Chemical Looping Combustion of Sour Gas

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Oilsands
Oilsands in Alberta

- Crude bitumen in Alberta: $169.8 \times 10^9$ bbl
- Less than 2% has been recovered
- 80% recoverable by in-situ methods
Steam Assisted Gravity Drainage (SAGD)

Source: Canadian Centre for Energy Information
SAGD

- Current SAGD production: 497,800 bbl/day
- Over 1 million bbl/day from 26 future in-situ projects
- Steam generation: conservative water consumption of 2.5 bbl of water/1 bbl of bitumen
- Equivalent to 1.06 Mcf of natural gas/bbl of bitumen, (~6100 MW_{th} for current projects)
- New SAGD installations will require in the order of 12,000 MW_{th} of new steam generation
Natural Gas Consumption

- Natural gas prices in the order of $10-12/GJ are required before the alternative fuels are competitive.
- Natural gas prices from 2009 to present day range from $2-6/GJ.
- Natural gas will be the primary fuel for SAGD.
Steam Generation with reduced GHG emissions
CO$_2$ capture in Alberta

- Industry is examining GHG emissions reduction and geological sequestration
- Capture studies in Alberta emphasize:
  - steam generator + post combustion CO$_2$ capture
  - Oxyfuel combustion: using oxygen instead of air in steam generators
- CLC option has economic and efficiency benefits
## Cost Comparison (80 MW$_{th}$)

<table>
<thead>
<tr>
<th>Technology</th>
<th>CO$_2$ Net capture (%)</th>
<th>CO$_2$ Unit cost ($/tonne of CO$_2$)</th>
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<tbody>
<tr>
<td>OTSG+CO$_2$ Capture</td>
<td>54.7</td>
<td>$168</td>
</tr>
<tr>
<td>Oxy-fuel combustion</td>
<td>70.5</td>
<td>$175</td>
</tr>
<tr>
<td>CLC</td>
<td>89.7</td>
<td>$92</td>
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</tbody>
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CLC Experiments with Sour Gas
Fluidized bed Test Rig at AITF
Experimental Conditions

- Tube dimensions: 5.5cm-ID, 110cm height, 75cm height above sintered plate
- 200 gr of Nickel based oxygen carrier (VITO)
- CH$_4$ in N$_2$ balance as fuel
- Bubbling fluidized bed: superficial velocity 0.1 m/s
- H$_2$S in concentration range applied in SAGD
### Experimental Conditions (cont...)

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<table>
<thead>
<tr>
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<tbody>
<tr>
<td><strong>CH$_4$ concentration</strong></td>
<td>17</td>
<td>%</td>
</tr>
<tr>
<td><strong>O$_2$ concentration</strong></td>
<td>15</td>
<td>%</td>
</tr>
<tr>
<td><strong>H$_2$S concentration in CH$_4$</strong></td>
<td>2000</td>
<td>ppm</td>
</tr>
<tr>
<td><strong>H$_2$S concentration in gas</strong></td>
<td>340</td>
<td>ppm</td>
</tr>
<tr>
<td><strong>Reduction temperature</strong></td>
<td>850</td>
<td>ºC</td>
</tr>
<tr>
<td><strong>Oxidation temperature</strong></td>
<td>900</td>
<td>ºC</td>
</tr>
<tr>
<td><strong>Reduction time</strong></td>
<td>9.5</td>
<td>min</td>
</tr>
<tr>
<td><strong>Oxidation time without H$_2$S</strong></td>
<td>21</td>
<td>min</td>
</tr>
<tr>
<td><strong>Oxidation time with H$_2$S</strong></td>
<td>15</td>
<td>min</td>
</tr>
</tbody>
</table>
Experimental Results

- Effect of sulphur on bed performance
  - Product gas composition changes
  - Oxygen consumption per cycle
  - Oxygen carrier characterization
Solid Characterization

- Oxidized sample after 34 hours and 56 cycles
- Reduced sample after 2 extra cycles and one reduction reaction
- Fresh sample from VITO
Energy Dispersive X-ray (EDX)

- Sulphur was observed uniformly distributed in the sample
- Carbon deposition was very low
Scanning Electron Microscopy (SEM)

Fresh sample

Reduced sample

Porosity loss

Oxidized sample

10 um
Solid Characterization Results

- Presence of sulphur (Ni$_3$S$_2$)
- Negligible carbon deposition
- Reduced porosity as the result of redox cycles and sulphur
- Some evidence of agglomeration
Conclusions

- Sulphur reacts with nickel during reduction
- Less metallic Ni available results in:
  - Higher unburned methane
  - Lower CO$_2$ production
  - Lower oxygen availability/consumption
- H$_2$S in reacting gas released as SO$_2$
  - Middle of oxidation step
  - Beginning of reduction step
Conclusions (cont…)

- Effect of sulphur disappears after few redox cycles without H$_2$S
- Porosity loss due to redox and sulphur
  - May affect performance and life time in long term
  - Irreversible
- Nickel-sulphur compounds may increase agglomeration
Other AITF CLC activities
Oxygen Carriers

- No oxygen carrier supply in North America
- Mining and metals processing industry in Alberta – potential industrial waste
- Require sulphur tolerant oxygen carriers suitable for natural gas
  - \( \text{H}_2\text{S} \) concentration for SAGD
- Suitable manufacturing and testing facilities at AITF
Demonstration of CLC

- Unique opportunity in Alberta for 10 MW\textsubscript{th} demonstration unit for steam generation with CO\textsubscript{2} capture and injection

- AITF as research support for:
  - Pilot plant design and operation
  - R&D support for demo plant
  - Oxygen carrier development
Questions?