Desalination Buoy

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PROJECT GOALS

• Concept: Create a buoy system that can desalinate ocean water
  • Use a piston to create pressure for reverse osmosis
  • Target coastal developing areas

• Target output: 1000 gal per day per device
  • Human drinking, sanitation & hygiene needs: 50 liters/day (13.21 gal/day)*

• Goal: Generate an appropriately scaled pressure with a prototype
  • Use a smaller device with a proportional flow rate

PROJECT REQUIREMENTS

• RO membranes require ~800psi to function properly

• Waves off the coasts of developing areas are approximately 2-4 meters high

• CTQs (Critical to Quality):
  • Low cost
  • Durable
  • Serviceable
  • Water quality standard
  • Minimize environmental impact

Timeline

Initial Presentation
CDR Report
Decide on Final Design
SolidWorks Drawings
Order Parts
Prototype Building
Testing Structure Building
Preliminary Manual Testing
Analyze/Reevaluate Prototype Design
Testing
Commerical Buoy Design Analysis
Final Presentations
Preliminary Design Ideas

- Two super-buoyant floats
- Gripping rods to make handling easier
- Protective chains prohibit design from overextending
- Support rod screws on/off
STABILITY IMPROVEMENT IDEAS
Final Prototype Design
SCALING DOWN TO PROTOTYPE

- Existing piston with fixed dimensions
  - Up to 250psi
  - 12in stroke length
  - 1.06in piston diameter

- Based on tire parameters, goal = 100psi
  - Calculations say ~200psi can be achieved
    - Does not include minor head/spring/friction losses

- Using scaled equations, we determined need for buoy of ~30in diameter and ~12in height

- Prototype piston is pneumatic, actual piston will be hydraulic
Design Features

The Buoy

- Used bus tire
  - Cheap
  - Environmentally responsible
  - Durable
- Filled with “Great Stuff” foam for buoyancy
- Bolted acrylic support sheets to either side of the tire to keep the foam in
Design Features

The Piston

- Specs:
  - Handles up to 250psi
  - 12” stroke length
  - 1.06” piston diameter
- Surrounded by PVC pipe for protection
- Connected to a spring at the base
  - Extends when the piston extends
  - Creates force to retract the piston after each stroke
Design Features

Support Structure

- Comprised of two aluminum support bars across an aluminum plate
- Plate: Has a threaded hole that the piston attaches to for support
- Support Bars: bolt into both the plate and the buoy
**Prototype Calculations**

**Constant Values**

\[
\begin{align*}
D_{\text{tire}} &= 32.5" \\
D_{\text{PVC}} &= 1.5" \\
H_{\text{buoy}} &= 10" \\
l_{\text{piston}} &= 12" \\
A_{\text{piston}} &= 1.04 in^2 \\
\rho &= 0.00112153 \text{slug/in}^3 \\
g &= 32.2 \text{ft/s}^2 \\
W &= 90 lbs
\end{align*}
\]

**Pressure Calculations**

\[
\begin{align*}
V_{\text{buoy}} &= \frac{\pi \cdot H_{\text{buoy}}}{4} (D_{\text{tire}}^2 - D_{\text{PVC}}^2) \\
&= 8278 \text{in}^3 \\
F_b &= V \cdot \rho \cdot g = 298.95 lbs \\
F_{\text{net}} &= F_b - W = 208.95 lbs \\
P &= \frac{F_{\text{net}}}{A_{\text{piston}}} = 200.91 \text{psi}
\end{align*}
\]
COMMERCIAL CALCULATIONS

PISTON DIMENSIONS

\[ V = 1000 \text{gal} \]
\[ \eta = 0.3 \]
\[ V' = \frac{V}{\eta \cdot 0.133680556} = 445.6 \text{ft}^3 \]
\[ P_{\text{req}} = 800 \text{psi} \]
\[ f_{\text{waves}} = 6 \frac{\text{waves}}{\text{min}} \cdot 60 \frac{\text{min}}{\text{hour}} = 360 \frac{\text{waves}}{\text{hour}} \]
\[ l_{\text{piston}}^{**} = 2.36 \text{ft} \]
\[ V_{\text{perstroke}} = \frac{V'}{f \cdot 24} = 0.05157 \text{ft}^3 \]
\[ A_{\text{piston}} = \frac{V_{\text{perstroke}}}{l_{\text{piston}}^{**}} = 0.02185 \text{ft}^2 \]
\[ D_{\text{piston}} = 2.0017 \text{in} \Rightarrow 2 \text{in} \]

