Overview of Membranes Technologies for Remediating Brackish Water

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**Abstract**—The shortage of drinking water is a major problem in the arid regions. In these regions, precipitations are insufficient to meet the demand for water and it is, therefore, necessary to resort to underground resources. In recent times, many of these aquifers have been over exploited and suffer serious problems of saline contamination. Groundwater aquifers are major sources of water in most of the Middle East countries. As such, seeking the best and optimal techniques in remediating brackish water becomes a necessary and critical target for these countries. Most of the desalination technologies rely on either distillation or membranes to separate salts from the product water. However, Membrane processes are currently the fastest-growing techniques. Ultimately, the selection of a desalination process depends on site specific conditions, including the salt content of the water, economics, and quality of water needed by the end user, and the local engineering experience and skills. This paper evaluates various membrane technologies adapted to improve the quality of brackish water and to make it suitable for different human uses. The presentation includes describing those technologies and discussing their advantages, disadvantages, and other implications associated with their current applications.

I. **INTRODUCTION**

Based upon the investigations conducted by the World Health Organization (WHO), it is to be noted that annual water availability of 1000 m3 per capita constitutes the limit below which it will not be possible to guarantee an acceptable living standard as well as economic development of a country (WHO, 2006). The global picture will become even more serious if the forecasts made by Food and Agriculture Organization (FAO) on the overall increase in world population is taken into consideration (FAO, 2001).

A wide variety of desalination technologies effectively remove salts from salty water (or extract fresh water from salty water), producing a water stream with a low concentration of salt (the product stream) and another with a high concentration of remaining salts (the brine or concentrate). Most of these technologies rely on distillation and/or membranes to separate salts from the product water. There is no best method of desalination. Ultimately, the selection of a desalination process depends on site conditions, including the salt content of the water, economics, and the quality of water needed by the end user, and local engineering experience and skills (Davis et al, 1997 and Maurel, 2002).

Two main directions survived the crucial evolution of desalination technology, namely evaporation and membrane techniques. The cost barrier broke during the last few years and is now down to the level of 50 to 80 cents/m3 of desalinated seawater, and the decreasing cost tendency continues. Desalination of brackish water is even cheaper, at costs ranging from 20 to 35 cents/m3. Membrane techniques penetrate deep in water treatment technology wherever possible. Wastewater also is treated with membranes, though rarely.

II. **REVERSE OSMOSIS (RO)**

**Technology Description**

Reverse Osmosis (RO) is a physical process that uses osmotic pressure difference between saltwater and pure water to remove salts from water. In this process, a pressure greater than the osmotic pressure is applied on saltwater (feed water) to reverse the flow, this results in pure water (freshwater) passing through synthetic membrane pores separated from the salt (Fig. 1). A concentrated salt solution is retained for disposal. Two common types of membranes are used in RO process for desalination; the Cellulose Acetate (CA) membranes and the Non-CA membranes.

