreases (Khan, 1986). The full review presents an extensive list of technical and economic factors that influence the desalination cost and the choice of desalting process. Three factors have a dominant effect on the cost of desalination per unit of fresh water produced: the feedwater salinity level, energy costs, and economies of size.

Feedwater salinity level

By definition, the feedwater is divided into two saline categories: brackish water (less than 60,000 ppm TDS) and seawater (greater than 60,000 ppm TDS). The general trend is increasing the salt content of the feedwater increases the operating costs, as more apparatus (such as membrane area or the number of stages of distillation) is needed (Popkin, 1968; Khan, 1986; Buros, 1999). Typically, the cost of desalting seawater is three to five times the cost of desalting brackish water from the same size plant for both membrane and thermal methods (Buros, 1999; Water Corporation, 2000). Membrane processes most economically achieve brackish water desalting with reverse osmosis presently the cheapest process (Larson and Leitner, 1979; Glueckstern and Kantor, 1983).

In Australia, rivers are becoming saline and provide an alternative source of water supply. Many of the rivers will remain well below seawater quality and so will be cheaper water sources to desalinate. An option is to allow established dams to become saline, then desalinate the water rather than revegetating the catchment. This is a realistic option as many of the water resources of the country are saline or have the potential of becoming saline without remedial work.

Energy costs

A major characteristic of all desalination processes is their requirement for thermal or electric energy input, which can represent 50 to 75 percent of operating costs (Mesa et al., 1996). The future of desalination technology will depend largely on reducing the energy cost by optimising power and water generation. The form of energy available and environmental constraints related to the energy source contribute to the cost of energy for desalination (Ammerlaan, 1982; Abulnor et al, 1983; Water Corporation, 2000). Reverse osmosis has the lowest energy demand and this consequently makes it more attractive in many instances, compared to the well-tried multistage flash distillation (Sackinger, 1982; Glueckstern, 1999). Wood (1982) observed that rising world energy prices would alter the relative costs of different desalination methods, increasingly favouring reverse osmosis.

Economies of size

Economies of size arise when increases in the plant size (kilolitres of water produced per day) bring decreases in the unit fresh water cost (ie. lower average total costs). Economies of size are evident in all desalination processes, but to different extents. Reverse osmosis exhibits little scope for economies of size, while distillation processes show the greatest potential. The operating and maintenance costs are not subject to economies of size, but are directly affected by the water quality to be treated (Morin, 1999). Exploiting economies of size for distillation methods has been proven an efficient means of reducing the cost of desalted water (Hammond, 1996).

Which method is cheapest overall?

Reverse osmosis has been shown to be the most economical in many cases due to its lower energy consumption, leading to lower unit water costs. However, the process has higher up-front investment costs compared to thermal processes. Its unit water costs are primarily determined by membrane life and energy cost (Ericsson et al, 1987; Wade, 1987). Reverse osmosis plants have flexibility of operation in the face of fluctuating water demand and benefit slightly from economies of size.

Several economic trends for multistage flash distillation plants are apparent: a relatively low investment cost, benefits from economies of size (relative to other processes), and site

specific costs (for example pretreatment requirements, energy costs) have a direct affect on the unit water costs, and low flexibility in response to variable water demand (meaning that freshwater production cannot be adapted to fluctuating demand) (d'Orival, 1967; California Coastal Commission, 1993). The main economic drivers for multistage flash distillation are costs of materials and energy, and increasing plant capacity to take advantage of economies of size (Water Corporation, 2000).

Comparing multistage flash distillation and reverse osmosis, the distillation process has been the preferred method due to its reputation as a mature and reliable process. However, reverse osmosis plants are replacing the older multistage flash distillation plants of the Middle East and being the first choice for desalination implementation in Australia. This is due to their simpler operation, reductions in energy consumption and ultimately, cheaper unit costs of fresh water (Anon, 1999a; Glueckstern, 1999). The overall cost of fresh water from a multistage flash distillation plant is often more than twice that which is produced by means of reverse osmosis (Water Corporation, 2000). As technical advancements of membrane processes improve their costs and efficiency, they will continue to be the preferred choice for countries moving into desalination.

Presently, the reported costs of desalinating water using current desalination technologies fall within the range of A$0.80/kL to A$2.10/kL, depending upon the process, location and the potential for blending with marginal quality groundwater (Water Corporation, 2000). These costs do not include disposal or distribution costs.

