Enhanced Environmental Performance in Oil Sands
In-situ Water Treatment and Steam Generation

NEW TECHNOLOGY FOR INSITU OILSANDS FACILITIES

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OUTLINE

1.0 Introduction
2.0 Overview - Oil Sands In-situ SAGD Operations
3.0 R&D - In-situ Water Treatment Technologies
4.0 Lab-Scale OTSG Program – CP/SAIT/COSIA/NSERC/AIEES
5.0 Anticipated Benefits-Enhanced Environmental Performance
6.0 Acknowledgements
1.0 INTRODUCTION – ConocoPhillips Canada

- ConocoPhillips Canada
  - Surmont Oil Sands (and other undeveloped leases)
  - Blueberry/Montney Gas Asset
- Surmont (50% partnership with Total)
  - Surmont 1 in operation since 2007
  - Surmont 2 in operation since 2015
  - Nameplate 150,000bpd facility
1.1 INTRODUCTION - COSIA

• What is COSIA - Canada’s Oil Sands Innovation Alliance
  • 12 Member Companies with Oil Sands Assets
  • 4 Environmental Priority Areas – Land, GHG, Tailings, Water
  • COSIA Water Aspiration - “reduce water use and increase water recycling rates without shifting environmental burden”

• Key Focus Areas include – Regional Water Resource Management, Water Treatment, Steam Generator Optimization and Technologies
1.2 INTRODUCTION — SAIT

• Founded in 1916; First publicly-funded Institute of Technology in Canada
• Provides relevant, skill-oriented education to more than 75,000 registrants each year
• Approximately 1,000 business and industry partners shape curriculum through 65 advisories
• Global leader in Applied Education and Innovation with a worldwide reach, including workforce nationalization
• Top Five for applied research colleges in Canada; Committed to growing highly skilled and qualified next gen professionals
• SAIT-ARIS is the gateway to Innovation; Technology transfer; Industry uptake; Enhanced Environmental Performance
2.0 OVERVIEW OIL SANDS IN-SITU SAGD OPERATIONS

Stage 1
Surface wellhead: Horizontal wells are drilled based on the location of bitumen deposits

Stage 2
Steam is injected underground to liquefy the bitumen

Stage 3
Bitumen is pumped to the surface through a recovery well

KEY NEEDS
✓ SOR Reduction
✓ High Efficiency Steam
✓ Energy/Emissions
✓ Advanced Water Efficiency

Source: http://www.canadasoilsands.ca/en/what-are-the-oil-sands/recoversing-the-oil
3.0 SAIT R&D - IN-SITU WATER TREATMENT TECHNOLOGIES

Typical SAGD Produced Water Treatment (PWT) Process To Meet Boiler Feed Water Quality

- PW
- NG
- OIL
- Solids

SKIM TANK

INDUCED GAS FLOTAITION (IGF)

OIL REMOVAL FILTERS (ORF)

HOT LIME SOFTENER (HLS)

LIME SLUDGE FILTER (LSF)

