Assessment of Traditional and Novel Membrane Processes for Recovery of Cooling Tower Water in Geothermal Power Plants

Nathan Walker and Tzahi Y. Cath, Colorado School of Mines
Amy E. Childress and Mirinda Hutton, University of Nevada, Reno
Assaf Weinberg, Ormat Technologies, Inc.

Geothermal 2008 Conference and Expo
October 6, 2008
Reno, NV

Outline

- The energy-water nexus
- Water use and reuse in cooling towers
- Pressure driven membrane processes
- Novel membrane processes
  - Osmotically and thermally driven
- Experimental
- Results
- Conclusion
Energy and Water

- 2006 US Department of Energy report
- Water is used in energy production
- Energy is used to treat drinking water and wastewater
- Waste streams

Water use for cooling

- Cooling towers
- Desert (swamp) coolers
Cooling Tower

- Water is cooled mainly through evaporation
- During evaporation cooling water is concentrated
- Some water is wasted as blowdown to maintain water quality
- Blowdown can be treated and reused

Geothermal Power Plant Operation

- Steam
- Brine
- Geothermal Reservoir
- Steam/Liquid Separator
- Turbine Level One
- Turbine Level Two
- Generator
- Condenser
- Organic Liquid Loop
- Heat Exchanger
- Warm Water
- Cool Water
- Blowdown Water (to waste)
- Treatment
- Evaporation and Drift
- Makeup Water
- Blowdown Water
- Warm air, evaporated water (no salt), and drift (high salt)
Membrane Processes for Treatment of Blowdown Water and Geothermal Brine

- Pressure-driven
- Osmotically-driven
- Thermally-driven

Pressure-Driven Membrane Processes

- In pressure-driven membrane processes pressure is applied to the feed stream to produce purified product water
Pressure Driven Membrane processes: Reverse Osmosis (RO) and Nanofiltration (NF)

- Water diffuses through dense membranes that retain ions and low-molecular-weight solutes
- Both RO and NF can remove salts and dissolved organics from water
- NF operates at lower pressure and generates higher flux
- NF = membrane softening process
  - Designed to remove multivalent ions (>98%) but can also remove sodium and chloride (up to 90%)
- Typical operating pressure:
  - NF: 70-210 psi
  - RO: 500-1,000 psi

Osmotically Driven Membrane Processes: Forward Osmosis (FO)

- Uses the osmotic pressure difference across a semi-permeable membrane to filter impaired water
Thermally-Driven Membrane Processes: Membrane Distillation (MD)

- Components of MD
  - Warm feed
  - Porous hydrophobic membrane
  - In Direct Contact MD (DCMD), cold fresh water on the permeate side
- Driving force
  - Partial vapor pressure gradient

Thermally-Driven Membrane Processes: Membrane Distillation (MD)

- Benefits
  - No pressure, energy in the warm feed water
  - Close to 100% rejection of non-volatiles
  - Membranes made of inert materials
  - Water flux minimally affected by feed salinity

- Limitations
  - Cooling is needed on the permeate side
  - Sensitivity to pressure and surface tension of liquids
  - Low rejection of volatile compounds
Objectives

- Evaluate feasibility of membrane processes for treatment of blowdown water and geothermal brine
  - Conventional
    - Reverse Osmosis (RO)
    - Nanofiltration (NF)
  - Novel
    - Membrane Distillation (MD)
    - Forward Osmosis (FO)

Experimental: NF and RO

- Tested on both bench and pilot scale
- Bench scale testing
  - Monitored water flux, batch recovery, and salt rejection
  - Water from cooling towers in Imperial Valley
  - Membrane cleaning tested at end of operation cycles
  - Membranes selection for pilot testing in the field
Experimental: NF and RO

- Pilot scale testing
  - Testing of commercial NF membrane at Steamboat Hills
  - Ultrafiltration pretreatment

Experimental: Forward Osmosis

- Tested on both bench and pilot scale
- Bench scale testing
  - Monitored water flux, batch recovery, and salt rejection
  - Water from cooling towers in Imperial Valley
  - Membrane cleaning tested at end of operation cycles
- Pilot scale testing at Xcel power plant, Denver, CO
Experimental: Membrane Distillation

- Tested on both bench and pilot scale
- Bench scale testing
  - Monitored water flux, batch recovery, and salt rejection
  - Water from cooling towers in Imperial Valley
  - Membrane cleaning tested at end of operation cycles
  - Degasification experiments
- Flat sheet membranes
  - Polypropylene
  - PTFE (Teflon®)
- Tubular membrane

Experimental: Membrane Distillation

- Pilot scale testing
  - Conducted with geothermal brine as feed solution
  - Monitored water flux, system temperatures, and salt rejection
- Tubular membrane
Results and Discussion

Experimental Water Quality

- Blowdown water from Imperial Valley, CA
- Geothermal brine from Steamboat Hills, Reno, NV
- High TDS, TSS, and SDI indicate high fouling potential
- High Ca, SO₄, Mg, and Si indicate high scaling potential
- Water quality varies over time

