Desalination – a critical element of water solutions for the 21st century

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In the face of climate change and the water needs from a growing world population, the use of seawater or brackish water through desalination has increased in importance. The energy efficiency and production costs for desalination plants have been markedly improved. Recent techniques have made it possible to acquire reasonably cheap desalinated water from plants that are fully powered from wind energy, or to perform desalination alongside power production.

Desalination (also called "desalinization" and "desalting") is the process of removing dissolved salts from water, thus producing fresh water from seawater or brackish water. While desalting technologies can be used for many applications, the most prevalent use today is to produce potable water from saline water for domestic or municipal purposes. Desalinated water, including wastewater treated with desalination technologies, may also be used for agricultural or industrial purposes.

Desalination is a natural, continual process and an essential part of the water cycle.

While the term is usually applied to man-made processes, desalination is actually a natural, continual process and an essential part of the water cycle. Rainwater falls to the ground and eventually flows to the sea, moving over and through the earth. On its route to the sea, it accumulates dissolved minerals and other materials and becomes increasingly salty. As water evaporates through the sun's energy, it leaves the salts behind, and the resulting water vapor forms clouds that produce rain, thus continuing the cycle.

In addition to nature, people have been desalinating water for centuries. In fact, one of the first references to desalination was by Aristotle, who wrote of seawater distillation in 320 BC. Since then, adventurers and scientists have experimented with and employed many different techniques in the quest for new sources of fresh water.

Today, with advances in desalination technologies and construction of desalting facilities all around the world, desalination has become an increasingly important part of the solution to the world's thirst for fresh water. Statistics point to its growing importance and use. For example, the 2008–2009 issue of the *IDA Desalination Yearbook*, published by Global Water Intelligence, reports that in 2007 alone, the total global contracted (planned) capacity rose by 43 per cent, as compared to the capacity contracted in 2006.

Growth in desalination is being spurred by a variety of factors. These reasons include the higher cost and availability of traditional surface water and groundwater supply, growing economies and populations in areas that rely on desalination for their water, the impact of climate change and drought, the desire of people to live coastally where water availability is limited, and the relative decrease in the cost of desalination.

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Today, there are nearly 14,000 desalination plants in more than 150 countries around the world, from Australia to China and

Japan, the United States, Spain and other European countries, the Middle East and North Africa. As of June 30, 2008, the cumulative contracted capacity of desalination plants around the world was 62.8 million m³/d (cubic meters per day), while the cumulative installed capacity (the amount currently being produced) was 52.3 million m³/d.

More than 80 per cent of the newly contracted capacity is composed of desalination of sea water or brackish water.

Sixty-two per cent (39 million m³/d) of the newly contracted capacity is composed of seawater desalination. Brackish water desalination represents another 19 per cent, or 12.2 million m³/d, followed by river water at 8 per cent, and 5 per cent for pure water. Wastewater applications of desalination technologies for water reuse are growing fast, currently representing 5 per cent of total capacity.

As of May 2009, the largest single desalination plant in operation was the 947,890 m³/d facility at Jubail-2 in Saudi Arabia. The largest operating hybrid MSF-RO (multi-stage flash distillation and reverse osmosis) plant is the 456,000 m³/d plant serving Fujairah 1 in the United Arab Emirates. Additionally, there are five other plants with capacities exceeding 500,000 m³/d under construction in the Middle East region. The largest of these is the 880,000 m³/d Shoaiba 3 unit in Saudi Arabia, which is expected to achieve full operational capacity by July 2009.

A thermal, multi-stage flash distillation (MSF) plant, in which successive condensation of evaporated brine generates energy for the next step.

While tightening across the world's credit markets has impacted the desalination industry, plans continue to advance. In fact, the desalination industry has found ways to minimize capital costs. Additionally, the industry has become more creative in using non-traditional procurement and financing, including privatization of some existing facilities. These topics are more fully explored in the following pages.

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The quest for water continues, and desalination is an important part of the solution for a thirsty planet. It is also critical to acknowledge that desalination, including its application to recycling water, is only part of the water supply solution. Water conservation, demand management and leak minimalization also play very important roles toward creating sustainable water supply systems for the 21st century.

An Overview of Desalination Technologies

Desalination technologies have advanced steadily through the years. Through the mid-1900s, the most commonly used techniques involved evaporation and distillation. The development of desalination processes took a major step forward in the 1940s during World War II, when military establishments operating in arid areas needed a way to supply their troops with potable water. By the late 1960s, commercial desalting units producing up to 8,000 m³/d – approximately 2 million U.S. gallons per day – began to be installed in various parts of the world. Most of these installations used thermal (distillation) processes.