The RO process is effective in removing total dissolved solids (TDS) concentrations of up to 45,000 mg/L, which can be applied to desalinate brackish water as well as wide range of seawater. Reverse osmosis needs energy to operate the pumps that raise the pressure applied to feed water. The amount of pressure required directly relates to the TDS concentration of the feed water. For brackish water, the pump pressure requirement is between 140 and 400 psi. Typical recovery rates for RO systems can be 30 to 80 percent depending on the quality of feed water, the pressure applied, the quality of the product, and the technology and membranes involved (Tamim and Kimberly, 2005). Water conversion can go as high as 90.95 percent in the case of light brackish water, down to 35 to 50 percent recovery in the case of seawater. The RO technique is usually used for small and large plants, amounting to about 22 percent of the world's larger plants of capacity above 4000 m3/day. RO systems can easily be integrated within other thermal desalination technologies, namely hybrid systems for efficient water production (Semih and Serkan, 2004).
An RO system is made up of the following basic components: pretreatment, high-pressure pump(s), membrane assembly, and post-treatment. Pre-treatment of feed water is essential in order to protect the RO membrane and prevent membrane contamination and fouling, reduce energy costs, and increase salt retention. Typical pre-treatment involves pre-filtration to remove suspended solids from feed water; dosage of acid (hydrochloric or sulfuric) to remove bicarbonate ions, followed by aeration to remove carbon dioxide; and filtration by active carbon to remove dissolved organic materials and chlorine compounds. Different anti-scalants are used in order to prevent precipitation of dissolved salts due to increased concentration (Raphael Semiat, 2000). A high-pressure pump generates the pressure needed to enable the water to pass through the membrane. The membrane assembly consists of a pressure vessel and a membrane that permits the feed water to be pressurized against the semi-permeable membranes. The membranes are fragile and vary in their ability to pass fresh water and reject salts. RO membranes are made in a variety of configurations. The two most commercially successful membrane configurations are spiral wound and hollow-fine fiber (Kim, 2005). Certain membrane materials are sensitive to oxidants such as chlorine; therefore, additional chemicals may be needed in order to remove the oxidants from the feed water prior to membrane treatment. Often, pH adjustment is also needed. Post-treatment of RO permeate may also be needed depending on the intended use of product water. For example, carbon dioxide and soda ash may be added to increase alkalinity of the treated water and to reduce corrosiveness of the product water. Post-treatment also prepares final product water for distribution, removes gases such as hydrogen sulfide, and adjusts pH. The energy requirement for RO depends directly on the concentration of salts in the feed water. Because neither heating nor phase change is necessary for this method, pressurizing the feed water accounts for the major use of energy. As a result, RO facilities are most economical for desalinating brackish water and increase in cost as the salt content of the water increases (Heather Cooley et al, 2006).

**RO Advantages**

Some of the advantages of RO systems are (Sourcebook of Alternative Technologies).

- The processing system is simple; the only complicating factor is finding a clean supply of feedwater to minimize the need for frequent cleaning of the membrane.
- Installation costs are low.
- Low maintenance, non-metallic materials are used in construction.
- Energy use to process brackish water ranges from 1 to 3 kWh per 1,000l of product water.
- In addition to removal of inorganic contaminants, RO technologies can be used to remove the major portions of most organic contaminants.
- Aside from the need to dispose of the brine, RO has a negligible environmental impact.
- The technology makes minimal use of chemicals.

**RO Disadvantages**

Some of the disadvantages of RO systems are (Sourcebook of Alternative Technologies).

The membranes are sensitive to abuse.

The feed water usually needs to be pre-treated to remove particulates (in order to prolong the membrane life).

Operation of a RO plant requires a high quality standard for materials and equipment.

There is often a need for foreign assistance to design, construct, and operate plants.

Brine must be carefully disposed of to avoid deleterious environmental impacts.

There is a risk of bacterial contamination of the membranes; while bacteria are retained in the brine stream, bacterial growth on the membrane itself can introduce tastes and odors into the product water.

**Implications with Current Applications**

The most severe limitation on reverse osmosis is the maximum limit of 50,000 milligrams per liter of total dissolved solids in the feed water. Another limitation is that there must be no iron in the feed water. This limitation is so rigid that only stainless steel and nonferric materials will be used downstream of the iron water. The solubility of alkaline earth sulfates and carbonates limits reverse osmosis treatment. Reverse osmosis is limited to waters that do not have silica saturation in the reject brine. Silica chemistry is extremely complex. When the molybdenum reactive silica concentration exceeds 30 milligrams per liter as SiO2 or the pH exceeds 8.3 in the brine stream, an environmental chemist or engineer should be consulted. Reverse osmosis is also limited to the treatment of waters with less than 1 milligram per liter of oil and grease. Cellulose acetate membranes are usually limited to pH levels between 4.0 and 7.5. Cellulose acetate membranes cannot be used on waters where the temperature exceeds 88
Electrodialysis (ED) and Electrodialysis Reversal (EDR) Technology Description

Electro dialysis (ED) is an electrochemical separation process that uses electrical currents to move salt ions selectively through a membrane, leaving fresh water behind. A basic ED unit or “membrane stack” consists of several hundred cell-pairs bound together with electrodes on the outside. Brackish water is pumped at low pressure between stacks of flat, parallel, ion-permeable membranes that form channels. These channels are arranged with anion selective membranes alternating with cation-selective membranes such that each channel has an anion-selective membrane on one side and a cation-selective membrane on the other (Fig. 2). Water flows along the face of these alternating pairs of membranes in separate channels and an electric current flow across these channels, charging the electrodes. The anions in the feed water are attracted and diverted towards the positive electrode. These anions pass through the anion-selective membrane, but cannot pass through the cation-selective membrane and are trapped in the concentrate channel. Cations move in the opposite direction through the cation selective membrane to the concentrate channel on the other side where they are trapped. This process creates alternating channels, a concentrated channel for the brine and a diluted channel for the product water (Heather Cooley et al, 2006).