<table>
<thead>
<tr>
<th>Analyte</th>
<th>Blowdown Water</th>
<th>Geothermal Brine</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ar</td>
<td>1.0</td>
<td>10.0</td>
</tr>
<tr>
<td>B</td>
<td>0.5</td>
<td>39.3</td>
</tr>
<tr>
<td>Ba</td>
<td>0.4</td>
<td>0.1</td>
</tr>
<tr>
<td>Ca</td>
<td>277.6</td>
<td>14.5</td>
</tr>
<tr>
<td>K</td>
<td>22.9</td>
<td>73.7</td>
</tr>
<tr>
<td>Mg</td>
<td>107.7</td>
<td>0.1</td>
</tr>
<tr>
<td>Na</td>
<td>402.7</td>
<td>654.5</td>
</tr>
<tr>
<td>S</td>
<td>430.3</td>
<td>81.6</td>
</tr>
<tr>
<td>Sc</td>
<td>B.D.L.</td>
<td>10.6</td>
</tr>
<tr>
<td>Si</td>
<td>13.3</td>
<td>139.4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Analyte</th>
<th>Blowdown Water</th>
<th>Geothermal Brine</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Anions (mg/L)**

- Cl⁻: 408, 825
- SO₄: 1.373, 123.4
- NO₃: 7.0, 1.8
- NO₂⁻: 1.6, 0.4
- PO₄³⁻: 8.0, N/D

**Water Quality**

- pH: 7.8, 7.9
- TDS, mg/l: Not Measured, 2.404
- TOC, mg/l: 10.0, 1.5
- Turbidity, NT: 3.0, Not Measured
- SDI: 90% blockage, Not Measured
NF/RO Membrane Selection

Selection based on initial flux, operating pressure, and product water salinity

<table>
<thead>
<tr>
<th>Membranes</th>
<th>Operating Pressure for initial flux experiments (psi)</th>
<th>Initial Flux (L/m²-hr)</th>
<th>Flux Decline</th>
<th>Flux After Cleaning (L/m²-hr)</th>
<th>Initial Conductivity of Permeate (μS)</th>
<th>Conductivity of Permeate After Cleaning (μS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NF90</td>
<td>48</td>
<td>19 Medium</td>
<td>17</td>
<td>145</td>
<td>211</td>
<td></td>
</tr>
<tr>
<td>4040</td>
<td>44</td>
<td>17 Medium</td>
<td>22</td>
<td>1,370</td>
<td>1,910</td>
<td></td>
</tr>
<tr>
<td>XLE</td>
<td>50</td>
<td>21 High</td>
<td>20</td>
<td>206</td>
<td>1,180</td>
<td></td>
</tr>
<tr>
<td>ULP</td>
<td>66</td>
<td>20 High</td>
<td>20</td>
<td>178</td>
<td>not available</td>
<td></td>
</tr>
<tr>
<td>TFCS</td>
<td>50</td>
<td>16 Medium</td>
<td>16</td>
<td>340</td>
<td>260</td>
<td></td>
</tr>
<tr>
<td>XN45</td>
<td>35</td>
<td>20 Low</td>
<td>24</td>
<td>2,690</td>
<td>2,980</td>
<td></td>
</tr>
</tbody>
</table>

NF/RO Performance Tests

Feed = Blowdown water, T = 23°C

30% water recovery experiment

Why Forward Osmosis?

- Pilot testing at Steamboat Hills was successful due to utilization of ultrafiltration pretreatment
- Forward Osmosis as pretreatment may achieve long term viability with lower energy requirements

No fouling seen after two weeks of operation
Forward Osmosis Pilot Testing:  
Xcel Coal Power Plant,  
Denver, CO

Membrane Distillation for  
Blowdown Water and Geothermal Brine Treatment
MD Performance Tests: Bench Scale Testing with BD Feed

- Water flux is high and is a function of membrane characteristics
- Water flux sensitive to temperature gradient across the membrane
- Salt rejection > 99.8%
- Fouling is reversible following mild cleaning

Membrane Distillation Pilot Testing: Steamboat Hills Geothermal Plant, Reno, NV
Membrane Distillation Pilot Testing: Steamboat Hills Geothermal Plant, Reno, NV

- Decline in flux was caused by decreasing temperature gradient caused by inadequate capacity of water chiller

\[
T_f = \sim 100^\circ C \\
T_p = \sim 60^\circ C
\]

Conclusions

- **RO/NF processes**
  - Capable of treating water to high quality
  - Pretreatment is essential for successful operation
  - Proven and commercially available technology

- **Forward Osmosis**
  - Long term operation of FO system has been successfully demonstrated at pilot scale
  - FO can be used as an advanced pretreatment for RO/NF
    - provides protection of downstream RO and NF membranes
    - can treat highly impaired water
Conclusions

- Membrane Distillation processes
  - Capable of treating blowdown water and geothermal brine with flux rates similar to those found in NF/RO processes
  - Quality of product water is extremely high
  - When used in conjunction with sources of waste heat, energy demand is minimal
  - Membrane fouling in MD is minimal and can be reversed with mild cleaning
  - Maintaining temperature gradients on larger scales is key for successful implementation in geothermal power plants

Acknowledgements

- Department of Energy, National Renewable Energy Lab (NREL)
- Ormat Technologies, Inc. for support of the study
- Dean Heil for analytical support
- Carl Lundin for logistical support on FO pilot system