Solar Membrane Distillation for Off-Grid, Decentralized Water Purification

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U.S. Water Stress Ratio
Water Stress: Leading Edge

- 21000 homes and 300,000 residents
- 40% no access to running water
- ~243 LPCD (~711 other places in USA)
- Water hauling ~ 60km round trip
- Water cost:

<table>
<thead>
<tr>
<th></th>
<th>Tucson</th>
<th>City of Phoenix</th>
<th>Navajo Nation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water cost</td>
<td>$0.0011/L</td>
<td>$0.0013/L</td>
<td>$0.038/L</td>
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</tbody>
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Why MD for Navajo?

- Large, brackish aquifer
- Off-the-Shelf
- O & M Simplicity

- Autonomous, off-grid operation
- Brine Minimization
- Solar compatibility
V/SG MD Research Objectives

1. Adapt and characterize commercial modules and off-the-shelf components for Membrane Distillation (MD) desalination

2. Develop predictive, mechanistic model (numerical simulation) and validate against experimental observations

3. Implement and monitor demonstration-scale system in field and train local ownership and operation team
**Hollow Fiber (HF) Contactors**

<table>
<thead>
<tr>
<th><strong>Liqui-Cel Membrane Module</strong></th>
<th></th>
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<tbody>
<tr>
<td>Membrane material [--]</td>
<td>PP/ PVDF</td>
</tr>
<tr>
<td>Area [m$^2$]</td>
<td>1.4</td>
</tr>
<tr>
<td>Pore size [$\mu$m]</td>
<td>0.03-0.1</td>
</tr>
<tr>
<td>Fiber length [m]</td>
<td>0.2</td>
</tr>
<tr>
<td>Fiber inner diameter [mm]</td>
<td>225</td>
</tr>
<tr>
<td>Fiber outer diameter [mm]</td>
<td>315</td>
</tr>
<tr>
<td>Porosity [%]</td>
<td>30</td>
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</tbody>
</table>

![Diagram of Hollow Fiber (HF) Contactors](image)
MD Study Progression

Bench scale

Prototype Scale

Pilot scale

Field scale
Model Development

- Finite Difference Method
- Coupled mass and energy balances
- Fractal analysis for inter-fiber distance
- Condensation term
- Fitted parameter: tortuosity
Sweep Gas Velocity Effect

- \( u_b \) constant
- Solid lines represent predicted values

Permeate Molar Flux (mol/min m\(^2\)) vs. \( u_a \) (m/s)

- \( T_b = 50 \, ^{\circ}\text{C} \)
- \( T_b = 70 \, ^{\circ}\text{C} \)
Pore Size Effect

- Experimental $d_p = 0.1 \mu m$
- Predicted $d_p = 0.1 \mu m$
- Predicted $d_p = 0.45 \mu m$

Permeate Molar Flux

$\text{Permeate Molar Flux} = \frac{\text{Permeate Molar Flowrate (mol/min m}^2)}{u_a \text{ and } u_b \text{ constant}}$

Feed Water Temperature (°C)
Partial Pressure of Water

- $u_a$, $u_b$ and $T_b$ constant
Integrating Solar and MD

Two “tank” system: one small h/x followed by large heat storage tank.
Insight 1: Component Scaling