PRESSURE CALCULATIONS

\[ F_{\text{req}} = \frac{P_{\text{req}}}{0.0069444 \cdot A_{\text{piston}}} \]
\[ = 2517.5 \text{lbs} \]
\[ \rho_{\text{seawater}} = 0.0011509 \frac{\text{slug}}{\text{in}^3} \]
\[ g = 32.2 \frac{\text{ft}}{\text{s}^2} \]
\[ W^{**} = 400 \text{lbs} \]
\[ F_{\text{buoyant}} = F_{\text{req}} + W^{**} = 2917.5 \text{lbs} \]
\[ V_{\text{buoy}} = \frac{F_{\text{buoyant}}}{\rho \cdot g} = 7.8724 \times 10^4 \text{in}^3 \]
\[ H_{\text{buoy}}^{**} = 25 \text{in} \]
\[ D_{\text{buoy}} = \sqrt{\frac{4 \cdot V_{\text{buoy}}}{\pi \cdot H_{\text{buoy}}^{**}}} = 63.32 \text{in} \]
BAR STRESS ANALYSIS
# Prototype Head Loss

<table>
<thead>
<tr>
<th>Point of Interest</th>
<th>Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entrance</td>
<td>$h_{m1} = K \rho \frac{V^2}{2} = (1.0) \left( \frac{0.0372 \text{ lbm}}{\text{in}^3} \right) \left( \frac{172.6 \text{ in}}{s} \right)^2 = 1.43 \text{ psi} $</td>
</tr>
<tr>
<td>Valve</td>
<td>$h_{m2} = f \frac{L_e}{D} \rho \frac{V^2}{2} = (0.045)(8) \left( \frac{0.0372 \text{ lbm}}{\text{in}^3} \right) \left( \frac{172.6 \text{ in}}{s} \right)^2 = 1.03 \text{ psi} $</td>
</tr>
<tr>
<td>Tee</td>
<td>$h_{m3} = f \frac{L_e}{D} \rho \frac{V^2}{2} = (0.045)(60) \left( \frac{0.0372 \text{ lbm}}{\text{in}^3} \right) \left( \frac{172.6 \text{ in}}{s} \right)^2 = 7.74 \text{ psi} $</td>
</tr>
<tr>
<td>Exit</td>
<td>$h_{m1} = K \rho \frac{V^2}{2} = (0.5) \left( \frac{0.0372 \text{ lbm}}{\text{in}^3} \right) \left( \frac{172.6 \text{ in}}{s} \right)^2 = 0.715 \text{ psi} $</td>
</tr>
<tr>
<td>Valve</td>
<td>$h_{m2} = f \frac{L_e}{D} \rho \frac{V^2}{2} = (0.045)(8) \left( \frac{0.0372 \text{ lbm}}{\text{in}^3} \right) \left( \frac{172.6 \text{ in}}{s} \right)^2 = 1.03 \text{ psi} $</td>
</tr>
<tr>
<td>Tee</td>
<td>$h_{m3} = f \frac{L_e}{D} \rho \frac{V^2}{2} = (0.045)(60) \left( \frac{0.0372 \text{ lbm}}{\text{in}^3} \right) \left( \frac{172.6 \text{ in}}{s} \right)^2 = 7.74 \text{ psi} $</td>
</tr>
</tbody>
</table>