WEAK ACID CATION ION EXCHANGE WAC

TO OTSG

DE-OILING

DE-SCALING

STEAM

KNOCK OUT

SKIM TANK

IGF

ORF

HLS

LSF

WAC
3.0 Produced Water Feed Characteristics

## Produced Water Sources Tested in our studies

<table>
<thead>
<tr>
<th>Feed Parameters</th>
<th>Alberta Refinery De-salter Water, HO Refinery</th>
<th>CCRL Saskatchewan CO-OP Refinery Produced Water</th>
<th>Northern Alberta CSS Produced Water</th>
<th>Northern Alberta SAGD Produced Water</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil and Grease (mg/L)</td>
<td>604 – 1154</td>
<td>199.3 – 603.8</td>
<td>1200</td>
<td>1200</td>
</tr>
<tr>
<td>Total Suspended Solids (mg/L)</td>
<td>1700</td>
<td>420 – 1605</td>
<td>890</td>
<td>498</td>
</tr>
<tr>
<td>Conductivity (mS/cm)</td>
<td>6.44</td>
<td>4.94-7.82</td>
<td>1.79</td>
<td>8.1</td>
</tr>
<tr>
<td>Total Dissolved Solids (mg/L)</td>
<td>3220</td>
<td>2470-3920</td>
<td>930-950</td>
<td>4212</td>
</tr>
<tr>
<td>Turbidity (NTU)</td>
<td>5.78</td>
<td>284-1850</td>
<td>330</td>
<td>340</td>
</tr>
<tr>
<td>pH (units)</td>
<td>8.0 – 8.7</td>
<td>2.25 – 6.75</td>
<td>7.75- 8.0</td>
<td>7.5 -9.5</td>
</tr>
<tr>
<td>Particle Size Distribution (μm)</td>
<td>1.7 – 15.4</td>
<td>0.393 – 153.8</td>
<td>*NR</td>
<td>*NR</td>
</tr>
<tr>
<td>Naphthenic Acids** (mg/L)</td>
<td>5.2</td>
<td>8.71</td>
<td>21.8</td>
<td>136</td>
</tr>
</tbody>
</table>

Note: *NR – Not requested; ** Naphthenic Acids - not a target parameter but was of cursory interest in the preliminary phase of this study
3.1 Water Treatment Technologies, Current and Potential

- Produced Water De-oiling (Ceramic and PTFE Membranes)
- High Temperature Membranes - BFW
- Brackish Water RO Desalination for Make up Water
- SAGD Electro-Flotation Produced Water Descaling
- SAGD Electro-Dialysis Desalination-BFW
- SAGD Blow down treatment – Advanced Oxidation Processes
- Advanced Hybrid water treatment - Disposal
### 3.2 Oil Droplet Removal Range

<table>
<thead>
<tr>
<th>SEPARATOR TYPE</th>
<th>TECHNOLOGY</th>
<th>OIL DROplet REMOVAL RANGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>API</td>
<td>Gravity</td>
<td>150 µm</td>
</tr>
<tr>
<td>CPI</td>
<td>Coalescer</td>
<td>20 µm-50 µm</td>
</tr>
<tr>
<td>DAF / IGF</td>
<td>Air Bubbles/Gas</td>
<td>Down to 25-30 µm</td>
</tr>
<tr>
<td>Hydrocyclone</td>
<td>Centrifugal Force</td>
<td>Down to 20 µm</td>
</tr>
<tr>
<td>Centrifuge</td>
<td>Centrifugal Force</td>
<td>Between 5 µm to 30 µm</td>
</tr>
<tr>
<td>Filtration</td>
<td>Adsorption, Filtration</td>
<td>≥ 2 µm</td>
</tr>
<tr>
<td></td>
<td>Coalescence</td>
<td></td>
</tr>
<tr>
<td>G.A.C</td>
<td>Adsorption</td>
<td>&lt;2 µm</td>
</tr>
<tr>
<td>Ultra Filtration</td>
<td>Membrane</td>
<td>&lt;1 µm</td>
</tr>
</tbody>
</table>

**An Example**

Cross Flow Filtration For De-oiling PW

\[ J = \frac{\Delta P}{(R_m + R_c) \mu} \]

CERAMIC AND PTFE Membrane Target
3.3 Cross Flow Filtration

**DEAD END FILTRATION**

- **Feed**
- **Permeate**

**CROSS FLOW FILTRATION**

- **Feed**
- **Permeate**
- **Retentate**
3.4 High Temperature De-oiling

[Diagram of a high temperature de-oiling system including components such as Feed Tank, Feed Pump, Heat Exchanger, Pressure Relief Return Line, Recirculation Line, Retentate Line, Permeate Line, BackPulse Unit, and Sample Collection Points.]