The Torrevieja 240,000 m³/day (63 MGD) Seawater Reverse Osmosis (SWRO) Desalination Plant located in Alicante, Spain. Designed and built by ACCIONA Agua, it consists of 16 trains of 15,000 m³/day capacity each with 20 PX-220 units per train.

In the post-war years, however, scientists also began studying osmotic processes to desalinate water. The first reported use of the term "reverse osmosis" – now a popular desalination technology – appeared in the1955 annual report of the US Department of Interior's Office of Saline Water Commission. Development continued, and in the 1970s, commercial membrane processes, such as reverse osmosis (RO) and electrodialysis (ED), began to be used more extensively. Since ED could desalt brackish water more economically than distillation, more interest was focused on using desalination as a way to provide water for municipalities with limited fresh water supplies and the availability of brackish water sources.

The use of membrane technologies for desalination became fully commercial in the 1980s. By that time, thermal desalination was well established, especially in the Middle East, where municipalities relied heavily on thermal desalination technologies.

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Today, the major desalination processes employ membrane and/or thermal technologies. Reverse osmosis (RO), the predominant membrane process, accounts for 58 per cent of installed capacity, followed by thermal processes such as multi-stage flash, or MSF, at 27 per cent and multiple effect distillation (MED) at 9 per cent. Electrodialysis and electrodialysis reversal (ED/EDR) constitute approximately 4 per cent of installed capacity and hybrid technologies, 1 per cent.

Membrane desalination technologies include RO, ED/EDR and Nanofiltration (NF)

RO involves separating water from dissolved salts by passing feedwater through a semi-permeable membrane at a pressure greater than the osmotic pressure caused by the dissolved salts. Steps in the RO process include:

- Pretreatment of the feedwater via mechanical and chemical means to remove suspended solids, adjust the pH and control scaling

- Use of high pressure pumps to increase the feed pressure before the raw water is delivered to the membranes

- Separation of the dissolved salts from the product stream through the membranes

- Degasification (if needed), pH adjustment and stability enhancement of the product water before it is transferred to the distribution system

Spiral wound elements, used in reverse osmosis (RO).

RO is the most prevalent technology used outside the Middle East region for purposes of desalinating water. Ongoing advances in this technology have produced membranes with improved performance characteristics and greater productivity and energy recovery devices that result in lower pumping energy requirements.

ED/EDR is the separation of a solution's ionic components through the use of semi-permeable, ion-selective membranes operating in a direct current (DC) electric field. ED was originally developed as a less expensive alternative to distillation as a method to desalinate brackish water.

Another desalting membrane process is nanofiltration (NF), which rejects solutes larger than approximately one nanometer (10 ångströms) in size. Nanofiltration is used primarily in water softening applications for removal of hardness ions. It has replaced lime softening in many municipal projects around the world and also removes color sometimes found in ground and surface water supplies. Nanofiltration has also found a niche application in the offshore oil and gas industry for purposes of treating injection water for water flooding of reservoirs in enhanced oil recovery processes.

Thermal desalination technologies

Multi-stage flash evaporation (MSF) is a desalination process where a stream of brine flows through the bottom of chambers, or stages, each operating at a successively lower pressure, and a proportion of it flashes into steam and is then condensed. MSF is also known as Flash Distillation.

Multiple effect distillation (MED) is a thin film evaporation process, in which the vapor formed in one chamber, or effect, condenses in the next one, providing a heat source for further evaporation.

Thermal processes are widely used for seawater desalination in the Middle East. Some "hybrid" plants in the region are now being built or retrofitted to employ both thermal (for example, MSF or MED) and membrane technologies (RO).

Many desalination plants produce both electrical power and desalinated water within the same facility.

It should also be noted that many desalination facilities, particularly in the Middle East and North Africa region, have been constructed as co-generation facilities, which simultaneously produce both electrical power and desalinated water within the same facility. Certain types of desalination processes, especially distillation, can be structured to take advantage of a co-generation situation.

Desalination and the Environment

The desalination industry has made major advances pertaining to environmental considerations, such as impact on marine life and energy requirements.

To mitigate impacts on marine life, the industry has created advanced seawater intake designs that greatly reduce the threat of entrainment or impingement of marine species, improved brine or concentrate outfall designs that efficiently discharge and diffuse the brine concentrate, and developed new methods for the handling and disposal of backwash solids.

