Latest Technologies in Water Desalination

Amy E. Childress
Department of Civil and Environmental Engineering
University of Nevada, Reno

1st Arab-American Frontiers Symposium
Kuwait Institute for Scientific Research and U.S. National Academies
October 17-19, 2011 in Kuwait City
Outline

- Introduction
  - Fresh water scarcity
  - Alternate sources and new technologies
  - Desalination by reverse osmosis

- Emerging Technologies for Desalination Applications
  - Membrane Distillation
  - Forward Osmosis
  - Pressure Retarded Osmosis

- Final Remarks
Global Water Stress

Forcing water providers to rely more on alternative sources
Alternative Sources and New Technologies

Saline waters

“Waste” waters

New concerns
- Salinity
- Recovery
- Energy
- Emerging Contaminants

Membrane Distillation (MD)

Forward Osmosis (FO)

Pressure Retarded Osmosis (PRO)
Desalination Applications and Salinity Levels

- Seawater desalination (35-41 g/L)
- In-land groundwater desalination (2-6 g/L)
  - RO brine (>40 g/L)
- Extreme salinity scenarios (>100 g/L)
  - Oil and gas applications
  - Mineral mining (water is by-product)
Current Leading Desalination Technology: Reverse Osmosis
Reverse Osmosis Separation

- Produces water with <500 mg/L salts
- Less energy intensive than distillation (~10x less)
- But… does have drawbacks
  1. passage of some contaminants → dual osmotic barrier (FO/RO) or MD
  2. reduced driving force at high salt concentrations → osmotic dilution or MD
  3. membrane fouling → FO as pretreatment for RO
In-Land Desalination

Brackish Groundwater Feed → RO

Drinking water

Concentrate

Drawback 4. Brine Disposal or Treatment → FO/RO or MD
Seawater Desalination

Drinking water

Concentrate

High pressure

Low pressure

Pressurized Feed
Seawater Desalination

Drinking water

Concentrate

High pressure

Low pressure

Pressurized Feed

Pressure

RO

PX
Seawater Desalination

Drinking water

Concentrate

High Salinity

Environmental Concern
Waste of Chemical Energy

Pressurized Feed
Emerging Technologies:

Membrane Distillation (MD)

Forward Osmosis (FO)

Pressure Retarded Osmosis (PRO)
Direct Contact Membrane Distillation

Heated Feed Stream

Hydrophobic, Microporous Membrane

Cooler Distillate Stream

Driving force: vapor pressure gradient
Driving Force in MD

Addresses RO Drawback 1: Reduced Driving Force at High Salt Concentration
Industrial Mineral Harvesting
Great Salt Lake, Utah

Tzahi Cath’s Lab at Colorado School of Mines
Desalination of Hypersaline Lake Water

<table>
<thead>
<tr>
<th>Constituent</th>
<th>g/L</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cl</td>
<td>83</td>
</tr>
<tr>
<td>SO₄</td>
<td>10</td>
</tr>
<tr>
<td>Ca</td>
<td>0.3</td>
</tr>
<tr>
<td>K</td>
<td>3</td>
</tr>
<tr>
<td>Li</td>
<td>0.03</td>
</tr>
<tr>
<td>Mg</td>
<td>6</td>
</tr>
<tr>
<td>Na</td>
<td>47</td>
</tr>
<tr>
<td>TDS</td>
<td>149 g/L</td>
</tr>
</tbody>
</table>

> 300 g/L
Removal of Emerging Contaminants

Osmotic Processes

Membrane Distillation

Addresses RO Drawback 3: Passage of Some Contaminants
Membrane Distillation with Solar Energy

Salinity Gradient
Solar Pond

Solar Thermal, Geothermal
Waste Heat

Membrane Distillation

Stand-alone energy collection/storage and water desalination
Emerging Technologies:

Membrane Distillation (MD)

Forward Osmosis (FO)

Pressure Retarded Osmosis (PRO)
Emerging Technology: Forward Osmosis

Three technologies promise to reduce the energy requirements of desalination by up to 30 percent. The race is on to see which will take the lead.