[Images of feed, permeate, and retentate samples.]
3.5 De-oiling Results, Advantages and Limitations

<table>
<thead>
<tr>
<th>Source of Sample</th>
<th>Membrane Module</th>
<th>Temp (°C)</th>
<th>Avg. TMP (bar)</th>
<th>Avg. Flux (L/m² hr·bar)</th>
<th>De-oiling (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CSS Northern Alberta</td>
<td>PTFE(3B) + N2</td>
<td>40</td>
<td>0.34</td>
<td>85</td>
<td>99</td>
</tr>
<tr>
<td></td>
<td>100 nm</td>
<td>60</td>
<td>0.36</td>
<td>110</td>
<td>99</td>
</tr>
<tr>
<td></td>
<td></td>
<td>80</td>
<td>0.35</td>
<td>173</td>
<td>99</td>
</tr>
<tr>
<td>SAGD Northern Alberta</td>
<td>Ceramic Membrane</td>
<td>40</td>
<td>0.26</td>
<td>110</td>
<td>99</td>
</tr>
<tr>
<td></td>
<td>100 nm</td>
<td>60</td>
<td>0.28</td>
<td>141</td>
<td>99</td>
</tr>
<tr>
<td></td>
<td></td>
<td>80</td>
<td>0.29</td>
<td>177</td>
<td>99</td>
</tr>
</tbody>
</table>

General Advantages
- High de-oiling Efficiency
- Resistance to relatively high pressure drops
- Superior chemical, thermal and mechanical stability
- Regeneration and re-usability
- Potentially eliminates produced water cooling

CM Limitations
- Rapid Membrane Fouling
- Long Regeneration times
- Propensity to Brittleness

PTFE Limitations
- Sustained flux over time can be very low
- Affinity to certain species – irreversible fouling
3.6 Application for Enhanced Environmental Performance?

Typical SAGD Produced Water Treatment (PWT) Process To Meet Boiler Feed Water Quality

PTFE AND/OR CERAMIC MEMBRANES
TEMPERATURES 40°C, 60°C AND 80°C

NEXT STEPS; HIGH TEMPERATURE
MEMBRANE TESTING FOR OTSG

~125°C- 80°C

~40°C-60°C

~40°C-60°C

TRL 4 TO 7
4.0 Oil Sands In-Situ Steam Generation

• Facility objective = reliably produce as much steam as possible & minimize makeup water usage

• Recycled Produced Water (PW) is main source of Boiler Feedwater (BFW)

• **Fouling and corrosion issues are significant operational concern**
4.1 Oil Sands In-Situ Steam Generation

• Boiler Feed Water (BFW) contains
  • Hardness*
  • Silica*
  • Dissolved Organics
  • Trace oil*
  • Other trace elements (Sulphur, boron, etc.)

(* denotes components reduced in the facility)

• Fouling of OTSGs is monitored by:
  • Thermocouple Readings
  • Pressure Drop
  • Stack Temperature
  • Flow rates – gas, water, steam, blowdown
4.2 OTSG FOULING

• Fouling consists of C, Mg, Si, O, Fe, Co
• Scale deposits lead to:
  • Down time for cleaning (pigging)
  • Failed Tubes due to localized heating
• Each operator experiences different OTSG fouling rates
• Understanding of fouling mechanism can be improved
  • <¼ ppm of BFW fouling per pass creates 100lbs of foulant in 2 months

Source: CHOA, Scientific Investigations into OTSG Tube Fouling presentation, November 2014
4.3 COSIA Industry Challenge

The Oil Sands industry is seeking:

*New technologies focused on tracking/reducing/eliminating fouling in steam generators for SAGD and CSS Oil Sands applications.*

- Extend time between OTSG cleaning
- Run at higher steam quality without compromising reliability
- Receiving lower quality water and operating at similar steam output
- Advanced monitoring in real time of OTSG fouling and scale
4.5 OTSG Operational Improvements - COSIA Companies

