Desalination: A Primer

In the United States, water is relatively inexpensive compared to many other parts of the world. However, the vagaries of weather, skyrocketing population growth, and subsequent increases in water demand for water in arid, semiarid, and coastal areas are contributing to heightened interest in water desalting as a way to augment existing supplies or tapping into new "unusable" sources. In addition, many communities are turning to desalination technology as a cost-effective method of meeting increasingly stringent water quality regulations.

Water desalting is a process used to remove salt and other dissolved minerals from water. Other contaminants, such as dissolved metals, radionuclides, bacterial, and organic matter, may also be removed by some membrane treatment methods. In addition, desalting processes are used to improve the quality of hard waters (high concentrations of magnesium and calcium), brackish waters (moderate levels of salt), and seawater.

Membrane Processes

Both the electrodialysis (ED) and reverse osmosis (RO) processes use membranes to separate salts from water. No one desalting process is "the best." A variety of factors come into play in choosing the appropriate process for a particular situation. These factors include the quality of the source water, the desired quantity and quality of the water produced, pretreatment, energy and chemical requirements, and concentrate disposal issues.

ED is an electrochemical process in which the salts pass through the membrane, leaving the water behind. It is a process typically used for brackish water. Because most dissolved salts are ionic (either positively or negatively charged) and the ions are attracted to electrodes with an opposite electric charge, membranes that allow selective passage of either positively or negatively charged ions can accomplish the desalting. Freshwater recovery rates for this type of unit range from 75 to 95 percent of the source water.

In RO, salt water on one side of a semi-permeable plastic membrane is subjected to pressure, causing fresh water to diffuse through the membrane, leaving behind a concentrate solution that contains most of the dissolved minerals and other contaminants. The major energy requirement for RO is for pressurizing the source, or "feed," water. Depending on the characteristics of the feed water, different types of membranes may be used. Because the feed water must pass through narrow passages in the membrane, suspended solids must be removed during an initial pretreatment phase.

A lower pressure RO technology called nanofiltration (NF), also known as "membrane softening," has been successfully used for treatment of hard, high color, and high organic content feed water. The NF membrane has lower monovalant ion rejection properties, making it more suitable to treat waters with low salinity, thereby reducing post-treatment and conditioning as compared with RO. The NF membrane also works as an absolute barrier for cysts and viruses.

Nanofiltration plants typically operate at 85 to 95 percent recovery. Brackish water RO plants typically transfer 70 to 85 percent of the source water into permeate, and seawater RO recovery rates range from 40 to 60 percent.

When selecting RO/NF systems, the following should be considered:

Membrane Selection. Two types of membranes are most commonly used. These are cellulose acetate based and polyamide composites. Membrane configurations typically include spiral wound and hollow fiber. Operational conditions and useful life vary depending on the type of membrane selected, quality of feed water, and process operating parameters.

Useful Life of the Membrane. Membrane replacement and power consumption represent major components in the overall water production costs. The relative contributions depend primarily on feed water salinity. In well designed and operated RO systems, membranes have lasted five to over ten years in suitable applications.

Pretreatment Requirements. Acceptable feed water characteristics are dependent on the type of membrane chosen and operational parameters of the system. Without suitable pretreatment or acceptable feed water quality, the membrane may become fouled or scaled, and consequently its useful life is shortened. Pretreatment is usually needed for turbidity reduction, iron or manganese removal, stabilization of the water to prevent scale formation, microbial control, chlorine removal (for certain membrane types), and pH adjustment. As a minimum pretreatment, cartridge filters are used for protection of the membranes against particulate matter.

Treatment Efficiency. RO is highly efficient in removing metallic salts and ions from raw water. Efficiencies, however, do vary depending on the ion being removed and the membrane utilized. For most commonly found ions, removal efficiencies will range from 85 percent to over 99 percent. Organics removal is dependent on the molecular weight, shape, and charge of the organic molecule, and the characteristics of the membrane utilized. Organic removal efficiencies may range from as high as 99 percent to less than 50 percent, depending on the membrane type and treatment objective.