Additional costs

Any economic evaluation of the total cost of water delivered to a customer must include costs for environmental protection, particularly disposal of brine (highly concentrated saline water) which is an output of desalination processes. There are also costs of distribution and of losses in the storage or distribution network. Typically the total cost of desalted water reported by desalination plants or literature is the combination of investment, capital, and operating and maintenance costs. Often no attempts are made to include the costs of environmental protection or water distribution.

The common element in all of the desalination processes is the production of the concentrate salt stream (brine). This stream contains the salts removed from the saline feed to produce the fresh water product, as well as some of the chemicals that may have been added during the process. It varies in volume, depending on the process, but there will always be a significant amount of highly saline water. The disposal of the brine in an environmentally appropriate manner is an important part of the feasibility and operation of a desalting facility. The disposal of brine into the ocean is generally considered safe, as the major solute in the brine is salt. However, in some cases marine impacts may need to be considered (California Coastal Commission, 1993; Hopner & Windelberg, 1996; Morton et al, 1996). Disposal of brine inland presents potential complications as it may either exacerbate groundwater salinity (Fath, 1998; Buros, 1999), or result in an additional expenses for other means of disposal (for example, lined evaporation basins or impounding underground). In some cases the brine may have an economic value (for example, salt production) (Water Corporation, 2000), but the potential scale of this would probably be small relative to the production of brine if desalination becomes a major source of fresh water. Further information is required to fully understand the environmental impacts caused by desalination processes and to develop regulatory measures (Squire et al, 1996).

Closing the cost gap between desalination and traditional water sources

For the time being, in most countries (including Australia) prices charged for traditional water supplies generally remain cheaper than the full cost of desalinating water. There are two ways that the gap might be closed: reductions in the cost of desalination (for example, by reducing energy costs or increasing energy efficiency), and increases in the cost of traditional water sources.

Reductions in the cost of desalination

One way to reduce the cost of desalinated water is to improve the desalination technology. Enhancements would increase the performance ratio (the ratio of fresh water to the amount of energy consumed). The performance ratio can be increased, for example, through the use of more vessels in distillation methods or by advances in membrane technology for reverse osmosis. Recent investigations have shown that the coupling of thermal and membrane desalination processes (hybrid systems) improves the overall efficiency (increasing the

performance ratio) and decreases desalination costs (Water Corporation, 2000). With increasing pressures for fresh water and the attractiveness of desalination, the improvements to technology should continue.

A second way is to reduce the cost of energy. Some efforts focus on the use of renewable energy to provide the required power to the desalination process, with the most popular source being solar energy. Another approach is the use of dual-purpose plants, where the desalination plant is connected to an electricity plant, utilising the waste heat from the electricity plant. It has been claimed that, under favourable conditions, dual-purpose plants decrease the cost of desalinated water below those of conventional desalination methods, primarily through energy conservation (Buros, 1999; Goosen et al, 2000; Water Corporation, 2000).

The volatility of international energy prices and the increasing concern for regional and global pollution problems has intensified interest in the application of clean renewable sources (solar energy) for all energy uses (Glueckstern, 1995; Tsur & Zemel, 2000). Solar distillation is a very simple and direct method, requiring large flat areas of land, having lower running costs and being very suitable for remote ares. However Goosen et al (2000) established that a general economic analysis is not easy to accomplish for solar desalination since only a few studies report on predicting the water cost or focus on economics. For solar distillation plants the problem is compounded with the fact that most of them are constructed from inexpensive local materials using local personnel. In such situations, prices differ considerably from one location to another.

However, studies have shown that solar desalination in remote regions can be cheaper than conventional desalination methods, primarily due to the significant reductions in fuel consumption (McCarthy & Leigh, 1979; Anon, 1999b; Chaibi, 2000). Solar systems are easy to operate and maintain, and also reduce pollution by not utilising fossil fuels (Abdelrassoul, 1998; Voivontas et al, 1999; Chaibi, 2000). Australia has high levels of incoming solar radiation in remote regions making solar desalination a potentially viable option. Reverse osmosis of brackish water (if available) using solar energy is potentially the cheapest way to provide new fresh water resources in remote areas (McCarthy & Leigh, 1979; Voivontas et al,

1999). However, costs depend heavily on climatic conditions (Glueckstern, 1995; Goosen et al, 2000). For the time being, solar processes are largely restricted to remote areas needing smaller desalination systems.

