Operation of Integrated Water Treatment Platform for Treatment of Produced Water, Bakersfield, CA

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- **Why?**
  - Membrane filtration is required to meet global water sustainability goals
  - Process conditions can be harsh and change too fast for humans to keep up in real-time

- **What?**
  - The world’s first intelligent membrane products with real-time self-adaptive flux optimization

*PolyCera®* membranes

*IntelliFlux®* controls
The Goal: Water Reusing

✓ **Wastewater water** is the only water resource on Earth that increases with increasing population and industrialization.

✓ Advanced treatment for water recycling takes ~1/4 the energy and ~1/3 the cost of seawater desal.

  - …MF/UF lies at the heart…

The Obstacle: Membrane Fouling

- Deposition of organics, bacteria, and solids onto membrane surfaces
  - Decreases throughput
  - Increases cleaning frequency
  - Shortens membrane life
  - **Increases OPEX**
Produced water generated in the oil and gas extraction industries provide a significant separations and treatment challenge.

The water is characterized by high hydrocarbons, inorganic leachates from the rock formation and chemicals used for extraction.

Durable membrane filtration with intelligent operation are needed to produce a high quality effluent.

450,000,000 gal/day
Scope of the Demonstration

- Truck loads of produced water from 10 different oil companies

- Representing different fields:
  - Kern Front, Elk Hills, Lost Hills, Buena Vista, McKittrick, Santa Clarita, Northridge, Midway, Edison, Comanche

- Demonstration location: Wasco, Kern County, CA
The Platform

Integrated Membrane System

Clean water tanks

Concentrate tanks

Produced water tanks
Optimized for Advanced Water Treatment

O&G Produced Water

- WQ 1
- WQ 3
- WQ 5
- WQ 7
- WQ 9
- WQ 2
- WQ 4
- WQ 6
- WQ 8
- WQ 10

UF Pretreatment
- Oil & Grease
- TSS
- Turbidity
- Bacteria

Advanced Treatment
- Dissolved constituents
Fast Kinetics of MF/UF Membrane Fouling

- UF/MF membranes foul quickly - fast and accurate reaction is needed
Yesterday… Passive Filtration

Sensors communicate membrane performance INDICATORS to controls.

Temp, flow and pressure sensors monitor membrane performance INDICATORS.

With conventional controls changes to operating conditions made by plant operators after the fact.

Conventional membranes passively interact with conventional controls.
Today… Intelligent Filtration

Sensors communicate membrane performance INDICATORS to controls

Temp, flow and pressure sensors monitor membrane performance INDICATORS

Intelligent controls automatically adjust operating conditions…freeing time for plant engineers & operators

Conventional membranes passively interact with conventional controls
IntelliFlux  Self-Adaptive Flux Enhancement & Recovery

- Self-adaptive flux maintenance controls decide what/how/when to perform flux maintenance.
- Artificial Intelligence-based controller works with standard PLC systems or PC based controller.
- Cloud-based remote monitoring services.

✓ Benefits
- 10-20% lower OPEX than S.o.t.A. controls
- Zero CAPEX increase (no hardware changes)
IntelliFlux – Maintains High Flux
Self-Adaptive Flux Enhancement & Recovery

...a slug of suspended solids hits the filter

...conventional operation loses production and never recovers...

...but IntelliFlux maintains high flux...
The Demo at Wasco, CA

- The integrated system capacity: 10-15 gpm (130-160 m³)
- Average flux: 120 lmh/bar
- Recovery: UF > 90%, RO > 60%
- The system employed the advanced IntelliFlux automated process controls
### Treatment Objectives

<table>
<thead>
<tr>
<th>Contaminant of Concern</th>
<th>Concentration (m)</th>
<th>Concentration (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Free O&amp;G</td>
<td>10</td>
<td>35</td>
</tr>
<tr>
<td>BTEX</td>
<td>0.5</td>
<td>NA</td>
</tr>
<tr>
<td>TSS</td>
<td>300</td>
<td>5</td>
</tr>
<tr>
<td>TDS</td>
<td>1000</td>
<td>650</td>
</tr>
<tr>
<td>Arsenic</td>
<td>0.0001</td>
<td>0.1</td>
</tr>
<tr>
<td>Boron</td>
<td>0.7</td>
<td>1</td>
</tr>
<tr>
<td>Sodium</td>
<td>200</td>
<td>175</td>
</tr>
</tbody>
</table>
Feed Sample Water Quality Range