Bypass Water. RO permeate will be virtually demineralized. If the raw water does not contain unacceptable contaminants, the design may provide for a portion of the raw water to bypass the unit and blend with RO permeate to maintain a stable water within the distribution system and to reduce capital as well as power and chemical costs.

Post-Treatment. Post-treatment typically includes degasification for carbon dioxide (if excessive) and hydrogen sulfide removal (if present), pH and hardness adjustment for corrosion control, and disinfection as a secondary pathogen control and for distribution system protection.

Desalting By-Product. By-product water or the "concentrate" may range from ten percent to 60 percent of the raw water pumped to the RO unit. For most brackish waters and ionic contaminant removal applications, the by-product is in the ten percent to 25 percent range, while for seawater it could be as high as 60 percent. The by-product volume should be evaluated in terms of availability of source water and cost of disposal.

Desalting by-product is commonly disposed of through one of six practices: 1) sewer discharge, 2) surface water discharge, 3) irrigation, 4) deep well injection 5) evaporation ponds, and 6) zero liquid discharge thermal processes. Each of these methods varies in complexity of permitting and costs, with sewer discharge commonly being the least complex and least costly and zero liquid discharge being the most complex and most costly.

Sewer Discharge is dependent on the ability of the wastewater treatment plant to accept high salinity discharge. The treatment plant outfall location may be affected by total dissolved solids restrictions or other limiting water quality concerns.

Surface Water Discharge involves discharge to a point of outfall such as a bay, tidal lake, brackish canal, or ocean. The location and potential required by-product treatment before discharge are determined by state and regulatory agency water quality standards and bioassay toxicity testing. An NPDES permit is required and maintained by the utility owner.

Irrigation is sometimes used for by-product streams relatively lower in salinity. Saline tolerant vegetation and habitat are required. This is usually determined by site-specific soil and drainage characteristics. An NPDES permit is required and maintained by the owner if run-off from irrigation is possible.

Deep Well Injection is common, especially with inland plants. This method injects the by-product stream deep below ground under at least one overlaying, confining geologic layer. The by-product is permanently stored in the injection zone.

Evaporation Ponds may be used to reduce or eliminate by-product flows. This method of disposal is land-intensive and requires relatively dry climates. Dry salt is the waste product, and it must be characterized and disposed of accordingly as solid waste.

Zero Liquid Discharge Thermal Processes greatly reduce or eliminate the by-product liquid stream through thermal treatment processes. These processes are energy intensive and are costly. Wastes must be characterized and disposed of accordingly.

Pilot Plant Study. Before initiating the design of a membrane treatment facility, the state reviewing agency should be contacted to determine if a pilot plant study will be required. In many cases, a pilot plant study will be necessary to determine the best membrane to use, type of pretreatment as well as post-treatment, bypass ratio, amount of reject water, system recovery, process efficiency, and other design and operational parameters.

Membrane Filtration (MF/UF)

Low pressure microfiltration (MF) and ultrafiltration (UF) membrane filtration technology have emerged as viable options for addressing the current and future drinking water regulations related to the treatment of surface water, groundwater under the influence, and water reuse applications for microbial and turbidity removal. Full-scale facilities have demonstrated the efficient performance of both MF and UF as feasible treatment alternatives to conventional granular media processes. Both MF and UF have been shown to exceed the removal efficiencies identified in the Surface Water Treatment Rule such as *Cryptosporidium oocyst*, *Giardia cyst*, and turbidity.

MF and UF membrane systems generally use hollow fibers that can be operated in the outside-in or inside-out direction of flow. Pressure (5 to 35 psi) or vacuum (-3 to -12 psi for outside-in membranes only) can be used as the driving force across the membrane. Typical flux (rate of finished water permeate per unit membrane surface area) at 20 degrees C for MF and UP ranges between 50 and 100 gallons per square foot per day.