EDR is a modification of ED and has a higher recovery rate (up to 94%) because of the feed water circulation within the system and alternating polarity. Experience suggests that EDR can also achieve higher water recovery than RO systems (Hays, 2000). EDR can produce more product water and less brine than distillation processes, can treat water with a higher level of suspended solids than RO, needs fewer pretreatment chemicals, and has less membranes sensitivity for fouling (Buchart, 2002).

ED Advantages: Some of the advantages of ED system are

- ED system separates without phase change, which results in relatively low energy consumption.

Fig. 2. Schematic of an Electrodialysis Desalination Plant, Source: Heather Cooley et al, 2006

In the early 1970s, a modification of ED was introduced – electrodialysis reversal (EDR). An EDR unit operates on the same principle as a standard ED plant except that both the product and the brine channels are identical in construction. Several times an hour, the polarity of the electrodes is reversed, and the brine channel and product water channel flows are switched. Immediately following the reversal of polarity and flow, the ions are attracted in the opposite direction across the membrane stack and product water is used to clean out the stack and lines. After flushing for a few minutes, the unit resumes producing water. The reversal process breaks up and flushes out scale and other deposits in the cells which creates a cleaning mechanism, and decreases the scaling and fouling potential of the membrane. Flushing also allows the unit to operate with fewer pretreatment chemicals. EDR systems can operate on highly turbid feed water and are less prone to biofouling than RO systems. The major energy requirement is the direct current used to separate the ions in the membrane stack (Wangnick/GWI, 2005). ED and EDR can remove or reduce a host of contaminants from feedwater and the process is not as sensitive to pH or hardness levels in the feedwater. The EDR process is adaptable to various operation parameters, requires little labour, and the maintenance costs are generally low (Manual of Water Supply, 1999). EDR has a higher recovery rate (up to 94%) because of the feed water circulation within the system and alternating polarity. Experience suggests that EDR can also achieve higher water recovery than RO systems (Hays, 2000). EDR can produce more product water and less brine than distillation processes, can treat water with a higher level of suspended solids than RO, needs fewer pretreatment chemicals, and has less membranes sensitivity for fouling (Buchart, 2002).
When brackish water is desalted by ED system, the product water needs only limited pre-treatment. Typically only chlorination for disinfection is required.

Because ED system removes only ionised species, it is particularly suitable for separating non-ionised from ionised components.

Osmotic pressure is not a factor in ED system, so the pressure can be used for concentrating salt solutions to 20% or higher. ED disadvantages. Some of the disadvantages of ED system are (www.separationprocesses.com).

- Organic matter, colloids and SiO2 are not removed by ED system.
- Feedwater pre-treatment is necessary to prevent ED stacks fouling.
- Laborate controls are required, and keeping them at optimum condition can be difficult.
- Selection of materials of construction for membranes and stack is important to ensure compatibility with the feed stream.

Implications with Current applications. While electrodialysis reversal has been used to treat water as saline as sea water, 4,000 milligrams per liter of total dissolved solids is considered to be an upper limit for economical operation. Some electrodialysis membranes can tolerate strong oxidants, like chlorine, but most cannot. The reversal of polarity used in electrodialysis reversal for removal of scale allows operation on water that is saturated with alkaline earth carbonates. Saturation with an alkaline sulfate with low carbonate alkalinity should be avoided (Technical Manual).

DC field reversal eliminated the need to feed either acid or anti-scalant chemicals into the desalination process. Not having to feed chemicals at remote water treatment sites is a major advantage of EDR over RO. As an electrically driven process, product water quality from EDR can be varied by controlling the voltage input into the membrane stack, and by controlling how many stacks in series (or stages) are reused.