FORWARD OSMOSIS
Water molecules migrate by natural osmosis, without energy input, into an even more concentrated “draw solution,” whose special salt (green) is then evaporated away by low-grade heat.
On the market: 2010-2012

CARBON NANOTUBES
An electric charge at the nanotube mouth repels positively charged salt ions. The uncharged water molecules slip through with little friction, reducing pumping pressure.
On the market: 2013-2015

BIOMIMETICS
Water molecules pass through channels made of aquaporins, proteins that efficiently conduct water in and out of living cells. A positive charge near each channel’s center repels salt.
On the market: 2013-2015
Osmosis and Forward Osmosis

Osmosis

Brine \rightarrow Water

Equilibrium

Brine \rightarrow Water

Forward Osmosis

Conc Draw Solution \rightarrow Feed Water

Osmotic pressure

membrane
FO Pretreatment for RO
(General Concept)

Addresses RO Drawback 3: Membrane Fouling
Addresses RO Drawback 3: Passage of Some Contaminants
Ammonia-Carbonate FO Process

Meny Elimelech’s Lab at Yale University
Emerging Technologies:

Membrane Distillation (MD)

Forward Osmosis (FO)

Pressure Retarded Osmosis (PRO)
What is Pressure-Retarded Osmosis?

- An osmotically driven membrane process similar to RO and FO

Osmosis: pressure > osmotic pressure

Reverse Osmosis (RO): pressure < osmotic pressure

Pressure Retarded Osmosis (PRO):
What is Pressure-Retarded Osmosis?

- An osmotically driven membrane process similar to RO and FO
- A source of renewable and sustainable energy

global energy production from mixing in estuaries: 2,000 TWh/y
current global energy production from all renewable sources: 10,000 TWh/y
What is Pressure-Retarded Osmosis?

- An osmotically driven membrane process similar to RO and FO
- A source of renewable and sustainable energy
- A process of capturing the energy released from the mixing of freshwater with saltwater

River 5 g/L

Ocean 35 g/L
What is Pressure-Retarded Osmosis?

- An osmotically driven membrane process similar to RO and FO
- A source of renewable and sustainable energy
- A process of capturing the energy released from the mixing of freshwater with saltwater
What is Pressure-Retarded Osmosis?

- An osmotically driven membrane process similar to RO and FO
- A source of renewable and sustainable energy
- A process of capturing the energy released from the mixing of freshwater with saltwater
Power Generation with PRO

chemical potential transformed to hydraulic potential

Norman, 1974
PRO System

Seawater

Low pressure pump

Low pressure pump

Pressure exchanger

Circulation pump

Hydroturbine and generator

Draw solution side

Membrane

Low pressure pump

Feed solution side

Flushing solution

Fresh water

Diluted seawater

Diluted seawater

Fresh water

Net power

Achilli, Cath, Childress, 2009
Adapted from Loeb, 2002
Seawater Desalination

Drinking water

Concentrate

High Salinity

Pressurized Feed

Environmental Concern
Waste of Chemical Energy

RO

PX
Proposed Energy Recovery in Seawater Desalination

1- Energy generation
2 - Concentrate dilution
Final Remarks

- There is no single best method for desalination
  - Water source and energy availability
  - Treatment needs
  - Sustainability considerations

- The needs for all processes are similar:
  - Commercial competition for membranes
  - New membrane modules / packing
  - Cost models

- MD, FO, and PRO have implications for wastewater reuse
Acknowledgements

- California Department of Water Resources
- National Aeronautics and Space Administration
- Office of Naval Research
- U.S. Bureau of Reclamation
- U.S. Department of Energy
- Hydration Technology Innovations

- Dr. Andrea Achilli
- Dr. Tzahi Cath
- Dr. Scott Tyler
- Dr. Francisco Suarez
- Katie Bowden, Jeri Prante, Guiying Rao, Jeff Ruskowitz