Since both processes have relatively small membrane pore sizes, membrane fouling, caused by the deposition of organic and inorganic compounds on the membrane, may occur at unacceptable levels if the system is not properly selected, designed, and operated. Automated periodic backflushing and chemical washing processes are used to maintain the rate of membrane fouling within acceptable limits. Chemical cleaning is employed once a maximum transmembrane pressure differential has been reached. Some systems utilize air/liquid backwash. Typical cleaning agents utilized include acids, caustic, surfactants, enzymes, and certain oxidants, depending upon membrane material and foulants encountered. Chemicals used for cleaning, and the method used in the cleaning process, must be acceptable to the membrane manufacturer.

Overall treatment requirements and disinfection credits must be discussed with and approved by the reviewing authority. Disinfection is recommended after membrane filtration as a secondary pathogen control barrier and distribution system protection.

MF and UF membranes are most commonly made from various organic polymers such as different cellulose derivatives, polysulfones, polypropylene, and polyvinylidene fluoride. Physical configurations include hollow fiber, spiral wound, cartridge, and tubular. MF membranes are capable of removing particles with sizes down to 0.1-0.2 microns. Some UF processes have a lower cutoff rating of 0.005-0.01 microns. Pressure or vacuum may be used as the driving force to transport water across the membrane surface.

When selecting MF/UF systems, the following should be considered:

- A review of historical source raw water quality and variability data, including turbidity, algae, particle counts, seasonal changes, organic contents, microbial activity, and temperature as well as other inorganic and physical parameters is critical to determine the overall cost of the system. The degree of pretreatment, if any, should also be ascertained. Design considerations and membrane selection at this phase must also address the issue of target removal efficiencies and system recovery versus acceptable membrane fouling rate. At a minimum on surface water supplies, prescreening is required.

- The life expectancy of a particular membrane under consideration should be evaluated (typically three to ten years). Membrane replacement frequency is a significant factor in operation and maintenance cost comparisons in the selection of the process. Warranties offered by manufacturers vary significantly and should be carefully evaluated.
- Some membrane materials are incompatible with certain oxidants such as chlorine. If the system must rely on pretreatment oxidants for other purposes, for example, zebra mussel control, taste and odor control, or iron and manganese oxidation, the selection of the membrane material becomes a significant design consideration.
- The source water temperature can significantly impact the flux of the membrane under consideration. At low water temperatures, the flux can be reduced appreciably (due to higher water viscosity and resistance of membrane to permeate), possibly impacting process economics by the number of membrane units required for a full-scale facility. System capacity must be selected for the expected demand under seasonal (cold and warm water temperature) conditions.
- Backwashing waste volumes can range from four to 15 percent of the permeate flow, depending upon the source water quality, membrane flux, frequency of backwashing, and the type of potential fouling.
- Membrane systems used for drinking water production should be provided with an appropriate level of finished water monitoring and direct integrity test features. Monitoring options may include laser turbidimeters, particle counters, and manual and/or automated integrity testing using pressure decay or air diffusion tests.
- Cross-connection control considerations must be incorporated into the system design, particularly with regard to the introduction and discharge of chemicals and waste piping. Membrane systems that use chemical washing processes with harsh chemicals require additional consideration.
- Redundancy of critical components and control features should be considered in the final design.
- Other post-membrane treatment requirements such as corrosion control and secondary disinfection must be evaluated in the final design. Other contaminants of concern such as color and disinfection by-product precursors should also be addressed.
- Before initiating the design of an MF or UF treatment facility, the state reviewing authority should be contacted to determine the disinfection credits available for the membrane process, and whether a pilot plant study will be required. In most cases, especially surface water applications, a pilot plant study will be necessary to determine the best membrane to use, particulate/organism removal efficiencies, cold and warm water flux, the need for pretreatment, fouling potential, operating and transmembrane pressure, and other design considerations. The state reviewing authority should be contacted prior to conducting the pilot study to establish the protocol to be followed.

How Much Does Desalted Water Cost?

