An Innovative Zero-Liquid Discharge Intermediate-Cold-Liquid Eutectic-Freeze Desalination System

Produced Water Working Group

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Outline

• Overview of Freeze-Desalination Technology
• Introduction to OU’s Concept
• Thermo-Economic Analysis
• Experimental Setup and Sample Results
Eutectic-Freeze Desalination

• Very old method of producing fresh water. Sailors in cold climates melted the frozen seawater to get fresh water on board ships.

• Application in food industries, wastewater treatment and seawater desalination.

Freeze separation with blue dye [2]

Applicability of various desalination technologies [1]

Principle of Operation

Phase diagram of a binary salt-water system

- Liquid (unsaturated solution)
- Salt solubility line
- Ice line
- Ice + salt
- Salt + saturated solution
- Eutectic point

Pure ice crystals float.
Salt sinks.

Temperature (°C)

Weight % NaCl

0 23.3 100

Saltwater

NaCl crystals + saltwater

Ice + saltwater

Ice + NaCl crystals
State-of-the-Art of Freeze-Desalination Technologies

- The major technologies:
  
  (i) direct contact freezing
  
  (ii) vacuum freezing
  
  (iii) indirect contact freezing

Direct Contact Freeze [2]

- Superior heat transfer
- Low quality water (the coolant forms chemical bonds with water)

Indirect Contact Freeze [4]

- High quality ice
- Poor heat transfer due to ice layer

Electrochemical freeze crystallization [4]

Freeze desalination of seawater using LNG cold energy [3]

- Simple; good heat transfer
- Requires significant compressor power

Vacuum Freeze [1]

OU’s Freeze-Desalination Technology

• Utilizes an immiscible inert liquid to remove heat from the brine by direct mixing

• Benefits from the superior heat transfer of direct contact freezing systems

• No attachment of ice to the cooling surfaces

• No chemicals

• Atmospheric Pressure

Schematic representation of the innovative freeze-desalination technology
Lab-Scale Freeze-Desalination Test Setup
Sample Experimental Results

The ice crystals formed from freezing a 10,000 ppm brine solution, (left) ice crystals transported to the settling tank from the freezing chamber, and (right) the ice crystals accumulated at the bottom of the freezing chamber.
### Preliminary Results of Thermo-Economic Performance Analysis

<table>
<thead>
<tr>
<th>Brine TDS = 200,000 ppm</th>
<th>Heat Exchanger Effectiveness</th>
</tr>
</thead>
<tbody>
<tr>
<td>ε = 1</td>
<td>ε = 0.9</td>
</tr>
<tr>
<td>100% Sep. efficiency</td>
<td>LCW ($/ton of brine)</td>
</tr>
<tr>
<td></td>
<td>LCW ($/barrel of brine)</td>
</tr>
<tr>
<td>90% Sep. efficiency</td>
<td>LCW ($/ton of brine)</td>
</tr>
<tr>
<td></td>
<td>LCW ($/barrel of brine)</td>
</tr>
<tr>
<td>80% Sep. efficiency</td>
<td>LCW ($/ton of brine)</td>
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<tr>
<td></td>
<td>LCW ($/barrel of brine)</td>
</tr>
<tr>
<td>70% Sep. efficiency</td>
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</tr>
</tbody>
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- Considering a plant capacity of 1000 ton brine/day and 30 years lifetime
- Considers the additional cost of deep-well disposal of rejected brine
- Based on current industrial electricity prices in Oklahoma
- Based on actual brine compositions from Beaver County in Oklahoma