ARTIKEL

WATER

Desal technology can help quench the world's thirst

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1. Introduction

The process of taking the salt out of seawater, or desalination, is as old as human civilization. Socrates taught students how to distill seawater to obtain fresh water. Sailors have been applying similar methods for over 2000 years. Solar ponds that were developed to harvest salt have let nature do the distilling for thousands of years already. The Sun's heat was used to desalt seawater, which served as the drinking water for troops during the siege of Alexandria in the days of Julius Caesar. Last but not least, all of the annual fresh water supply for the planet comes from evaporation from the seas.
An imminent shortage of drinking water in many coastal regions and megacities is quickly emerging as one of the major natural resource issues of this century. The abundance of salt water presents an obvious opportunity for the review and assessment of the process of desalination as a possible solution to the issue of an adequate sustainable drinking water supply. Currently, only about 1% of the world's potable water is derived from desalination plants. The percentage for industrial use is even lower, while the percentage of irrigation water is practically zero. The total capacity was recently (in 2000) about 26 million m^3/day, up from 20.3 million m^3/day in 1995.
Of this total capacity, about 60% comes from seawater and 40% from brackish water.
The desalination market has become an annual billion-dollar business, which will continue to grow to at least five billion dollars/year in the coming decade. Recent and potential desalination developments indicate that there will be a very substantial increase in the use of these technologies to produce pure and fresh water from seawater and brackish water, and not in the least place from waste water for recycling. It is difficult to predict the precise future shares of desalination and recycling in the water market, but the strategic opportunities are impressive.

The major impetus for these opportunities are:

- growing populations along the many coastal regions of the world. By 2025, megacities may very well be home to some five billion people. The huge demand and the willingness to pay for municipal water supplies will affect the availability of subsidized water for agriculture and the minimal water needs of ecosystems, a subject of great concern at World Water Fora.
- breakthroughs in the reduced energy requirement and investment costs of desalination processes, resulting in cost levels of \$0.40 to \$0.80/m^3 before distribution. This is much lower when we compare it to the approximately \$3.00 to \$5.00, 10 years ago and the \$1.50 to \$2.50/m^3 only 3-5 years ago. At the same time, the real costs of traditional water supplies are on the increase, and in many cases they have already surpassed the cost figures of the above.

Traditionally, there has been a strong and emotional opposition to the large-scale introduction of desalination because it is considered:

- a "technical fix";
- as requiring an unacceptable level of fossil fuels;
- as too costly, too large in scale, and too technical for universal solutions;
- an impediment to awareness raising and efficient water management.

In addition, it does not fit in with the traditional water supplier's culture.
However, the innovative forces and the entrepreneurial creativity resulting from the increased awareness that we have a worldwide water problem, are now clearly on the way to offering technological solutions that are ecologically and economically sound as well as socially beneficial.
Corporations and research institutes, and in certain regions, governments are paying a great deal of attention to the applicable developments as noted in publications and various conferences. However, the strategic importance of desalination has thus far not extended to include a broader discussion among the major political and institutional conferences devoted to the world's water situation. At the Second World Water Forum in March 2000 in The Hague, The Netherlands it was mainly the desalination industry lobby that presented the case.
In this article, the major elements concerning changes and challenges in desalination technologies will be reviewed in general terms.
For the details I will refer interested readers to the primary and secondary sources I consulted. If I were to go into all the details, it would just blur the general message I want to convey. The article, therefore, does not claim to be an in-depth analysis but more of an overview. Up until now, the subject has mainly been the concern of technical professionals. By concentrating on the broader scope within which this subject must be addressed, especially in the world's coastal areas, I hope to reach policy makers as well.
The major breakthroughs in desalination technologies are and will continue to be so substantial that its contribution to solving major world-wide water issues - i.e., water for food production, drinking water, industrial use and last but not the least, for natural ecosystems—can no longer be ignored by policy makers. For instance, the topic should receive a great deal of attention at the Third World Water Forum as well as the Ministerial Conference on Water in March 2003 in Japan. Desalination technology should no longer be considered some kind of forbidden fruit.