**Total Head Loss** = 19.7 psi
# Commercial Head Loss

<table>
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<tr>
<td>Entrance</td>
<td>[ h_{m1} = K \rho \frac{V^2}{2} = (1.0) \left( \frac{0.0372 \text{ lbm}}{\text{in}^3} \right) \left( \frac{90 \text{ in}}{s} \right)^2 = 0.4 \text{ psi} ]</td>
</tr>
<tr>
<td>Valve</td>
<td>[ h_{m2} = f \frac{L_e}{D} \rho \frac{V^2}{2} = (0.045)(8) \left( \frac{0.0372 \text{ lbm}}{\text{in}^3} \right) \left( \frac{90 \text{ in}}{s} \right)^2 = 0.3 \text{ psi} ]</td>
</tr>
<tr>
<td>Tee</td>
<td>[ h_{m3} = f \frac{L_e}{D} \rho \frac{V^2}{2} = (0.045)(60) \left( \frac{0.0372 \text{ lbm}}{\text{in}^3} \right) \left( \frac{90 \text{ in}}{s} \right)^2 = 2.1 \text{ psi} ]</td>
</tr>
<tr>
<td>Exit</td>
<td>[ h_{m1} = K \rho \frac{V^2}{2} = (0.5) \left( \frac{0.0372 \text{ lbm}}{\text{in}^3} \right) \left( \frac{90 \text{ in}}{s} \right)^2 = 0.2 \text{ psi} ]</td>
</tr>
<tr>
<td>Valve</td>
<td>[ h_{m2} = f \frac{L_e}{D} \rho \frac{V^2}{2} = (0.045)(8) \left( \frac{0.0372 \text{ lbm}}{\text{in}^3} \right) \left( \frac{90 \text{ in}}{s} \right)^2 = 0.3 \text{ psi} ]</td>
</tr>
<tr>
<td>Tee</td>
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</tr>
</tbody>
</table>

**Total Head Loss = 5.4 psi**
**LAND-BASED TESTING**

- **Goals**
  - Verify that each part of the device functions properly
  - Verify that the testing configuration was dependable
  - Gauge approximate force-pressure relationship by measuring the head height

- **Configuration**
  - 4 pulleys – 2 at the end of the piston rod, 2 anchored to beam below
  - Magnified force by 4 and reversed direction
  - Input hose in water
  - Output hose was oriented vertically to measure head

Location: Energy Lab, Hudson Hall
WATER-BASED TESTING

- **Goals**
  - Verify that predicted pressures can be generated using only buoyant force to support the tire
  - Obtain force-pressure relationship using precise force meter and pressure gauge measurements

- **Configuration**
  - Same configuration tested previously
  - Anchored to the floor with the weight of sandbags

Location: Central Campus Swimming Pool
INDIVIDUAL TRIAL PULL
CONSECUTIVE PULLS
RESULTS

Force vs. pressure in wet test

\[ y = 0.5554x + 17.385 \]
\[ R^2 = 0.78899 \]
RESULTS

- Based on results and derived regression, 209 lbf generates approximately 131 psi of pressure.

- This does not quite meet theoretical expectations of 180 psi, but is well above our goal of 100 psi.

- Discrepancies can be attributed to:
  - reduced stroke length
  - the use of a pneumatic vs. hydraulic cylinder
  - Friction losses (pulleys, ropes, piston)
## Prototype Budget

<table>
<thead>
<tr>
<th>Part</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Threaded bolts (large)</td>
<td>$22.56</td>
</tr>
<tr>
<td>Threaded bolts (small)</td>
<td>$11.32</td>
</tr>
<tr>
<td>Great Stuff</td>
<td>$39.80</td>
</tr>
<tr>
<td>Acrylic sheets</td>
<td>$39.96</td>
</tr>
<tr>
<td>Aluminum rectangular tubes</td>
<td>$28.08</td>
</tr>
<tr>
<td>Aluminum plate</td>
<td>$19.76</td>
</tr>
<tr>
<td>Check valves</td>
<td>$159</td>
</tr>
<tr>
<td>Tube fittings</td>
<td>$8.70</td>
</tr>
<tr>
<td>Reducing coupling nut</td>
<td>$5.28</td>
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<tr>
<td>Threaded rod</td>
<td>$1.37</td>
</tr>
<tr>
<td>Springs</td>
<td>$7.69</td>
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<tr>
<td>Sandbags</td>
<td>$11.92</td>
</tr>
<tr>
<td>Rope</td>
<td>$11.70</td>
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<tr>
<td>Additional nuts</td>
<td>$0.22</td>
</tr>
<tr>
<td>Tire</td>
<td>$0.00</td>
</tr>
<tr>
<td>Piston</td>
<td>$0.00</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>$367.36</strong></td>
</tr>
</tbody>
</table>
# Commercial Budget

