Pretreatment System for Reverse Osmosis

Adam Avey, David Criswell, & Kelsey Criswell
“AquaTech Engineering Solutions’ mission is to use its technical expertise and resources to provide customers with more affordable, longer lasting products.”
Client: Pumps of Oklahoma

- Wholesale Supplier of Pumps
  - Water Well, Environmental, Solar, Petroleum
- 18 employees
- Located in Oklahoma City
Reverse Osmosis System
Reverse Osmosis
Problem Statement

“To design and fabricate a flow-through iron removal pretreatment module for a household reverse osmosis (RO) system.”
Iron Fouls Membranes

- EPA Standard: .3 pmm
- Requires extra maintenance and cost
Scope of Work

- Precedes a household RO unit
- Refrain from using:
  - Air pump
  - Power source
Standards

- NSF drinking water standards
- EPA drinking water standards
Target Group

- Rural Homeowners
- Small Businesses

http://geology.com/articles/bottled-water.shtm
Customer Requirements

• Treat a continuously flowing stream.

• Avoid additional mechanical hardware (such as a compressor).

• The device should be able to remove whatever substances (such as air) that have been added to the water stream.
Market Analysis

• Agriculture Business Teammate: Sergio Ruiz Esparza Herrera

• Strategy:
  – Design standard prototype
  – Sell RO system to construction firms

  ▪ According to www.bccresearch.com the Reverse Osmosis industry is expected to have a compound annual growth rate of 7.3% over the next 5 years.
Competitors

• Advanced Water Solutions
• Culligan
  – Under counter drinking water systems

• Haynes Equipment Company
  – Industrial RO systems
## Competitors

<table>
<thead>
<tr>
<th>Product</th>
<th>Technique</th>
<th>Price Range</th>
<th>Website</th>
</tr>
</thead>
<tbody>
<tr>
<td>Terminox ISM</td>
<td>Chlorine injector and mixing tank</td>
<td>$550 - $975</td>
<td><a href="http://www.budgetwater.com">www.budgetwater.com</a></td>
</tr>
<tr>
<td>Pyrolox</td>
<td>Granular water filtration media</td>
<td>$670 - $885</td>
<td><a href="http://www.qualitywaterforless.com">www.qualitywaterforless.com</a></td>
</tr>
<tr>
<td>Greensand</td>
<td>Glauconite greensand filtration media</td>
<td>$625 - $885</td>
<td><a href="http://www.qualitywaterforless.com">www.qualitywaterforless.com</a></td>
</tr>
<tr>
<td>Birm</td>
<td>Filtration media</td>
<td>$435 - $710</td>
<td><a href="http://www.qualitywaterforless.com">www.qualitywaterforless.com</a></td>
</tr>
<tr>
<td>Eagle Redox Alloy</td>
<td>Iron Oxidization Catalyst</td>
<td>$25</td>
<td><a href="http://www.qualitywaterforless.com">www.qualitywaterforless.com</a></td>
</tr>
</tbody>
</table>
Technical Analysis

• Wastewater Treatment Systems
• Household Treatment Systems
• Patents
• Chemical Analysis
Wastewater Treatment Systems

1. Diffusion-Air Systems
2. Mechanical Aeration
Cascading Aerator

- Economical
- Low Tech
Cascading Aerator

\[ H = \frac{R-1}{0.11ab(1+0.046T)} \]  

(English Units)

- where \( R = \) deficit ratio = \( \frac{C_s-C_O}{C_s-C} \)
- \( C_s = \) DO saturation concentration, mg/L
- \( C_O = \) DO concentration of influent, mg/L
- \( C = \) required DO level, mg/L
- \( a = \) water-quality parameter
- \( b = \) weir geometry parameter for a weir
- \( T = \) water temperature, °C
- \( H = \) height through which water falls, ft
Household Treatment Systems

- Aeration via air pump
- Water softeners
Chemical Analysis

Fe(II) + $\frac{1}{4}$ O$_2$ + 2OH$^-$ + $\frac{1}{2}$ H$_2$O $\rightarrow$ Fe(OH)$_3$(s)  
(Stumm, 1961)

