Advances in desalination technology

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Abstract: Seawater desalination has been the cornerstone of the Middle East’s water supply strategy since the mid-1950s, and most of the installed desalination capacity is still provided by multistage flash evaporators. But, desalination is changing. In fact, the term ‘desalination’ is no longer limited to seawater applications; desalination technologies are now routinely employed to desalinate brackish groundwater and repurify municipal effluents.

Recent advances in desalination technology have simultaneously reduced costs while dramatically improving performance and reliability to the point where desalination technologies now compete with ‘conventional’ treatment processes in many applications. New commercial strategies and a realisation of the economies-of-scale have led to further improvements in plant economics, and an increase in the size of plants now being developed and constructed.

This presentation reviews advances in membrane and membrane pretreatment systems, energy recovery devices, materials of construction, hybrid process configurations, increased unit capacities, and the use of public-private partnerships; all of which have led to reduced capital and operating costs, enabling desalination to be economically competitive with traditional treatment options.

Advances in desalination technology have resulted in better performances, lower capital and operating costs, and increased application of desalination systems. In the face of increased water shortages and growing costs of ‘conventional treatment’, this trend will certainly continue.

Keywords: DBO; desalination; distillation; energy recovery; MED; MF; microfiltration; MSF; multiple effect; multistage flash; nanofiltration; pretreatment; public-private partnerships; reverse osmosis; RO; UF; ultrafiltration.


Biographical notes: Tom Pankratz studied Environmental Engineering at the University of Houston and has written several books including ‘desalination.com’. He has also published technical papers on environmental subjects ranging from seawater desalination to zero liquid discharge. He sits on the International Desalination Association’s Board of Directors and is a member of the Research Advisory Committee for the Middle East Desalination Research Center, the Desalination Roadmap Review Committee for the National Academy of Sciences, the Water Environment Federation, and the American Water Works Association. Currently based in Houston, Texas, he is Vice President with CH2M Hill.

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1 Membrane systems

Advances in membrane technology have had the greatest effect on the desalination market. The latest IDA (World Desalting Inventory) prepared by Dr. Klaus Wagnick shows the impact that membrane systems have on the desalination market (Table 1).

Table 1 Percentage of desalting by thermal and membrane systems

<table>
<thead>
<tr>
<th>Installed/Contracted Desalting Capacity</th>
<th>Thermal Capacity (%)</th>
<th>Membrane Capacity (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total, brackish and seawater</td>
<td>50%</td>
<td>50%</td>
</tr>
<tr>
<td>Total, 1991–2001</td>
<td>40%</td>
<td>60%</td>
</tr>
<tr>
<td>Total, seawater</td>
<td>80%</td>
<td>20%</td>
</tr>
<tr>
<td>1991–2001, seawater</td>
<td>66%</td>
<td>34%</td>
</tr>
</tbody>
</table>

Reverse osmosis (RO) membrane systems are the fastest growing segment of the desalination market and an integral part of almost every water reclamation/reuse project. This growth can be attributed to technology advances over the past ten years that have improved membrane performance and reduced manufacturing costs.

RO systems use pumping pressure to force fresh water through a semi-permeable membrane, while preventing passage of dissolved solids. Within the last few years, advances in membrane technology have contributed to RO’s application in new and larger installations. These advances include:

- salt rejection improvements from 98.6 to 99.8%
- flux increases of 86%
- improved chlorine tolerance
- greater fouling resistance reduces cleaning costs, improves availability
- improvements in durability and longevity.

2 Membrane pretreatment alternatives

The capital and operating cost of a membrane pretreatment system can be greater than 50% of the overall cost of a membrane desalination or wastewater reclamation facility. The pretreatment system also represents a plant’s biggest performance and operating cost variable. Improved pretreatment alternatives have had a significant effect on the increase in the number of RO desalination systems.

RO membranes which are capable of preventing the passage of certain individual molecules are highly susceptible to fouling by organics and suspended solids. Therefore, it is important to remove these solids ahead of the RO membrane to maintain performance and prevent irreversible damage. In fact, the most critical aspect in the success of an RO system is the effectiveness of its pretreatment system.