2. The energy question

The main desalination technologies were first implemented in the 1960s and 1970s. They are either based on the principle of seawater evaporation to separate water from salt, or on the principle of semi-permeable membranes, which involves forcing salty water through a membrane that prevents the salt from passing through. The first method requires heat and boilers, while the second method requires pressure and pumps. Thus, both methods require some form of energy.

In this article, I will forego the technical details of all the numerous existing technologies, and instead mention that at present there are five major applications. There are three that apply to the evaporation method—multi-stage flash (MSF), multi-effect distillation (MED), and vapour compression—while for membrane separation processes there are two applications—reverse osmosis (RO) and electrodialysis reversal process. In just the past 3 years, all of these technologies have developed energy recovery systems, higher process efficiencies, new or improved construction materials, dramatic decreases in membrane prices, high-tech ultra- or microfiltration for pretreatment, the use of waste energy from other processes, and the use of low-grade energy from electricity generating plants, all contributing to substantially decreasing external energy use.

This trend continues as the challenge remains to approach the theoretical minimum energy requirement necessary to remove salt from a water solution. Of course, realistically speaking, this theoretical minimum can never be achieved in practice.

The theoretical energy needed to remove salt from a 4% salt solution is 3.6MJ/m^3 or the equivalent of 1 kWh/m^3. The actual sea contains between 3% and 4% salt. Brackish water contains between 0.5% and 1.5% salt, and therefore requires proportionately less theoretical energy.

In the days back when energy was cheap and desalination application still limited, little attention was paid to energy consumption involved in the process. Energy use for evaporation methods like MSF, including pumping work, can still be as high as 400MJ/m^3 for desalinating seawater containing 3.5% salt Darwish (2001). It can be as low as 200MJ/m^3 using MED and cogeneration with adjacent power plants.

The osmosis method requires significantly less than the equivalent energy used by the evaporation method. In the early days, maximum consumption was about 12 kWh/m^3 from seawater containing 3.5% salt. However, by introducing energy recovery systems this was reduced to 7 kWh/m^3. In the newest RO plants, the energy requirement has been reduced to between 4 and 5 kW h/m^3 and further reductions to 3 kW h/m^3 are foreseen with additional technical improvements.

If one wants to compare these kWh/m^3 data for RO with the caloric requirements for evaporation, one can use the “exergy” concept, translating the caloric energy into the kWh that could equivalently have been produced with this energy. When making this translation MSF operates in the range between 15 and 25 kWh/m^3 and MED at around 10kWh/m^3, depending on process temperatures (Borsani, 2000). The reduction from a maximum of 25 kWh/m^3 to a level of 3 kWh/m^3 represents a significant breakthrough in energy requirement for desalination, resulting from technical innovations of the last 3-5 years.

For brackish water, the RO consumes even less energy in direct proportion to the salt content. For the evaporation methods, consumption remains at about the same level as for seawater conversion, effectively ruling out this desalination method for brackish water. For the very large units, when used in conjunction with power generation, the MSF still has scale advantages for seawater desalination. The MED has better cards than the MSF for the medium to large sizes, because of its up to 25% lower power requirements while the RO has the advantage of being competitive in all sizes, but still remains dependent on the availability of electricity from fossil fuels.

The next challenge is of course to apply renewable energy sources such as solar, photovoltaic, or fuel cell technologies. But because these alternatives will be more difficult to apply to evaporation technologies than to osmosis, the prospects for RO are brighter. The renewable energy challenge has already been acknowledged by the industry and research institutes worldwide, and will undoubtedly pave the way for a more widespread application of desalination technologies in the future.

Currently, about 35% of the world’s desalination installations are RO based, and this percentage is rapidly increasing, in response to the aforementioned factors, and one can foresee even more dramatic increases once the fundamental issue of effective pretreatment is satisfactorily resolved.