<table>
<thead>
<tr>
<th>Sample</th>
<th>TDS</th>
<th>TSS</th>
<th>Free O&amp;G</th>
<th>BTEX</th>
<th>Boron</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td>8,200</td>
<td>26</td>
<td>12</td>
<td>0.065</td>
<td>1.4</td>
</tr>
<tr>
<td>#2</td>
<td>23,000</td>
<td>54</td>
<td>26</td>
<td>8.140</td>
<td>75</td>
</tr>
<tr>
<td>#3</td>
<td>39,000</td>
<td>110</td>
<td>11</td>
<td>0.087</td>
<td>72</td>
</tr>
<tr>
<td>#4</td>
<td>18,000</td>
<td>240</td>
<td>150</td>
<td>0.067</td>
<td>45</td>
</tr>
<tr>
<td>#5</td>
<td>12,000</td>
<td>1.2</td>
<td>13</td>
<td>0.058</td>
<td>52</td>
</tr>
<tr>
<td>#6</td>
<td>78,000</td>
<td>100</td>
<td>1.9</td>
<td>0.006</td>
<td>ND</td>
</tr>
<tr>
<td>#7</td>
<td>19,000</td>
<td>110</td>
<td>33</td>
<td>0.560</td>
<td>85</td>
</tr>
<tr>
<td>#8</td>
<td>910</td>
<td>58</td>
<td>64</td>
<td>0.047</td>
<td>6.2</td>
</tr>
<tr>
<td>#9</td>
<td>19,000</td>
<td>52</td>
<td>26</td>
<td>0.187</td>
<td>92</td>
</tr>
<tr>
<td>#10</td>
<td>920</td>
<td>80</td>
<td>73</td>
<td>0.034</td>
<td>4.2</td>
</tr>
<tr>
<td>avg</td>
<td>21,802</td>
<td>82</td>
<td>41</td>
<td>0.925</td>
<td>48</td>
</tr>
</tbody>
</table>

- TSS ranged from 1-240 ppm
- O&G ranged from 2 – 150 ppm
- TDS ranged from Brackish to Hypersaline
## Treatment Efficacy

<table>
<thead>
<tr>
<th>Effluent Characteristics</th>
<th>Removal</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>UF</td>
</tr>
<tr>
<td><strong>Total O&amp;G</strong>*</td>
<td>ND for 6 samples, 0.8 -1 ppm for 4 samples</td>
</tr>
<tr>
<td><strong>TSS</strong></td>
<td>ND for all 10 samples</td>
</tr>
<tr>
<td><strong>Turbidity</strong></td>
<td>Less than 0.2 ppm for all samples</td>
</tr>
<tr>
<td><strong>TDS</strong></td>
<td>Less than 650 ppm for 6 samples</td>
</tr>
<tr>
<td><strong>Boron</strong></td>
<td>Less than 1 ppm for 1 samples</td>
</tr>
<tr>
<td><strong>BTEX</strong></td>
<td>0.0163 – 0.061 ppm</td>
</tr>
</tbody>
</table>

* Per EPA 1664 method
UF normalized permeability chart

Overall Operating Permeability Chart

Sample 1  Sample 2  Sample 3  Sample 4  Sample 5  Sample 6  Sample 7  Sample 8  Sample 9  Sample 10

- **Normalized permeability**
- **Clean Water Permeability**
- **Temperature**
- **Influent O&G**
- **Influent turbidity**
Key Takeaways

- Despite variations in influent water quality, the IntelliFlux based system operated stable with good flux recovery.
- The system consistently produced excellent quality filtered water suitable for reuse.
- Second pass RO will be required to remove boron and polishing step for BTEX may would require further polishing to meet agricultural reuse water quality targets.
- Advanced controls needed to deal with the fast kinetics of MF/UF fouling to keep the operation stable and efficient.
- More Water + Less cost = successful wastewater reuse.
The integrated system capacity: 15 gpm (195 m³) to 300 gpm (~10000 m³)

Recovery: UF > 98%, RO pass 1 > 75%, RO pass 2 > 90%

The system employed the advanced IntelliFlux automated process controls
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