• From Pumps of Oklahoma, 3.2 ppm Iron
  – Assumption: 3.2 ppm Fe(II)

  \[3.2\text{mg/L Fe} \times \frac{\text{mol}}{55.85\text{g Fe}} \times \frac{1\text{g}}{1000\text{mg}} \times \frac{\frac{1}{4} \text{mol O}_2}{1 \text{ mol Fe}} \times \frac{32\text{g O}_2}{1 \text{ mol O}_2} = 0.000458 \text{ g/L O}_2\]

  \[= 0.458 \text{ mg/L O}_2 \text{ needed to oxidize } 3.2 \text{ mg/L Fe(II)}\]
Chemical Analysis

Chemical Analysis for 5 ppm Fe(II)

\[
\text{Fe(II)} + \frac{1}{4} \text{O}_2 + 2\text{OH}^- + \frac{1}{2} \text{H}_2\text{O} \rightarrow \text{Fe(OH)}_3(s) \quad \text{(Stumm, 1961)}
\]

Concentrations needed to oxidize 5 ppm Fe(II):

For \( \text{O}_2 \): 0.716 ppm
For \( \text{H}_2\text{O} \): 0.8 ppm
For \( \text{Air} \): 3.41 ppm

Note: Air is about 21% \( \text{O}_2 \)
Chemical Analysis

Design Flow Rates

Known: 8 gpm water through eductor

\[ Q_{air} = 8 \text{ gpm } H_2O \times \frac{3.758 \text{ L}}{\text{gal}} \times \frac{0.8 \text{ mg } H_2O}{\text{L}} \times \frac{1 \text{ mol}}{18 \text{ gH}_2\text{O}} \times \frac{0.25 \text{ mol } O_2}{0.5 \text{ mol } H_2O} \]

\[ \times \frac{32gO_2}{\text{molO}_2} \times \frac{28.97 \text{ g air}}{6.704 \text{ g } O_2} \times \frac{1 \text{ L}}{3.41 \text{ mg air}} \times \frac{1 \text{ gal}}{3.785 \text{ L}} \]

= 7.2 gpm air needed
# Lab Preparation

## Standard curve for ferrous iron

### Reagents List:

<table>
<thead>
<tr>
<th>Reagent</th>
<th>Molecular Formula</th>
<th>Use</th>
<th>Concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ferrous Ammonium Sulfate 6-Hydrate</td>
<td>Fe(NH₄)(SO₄)₂•6H₂O</td>
<td>Known amount of ferrous iron in standard</td>
<td>0.7022 g in 1 L</td>
</tr>
<tr>
<td>(1,10) Phenanthroline</td>
<td>C₁₂N₂H₈</td>
<td>Coloring Agent</td>
<td>0.1 g in 100 mL</td>
</tr>
<tr>
<td>Sodium Acetate</td>
<td>NaOOCOCH₃</td>
<td>Buffering agent to fix pH</td>
<td>10 g in 100 mL</td>
</tr>
<tr>
<td>Sulfuric Acid</td>
<td>H₂SO₄</td>
<td>Stabilizes Fe(II) and takes care of impurities</td>
<td>2.5 mL in 1 L</td>
</tr>
</tbody>
</table>
Lab Preparation

Fe\(^{2+}\) + 3 Phen\(\rightarrow\) [Fe(Phen)\(_3\)]\(^{2+}\) (Muller, 2010)

• Used Mass Spectrophotometry to test Hanna Checker readings of Fe(II)
• Absorption vs. Concentration is linear (Beer’s Law)
Lab Preparation

<table>
<thead>
<tr>
<th>Standard (ppm)</th>
<th>Absorption</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0.1</td>
<td>0.034</td>
</tr>
<tr>
<td>0.5</td>
<td>0.158</td>
</tr>
<tr>
<td>1.0</td>
<td>0.239</td>
</tr>
<tr>
<td>2.0</td>
<td>0.562</td>
</tr>
<tr>
<td>3.0</td>
<td>0.75</td>
</tr>
<tr>
<td>4.0</td>
<td>1.145</td>
</tr>
<tr>
<td>5.0</td>
<td>1.43</td>
</tr>
</tbody>
</table>