Although the eyes of the world are focused on the energy equation of the improved desalination technologies, the investment and operating costs constitute a second major factor in the successful introduction of these technologies on a broader scale.

3. The cost question

Recent literature on new installations in both evaporation and osmosis technologies offers a wealth of information, on specific capital costs and operational costs. Although these sources sometimes do not completely match: Redondo (2001), Kuligiro (2001), Glueckstern (2001), Global Water Intelligence (2001), New York Herald Tribune, (2001).

For the very large-scale seawater desalination installations such as those recently ordered by Israel, Saudi Arabia, Kuwait, Dubai, Bahrain, Jordan, Florida, Honolulu, Trinidad, and Spain, which produce up to 150,000 m^3/day, the specific investment costs range from:

MSF	\$1100 to \$1600/m^3/day	large capacities
MED	\$900 to \$1250/m^3/day	medium capacities
RO	\$500 to \$1000/m^3/day	broad range of capacities IHE (2000); Newsletter, European Desalination Society (2001, p. 3-4)

Exact figures vary according to the location, saline levels and available types of energy and electricity. With the upgraded designs and the improved energy efficiencies, these units can currently deliver fresh water from the sea at costs that range from \$0.40 to \$0.80/m^3, whilst freshwater from brackish water can now be produced at the rate of \$0.10 to \$0.20/m^3, depending on the salt content. These cost levels, however much they vary with respect to the conditions, are a far cry from the costs of 10 years ago when they were in the range of \$3.00 to \$5.00/m^3 for seawater desalination. By comparison, the costs to produce freshwater from ground and/or surface water in western countries range from \$0.40 to \$0.75/m^3, before distribution Global Water Report (2001, p. 4.).

In the other areas of the world, subsidized consumer prices do not reveal the true costs necessary to produce fresh water, but my guess is that true costs will be applied more and more frequently in the future, especially concerning supplying municipalities and megacities. Also, these true cost prices will tend to increase, as referred to in the next chapter.

As desalination cost prices progressively break through the level of real cost prices of traditional methods of producing fresh water, this will contribute to a broader use of desalination technologies, especially in coastal areas with megacities.

4. The market place

The costs of traditional methods of purifying surface water and ground water are increasing around the world. There are a variety of reasons for this: increased scarcity, ground water depletion and the need to dig ever deeper wells, growing awareness and the need to work within the realm of actual costs, increased ground water taxes, higher purification costs, increased energy costs, and increasing distances to transport the water. As prices increase, the marketplace will begin searching for alternatives to rising costs. These include better water supply and demand management, seasonal storage, reuse of sewage effluent, distributing various qualities of water based on its utilization, additional renewable water resources, transfer of water from region to region, importation of water and desalination of seawater.

Until quite recently, desalination was always last on the list. However, the evolving state of the art, as we noted earlier, will propel it upwards, at least in the coastal regions. And we must not forget that 70% of the world population lives within 50 miles of the world’s seas and oceans.

The following is an interesting illustration of the growing competitiveness of desalination technology. Recently, details were published about the negotiations between Turkey and Israel concerning the shipping of water from the Manavgat River in Antalia to the port of Ashkelon. They agreed on a price of \$0.15/m3, but shipping costs of between \$0.80 and \$0.90/m^3, prevented the deal from going through. Meanwhile, the bids for the BOT desalination project at Ashkelon have set the price at approximately \$0.60 to \$0.65/m^3, thus providing a cheaper, safer source Global Water Intelligence (2001, p. 9). The price ceiling in the future water market at the end of the day will probably be determined by the desalination technologies with the overall lowest costs.