In the last decade alone, the industry has been able to reduce power consumption and also significantly lower or eliminate greenhouse gas emissions. Technological advances include development of more efficient energy recovery devices (ERDs); improved efficiency, lower RO flux designs; straight-through pumping designs; and indirect coupling of renewable energy and desalination on a large scale.

In Australia, a high growth in desalination has been combined with strong environmental consideration.

There is no question that desalination can be implemented in an extremely environmentally conscious way. Australia is perhaps the most vivid example of high growth in desalination combined with dramatic environmental pressures. This continent has witnessed an annual growth in desalination of over 30 per cent, most of which is powered by renewable energy with high design standards for environmental requirements and monitoring.

The Perth Seawater Desalination Plant is an excellent example of a plant where environmental considerations were factored heavily into the design. At this plant, salinity issues associated with brine discharge and potential dissolved oxygen impacts have been closely monitored over several years, and studies indicate no evidence of negative effects due to dissolved oxygen levels or brine discharge. The plant, which produces 140,000 m^3/day of desalinated water using RO, is indirectly fully powered using wind energy.

The International Desalination Association encourages the use of desalination in an environmentally responsible way, and actively supports the ongoing development and application of technologies that address environmental aspects of the processes involved.

The Cost of Desalination

As with environmental concerns, the desalination industry has focused heavily on cost considerations. Today, with tremendous advances in technology, the cost of desalinating water has been reduced significantly.

The cost issue involves two major elements: the capital costs associated with construction and the operating costs.

Desalination plants are major pieces of infrastructure, and as such, they are not inexpensive to build. In addition to construction labor and the cost of financing, materials costs comprise the significant portion of this overall capital expense. Over the past few years, the financing component as well as some material costs (for example, metals) have experienced wide swings, and thus affected the funding needed for construction. Of course, desalination plants are not the only construction projects to feel these effects.

When people talk about the cost of desalination, however, many are referring to operating costs, which are driven largely by the cost of energy.

As stated above, technological advances have been successful in making desalination much more cost-effective to operate. For example, in the early 1970s, typical multi-stage flash distillation systems consumed more than 20 kilowatt hours per cubic meter (kWh/m^3) or 76 kWh per 1000 gallons.

In the late 1970s, coincident with the development of high performance reverse osmosis membranes, the first large scale municipal seawater reverse osmosis (SWRO) plant was installed. Energy requirements for this plant were approximately 8 kWh per cubic meter – just 40 per cent of the energy requirement of early large scale distillation plants.

Further advances in SWRO have continued to lower energy requirements. One of the major developments was the introduction of energy recovery devices in RO desalination plants. For example, in 2006, energy consumption in the core SWRO process of a demonstration plant in Southern California was measured at just 1.58 kWh/m^3 (6.0 kWh/kgal), and the overall energy consumed by this plant was 3.1 kWh/m^3 (12 kWh/kgal) – comparable to the power required to convey surface water to Los Angeles and treat it (approximately 2.4 kWh/m^3, or 9.2 kWh/kgal).

Today's thermal MED plants use less than 3 kWh of electrical energy per m^3 of desalinated water in addition to the steam input required, very significantly less than the thermal plants built in the 1970s.


A thermal MED plant.
Photo: Courtesy Sidem/Water Desalination Report.

One way of looking at the cost issue is to examine the estimated "water cost" for various plants around the world. (Water cost is defined as the amortized capital cost plus all operating costs divided by the total volume of water produced).

In September 2008, the *Water Desalination Report* explored this issue. According to the report, the lowest water cost, estimated between 2006–2008, among plants in operation was \$0.48/m^3 for the Tuas, Singpore SWRO plant, with a capacity of 136,360 m^3/d. The highest for a land-based facility was \$1.53/m^3 at the Taunton, Massachusetts, USA SWRO plant, which has a capacity of 18,925 m^3/d Most of the facilities reported water costs in the \$0.70–1.10/m^3 range.

The cost issue regarding desalination is complex, not only because of varying construction and energy costs, but also because of varying governmental policies, including subsidies, in different parts of the world. While cost is, of course, an important consideration, the International Desalination Association believes that the fundamental issue is the value – not simply cost – of water. Access to clean, fresh water is vital for human life and health, and is also critical to the economy.

According to the World Health Organization (WHO), “About 20 per cent of the world’s population lives in countries where water is scarce, or where they have not been able to access the natural sources available. At present, 1.1 billion people lack access to safe water.”

