Chemical Looping Combustion for inherent CO₂ capture in a coal-based IGCC power plant

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Presentation to the 2011 AIChE Spring Meeting, Chicago, IL
March 13-17, 2011

Objectives

- Evaluate CLC using syngas as fuel
  - Effect of fuel
  - Effect of operating conditions
- Use CLC for CO₂-capture in a coal-based IGCC power plant using different gasification technologies
What is CLC

- Indirect combustion process
- Produces a high purity CO₂ stream
- Oxygen supplied by an oxygen carrier
- Possible OC
  - Ni
  - Cu
  - Fe
  - Mn

Reactions

- Ni + ½ O₂ ⇌ NiO
  \[ \Delta H = -234 \text{ kJ/mol} \]
- CH₄ + 4NiO ⇌ CO₂ + 2H₂O + 4Ni
  \[ \Delta H = 134 \text{ kJ/mol} \]
- CO + NiO ⇌ CO₂ + Ni
  \[ \Delta H = -43.3 \text{ kJ/mol} \]
- H₂ + NiO ⇌ H₂O + Ni
  \[ \Delta H = -2.1 \text{ kJ/mol} \]
- xCO + yH₂ + zCH₄ + (x+y+4z)NiO ⇌ (x+z)CO₂ + (y+2z)H₂O + (x+y+4z)Ni
Conversion decreases with temperature

\[ \gamma_{CO} = \frac{P_{CO}}{P_{CO} + P_{CO}} \quad \gamma_{H2O} = \frac{P_{H2O}}{P_{H2O} + P_{H2O}} \]

100% conversion not possible with Ni/NiO

CLC in a combined cycle power plant
CLC model assumptions

- **Fuel**
  - 100% CO
  - 75% CO, 25% H₂
  - 50% CO, 50% H₂
- **Air reactor (AR)** – isothermal, 20 bar
  - 1000°C, 1100°C, 1200°C
- **Fuel reactor (FR)** – adiabatic, 20 bar
- **Stoichiometric MeO**
- **Air-fuel ratio**
  - Stoichiometric – 3*Stoichiometric
- **Gas turbine**
  - No special changes required for depleted air or CO₂/H₂O expansion
- **Steam cycle**
  - Heat rate – 8,740 kJ/kWh

CO₂ purity

<table>
<thead>
<tr>
<th>Temperature</th>
<th>100% CO</th>
<th>75% CO, 25% H₂</th>
<th>50% CO, 50% H₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000 °C</td>
<td>99.1</td>
<td>99.0</td>
<td>98.8</td>
</tr>
<tr>
<td>1100 °C</td>
<td>99.0</td>
<td>98.7</td>
<td>98.7</td>
</tr>
<tr>
<td>1200 °C</td>
<td>98.9</td>
<td>98.8</td>
<td>98.6</td>
</tr>
</tbody>
</table>
Efficiency increases with CO%.

AR Temperature = 1000 °C

Efficiency (% HHV)

Excess air (%)

- 100% CO 0% H2
- 75% CO; 25% H2
- 50% CO; 50% H2

Efficiency increases with temperature.

50% CO; 50% H2

AR temp 1200°C
AR temp 1100°C
AR temp 1000°C

Efficiency (% HHV)

Excess air (%)

0 10 20 30 40 50
0 50 100 150 200
Application to IGCC

IGCC without CCS
IGCC with physical absorption CCS

IGCC with CLC
**Clean syngas from different gasifiers***

<table>
<thead>
<tr>
<th>Component</th>
<th>GE (1,316 °C 5.6 MPa)</th>
<th>EGas (1,040 °C 4.2 MPa)</th>
<th>Shell (1,427 °C 4.2 MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO</td>
<td>38.9</td>
<td>45.4</td>
<td>61.5</td>
</tr>
<tr>
<td>H₂</td>
<td>38.4</td>
<td>32.4</td>
<td>31.2</td>
</tr>
<tr>
<td>CH₄</td>
<td>0.3</td>
<td>4.7</td>
<td>0.0</td>
</tr>
<tr>
<td>CO₂</td>
<td>17.8</td>
<td>15.1</td>
<td>0.1</td>
</tr>
<tr>
<td>H₂O</td>
<td>0.1</td>
<td>0.2</td>
<td>0.1</td>
</tr>
<tr>
<td>N₂</td>
<td>3.6</td>
<td>1.2</td>
<td>6.0</td>
</tr>
<tr>
<td>Ar</td>
<td>0.9</td>
<td>1.0</td>
<td>1.1</td>
</tr>
<tr>
<td>MW (kg/kmol)</td>
<td>21</td>
<td>22</td>
<td>20</td>
</tr>
<tr>
<td>HHV (kJ/kmol)</td>
<td>222,430</td>
<td>263,200</td>
<td>263,900</td>
</tr>
</tbody>
</table>


**Fuel reactor temperature**

![Graph showing fuel reactor temperature vs. air reactor temperature]
CO₂ purity

CLC efficiency for different fuels
IGCC efficiency for different fuels

Air reactor temperature = 1200C

- Shell
- E-Gas
- GE

IGCC efficiency at different temperatures

Syngas from GE gasifier

- 1200 C
- 1100 C
- 1000 C
Conclusions

- CLC system efficiency doesn’t change with fuel
- IGCC system efficiency changes