Many RO installations now use a ‘dual membrane’ process where the RO membrane is preceded by a porous, high flux, low-pressure membrane which removes suspended
solids that would otherwise foul the membranes. These pretreatment membrane systems include:

- **microfiltration (MF)** – reduces turbidity and removes suspended and biological solids
- **ultrafiltration (UF)** – removes colour, odour, some volatile organics and suspended solids
- **nanofiltration (NF)** – provides membrane softening and sulfate removal.

MF/UF systems are so effective at removing suspended solids that they are used in virtually every wastewater reclamation/reuse system prior to RO desalination. Nanofiltration systems are currently used for membrane softening of hard ground-waters.

### 3 Membrane pretreatment for thermal evaporators

Another innovative use of nanofiltration is as a pretreatment process for multistage flash (MSF) evaporation.

The maximum temperature and performance of MSF units is limited by scaling. Nanofilters can be used prior to evaporation for membrane softening and/or sulfate removal to further improve performance of evaporators and allow operation at a higher temperature with a corresponding increase in product water production.

### 4 Energy recovery devices

Although energy costs vary widely from region-to-region and among various desalination processes, they usually represent 33% of an installation’s operating cost. There are a number of design considerations that can significantly reduce the specific energy consumption of a system.

New energy recovery devices are able to recover increasing amounts of energy from pressurised, concentrated brine in seawater RO systems, and can reduce energy requirements by 10–50%.

A ‘work exchanger’ transfers hydraulic energy directly from the brine stream to the seawater across a piston rather than by conversion to rotating energy and back to hydraulic energy, as in a pump/turbine system.

A work exchanger system will be installed on the 325,510 m$^3$/d Ashkelon project, and will produce permeate with a TDS of less than 300 mg/L from 40,700 mg/L feedwater at a specific energy consumption of 3.9 kWh/m$^3$.

### 5 Thermal desalination

Improvements in thermal seawater desalination technology are not as dramatic as those apparent in membrane desalination systems. However, new materials of construction,
better construction techniques, improved methods of chemical scale control and the
development of new pretreatment alternatives have significantly improved the
performance and reduced operating costs of thermal desalination technologies.

*MSF Distillers*: Multistage flash (MSF) desalination systems have been the
‘workhorse’ thermal desalination technology since the early 1960’s. Until recently, MSF
was the only process used on large, land-based seawater desalination systems.

In an MSF plant, a stream of heated brine flows though a vessel containing up to 40
chambers, or stages, each operating at a slightly lower pressure than the previous one. As
brine enters each stage, a portion of it ‘flashes’ into steam and is then condensed to
produce a pure distillate. The concentrated brine remaining at the end of the process is
rejected as blowdown.

MSF operating temperatures range from 100° to 110°C and they produce 6.0 to
11.0 kilograms of distillate per kilogram of steam applied. To take advantage of
economies-of-scale, MSF systems are now being designed in unit sizes to 75,700 m³/d
(16.7 MiGD).

*MED Distillers*: The newer, multiple effect distillation (MED) process has several
process advantages that are increasing its application around the world.

In the MED process, distillation takes place in a series of chambers, or effects,
operating at progressively lower pressures. As seawater is sprayed in a thin film over a
heat exchanger tube bundle, steam flowing through the tubes is condensed into pure
product water. The seawater film on the outside of the tube boils as it absorbs heat from
the steam and its vapour is introduced into the tubes in the next effect. The process is
repeated through the plant and the product water is collected and extracted.

Vapours produced in this process contain brine droplets, which are removed as the
vapour passes through mist eliminators installed in each effect. A portion of the vapour
produced in the last effect is entrained in an ejectocompressor. The ejectocompressor
utilises the pressure of the supply steam to recycle the heat remaining in the last effect
steam. By boosting this steam pressure, it can be used as heating steam in the first effect.
The use of ejectocompressors improves the energy efficiency of the MED plant by
utilising the kinetic (pressure) energy of the steam to recycle and reuse the enthalpy of
the lower pressure vapour within the process.

MEDs use approximately 33% of the electrical power required by an equivalent MSF
system, and also operate at lower temperatures (e.g., 65°C versus 110°C) than MSF
systems, reducing operational problems caused by scaling and corrosion. Seawater intake
water requirements can be up to 50% smaller than that of a similarly sized MSF
installation.