Today, a majority of existing and projected desalination capacity is of the very large-scale variety. Saudi Arabia currently has 20% of the world’s large-scale plants and will place further orders for more plants for the next 20 years to the tune of 50 billion dollars. The Gulf States had more plants in 1990 than rest of the entire world combined. But, as I noted earlier, major large capacity desalination projects have now also been commissioned by nations from other parts of the world. According to recent market projections, with the increase in experience and with improved techniques, this trend will continue at an increasing rate and will spread to other coastal regions in Asia and Africa. Recent market projections show that new desalination plants could be supplying up to 120 million m^3/day by 2025 in the 18 driest countries in the world, where water supply per capita falls well short of daily demand (IHE 2001; Bremere, Kennedy, Schippers & Stikker, 2001). As for the rest of the world, forecasts are difficult to make, but the potential is immense. And it is not just large-scale installations that will be entering the market. RO has the advantage of being applicable to both large- and small-scale needs and is already in use in various capacities in the shipping industry, horticulture, small industries and small communities.

The largest market for desalination will be for supplying drinking water, which will most likely be supplied by the MSF and the RO. The second largest demand will be for industrial water, which will most likely be supplied by the MED and the RO, that is, if there are no further major developments on the desalination horizon. Not only are the improved technologies becoming competitive in converting seawater to fresh water, but they can also be applied to produce clean water from waste-water. This area is still under development, but as the prices for water go up, reuse technologies will be applied more and more frequently as large-scale recycling projects in the water management sector can supply water at prices that will compete with traditional water supplies.

These complementary trends of reuse and desalination will in all probability revolutionize the future of the water supply industry in many parts of the world.

5. News on the horizon

There are at least two developments on the desalination horizon that may yet cause another boost to the competitiveness of desalination applications in coastal areas. The first one is that recent research suggests that offshore Paleolithic underground brackish water reserves represent an almost unlimited water resource that is distributed along the coastal regions of all the continents. Very little scientific research has been carried out to study these resources. Lack of data about the quality of the brackish water and its consistency makes it difficult to assess the opportunities at this stage, but a hydro-geological research program on this resource has been instituted at the Amsterdam Free University in the Netherlands. If we assume that the water quality - the consistency and chemistry - of these reserves, are acceptable, desalination of these brackish waters could supply densely populated coastal cities. Examples of where these offshore underground resources could relieve present-day water shortages are, Bangkok, Alexandria, Jakarta, and Taipei. Preliminary calculations have been made on the costs of extracting the water by using horizontal offshore wells including pipeline transport and unloading facilities, and drawing on the experience of oil companies. With the application of today's best option for brackish water, the RO desalination plant, preliminary calculations show that the advantage over seawater desalination ranges from between \$0.20 and \$0.35/m^3 depending on capacity and distances out at sea IWACO (2001). The break-even point lies at a capacity of 11,000 m^3/day for wells 15 km from shore. The best cost is realized at a capacity of about 70,000 m^3/day at a maximum distance of 35 km from shore. If the option to desalinate brackish offshore water proves feasible, the costs of producing fresh water could end up between \$0.20 and \$0.40/m^3.

The second development that needs mentioning is, that the search for innovation in desalination is an ongoing process. A recent example of innovation is the combination of membrane technology with distillation technology through energy efficient and controlled transmembrane evaporation created by a temperature differential at a level below boiling point (Guijt, Racz, Reith, de Haan, & Twente, 1999, 2000; Guijt, Meindersma, Reith, de Haan & Twente, 2001; Guijt, Meindersma, Reith & de Haan, 2001). Although this technology, called membrane distillation, is not unknown, it has never before been developed into a technologically feasible, ecologically responsible and economically acceptable concept.

The author has been directly involved in a revival of this technology since 1996, and is still participating, via the Ecological Management Foundation, in a long-term research and development program at the Institute for Applied Scientific Research (TNO) in the Netherlands. The program is subsidized—50% by government grants and the remainder by the TNO and some industrial partners. The current plan is that around 2004 or 2005 one or two demonstration models will be operational on an industrial site of one of the participating industrial partners. Although the details are confidential, a recently approved patent application describes the general principles of the innovation, under the registered name Memstill.