Moreover, the United Nations Committee on Economic, Cultural and Social Rights considers access to safe drinking water a human right, commenting that, “The human right to water is indispensable for leading a life in human dignity. It is a prerequisite for the realization of other human rights.”

Desalination technologies are a key aspect to ensuring a reliable supply of potable water, whether augmenting the existing local supply or providing the primary source of water in regions where other sources are scarce or virtually non-existent. IDA is a strong proponent of making desalination as affordable as possible, while also taking the necessary steps to utilize desalination in an environmentally responsible manner.

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Innovations in Financing

Technology is not the only arena for innovation within the desalination industry. The industry has been aggressive in responding to the effects of the global economic crisis, seeking new funding and creative alternatives to combat tightening of traditional sources of funding.

According to sources such as Global Water Intelligence, which has been tracking the situation closely, some of the emerging trends include:

- Use of bridge financing. With this arrangement, one pays a higher interest rate for a time to get through to a healthier place in the market. This option is being looked at by both very large and small projects around the world.

- A shift to regional sources of financing, rather than traditional Western sources. This is especially prevalent in the Middle East, where many regional banks have come together to provide funding for projects.

- Curtailment of some capital expenditures on the front end to reduce the overall financing package.

- More distinct phasing of projects, with shifting of more capital expenditures for expansions into out-years.

- Investment in projects by private equity sources and water funds, especially for projects such as vessel-based desalination.

Over the past few years, one of the most significant emerging trends in financing and operation of desalination plants has been the increased involvement of the private sector.

This represents a shift from the traditional model, where the financing, construction oversight, plant operation and facility maintenance are the province of governments. Today, the industry is witnessing a new model where the private sector is assuming responsibility for the financial and/or operational aspects of the plants, leaving governments free to focus on maintaining and policing regulatory frameworks regarding quality standard, service, protection of the health of their people, and sustainability.

Privately financed water projects are identified by such titles as:

- Private-Public-Partnerships (PPP)
- Concessions or Utility Outsourcing model of contracts
- Independent Water and Power Projects (IWPP), where water is produced usually through desalination alongside power generation
- Build Own Operate (BOO), or
- Build Own Operate with a Transfer component attached (BOOT)

To date, private sector involvement has proven to be successful using such measurement criteria as project completion dates, quality of services provided, and adherence to budgets. There is also evidence that transferring the responsibility to finance, design, build, operate and maintain the necessary infrastructure is also leading to innovation, particularly true when competitive procurement processes are utilized to select and award long duration water supply contracts.

There are several examples to prove the efficacy of this new paradigm. For instance, a plant with capacity to deliver 800,000 cubic meters per day (m^3/d) utilizing the multiple effect distillation (MED) process is currently being undertaken with private finance in one of the largest co-generation projects underway in the world, utilizing the IWPP framework.

Similarly, increasingly large desalination plants are now being undertaken which utilize the reverse osmosis technology.

These cases include a plant of 400,000 m3/d under development using the IWPP model.

These examples point to the efficacy of the PPP/IWPP model. At a time when global financial issues demand creative problem-solving, this is very good news for both the desalination industry and the end-users who need a reliable supply of quality water to meet their needs.

Summary

Desalination is a vital part of the solution to addressing global water issues in the 21st century. Its use is expected to continue to grow throughout the world, with the industry continually developing new or enhanced technologies aimed at environmental considerations and reducing cost, and utilizing new financing models to ensure that new projects continue to come online to meet increasing water demand.

Acknowledgements

- SWRO figures for energy requirements were provided by Energy Recovery, Inc.

- P. Padmanathan, ACWA Power International provided estimates of water costs.

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Drinking Water – Sources, Sanitation and Safeguarding
R4:2009, printed in August 2009
ISBN 978-91-540-6034-4
ISSN 1653-3003
The Swedish Research Council Formas
Editor: Jonas Förare
Proofreader: Lewis Gruber
Design: Lupo Design
Illustrations: Pertti Salonen
Print: 08-Tryck AB
Picture credits: Page 8 Johnér. Page 20 and 34 NordicPhotos. Page 46 Johnér. Page 58, 61 and 65 Black&Veatch. Page 49 Courtesy Tom Pankratz. Page 50 Courtesy of ACCIONA Agua and Energy Recovery, Inc. Page 51 Courtesy Miller Truby. Page 92 Johnér. Page 101 iStockPhoto. Page 102 Johnér. Page 112 iStockPhoto. Page 134 iStockPhoto. All other pictures by the respective authors.