Dual-purpose plants are built as part of a facility that produces both electric power and desalted seawater. The main advantage of a co-generation system is that it can significantly reduce the consumption of fuel when compared to the fuel needed for two separate plants. The energy costs for desalination from a dual-purpose plant are one third to one half that of a stand-alone desalination plant (Hammond, 1996; Water Corporation, 2000). This is attributed to costs being shared between water and power production. Unfortunately, the two processes are permanently connected together, making operation more complex and potentially less convenient than single purpose plants (Buros, 1999). This permanent coupling can create a problem for water production when the demand for electricity is reduced or when the electricity component is down for repairs. The failure of one component has an effect on both water and power production. Apart from this limitation, dual-purpose plants can effectively reduce the costs of power and fresh water (Buros, 1999).

Many new power plants are designed to operate in conjunction with a desalination facility in Australia. They produce lower air emissions than existing power plants if the new plant is fired with natural gas and uses the latest air emission control technologies (Water Corporation, 2000). Co-generation is applicable to many situations including the commercial sector, large institutions, resource based industries, industries based on agricultural production and the chemical industry (Hopkins, 1997). One such co-generation facility commenced operation recently at the Worsley Aluminium refinery near Collie, Western Australia.

Another example of sharing costs is a scheme being investigated for the town site of Merredin in the wheatbelt of Western Australia. The proposal is to pump highly saline groundwater from under the town in order to reduce damage to infrastructure when that groundwater rises to near the soil surface. The pumped water would be desalinated and injected into the water supply pipeline. In this case, the cost of desalination would be reduced because the cost of pumping may be partly attributed to the aim of preventing damage to infrastructure. The provision of this water would also reduce the cost of pumping fresh water from Perth, which

is not fully reflected in the price charged to domestic consumers in the town. Thus the existing water source (for which desalinated water provides a partial substitute) is relatively expensive, increasing the prospects for economic competitiveness of desalination.

Increases in the cost of water from traditional sources

There are a number of ways in which costs of traditional water sources may rise in the future:

- Increasing levels of treatment being required to meet more stringent water quality standards;
- Increasing demand for freshwater;
- Decreasing supplies of freshwater;
- Increasing costs of maintaining existing water supplies in a fresh state;
- Alteration of existing pricing schedules to reflect true costs of provision.

As the demand for water rises, the "marginal opportunity cost" of water will also rise, regardless of the price charged for water. With a more or less fixed supply of water, an increase in consumers' demand for water requires some substitution away from existing uses (such as irrigation). Steadily rising demand means that more valuable existing uses for the water must be sacrificed, increasing the "opportunity cost" of the water.

For Australia, possibly the most important items on the list are those relating to decreasing supplies and increasing costs of protecting water resources. Where provision of fresh water requires expensive revegetation and/or engineering methods, the economic attractiveness of desalination is enhanced. This is not to say that desalination will necessarily provide the best strategy, but that it's prospects of being the better strategy are enhanced as the cost of salinity prevention rises. Given the very considerable costs already being borne to prevent salinisation of the Murray-Darling River system, it may be a cheaper option to desalinate water supplies to users of that water resource.

The example given above for Merredin town site illustrates a case where prices charged for water do not reflect the true cost to society of providing the water. Water prices that are set on an administrative basis, often with an eye to political advantage, are not appropriate to use as the basis for comparison with desalination. Unfortunately, determining the true cost of water

(the so-called "shadow price") is very difficult in a highly regulated system with a monopoly supplier. It is likely, however, that based on true costs of provision, desalination is already more competitive with traditional sources than it appears based on prices currently charged.

Conclusion

It appears that in Australia, based on current prices charged for water, desalination is currently only competitive with traditional water sources in remote locations. There are two ways that this might change. There may be a continuation of advances in technology for desalination to make better use of solar energy and/or to improve the efficiency of current desalination systems. Alternatively, the true cost of traditional fresh water sources may rise. Even if the former does not occur, the latter appears certain, due to: losses of some traditional sources (due to salinisation), the high cost of preventing salinisation of other traditional sources, and an increasing demand for fresh water as population continues to grow. Desalination appears to be an option deserving serious analysis and investigation.

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