The main features of the Memstill technology are:

- compact, easily operated modules, that require much less space than conventional units and can be designed and built to any specifications, from household applications to large-scale industrial use;
- operational on renewable and/or conventional energy, especially waste energy, where it becomes very competitive with existing technologies;
- an ingenious module design that reduces heat-transfer losses to an absolute minimum, resulting in an energy requirement for seawater desalination of 100-200 MJ/m^3 of (waste) heat, or to the equivalent of 3-6kWh/m^3 in exergy;
- limited fouling and/or scaling, minimum pretreatment and maintenance, using synthetic components;
- targeted specific investment costs of \$500/m^3/day;
- targeted costs price of \$0.50/m^3

The flexibility of this technology with respect to the use of various kinds of waste energy is an essential asset, as there is an abundance of waste energy available in industrialized coastal areas.

One illustration is that, theoretically, more than 50% of the Netherlands' water needs could be supplied at very competitive prices if use were made of the waste energy that is available from the industrial activities along the coast of the Netherlands. Of course, this is a hypothetical equation, but it indicates potential of avoiding additional fossil energy use.

As the Memstill development program is still in a late fundamental, early industrial phase, the outcome remains uncertain.

However, it proves that we may not have reached the end in desalination technology innovation and that more could happen in the next decades, at which time desalination will probably be established as a major component in solving the world's water problems.

6. Environment and water quality

The large-scale introduction of desalination applications raises the question of how this technology will affect the environment and the quality of the water produced. A country that has done a considerable amount of work on the environmental aspect is Cyprus. Before making the decisions to substantially expand their RO desalination capacity to cope with increasing water demand on the island in the face of decreasing availability, extensive environmental assessment studies were and are currently still being carried out, monitoring the marine environment at regular intervals. The brine that results from desalination typically contains two times the salt content of the feed water and usually has a higher temperature and a lower pH than the seawater. By dumping the brine into the sea at a depth of 10-15 m, and by imposing limitations on the chemicals used in the pretreatment and membrane maintenance processes, only negligible and temporary effects on the benthos life were discovered. In Cyprus, the affected area was limited to a radius of 200m (Tsiouris, 2001). The Electric Power Research Institute in the US has recently sponsored a program to evaluate the impact of brine discharge from desalination plants into the ocean. One of their conclusions was that dense brine discharge plumes can have a negative impact on the ocean floor and the benthic environment.

The California Coastal Commission has raised concern over the effect of brine disposal on marine life and public health protection of the state's beaches (Del Bene, 1998). Model studies reveal that dilution and the spreading of the brine effluent can solve these problems. Obviously, environmental regulation must be implemented to avoid the negative effects of coastal desalination installations, but it seems that the problem is manageable. Concerning the issue of the quality of the water produced by desalination, thus far, no negative effects have been noted in the published literature, but the subject will need to be studied in greater detail. For drinking water to win approval, very stringent regulations already exist, both at an international and at a national level, but it might become necessary to investigate the specific effects of the processes on the chemistry of water produced by desalination in greater detail.

For industrial water, the regulations can be extremely strict and some of the desalination technologies probably would not be able to comply, such as the RO, for instance, because of the use of chemicals in pretreatment.

7. Conclusion

The developments described in this article clearly demonstrate that desalination and recycling will play an increasingly important role in contributing to the solution of water availability problems in the world's coastal regions. Energy requirements of 100 to 200 MJ/m^3 or 3-6kWh/m^3 and costs of \$0.10 to \$0.20/m^3 from brackish and \$0.40 to \$0.80/m^3 from seawater have been proven to be feasible, opening up the road to wide scale commercial applications.

The inventive forces of the human imagination in the field of desalination have produced and are still producing a number of technologically accessible, ecologically responsible, economically feasible, and socially beneficial solutions to one of the gravest problems humanity will face in the course of 21st century. These solutions will help to alleviate a severe shortage of fresh water affecting billions of people living in areas near the world's coastlines.

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