Concentration vs. Absorption

\[ y = 3.5258x + 0.047 \]

\[ R^2 = 0.9943 \]
Lab Preparation

Ferrous Iron standards starting from 0.1 ppm on left to 5 ppm on far right
Testing Local Well

- Hanna Instruments HI 721
Testing Local Well

2 Tests Conducted

• Total Iron
• Ferrous Iron
Testing Local Well

Ferrous Iron Content

• Field Test Procedure
  – Fill 10 mL cuvette with well sample to zero Checker
  – 1.0 mL of (1,10) Phenanthroline solution
  – 0.8 mL of sodium acetate solution
  – Fill to volume (10 mL) with raw well water
  – Place in Checker and read concentration in ppm
Testing Local Well

Total Iron Content

• Field Test Procedure
  – Fill 10 mL cuvette with well sample to zero Checker
  – Add one packet of HI721-25 Iron HR Reagent
  – Gently swirl until dissolved
  – Place in Checker and read concentration in ppm
# Testing Local Well

## Results from Well Test

<table>
<thead>
<tr>
<th>Sample</th>
<th>Ferrous Iron (ppm)</th>
<th>Total Iron (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.45</td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td>0.44</td>
<td>-</td>
</tr>
<tr>
<td>3</td>
<td>0.39</td>
<td>-</td>
</tr>
<tr>
<td>4</td>
<td>0.41</td>
<td>-</td>
</tr>
<tr>
<td>5</td>
<td>-</td>
<td>0.60</td>
</tr>
<tr>
<td>6</td>
<td>-</td>
<td>0.53</td>
</tr>
<tr>
<td>7</td>
<td>-</td>
<td>0.56</td>
</tr>
<tr>
<td>8</td>
<td>-</td>
<td>0.52</td>
</tr>
<tr>
<td>Mean</td>
<td>0.42</td>
<td>0.55</td>
</tr>
</tbody>
</table>
Design Analysis

• Minimize:
  – Power Requirement
  – Space Requirement
  – Maintenance
Eductor
Design Concept
Air Relief Valve
Design Concept 1
Aeration via misting nozzles
Calculations

• Continuity:
  \[ Q = V_1 A_1 = V_2 A_2 \]

• Bernoulli’s Equation:
  \[ \frac{p_1}{\gamma} + \frac{V_1^2}{2g} + z_1 = \frac{p_2}{\gamma} + \frac{V_2^2}{2g} + z_1 + h_L \]

• Head Loss Equation:
  \[ h_L = h_{L_{major}} + h_{L_{minor}} = f \frac{l}{D} \frac{V^2}{2g} + K_L \frac{V^2}{2g} \]
Calculations

• Venturi Equation:

\[ Q = C_v A_T \sqrt{\frac{2(p_1 - p_2)}{\rho(1 - \beta^4)}} \]

• \( \Delta p = 8.5 \, \text{psi} \)
Calculations

• Reaction Vessel Sizing
  – 30 second residence time, +- depending on pH, etc.
  \[(8 \text{ gal/min})(0.5\text{ min}) = (4\text{ gal})\]

\[
D = 6.065\text{in} \\
A = 28.89\text{in}^2 \\
4\text{gal} = 924\text{in}^3 \\
H = 32\text{in}
\]
<table>
<thead>
<tr>
<th>Velocity (ft/s)</th>
<th>Pressure (psi)</th>
<th>Head Loss (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3.3</td>
<td>60</td>
</tr>
<tr>
<td>2</td>
<td>3.3</td>
<td>58.3</td>
</tr>
<tr>
<td>3</td>
<td>23.3</td>
<td>55.9</td>
</tr>
<tr>
<td>4</td>
<td>52.4</td>
<td>47.4</td>
</tr>
<tr>
<td>5</td>
<td>93.3</td>
<td>8.4</td>
</tr>
<tr>
<td>6</td>
<td>0.09</td>
<td>48.4</td>
</tr>
<tr>
<td>7</td>
<td>3.3</td>
<td>48.3</td>
</tr>
</tbody>
</table>

