Review of Thermal Recovery Technologies for the Clearwater and Lower Grand Rapids Formations in the Cold Lake Area in Alberta

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Outline

• Commercial Thermal Projects in Cold Lake
• Reservoir Characteristics of Taiga Project
• Recovery Process Selection for Taiga Project
• Performance Forecast for Taiga Project
• Conclusions
CSS has been commercial since mid 1980s in Clearwater

IOL and CNRL have a combined thermal production of over 220,000 Bbl/d (mostly from CSS)

SAGD has been tested in Clearwater since mid 1990s

Two commercial SAGD projects by Husky and Shell are still in the early stage

One commercial SAGD project in Lower Grand Rapids by CNRL in Wolf Lake

CSS and SAGD are two commercially applied processes
## Comparison of Reservoir Properties

<table>
<thead>
<tr>
<th>Project</th>
<th>Operator</th>
<th>Zone</th>
<th>Depth (m)</th>
<th>Avg $\phi$</th>
<th>$K$ (μm$^2$)</th>
<th>Soi(%)</th>
<th>Net Pay (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cold Lake</td>
<td>IOL</td>
<td>CLWTR</td>
<td>400</td>
<td>32</td>
<td>1-4</td>
<td>70</td>
<td>18-70</td>
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<tr>
<td>Wolf Lake</td>
<td>CNRL</td>
<td>CLWTR</td>
<td>485</td>
<td>33</td>
<td>2.5-4</td>
<td>47-59</td>
<td>10-42</td>
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<tr>
<td>Tucker Lake</td>
<td>Husky</td>
<td>CLWTR</td>
<td>450</td>
<td>33</td>
<td>1-5</td>
<td>55-69</td>
<td>30-60</td>
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<tr>
<td>Primrose*</td>
<td>CNRL</td>
<td>CLWTR</td>
<td>500</td>
<td>32</td>
<td>2.9-3.2</td>
<td>41-75</td>
<td>7-29</td>
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<tr>
<td>Burnt Lake*</td>
<td>CNRL</td>
<td>CLWTR</td>
<td>500</td>
<td>32</td>
<td>2-4</td>
<td>65-70</td>
<td>10-30</td>
</tr>
<tr>
<td>Orion*</td>
<td>Shell</td>
<td>CLWTR</td>
<td>425</td>
<td>35</td>
<td>3-5</td>
<td>60-64</td>
<td>20-27</td>
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<tr>
<td>Taiga</td>
<td>Osum</td>
<td>CLWTR</td>
<td>440</td>
<td>32-35</td>
<td>1-4</td>
<td>65-70</td>
<td>10-21</td>
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* Analogue to Taiga Clearwater
Recovery Processes in Cold Lake

• Primary Thermal Recovery Process
  – Cyclic Steam Stimulation (CSS)
  – Steam Assisted Gravity Drainage (SAGD)

• CSS Follow-up or Enhancement Process
  – Pressure Up and Blow Down (PUBD)
  – Mixed Well Steam Drive and Drainage (MWSDD)
  – Vapor Extraction (Vapex)
  – Liquid Addition to Steam for Enhanced Recovery of Bitumen (LASER)
  – HPCSS Assisted SAGD and Hybrid Process
HPCSS in Clearwater Formation

- Horizontal and vertical wells
- Injection at fracture pressure
- 60 m to 180 m spacing for horizontal wells
- 2 to 8 Acre spacing for vertical wells
- Development as low as 7 m net pay
- In areas generally with no to minimal bottom water or top gas
- CSOR: 3.3 to 4.5
- Predicted Ultimate recovery: 15 to 35%
SAGD in Clearwater and Lower Grand Rapids Formations

- Horizontal Well Pairs (700 to 1000 m)
- Operating pressure 3 to 5 MPa, Burnt Lake SAGD was started with higher operating pressure close to dilation pressure
- 75 m to 120 m spacing
- Development to as low as 10 m net pay
- In areas with or without bottom water
- CSOR: 2.8 to 4.0 (at 100% quality)
- Predicted ultimate recovery: 45% to 55%
### Performance of Thermal Projects
(From 2008 ERCB Performance Presentation)