When electrodialysis reversal is being designed, it is essential to determine the types of available electrical power. The voltage, phase, frequency, and available amperage of all electrical power sources must be considered in the design. EDR is not affected by as many feed water constituents as RO. EDR is capital competitive or slightly higher in cost compared with RO, unless RO requires additional treatment, which EDR does not (the need to add acid to RO feed + post RO2, decarbonation to strip out CO2 (Eugene, 2006).

Project costs are usually measured in terms of combined capital and long term O&M costs. On 800 ppm to 2,000 ppm waters the combination of capital (equipment, installation and building required) along with long term O&M can favor EDR. This is especially true on applications requiring higher water recovery. EDR systems operate with up to a 60% TDS4, reduction per stage, depending on the specific constituents in the water. EDR is usually most competitive when a one or two stage system is used to desalt raw water sources. However, three stage and four stage EDR systems have also been shown to be more cost effective than RO when certain combinations of feed water constituents are present with the need for high water recovery. EDR technology requires fewer acid or anti-scalant chemicals than reverse osmosis, and in many cases requires close to none. Also, unlike polyamide reverse osmosis technology, EDR technology can treat water with a free chlorine residual, making EDR an ideal desalination technology to treat many municipal drinking and reclaimed wastewaters where chlorine is used as a disinfectant. EDR is not affected by as many feed water constituents as RO, which limit that processes performance. Normally, on larger systems (1.5+ mgd or 6,000+ m3/day) the EDR building required will be larger than that for RO. Offsetting this is EDR’s lower O&M cost with reduced (or no chemical feed), with reduced pretreatment/ post treatment costs, and with reduced longterm membrane replacement costs. On lower TDS waters (less than 1500 ppm), the EDR electrical power consumption can be less than RO. When “ancillary costs” such as raw water pumping, and waste brine disposal are added in, the O&M cost consideration often times outweighs the higher capital costs for EDR(Eugene, 2006).

Microorganisms are not removed by electrodialysis reversal as well as small suspended material. The pretreatment for electrodialysis reversal should remove any material that will plug a 10-micron filter. Loosened scale and particulate matter may require post desalination removal. Suspended solids removal during pretreatment is the preferred design for electrodialysis-reversal facilities. Pretreatment of suspended solids removes particulates, including microorganisms, which are prone to blind electrodialysis reversal membranes. This removal reduces the time between cleanings. When electrodialysis-reversal product water turbidity cannot be controlled economically by pretreatment, then an attempt will be made to eliminate all pretreatment suspended solids. If this is feasible, suspended solids control will be a post-treatment process at the electrodialysis reversal facility (Bernardes, 2000).

III. CONCLUSION

Overview of two membrane desalination technologies was covered in this study which leads us to the following conclusions:

- Membrane desalination of brackish water is one of the feasible processes to produce water quality that fits many end-use water quality requirements.
- The quality of feed water is a determining factor for deciding which type of membrane process to use.
- Some problems associated with using membranes may include short design life; membrane cleaning (backwashing or chemical treatment); high membrane replacement costs; low resistance to chlorine, and lack of resistance to fouling.
- RO processing system is simple; the only complicating factor is finding a clean supply of feed water to minimize the need for frequent cleaning of the membrane, has low installation costs, and uses energy ranging from 1 to 3 kWh per 1000ft product water. However, the membranes are sensitive to abuse, the feed water usually needs to be pre-treated to
remove particulates (in order to prolong the membrane life) and Brine must be carefully disposed of to avoid deleterious environmental impacts.

5. ED system separates without phase change, which results in relatively low energy consumption, the product water needs only limited pre-treatment and it is suitable for separating non-ionised from ionised components. However, organic matter and colloids are not removed by ED system, feedwater pre-treatment is necessary to prevent ED stacks fouling and Selection of materials of construction for membranes and stack is important to ensure compatibility with the feed stream

6. ED is an economic desalination process for brackish groundwater with TDS up to 2500 ppm where RO is more economical for brackish water with higher TD levels.

7. It is clear that the water desalination industry is currently at an important stage, where the need for water availability and quality is increased in many places. No arguments are needed with respect to the quality of the water; the main struggle is still the cost of the production.

8. Water treatment processes in the future may readily employ integrated membrane processes that can effectively treat fresh, brackish, and saltwater.

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