Total Head Loss = 8.4 ft
For $p = 47.4 \text{ psi} = 4.13 \text{ Bar}$, Nozzle is rated to 19.0 gpm
Design Concept 2
Aeration via porous media
<table>
<thead>
<tr>
<th></th>
<th>Velocity (ft/s)</th>
<th>Pressure (psi)</th>
<th>Head Loss (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3.3</td>
<td>60</td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td>3.3</td>
<td>58.3</td>
<td>0.18</td>
</tr>
<tr>
<td>3</td>
<td>23.3</td>
<td>55.9</td>
<td>2.66</td>
</tr>
<tr>
<td>4</td>
<td>52.4</td>
<td>47.4</td>
<td>2.87</td>
</tr>
</tbody>
</table>
Pump Curve
Proposed Budget

Aeration via Misting Nozzles

<table>
<thead>
<tr>
<th>Part</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eductor</td>
<td>$160.00</td>
</tr>
<tr>
<td>Piping &amp; Fittings</td>
<td>$20.00</td>
</tr>
<tr>
<td>Air Release Valve</td>
<td>$100.00</td>
</tr>
<tr>
<td>Nozzles</td>
<td>$15.00</td>
</tr>
<tr>
<td><strong>Total:</strong></td>
<td><strong>$295.00</strong></td>
</tr>
</tbody>
</table>
# Proposed Budget

## Aeration via Porous Media

<table>
<thead>
<tr>
<th>Part</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eductor</td>
<td>$160.00</td>
</tr>
<tr>
<td>Piping &amp; Fittings</td>
<td>$20.00</td>
</tr>
<tr>
<td>Air Release Valve</td>
<td>$100.00</td>
</tr>
<tr>
<td>Filter Media</td>
<td>$100.00</td>
</tr>
<tr>
<td><strong>Total:</strong></td>
<td><strong>$380.00</strong></td>
</tr>
</tbody>
</table>
Next Step

• Order Components
• Assembly
• Testing
## Schedule

<table>
<thead>
<tr>
<th>Task Name</th>
<th>Duration</th>
<th>Start</th>
<th>Finish</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physically test local water samples to determine max real-world oxidation values</td>
<td>2 days</td>
<td>Mon 11/5/12</td>
<td>Tue 11/6/12</td>
</tr>
<tr>
<td>Analyze test results in regards to potential product designs</td>
<td>1 day</td>
<td>Wed 11/7/12</td>
<td>Wed 11/7/12</td>
</tr>
<tr>
<td>Sketch and evaluate potential product designs</td>
<td>1 day</td>
<td>Thu 11/8/12</td>
<td>Thu 11/8/12</td>
</tr>
<tr>
<td>Assemble Fall designing report</td>
<td>2 days</td>
<td>Wed 11/21/12</td>
<td>Thu 11/22/12</td>
</tr>
<tr>
<td>Give fall design presentation for client</td>
<td>0 days</td>
<td>Fri 11/23/12</td>
<td>Fri 11/23/12</td>
</tr>
<tr>
<td>Determine and locate materials for prototype</td>
<td>10 days</td>
<td>Mon 1/14/13</td>
<td>Fri 1/25/13</td>
</tr>
<tr>
<td>Acquire materials</td>
<td>10 days</td>
<td>Mon 1/28/13</td>
<td>Fri 2/8/13</td>
</tr>
<tr>
<td>Assemble prototype</td>
<td>14 days</td>
<td>Mon 2/11/13</td>
<td>Thu 2/28/13</td>
</tr>
<tr>
<td>Test prototype</td>
<td>7 days</td>
<td>Fri 3/1/13</td>
<td>Mon 3/11/13</td>
</tr>
<tr>
<td>Final product presentation and report</td>
<td>0 days</td>
<td>Tue 4/30/13</td>
<td>Tue 4/30/13</td>
</tr>
</tbody>
</table>
Gantt Chart
References


Appreciation

- Dr. Paul Weckler, Biosystems & Ag. Eng.
- Micah Goodspeed, Pumps of Oklahoma
- Dr. Greg Wilber, Civil & Environmental Eng.
- Dr. Chad Penn, Plant & Soil Sciences
- Stuart Wilson, Plant & Soil Sciences
- John Rodgers, Water Well Owner
- Sergio Ruiz Esparza Herrera, Ag. Business Teammate
Questions or Comments?