Application of a Heat Integrated Post-Combustion Carbon Dioxide Capture System with Hitachi Advanced Solvent into Existing Coal-Fired Power Plant (DE-FE0007395)

Heather Nikolic, Kunlei Liu, Jesse Thompson and Reynolds Frimpong

University of Kentucky - Center for Applied Energy Research
https://caer.uky.edu/power-generation/
Current Accomplishments

- Additional advanced solvent campaign complete
- Intensified process modification design and construction complete
- Commissioning and startup complete
- Initial evaluation on modified process complete

Team Members

Funding

Federal – $16,291,967
Cost Share – $5,932,902
Project Performance Dates

BP1: October 1, 2011 to January 31, 2013 (16 months)
BP2: February 1, 2013 to August 31, 2013 (7 months)
BP3: September 1, 2013 to March 31, 2015 (19 months)
BP4: April 1, 2015 to March 31, 2020 (60 months)

Added Scope:
- Testing of additional advanced solvents
- Process modification to include pre-concentrating membrane and solid-assisted water washing
**BP4 Milestones**

- Advanced solvent campaign and degradation study – 12/31/2018
- Fabrication of process modification equipment complete – 1/4/2019
- Modified pilot unit commissioning complete – 7/16/2019

**BP4 Success Criteria**

- Documented delivery of equipment onto plant site according to design and construction specifications – 4/30/2019
- Certification that the completed process modification system meets the design performance specifications – 7/16/2019

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**AS 2 Campaign**

- **Modification Construction**
- **Commissioning**
- **Modification Evaluation**

Q4 2018 | Q1 2019 | Q2 2019 | Q3 2019

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**UK Blend Solvent Campaign**

- June to November 2018
- Construction: February 2018 to May 2019
- Commissioning: June 2019
- Membrane and Water Wash Preliminary Evaluation: Since July 2019
Project Overview

• 0.7 MWe advanced post-combustion CO₂ capture small pilot
• Modular design
• Installed at Kentucky Utilities E.W. Brown Generating Station in Harrodsburg, KY, approximately 30 miles from UKy-CAER
• Includes several UKy-CAER developed technologies
• Over 4500 hours of operation
• Five solvents tested: 30 wt% MEA baseline, H3-1, AS 1, 6M MEA, AS 2
• Installation of process modification including a CO₂ preconcentrating membrane and water wash system
UKy-CAER Advanced CO$_2$ Capture Technology

**Motivation**

- Reduced energy penalty and costs
- Utilization of low grade heat via internal heat pump
  - Secondary air stripper
  - Liquid desiccant for cooling tower
- Near-zero makeup water for amine loop to save operation costs
- Advanced Solvents
Performance Metrics Obtained

- Mass Transfer Intensification: increase in absorption rate, 5-11% increase in rich loading, absorber with 40 ft packing with near equilibrium loading achievable
- Two-Stage Solvent Regeneration: leading to 8% less energy compared to conventional with >10% of regeneration in secondary air stripper demonstrated, 15-17% vol% CO₂ at absorber inlet due to recycling
- Robust Process Performance proven for various solvents: ≥80% trouble free startups, capable of both daily startups and shutdowns and 24/7 operations
- Process Stability: Generally ≤5% variation of key process parameters
- Solvent Quality: Low makeup rate required due to low primary stripper bottom T <245 °F and negligible effect of secondary stripper on solvent degradation
- Amine Loop Water Makeup: No DI water system needed with the application of water evaporator for air stripper
Costs of UKy-CAER CCS

- Plant Efficiency (HHV basis) of 34.0%, a 5% increase compared to RC B12B
- Capital Cost of $61.90/MWh, a 14% reduction compared to RC B12B
- Cost of Electricity of $117/MWh, a 12% reduction compared to RC B12B
- CO₂ Capture Cost of $41.40/tonne CO₂, excluding T&S, a 29% reduction compared to RC B12B

<table>
<thead>
<tr>
<th></th>
<th>RC B12B</th>
<th>UKy-CAER CCS</th>
<th>Percent Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Net Power, Mwe</td>
<td>550</td>
<td>550</td>
<td>0%</td>
</tr>
<tr>
<td>Total Plant Cost (2011 $/kW)</td>
<td>3524</td>
<td>2977</td>
<td>-16%</td>
</tr>
<tr>
<td>Total Overnight Cost (2011$/kW)</td>
<td>4333</td>
<td>3660</td>
<td>-16%</td>
</tr>
<tr>
<td>Total As-Spent Cost (2011$/kW)</td>
<td>4940</td>
<td>4173</td>
<td>-16%</td>
</tr>
<tr>
<td>Cost of Electricity ($/MWh, 2011$)</td>
<td>133.2</td>
<td>116.9</td>
<td>-12%</td>
</tr>
<tr>
<td>CO₂ T&amp;S Costs</td>
<td>9.6</td>
<td>8.3</td>
<td>-13%</td>
</tr>
<tr>
<td>Fuel Costs</td>
<td>30.9</td>
<td>29.5</td>
<td>-5%</td>
</tr>
<tr>
<td>Variable Costs</td>
<td>12.3</td>
<td>12.4</td>
<td>1%</td>
</tr>
<tr>
<td>Fixed Costs</td>
<td>15.4</td>
<td>13.0</td>
<td>-16%</td>
</tr>
<tr>
<td>Capital Costs</td>
<td>72.2</td>
<td>61.9</td>
<td>-14%</td>
</tr>
<tr>
<td>Cost of CO₂ Captured ($/tonne CO₂)</td>
<td>58.2</td>
<td>41.4</td>
<td>-29%</td>
</tr>
</tbody>
</table>
Advanced Solvent 2 Campaign – Regeneration Energy

Despite differences in chemistry and physical properties, advanced solvents tested perform similarly.

