PRODUCED WATER TREATMENT FOR REINJECTION OR DISCHARGE WITH SILICON CARBIDE (SiC) MEMBRANES

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Membrane properties

High permeability

<table>
<thead>
<tr>
<th>Pore size - micron</th>
<th>Flux (L/m².h) – at 1 bar TMP</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.05</td>
<td>3,000</td>
</tr>
<tr>
<td>0.1</td>
<td>4,000</td>
</tr>
<tr>
<td>1</td>
<td>10,000</td>
</tr>
<tr>
<td>3</td>
<td>&gt; 12,000</td>
</tr>
</tbody>
</table>

Water flux on fouling free water at 25 °C

- The standard OD 25x1178mm (ID3mm channels) offers 0.34 m²
- The process flux depends on the individual application – concentrated biomass (LMH 100) to in-organic water streams (LMH 2,000)
Membrane properties

- **pH range:** 0 to 14. No limitations
- **Temperature:** Up to 800 °C in air
- **Solvents:** Completely stable
- **Oxidizers:** Any concentration
- **Permeability:** Highest for any membrane material

**Material** | **Typical porosity**
--- | ---
SiC | > 45%
Al2O3 (alumina oxide) | ~ 40%
Polymer | < 10%
Membrane properties

High permeability

The high permeability is achieved due to

- high porosity
- large pore sizes in support/carrier
- low contact angle to water

- The high permeability/flux means low resistance to transport water
- The benefit is a large filtration capacity per installation volume (reduced footprint) and/or reduced energy consumption
- The large capacity per membrane volume means reduced costs for auxiliary valves, piping, instruments and installation area
Why use SiC membranes for Produced Water treatment?

1. For discharge:
   1. Meet discharge levels for oil content

2. Re-injection:
   1. Remove particles and oil to maintain reservoir permeability
      • Increase production
      • Extend well lifetime
      • Reduce energy consumption
   2. Removes solids to protect high pressure pumps
   3. Recover more oil
   4. Bacteria removal (for H2S reduction)

3. Produced water reuse for other purposes:
   1. Remove oil prior to RO or MBR process
   2. Irrigation
   3. Cooling systems
Why use SiC membranes for Produced Water treatment?

- SiC membranes can separate oil out of emulsions (difficult with conventional technologies)
- SiC membranes can handle large fluctuations in TSS, oil concentration and temperature in the feed and **deliver consistent permeate quality**
- Weight and footprint reduction compared to other technologies/membrane materials
- Can handle harsh cleaning schemes with chemicals and steam (efficient in oil applications)
Typical SAGD setup

Walnut shell filter (and sample of permeate hereof) (Note how turbid the water is when it is not possible to meet specifications)
TESTING ON PRODUCED WATER

In order to determine the performance of SiC’s ceramic membranes and evaluate different replacement regimes, two different tests were carried out:

1) Membrane operation before the skimming tank
(UF as replacement for skimming tanks, micro-flotation and walnut shell filters)

2) Membrane operation after skimming tank
(UF as replacement for micro-flotation and walnut shell filters)
01- PWT BEFORE SKIMMING TANK

Test was performed for two months at an onshore produced water treatment facility

- Average flux of 300 LMH at TMP = 1.0 bar
- Up to 2000 ppm in feed
- Permeate below 5 ppm oil
- Cross flow of 2-4 m/s

Feed       Permeate
02- PWT AFTER SKIMMING TANK

• Average flux of 300 LMH at TMP = 0.8 bar
• Up to 60 ppm in feed
• Permeate below 5 ppm oil
• Cross flow of 2 m/s
## RESULTS FROM PRODUCED WATER FIELD TRIAL

<table>
<thead>
<tr>
<th></th>
<th>TEST 1 – Before skimming tanks</th>
<th>TEST 2 – After skimming tanks</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Feed</td>
<td>Permeate</td>
</tr>
<tr>
<td>OiW</td>
<td>20-1200 ppm</td>
<td>0.25 ppm – 5 ppm, consistently below 5 ppm</td>
</tr>
<tr>
<td>TSS</td>
<td>5-20 ppm</td>
<td>TSS: &lt; 0.45 ppm</td>
</tr>
<tr>
<td>Flux</td>
<td>220-350 LMH</td>
<td></td>
</tr>
<tr>
<td>TMP</td>
<td>0.7-1.0 bar</td>
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**Cross-Flow**

1.2-1.6 m/s

**Back PULSE frequency**

Every 60 seconds (duration ½ second)

**Back FLUSH frequency**

Every 300 s (duration ~30 seconds)

**Cleaning CIP**

Highly depends on feed water, from a daily to a weekly basis
Alkaline (NaOH) and Acid cleaning (Oxalic acid)
CONCLUSIONS

1. it is possible to remove both oil and TSS from the produced water below required limits and regardless of the feed water oil concentration;

2. SiC membranes can replace conventional technologies such as skimming tanks, micro flotation and walnut shell filters with one step filtration;

3. The SiC membranes provided oil and TSS removal below the required limits of 5 ppm in both cases thus making the water suitable for reuse or discharge.