Ceramic Membrane Ultrafiltration Enables Cost Effective Produced Water Reuse

Siemens Water Solutions
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Topics Addressed in this Presentation

- Drivers for ultrafiltration of produced water
- Challenges for membranes for produced water
- Cost comparison
- Test data
Drivers for higher degree of produced water treatment

Water scarcity
- Tight discharge limits
- Required reuse
- Intake limits
- Permitting issues

Public image
- Excess produced
- Cost and availability of disposal
- Incremental cost of treatment

Produced water fate
- Availability
- Cost of water sourcing vs. treatment

Regulations
Why Use Ultrafiltration Membranes

Low TSS / O&G requirements
- Surface discharge
- Reuse
- IX or RO feedwater
- Re-injection

High temperature operation
- Heavy oil
- EOR
- SAGD
- Feed to evaporator / boiler

Pretreatment for reuse
- Boiler feed water
- Cooling tower make-up
- Process water
- Irrigation
- Surface discharge
Why Use Ultrafiltration Membranes

Combination of flotation and filtration in a single step

- <1 mg/L O&G
- <1 mg/L TSS
- Lower OPEX
- Oil recovery
- No polymer
Ultrafiltration Membrane Treatment Fit

- Primary separation (API, CPI, hydrocyclones)
- Flotation (IGF, DAF/DGF)*
- Walnut shell filters
- Membranes

*requires chemicals
** <1 mg/L non-detectable
Reuse - How to Meet Requirements?

Produced Water after Primary Separation
- TDS >1000 mg/L
- TSS 50-200 mg/L
- O&G >50 mg/L

Reinjection
- 95% removal of suspended solids > 2 microns or depending on reservoir for injection

RO Feedwater
- COD < 10 mg/L
- TOC < 3 mg/L
- O&G < 0.1 mg/L
- SDI < 5 – lower the better
- Turbidity < 1 NTU with < 0.5 NTU recommended for long-term, reliable operation

Irrigation
- TDS limit, typically requires RO
- Sometimes a BOD limit as well
Conventional Approach to Meeting Strict Effluent Requirement

Produced Water → CPI → Flotation → Oil Reject → Walnut Shell Filters → Polishing Filters → Treated Effluent
Submerged Ultrafiltration Process

Produced Water → CPI → Submerged Ultrafiltration → Recoverable Oil → Treated Effluent

Gas
Cost Savings of Ultrafiltration for Produced Water Treatment

- Elimination of flotation chemicals
- Elimination of flotation
- Less sludge and higher oil recovery
- Elimination of polishing filters
- Elimination of walnut shell filters
Tubular Ultrafiltration Process

Produced Water -> CPI -> Flotation -> Oil Reject -> Walnut Shell Filters -> Separation Tank -> Tubular Ultrafiltration

Oil Reject

Treated Effluent

Gas

Typically used
Cost Savings of Submerged Ultrafiltration Over Tubular Ultrafiltration

Elimination of flotation chemicals
Elimination of flotation
Less sludge reduction and higher oil recovery
Less prone to fouling
Requires high crossflow to prevent fouling = high pumping cost
Either large reject stream or requires recycle (more pumping cost)
More prone to fouling
Typically used

Produced Water

CPI

Flotation

Oil Reject

Walnut Shell Filters

Separation Tank

Tubular Ultrafiltration

Treated Effluent

Need to remove oil since all oil contacts ultrafiltration membranes
Pumping shears oil into making difficult to recover
### Cost Savings of Submerged Ultrafiltration Over Tubular Ultrafiltration

<table>
<thead>
<tr>
<th>Pumping comparison between submerged and tubular system (100,000 BPD basis)</th>
<th>Power Consumption</th>
<th>Annual Cost (at $0.10/kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tubular system</td>
<td>Feed pump: 1,300 m³/h (50% recovery per pass), 7 bar, 600 HP</td>
<td>9,390 kWh/day</td>
</tr>
<tr>
<td>Submerged system</td>
<td>Filtrate pump: 2 x 360 m³/h, 1 bar, 2 x 25 HP</td>
<td>740 kWh/day</td>
</tr>
<tr>
<td>Savings of submerged vs. tubular system</td>
<td>8,650 kWh/day</td>
<td>$316,000</td>
</tr>
<tr>
<td>Total savings with submerged membrane system vs. tubular</td>
<td>&gt;90%</td>
<td>&gt;90%</td>
</tr>
</tbody>
</table>
Study Objectives

- Membrane robustness
- High permeability
- Filtrate with <1 mg/L solids and oil
- High water recovery
- Low reject volume
- Hot temperature operation
Ceramic Membrane Performance Study #1—Oil Removals

87 total data points with 2 data points over 1 mg/L and a maximum oil of 2.7 mg/L in the filtrate.

1 mg/L detection limit.
Ceramic Membrane Performance Study #2—Particle Size Distribution

Still image during in-line Canty particle size analysis

Feed

Filtrate

No particles in filtrate to analyze

% by count

0 5 10 15 20 25 30 35

0 5 10 15 20 30 40 60 80 100 100 - Inf

Particle Size (microns)
Ceramic Membrane Performance Study #2—TMP

Two different heavy crude oils

No fouling with heavy crude oil

No chemical cleanings

Up to 196 LMH flux

Graph showing TMP and flux over time for two different heavy crude oils.
Ceramic Membrane Performance Study #2 – Detailed Analysis

SDI
- Avg <3

TSS
- All < 2 mg/L (detection limit)

O&G
- Avg < 1 mg/L (detection limit)

Turbidity
- Avg <0.1 NTU
- Max 0.3 NTU
Ceramic Membrane Performance Study #2—Oil Removals

Heavy crude oil (as noted previously)
Feed oil variation to simulate after primary separation
99.9% water recovery – scooped oil off top of tank
4 month test

Graph showing oil and gas (O&G) concentration over the course of the study, with various flow rates indicated. The graph includes data points for different days of study, with the x-axis representing the day of study and the y-axis representing the concentration of O&G in mg/L. The graph also includes a detection limit of 1 mg/L.
Submerged Ultrafiltration Performance

- Feed oil concentration > 200 mg/L
- Permeability 700-1000 LMH/bar despite no cleanings
- >99.9% water recovery
- Filtrate TSS < 2 mg/L
- Filtrate oil < 1 mg/L
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