<table>
<thead>
<tr>
<th>Facility</th>
<th>Representation of Maximum Allowable Steam Quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>AA</td>
<td>82%+ 75% 65-70% and reduce BFW rate 25% 60%</td>
</tr>
<tr>
<td>BB</td>
<td>80%+ 75% 70% 60% - consider shutdown 60% - shutdown all but 1 gen</td>
</tr>
<tr>
<td>CC</td>
<td>80%+ 75% 70% 65% 60%</td>
</tr>
<tr>
<td>DD (Si&lt;50ppm)</td>
<td>80%+ 70% 65% 60% - consider shutdown</td>
</tr>
<tr>
<td>EE (Si&lt;50ppm)</td>
<td>73%+ 65% 55% and reduce BFW flow 20% 45% and 30% reduce flow 25% and 50% reduce flow (consider SD)</td>
</tr>
<tr>
<td>FF (Si&lt;50ppm)</td>
<td>75%+ 65% 55% and reduce BFW flow 20% 45% and 30% reduce flow 25% and 50% reduce flow (consider SD)</td>
</tr>
<tr>
<td>GG</td>
<td>80%+ 76% 72% 64% 60% 50% Consider shutdown</td>
</tr>
<tr>
<td>HH</td>
<td>80%+ 75% 70% Consider shutdown</td>
</tr>
<tr>
<td>II (Si&lt;50ppm)</td>
<td>80%+ 75% 70% 65% 30% reduce low 65% min BFW flow</td>
</tr>
<tr>
<td>JJ (Si&lt;50ppm, TH&gt; 50% DH)</td>
<td>80%+ 75% 60%</td>
</tr>
<tr>
<td>Hardness (ppm)</td>
<td>0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1 1.1 2 3 &gt;3</td>
</tr>
</tbody>
</table>

- Industry collaborations include:
  - Improved OTSG tube skin temperature monitoring
  - Control of BFW quality
    - Analytical techniques
  - Management of off spec BFW (see chart)
  - BFW chemical additives to limit fouling

I have yet to see any problem, however complicated, which, when you looked at it in the right way, did not become still more complicated.

-writer Poul Anderson
4.4 LAB-SCALE OTSG PROGRAM UNIQUE COLLABORATION
4.7 ConocoPhillips lab-scale OTSG Technology Transfer

- 3 miles of 3” pipe
- 80,000,000 watt burner
- 1,500 psig steam

- 30 ft of pipe
- 15,000 watts of electrical heat
- 1,500 psig steam
4.8 ConocoPhillips Laboratory Scale OTSG Diagram

**Double syringe pump**

**Pre-Heat Section**
- 12+ ft ½” Sch 80 (heated section = 2 x 6 ft)
- Electrical heaters

**Point of initial net steam production**

**Steam Section**
- 20+ ft 1/8” Sch 80 (heated section = 4 x 5 ft)
- Electrically heated
4.9 ConocoPhillips OTSG System

- ConocoPhillips design used as basis for SAIT design.
- SAIT lab-scale OTSG TRIALS between 2018 to 2021
Program: NSERC IRCC in Oil Sands In-situ Steam Generation

Research Challenge: OTSG tube fouling causes decreased overall facility efficiency (GHG and water intensity increase). Improving OTSG reliability will improve overall environmental performance.

OTSG Research: Build, Test, and Assess the fouling and efficiency issues that impede steam generation with a 1/1000th scaled down bare tube OTSG

Collaboration: CP has transferred the Intellectual Property of the Bare Tube OTSG via COSIA to SAIT (Est., value - $2.5 M).

Funding: $1.75 M from COSIA, Alberta Innovates, and NSERC

Research Deliverable: The bare tube OTSG program will provide evidenced based results and best in class practices

A Key Outcome: Reduce tube fouling during steam production and evaluate fouling potential at above design steam qualities
5.0 ANTICIPATED BENEFITS – ENHANCED ENVIRONMENTAL PERFORMANCE

• Knowledge Dissemination
  • Improve COSIA member’s understanding of OTSG fouling mechanisms
  • Assess the comparison of fouling rates/mechanisms across COSIA companies
  • Explore the ability to research a variety of OTSG operating scenarios
  • Collaborate on increasing Industry and COSIA’s working relationship with Academia
  • Transform Education; Students will understand challenges of SAGD waters

• Best in Class Practices for Industry
  • Improve understanding of OTSG fouling for Operators
  • Enhance Environmental Performance for COSIA Member Companies
6.0 ACKNOWLEDGEMENTS

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✓ NSERC, ConocoPhillips, COSIA, AI; Industry and Other Stakeholders
✓ SAIT and the Department of ARIS, Technology and SME partners and Consultants
✓ Conference Organizers- Canadian Business Conferences

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THANK YOU

QUESTIONS?