The design complexity and operation of a large-scale desalination plant is not
significantly different than that of a smaller plant, and economies-of-scale contribute to
substantial reductions in the unit cost of water production as plant sizes increase. The
capital, operating and energy cost advantages of MED’s over the MSF systems are well
known. Until recently, the size of commercial MED units was generally limited to small
and mid-size plants. New installations have demonstrated that the MED’s economic
advantages can now be exploited in larger plants as individual units are produced with
rated capacities of up to 22,700 cubic meters per day.
6 Dual-purpose plants

Dual-purpose power and water plants use steam to drive an electric generator and thermal energy to evaporate seawater as part of the desalination process. The most common method is to utilise extraction or back pressure steam turbines for power generation with the low pressure steam being used for desalination. This concept can be used on the steam cycle and combined cycle power generation schemes, and has been applied to some of the world’s largest seawater desalination plants.

The energy consumption of a dual-purpose plant is considerably lower than that of a single-purpose installation where a boiler is used only for desalination purposes.

Dual-purpose plants are usually able to utilise common seawater intakes and outfalls to reduce the plant construction and permitting costs, and may be able to share operating and maintenance personnel, resulting in lower labour costs.

7 Hybrid plants

A hybrid seawater desalination plant integrates the use of both thermal and membrane processes with an electric generating station. This alternative provides flexibility by using two different forms of energy; electricity for the RO plant and low pressure steam for the MED plant, eliminating the dependence on a single desalination technology.

Under this scheme, the thermal efficiency of the power plant improves as a greater percentage of the installed power capacity can be beneficially utilised, even during periods of low power demands.

The overall process efficiency can often be further improved by allowing operation at an increased membrane flux rate when using warm cooling water from the thermal desalination process as RO feedwater.

Such an arrangement provides maximum flexibility to meet fluctuating demands.

8 Public-private partnerships

As the capacity of water supply projects continues to increase, so does the required capital investment necessary to develop them. Many governmental entities are turning to public – private partnerships where financing and/or operational tasks are delegated to a private enterprise. There are specific advantages to each privatisation model, but all share some common elements. Technical, economic and compliance risks to the public are minimised and the developer usually arranges financing, minimising a community’s immediate financial burden. Long-term contracts usually result in lower, fixed water rates by amortising capital costs over the contract life.

Under one of the most popular type of contractual arrangements, a private party provides the capital to design, build, and operate the treatment plant for a fixed period of time, often fifteen to thirty years. The cost of the facility is then recovered by furnishing product water or treatment capacity at a contracted price, usually on a ‘take-or-pay’ basis.
The design-build-operate (DBO) project delivery model streamlines the procurement process and saves money by eliminating the separate stages and selection procedures for engineering, construction, procurement, and operations disciplines. DBOs are particularly popular with industrial clients, fast track projects, or projects where performance and the value of the service to be provided is more important than the details of what happens with the various procurement steps in between.

Clients may grant their partners wide latitude in the technologies used and the ways in which they are applied. Water is usually the private-sector company’s core-competency and the use of innovative and/or proprietary solutions to lower production costs is preferred. Companies specialising in water treatment also have ready access to new technologies that will improve plant performance as they are developed.

Public – private partnerships are not a panacea. Projects must be well structured, technically sound and financially practical or they will not survive the due diligence process. Clients must be credit-worthy and offer a secure payment mechanism, while private-sector partners must exhibit the financial and technical strength to assume responsibility for the service provided.

By thoroughly pre-qualifying prospective partners, the public’s interest for reliable services at affordable prices can be balanced against a private sector company’s desire to generate profits and provide the needed services using a public – private partnership format.

9 Summary

The benefits of R&D are apparent in the growth of desalination’s installed capacity, and new R&D initiatives have been announced that should continue this trend.

The US government has recently developed a Desalination and Water Purification Technology Roadmap to serve as a strategic research pathway for desalination technologies. The Arab Science & Development Foundation has begun development of a similar Roadmap to coordinate the R&D efforts for 22 Arab countries, while the Middle East Desalination Research Centre continues an ambitious seawater desalination research program.

Advances in desalination membrane technologies have resulted in better performance, lower capital & operating costs, and increased application of membranes in a variety of desalination applications. In the face of increased water shortages and growing costs of “conventional treatment,” this trend is expected to continue.