Effects of Salinity and Feed Temperature on Permeate Flux of an Air Gap Membrane Distillation Unit for Sea Water Desalination

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Water issues

• Roughly 80% of the world population live in developing countries.
  o 1.3 billion lack access to water
  o 2.6 billion deprived of electricity
  o 84% in rural regions
    o (44% Africa and 38% Asia)

• Lack of access to potable water and high cost of purification pose a major challenge.
Access to an improved water source
In % of total population (in 2004)

- more than 95 %
- 83 to 95 %
- 65 to 83 %
- less than 65 %
- No data

1. According to the definition of UNICEF and WHO: piped water into dwelling, Public tap/standpipe, Tubewell/borehole, Protected dug well, Protected spring, Rainwater collection.

Sources: World Health Organization (WHO) and United Nation’s Children’s Fund (UNICEF), Meeting the MDG Drinking Water and Sanitation Target. The Urban and Rural Challenge of the Decade, Geneva (WHO) and New York (UNICEF), 2008.
Problem statement

Humanity’s Top Ten Problems for next 50 years

1. ENERGY
2. WATER
3. FOOD
4. ENVIRONMENT
5. POVERTY
6. TERRORISM & WAR
7. DISEASE
8. EDUCATION
9. DEMOCRACY
10. POPULATION

Source: Professor Smalley, Rice University
Membrane Distillation (MD)

Advantages:
1. Low operating pressures than RO
2. Can treat high salinity brines
3. Requires less space than others
4. Minimal reactions membranes/feed solutions
5. Low operating temperature < feed boiling point – waste heat, solar, wind, geothermal

Disadvantages:
1. Low permeate flux than RO
2. Dependence on feed concentration, temperature
3. Fouling, Membrane deterioration
OBJECTIVE

- Distillation of seawater using affordable technology – renewable energy or waste heat.
MD Introduction

Direct Contact MD
A)  

Air Gap MD
B)  

Vacuum MD
C)  

Sweeping Gas MD
D)  

Diagram cues:
- Direct Contact MD
- Air Gap MD
- Vacuum MD
- Sweeping Gas MD

Diagram details:
- Feed water
- Permeate
- Cooling plate
- Vacuum
- Sweeping gas
MD module

- Scarab AB AGMD unit
  - 2.8m² membrane area
  - PTFE & PP materials
  - Parallel cross-flow
MD Objective

Characterize a Scarab AB MD unit

• Test MD unit within operating limits
  o Effect of hot side temperature ($T_h$)
  o Effect of cold side temperature ($T_c$)
  o Effect of Salinity (C)
  o Effect of temperature drop across membrane ($\Delta T$)
• Thermal energy required to produce water
Membrane Distillation (MD) Schematic

Heat rate: \[ Q = m_h \times C_p \times (T_{f_i} - T_{f,Hx,i}) \]
Membrane Distillation (MD) Schematic

Heat consumption rate: $Q_{in} = m_h \cdot C_p \cdot (T_{hi} - T_i)$
1. Circulation pumps, one for each circuit;  
2. Membrane module;  
3. Warm water tank with heaters; 4. Cold water tank;  
5. Expansion tank; 6. Monitoring instruments and transducers;  
7. Plate heat exchangers on warm water side; 8. Air to liquid heat exchanger;  
Results Comparison

![Graph showing the comparison of product water flow rate (l/m²·hr) against temperature drop (deg. C). Legend includes data points for different conditions, with symbols indicating different researchers' data: ifegwu Th=70-85, Tc=22; Alaa's data Th=70-85, Tc=20, 30, 40.]
Effect of feed water temperature
Permeate flux vs. feed Temperature

![Graph showing permeate flux vs. feed temperature with different concentrations of solution: 0 grams/Liter (stars), 35 grams/Liter (blue dots), and 55 grams/Liter (green dots). The x-axis represents the feed temperature (°C) ranging from 20 to 90, and the y-axis represents the permeate flux ($J_0$) in kg/m²*hr.]
Specific Energy Consumption

![Graph showing specific energy consumption ($e_{th}$) vs. $T_f$ (°C) for 35 grams/Liter (blue dots) and 55 grams/Liter (green squares). The graph indicates an increase in specific energy consumption with an increase in $T_f$. At 50 °C, $e_{th}$ is around 1200 kWh/m^3 for 35 grams/Liter and slightly higher for 55 grams/Liter. As $T_f$ increases to 90 °C, $e_{th}$ for 35 grams/Liter rises to around 2200 kWh/m^3, while for 55 grams/Liter, it remains above 1800 kWh/m^3.](image)
Contaminant removal

% Removed

Compounds

Li  Al  Cr  Mn  Ni  Co  Zn  As  Sr  Cd  Ba  Pb  Chloride  Sulfate  TOC  TDN
## Distillate Quality

<table>
<thead>
<tr>
<th>Element</th>
<th>Concentration Before</th>
<th>Concentration After</th>
<th>EPA (maximum allowable contaminant level)</th>
<th>Units</th>
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</thead>
<tbody>
<tr>
<td>Li</td>
<td>674</td>
<td>3.9</td>
<td>50 to 200</td>
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<td>Al</td>
<td>2898</td>
<td>2.4</td>
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<td>Ppb</td>
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<td>Cr</td>
<td>4776</td>
<td>4.8</td>
<td>100</td>
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<tr>
<td>Mn</td>
<td>713</td>
<td>1</td>
<td>50</td>
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<tr>
<td>Ni</td>
<td>5080</td>
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<tr>
<td>Co</td>
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<td>Ppb</td>
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<tr>
<td>Cd</td>
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<td>Ppb</td>
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<tr>
<td>Ba</td>
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<td>0.27</td>
<td>2000</td>
<td>Ppb</td>
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<tr>
<td>Pb</td>
<td>368</td>
<td>0.53</td>
<td>0; action level = 15</td>
<td>Ppb</td>
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<tr>
<td>Chloride</td>
<td>680mM</td>
<td>3.7mM</td>
<td>250 mg/L</td>
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<tr>
<td>Sulfate</td>
<td>28mM</td>
<td>0.148mM</td>
<td>250 mg/L</td>
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<tr>
<td>TOC</td>
<td>123 µM</td>
<td>72 µM</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TDN</td>
<td>29 µM</td>
<td>31 µM</td>
<td>1mg/L or 10mg/L</td>
<td></td>
</tr>
</tbody>
</table>
Conclusions

1. Increased temperature increases permeate flux (raises vapor pressure gradient)

2. Increased salt concentration reduces permeate flux (reduction in vapor pressure gradient) and increases specific energy consumption

3. Required low grade heat allows for use of waste heat, solar and other renewable sources