KEY POINT: The selection of a membrane treatment process for desalinating brackish water depends on the quality of the feed and the finished water objectives.

SUMMARY OF ISSUES

- Membrane processes for brackish water desal include:
  - Reverse Osmosis (RO)
  - Nanofiltration (NF)
  - Electrodialysis (EDR)
- In the U.S. almost all desal applications utilize RO or NF, although EDR is also employed on a more limited basis.
- Pressure is the driving force for RO and NF processes.
- RO is used to reject most of the contaminants in water, including total dissolved solids (TDS), organics, and pathogens. The rejection efficiency of RO membranes relative to dissolved solutes is based on a number of factors, including charge, size, and steric (i.e., the “branched” nature of the structure) characteristics. As a general guideline, BWRO membranes reject over 95% of all ionic species.
- NF membranes are designed to selectively provide a high degree of rejection for compounds such as multivalent ions or organic contaminants, while rejecting monovalent ions less efficiently. Because this characteristic property reduces overall rejection, NF membranes can be operated at lower feed pressures, and thus have lower energy requirements.
- In RO and NF, water passes through the membrane while its constituents are rejected. Thus, these processes are both considered “barrier technologies” for the purpose of removing pathogenic microorganisms. In EDR, charged species pass through the membranes rather than the water, and it is therefore not considered a barrier technology for pathogen removal.
- Electric current is the driving force for EDR. By drawing ionic constituents across selectively permeable membranes (either cation-permeable or anion-permeable, as applicable) the EDR process removes salinity. Because the energy consumption and cost
of EDR increases significantly with higher salinity, EDR is typically used to desalt brackish waters with up to about 8,000 mg/L of TDS. In general, EDR only compares favorably with RO and NF in terms of economics and/or performance under limited conditions, as summarized in Table 1.

Table 1. Summary of Conditions Potentially Favoring EDR vs. RO/NF

<table>
<thead>
<tr>
<th>Condition Advantageous for the Use of EDR</th>
<th>Rationale</th>
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<tbody>
<tr>
<td>High feed water silica concentrations</td>
<td>Silica can be a significant scaling problem with RO. However, because silica does not carry a charge it is not removed by EDR and does not foul the selectively permeable membranes.</td>
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<tr>
<td>Feed TDS = 1,000 to 3,000 mg/L with low fouling potential</td>
<td>For low TDS with low scaling potential, EDR can achieve recoveries up to approximately 10 percent higher than single pass RO.</td>
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<tr>
<td>Warm feed water</td>
<td>While the salt passage associated with RO membranes increases at warmer feed water temperatures, the rejection of EDR membranes improves. Thus, EDR membranes perform better than RO for warm feed waters and worse at colder temperatures.</td>
</tr>
<tr>
<td>Presence of chlorine in the feed water</td>
<td>While RO membranes are rapidly and irreversibly damaged by chlorine, EDR membranes are chlorine-tolerant up to about 0.5 mg/L (^a).</td>
</tr>
</tbody>
</table>

\(^a\). This statement is true for polyamide and thin film composite membranes but not for cellulosic membranes some of which are chlorine tolerant to the 0.5 mg/L level and perhaps slightly above

STRATEGIES

**RO is the most versatile technology**, as it is the most economically viable option for a wide range of applications and feed water quality. NF is commonly used for applications in which the more robust salt rejection properties of RO are unnecessary.

**NF can be used to reduce operating costs in some cases.** NF membranes are considered “looser” than RO membranes, efficiently rejecting multivalent ionic species (i.e., those with a charge exceeding +/- 1) while allowing a greater percentage of monovalent ionic species (i.e., those with a charge of precisely +/- 1) to pass through the membranes. Thus, the difference in TDS between the two sides of the NF membrane is lower. Since the pressure required for reverse osmosis is proportional to the difference in TDS between the two sides of the membrane, the
energy requirements for NF are lower. Consequently, it is generally advantageous to use NF over RO, treated water quality objectives permitting.

Examples of brackish water applications for which NF may be best suited include:

- Softening (i.e., the selective rejection of divalent calcium (Ca+2) and magnesium (Mg+2))
- Softening (i.e., the selective rejection of divalent calcium (Ca^{2+}) and magnesium (Mg^{2+}))
- Selective rejection of multivalent contaminants of concern in cases in which overall TDS reduction is not an issue
- Modest TDS reduction when significant concentrations of divalent ionic species are present.

**RO and NF systems can be configured in various ways to meet site-specific treatment objectives.** For example, a portion of the flow might bypass the RO or NF system and be blended with the permeate downstream in order to both more precisely target the TDS goal for the finished water and avoid the expense of desalting more water than necessary. Further, a second stage of RO membranes might be utilized to treat the concentrate from the first stage, thus maximizing the process recovery (albeit at increased cost).

**Conceptual process designs** can be created to model membrane functionality. The various RO and NF membrane element manufacturers have developed software to enable users to develop conceptual process designs using their respective proprietary membrane products. At a minimum, source water quality is a necessary input for these modeling programs. These programs are generally available for free public download at each of the respective manufacturers’ web sites.

To minimize costs, bypass flow should be maximized if possible. In some cases, the entire treatment plant flow may not need to be subjected to the desal process in order to meet treated water quality objectives for TDS or other constituents.

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**BENEFITS & COSTS**

**Benefits**

- In addition to dissolved solids, RO and NF processes also remove contaminants such as volatile organic compounds (VOCs), synthetic organic compounds (SOCs), endocrine
disruptors, pharmaceutically active compounds, and disinfection by-products to varying extents.

- RO and NF systems can be configured in various ways to meet site-specific treatment objectives and/or increase energy efficiency.

**Costs**

- Power requirements comprise a substantial portion of the total cost to produce desalinated water (i.e., amortized capital plus operating costs). Thus, small changes in the cost of energy and/or power consumption can significantly influence the cost of desal.

- Because the energy necessary to accomplish RO is proportional to the TDS of the feed water, more saline applications render the cost of desal using RO increasingly sensitive to power consumption and commensurate costs.

**KEY UNCERTAINTIES**

- **Membrane fouling and scaling.** Membrane fouling and scaling are considered major obstacles for efficient membrane operation due to:
  - Declining permeate flux
  - Increased energy consumption
  - Deteriorated permeate quality
  - Shortened membrane life
  - Increased operational cost

Strategies to prevent and control membrane fouling/scaling are discussed in the PIM cell discussion on engineering and technical issues related to pretreatment.

- **With RO and NF membranes, certain trace organic pollutants,** such as pesticides, disinfection by-products (DBPs), endocrine disrupting compounds (EDCs), and pharmaceutically active compounds (PhACs), have been rejected to varying extent during full- and pilot-scale high-pressure membrane applications. This is due to their wide range in size, charge and conformation. The removal of these compounds is of great importance where a high product water quality is desired.
Complexity in operation of EDR. The operation of EDR is more complex than RO and NF due to electrical rectification, and the need for flow reversal valves in addition to reversing current. It often requires more maintenance and repair than high-pressure membrane systems.

ADDITIONAL RESOURCES