The growing demand for fresh water in many areas of the nation, due to drought, water shortages, population increases, and the desire for higher quality water, has spurred unprecedented interest in the process of desalting seawater or brackish water to increase the reliability of water supplies. Long used on ships, island resorts, and in water-short countries, the practice of using desalting technology to produce large-scale domestic supplies is only a few decades old in the United States.

The most common objection to using desalted water to help meet the nation's growing municipal water needs is that the process is too expensive. This is no longer the case. Due to developments in technology and improvements in desalting processes, the cost of desalting water has decreased dramatically over the past 30 years.

Cost comparisons are often made to existing water supplies. Actually, since desalted water represents a new source of supply, comparisons should be made to the cost of developing other new sources, such as surface water impoundments, remote well fields, and long distance pipelines.

The price comparison of desalting includes capital costs and operating and maintenance costs. Costs can vary considerably from one site to another based on a number of factors. In general the amount of salt to be removed greatly affects the cost of desalting. The more salts to be removed, the more expensive the desalting process. The capacity of the desalting plant also impacts costs, with larger plants generally being more economical. Energy is the most significant factor, amounting to about 20 to 50 percent of the operating cost, depending on the technology used, and price of power. Other factors include the amount and type of pretreatment required, treatment process selected, reliability, disposal of the removed salts (concentrate), regulatory issues, land costs, and conveyance of the water to and from the plant.

Water quantity is measured in myriad different units—acre-feet, cubic feet, and million gallons, among others. Discussing desalting costs, however, in terms of dollars per 1,000 gallons is one common way to show how desalting costs compare with the costs of existing supplies. Table 1 compares the approximate cost of existing

Table 1. Cost as a Percentage of Total Supply

Supply Type	Water Costs To Consumer[1] ($/gal)	Total Family Cost[2] ($/gal)
Existing Traditional Supply	0.90-2.50	8.40-30.00
New Desalted Water		
Brackish[3]	1.50-3.00	18.00-36.00
Seawater[4,5]	3.00-8.00	36.00-96.00
Combined Supply[6]		
Traditional + Brackish	1.20-2.75	13.20-33.00
Traditional + Seawater	1.10-3.05	13.20-36.00

1 Cost includes all costs to consumers for treatment and delivery.
2 Cost is based on a family of four using 100 gpd, for a total monthly use of 12,000 gal. Cost is based on the average of the "To Consumer" cost shown.
3 Brackish is moderately salty—1,000 to 5,000 mg/L total dissolved solids.
4 Sea water contains 30,000-35,000 mg/L total dissolved solids.
5 Cost is for typical urban coastal community in the U.S. Costs for inland communities may be higher.
6 Combined supply costs are for the traditional supply augmented with 50 percent of desalted brackish water, or ten percent of desalted sea water.

traditional supplies and new supplies using desalting technologies.

Cost As a Percentage of Total Supply

In most cases, desalted water is not the sole source of a community's supply. It is usually combined with water from less expensive sources. For instance, as shown in Table 1, if a community paying $2.50/1,000 gallons for its existing water decides to double its supply with desalted brackish water, a typical family's monthly water bill would increase by about $3. If the augmented supply comes from desalted seawater, the monthly increase would be less than $6.60.

In the United States, most inexpensive traditional water resources have already been developed. The development of most new traditional supplies will be much more expensive than previous development of existing supplies. Of the potential treatment options, in many cases desalting a local resource is financially and environmentally competitive with traditional development methods such as building dams, aqueducts, canals, and treatment plants to develop new water supplies.

In the last decade, desalting technology has improved significantly and costs have dropped by over 50 percent. At the same time, the cost of developing traditional water sources has escalated, as drinking water quality and environmental standards have become more stringent, and the distances from source to consumer have increased. In water-short areas, the costs for desalted water are already competitive with the development of new traditional supplies. As alternative energy sources and improved processes and equipment are developed, additional desalting cost reductions can be expected. GE

The preceding is based on information provided by the American Membrane Technology Association, 2409 SE Dixie Highway, Stuart, FL 34996, P: 772-463-0820, F: 772-463-0860, E: admin@amtaorg.com, W: amtaorg@aol.com.