<table>
<thead>
<tr>
<th>Part</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tire</td>
<td>$0.00</td>
</tr>
<tr>
<td>Great Stuff</td>
<td>$378.50</td>
</tr>
<tr>
<td>Rectangular tubes</td>
<td>$487.50</td>
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<tr>
<td>Plate</td>
<td>$266.00</td>
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<tr>
<td>Check valves</td>
<td>$300.00</td>
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<tr>
<td>Tube fittings</td>
<td>$20</td>
</tr>
<tr>
<td>Spring</td>
<td>$10</td>
</tr>
<tr>
<td>Piston</td>
<td>$2200.00</td>
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<tr>
<td>Threaded bolts (large, stainless steel)</td>
<td>$50</td>
</tr>
<tr>
<td>Threaded bolts (small, stainless steel)</td>
<td>$30</td>
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<tr>
<td>Chain</td>
<td>$110</td>
</tr>
<tr>
<td>Anchor</td>
<td>$20</td>
</tr>
<tr>
<td>Labor costs (capital)</td>
<td>$300</td>
</tr>
<tr>
<td>Labor costs (O&amp;M)</td>
<td>$100</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>$4272.00</strong> - bulk discount</td>
</tr>
</tbody>
</table>
FUTURE CONSIDERATIONS

- Tidal activity
  - Tides have less effect further out to sea; will need to evaluate buoy placement on a case-by-case basis to minimize tidal interaction
  - Consider SEARASER height-adjustable wave powered pump configuration: UK Patent No. GB 2445951

- Corrosion
  - Stainless steel parts for final design; may need to use replaceable cathodic protection

- Brine dispersion
  - Desalinating water produces ~2000 gals/day of concentrated brine solution ➔ NEGLIGIBLE
THE BUOY BUSINESS

• Two approaches to commercialization
  • Manufacture in US and distribute abroad
  • Partner with local manufacturer near target site

• Must establish maintenance system, oversight

• Requires trained partners in the region for site-visits and maintenance
LOCAL IMPLEMENTATION

• Public Use
  • Governments purchase and maintain the buoys

• Private Use
  • For areas underserved by governments
  • Purchased by an individual or a cooperative of residents
  • Potential for income, or income-enhancement
  • Strong candidate for microfinance loan
• 50% failure rate of clean water projects, so bank loans not viable

• Sustainability organizations supporting microfinance programs
  • Providing technical solutions, attracting lenders
  • Water.org and WaterCredit – securing funding for local water projects
  • ACCESS Development Services – supporting clean water projects, partnering with UniLever to develop technology for local use in India

• Intermediary firms would serve as go-between for project management team, local microfinance institutions, and customer
QUESTIONS?

Original Artist

I KNOW THIS SOUNDS SILLY BUT I'M THIRSTY!
Preliminary Pressure Calculations

\[ \bar{F}_{Net} = \bar{F}_B + \bar{F}_g + \bar{F}_{ext} \]

\[ V_{buoy} = V_{water,displaced} \]

\[ V_{buoy} = \Pi \times (r_o^2 - r_i^2) \times l \]

\[ F_B = W_{w,disp} = \rho_w \times V_{w,disp} \times g \]

\[ F_{Net} = \rho_w \times \Pi \times (r_{tire}^2 - r_{PVC}^2) \times l \times g - W_{buoy} - F_f \]
## Preliminary Pressure Calculations

<table>
<thead>
<tr>
<th>LARGE TIRE</th>
<th>SMALL TIRE</th>
</tr>
</thead>
<tbody>
<tr>
<td>$d_{tire} = 32.5''$</td>
<td>$d_o = 22''$</td>
</tr>
<tr>
<td>$d_{PVC} = 1.5''$</td>
<td>$d_i = 1''$</td>
</tr>
<tr>
<td>$l = 10''$</td>
<td>$l = 6.5''$</td>
</tr>
<tr>
<td>$W = 90 lbs$</td>
<td>$W = 23 lbs$</td>
</tr>
<tr>
<td>$F_{Net} = 209 lbs$</td>
<td>$F_{Net} = 66.0 lbs$</td>
</tr>
<tr>
<td>$P = 201 psi$</td>
<td>$P = 63.5 psi$</td>
</tr>
</tbody>
</table>