<table>
<thead>
<tr>
<th>Project</th>
<th>Operator</th>
<th>Zone</th>
<th>Bottom Water (m)</th>
<th>Technology</th>
<th>Commercial since</th>
<th>Well Type</th>
<th>Current Oil Rate (B/d)</th>
<th>Current SOR</th>
<th>Cum. SOR</th>
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<tbody>
<tr>
<td>Cold Lake</td>
<td>IOL</td>
<td>CLWTR</td>
<td>N/A</td>
<td>CSS</td>
<td>1985</td>
<td>VW &amp; HW</td>
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<td>3.3</td>
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<td>CLWTR</td>
<td>N/A</td>
<td>CSS</td>
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<td>VW &amp; HW</td>
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<td>-</td>
<td>6.0</td>
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<td>CLWTR</td>
<td>N/A</td>
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<td>1992</td>
<td>HW</td>
<td>62,000</td>
<td>5.0</td>
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<tr>
<td>Burnt Lake</td>
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<td>CLWTR</td>
<td>N/A</td>
<td>SAGD</td>
<td>Pilot</td>
<td>HW</td>
<td>700</td>
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<td>LGR</td>
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<td>SAGD</td>
<td>2001</td>
<td>HW</td>
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<td>CLWTR</td>
<td>0-10</td>
<td>SAGD</td>
<td>2006</td>
<td>HW</td>
<td>2,000</td>
<td>8.0</td>
<td>4.0</td>
</tr>
<tr>
<td>Tucker Lake</td>
<td>Husky</td>
<td>CLWTR</td>
<td>5-20</td>
<td>SAGD</td>
<td>2006</td>
<td>HW</td>
<td>2,500</td>
<td>13.0</td>
<td>-</td>
</tr>
</tbody>
</table>

Majority of thermal production is from CSS
Recovery Factor and Cum. SOR
(From 2008 ERCB Performance Presentation)

Ultimate recovery: 25-35% for CSS and 45 to 55% for SAGD
Fuel Required for 1.0 m³ CWE Steam

15 to 25% more fuel required to increase steam quality from 75% to 100%
CSS vs. SAGD

- **SAGD**
  - Generally higher recovery
  - Better justified SOR at higher recovery factor
  - Requires higher vertical to horizontal permeability ratio
  - Applicable in areas with thick bottom water or top gas

- **CSS**
  - Generally lower recovery factor
  - Lower SOR initially
  - More robust and tolerate to heterogeneities
  - Not applicable in areas with thick bottom water or top gas

Reservoir characteristics and fluid Contacts are the keys for Selection of Recovery Process
Osum’s Taiga Project

Clearwater and Lower Grand Rapids
Reservoir Characteristics in Taiga Project

M1 is beneficial for areas with top gas and M2 for areas with bottom water.
Performance for Taiga Project

• Analogs
  – Clearwater Formation:
    • CSS: CNRL’s Primrose
    • SAGD: Burnt Lake and Shell’s Orion
  – Lower Grand Rapids Formation:
    • CNRL’s B10 SAGD at Wolf Lake

• Reservoir Simulation
  – 3D geostatistical model
Recovery Process Selection

• Lower Grand Rapids Formation:
  – SAGD due to presence of bottom water

• Clearwater Formation:
  – SAGD for areas with no or minimal M1 mudstone or with bottom water or top gas
  – CSS for areas with continuous M1 mudstone and no bottom water
3-D Modeling for Lower Grand Rapids Formation

SAGD producers should be placed 2-3 m above Bottom Water.
3-D Modeling for Clearwater Formation

Kv in M1 mudstone determines accessibility of S1 sand
Effect of M1 Permeability on SAGD Performance

Operating Strategy to take advantage of geomechanic effects
Operating Pressures

• Lower Grand Rapids SAGD:
  • Steam chamber at 2.0 to 3.0 MPa in balance with bottom water pressure

• Clearwater:
  – SAGD:
    • Steam chamber at 3 to 4 MPa during normal operations
    • Injection pressure close to dilation for a short period is anticipated in some areas to enhance vertical permeability
  – CSS:
    • Injection at fracture pressure is required to access top S1 sand by breaking through M1 mudstone layer
Conclusions (Cold Lake Area)

- HP CSS is a proven commercial recovery process for the Clearwater Formation
- Pilot test of SAGD has been success and applied commercially in the Clearwater Formation
- Vertical permeability, thickness and extension of bottom water or top gas will be the major factors affecting the selection of recovery process between CSS and SAGD for Clearwater
- SAGD has been proven to be a commercial viable process for Lower Grand Rapids Formation
Conclusions (Taiga)

- SAGD will be applied in Osum's Lower Grand Rapids due to the presence of thick bottom water.
- High pressure assisted SAGD and HPCSS will be considered for Clearwater Formation. Low pressure SAGD will be considered for the areas with bottom water or top gas.
- In some areas of the Clearwater in the Taiga project, operating SAGD at a pressure close to the dilation pressure is necessary to enhance SAGD performance.
- For Lower Grand Rapids Formation, over 50% recovery is predicted using SAGD at a CSOR of 3.0 to 3.5
- For Clearwater Formation, 35 to 55% recovery and CSOR of 3.5 to 4.2 are predicted for SAGD
Acknowledgement

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