<table>
<thead>
<tr>
<th>Performance Compared to 30 wt% MEA</th>
<th>Hitachi H3-1</th>
<th>Advanced Solvent 1</th>
<th>Advanced Solvent 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy Penalty</td>
<td>33% savings</td>
<td>30% savings</td>
<td>14% savings</td>
</tr>
<tr>
<td>Solvent Circulation Rate</td>
<td>~35-45% reduction</td>
<td>~30% reduction</td>
<td>~same</td>
</tr>
<tr>
<td>Cyclic Capacity</td>
<td>~1.5X</td>
<td>~1.5X</td>
<td>~1.0X</td>
</tr>
<tr>
<td>Viscosity</td>
<td>2.5 – 3X</td>
<td>~1.5X</td>
<td>~1.0X</td>
</tr>
<tr>
<td>Surface Tension</td>
<td>~0.6X</td>
<td>~1.0X</td>
<td>~0.8X</td>
</tr>
<tr>
<td>Degradation Products</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Solvent Regeneration Energy Measured at UKy-CAER 0.7 MWe CCS</td>
<td>1022 Btu/lb CO₂</td>
<td>1070 BTU/lb CO₂</td>
<td>1315 BTU/lb CO₂</td>
</tr>
</tbody>
</table>
Advanced Solvent 2 Campaign – Effect of Ambient T

-50 BTU/lb CO₂ captured decrease in regeneration energy with 20 °F increase in ambient temperature

Same L/G = 3.5, Stripper pressure = 22 psia
Advanced Solvent 2 Campaign – Solvent Stability

Total HSS levels are similar for the three campaigns conducted at similar run hours.
Advanced Solvent 2 Campaign – RCRA Elements

RCRA regulated metals all under limits.

Similar Fe, Cr and Se accumulation rates for advanced solvents.
Modification of UKy-CAER 0.7 MWe CCS

- Process Intensification
- Two-Stage Solvent Regeneration
- System Integration and Heat Recovery
- Advanced Solvent
Process Modification Construction

- Blau Mechanical contracted for the installation of new equipment
- New level/grating added at top of module for membrane skid
- Structural modifications made
- Water wash column and circulation pump
- Membrane, vacuum pump and blower
- Piping modifications
- Electrical modifications
- Control system modifications
Preliminary Membrane Results with Fixed Vacuum Pump Intake

Permeate concentration of 19 vol% CO₂ achievable with inlet feed CO₂ concentration of 12 vol%.

<table>
<thead>
<tr>
<th>Gas flow (acfm)</th>
<th>Membrane Inlet (psia)</th>
<th>Vacuum (psia)</th>
<th>Membrane Inlet (°F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>825</td>
<td>14.8</td>
<td>4.6</td>
<td>101</td>
</tr>
<tr>
<td>1000</td>
<td>15.1</td>
<td>4.7</td>
<td>107.5</td>
</tr>
<tr>
<td>1300</td>
<td>15.7</td>
<td>5</td>
<td>120</td>
</tr>
<tr>
<td>1500</td>
<td>16.2</td>
<td>5.4</td>
<td>134</td>
</tr>
</tbody>
</table>
New Knowledge Gained

- Despite differences in chemistry and physical properties, 2\textsuperscript{nd} generation advanced solvents have similar performance

- Decrease in regeneration energy with increase in ambient temperature

- 19\% CO\textsubscript{2} in permeate achievable with preconcentrating membrane
Remaining Tasks

1) Complete pre-concentrating membrane performance evaluation

2) Complete water wash system evaluation

3) Update TEA and EH&S assessment
Technology Development Plan

Scale

- Proof of Concept
- Fundamental Thermodynamic and Kinetic Studies
- Concept
- Testing on 0.03 MWe (0.1 MWth) Lab-scale Unit
- 0.7 MWe Small Pilot CCS
- 10 MWe Large Pilot CCS Engineering Design
- 150 - 550 MWe Deployment

TRL 1-2
RL 3-4
TRL 5-6
TRL 7-8

NETL CO₂ Capture Technology Project Review Meeting

August 26-30, 2019
Acknowledgements

- Andy Aurelio, José Figueroa and Lynn Brickett, U.S. DOE NETL
- Gerald Arnold, Zach Watson, Aron Patrick, Mahyar Ghorbanian, and Jeff Fraley, LG&E and KU
- UKy-CAER Small Pilot CCS Team