Pilot Testing of a Heat Integrated 0.7 MWe CO$_2$ Capture System with Two-Stage Air-Stripping

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http://www.caer.uky.edu/powergen/home.shtml
University of Kentucky Center for Applied Energy Research

- Biofuels and Environmental Catalysts
- Carbon Materials
- Clean Fuels and Chemicals
- Environmental and Coal Technology
- Electrochemical Power Sources
- Power Generation and Utility Fuels
Areas of Research

**Corrosion**
- Non-metallic coating
- Inhibitors
- Localized effects

**Membrane Separations**
- Zeolite membranes
- Solvent enrichment

**Conversion**
- Gasification
- CO₂ Utilization
- NG Upgrading

**Solvents**
- Chem/Physical Properties
- Emission
- Degradation

**Chemical Looping**
- Spouting Fluidized bed
- Combustion/ gasification
- Solid particle handling

**Electrochemistry**
- Water treatment
- Solvent enrichment

**Pilot Plants**
- Heat Integration
- Hybrid Processes
- Solvent & process testing
Presentation Outline

• Overview of Project
  • Technology Description
• Emission and Degradation assessment

2 MW_th Pilot-Scale CO_2 Capture Project
KU E.W. Brown Generating Station

Sponsored by:
U.S. Department of Energy Office of Fossil Energy
National Energy Technology Laboratory
Kentucky Department of Energy Development and Independence
Carbon Management Research Group
University of Kentucky

Cooperative Agreement DE-FL0007395
Current UKy-CAER CO₂ Capture Project

- Host site at Kentucky Utilities EW Brown Generating Station, Harrodsburg, KY
- 0.7 MWe advanced post-combustion CO₂ capture pilot plant
- Capture and release program (~1400 scfm flue gas)
- Designed as a modular configuration
- Includes several UKy-CAER developed technologies
- Tested two different amine solvents (MEA and H3-1)
- Funded in part by DOE-NETL (DE-FE0007395)
Small Pilot (1400 scfm) CO$_2$ Capture

- Unique UKy-CAER CO$_2$ Capture Process
- **Heat integrated cooling tower** and liquid desiccant air drying system for decreased energy consumption
- **Two-stage stripping** for increased solvent working capacity
- Continuous gas stream composition monitoring (**CEMS**)
- Continuous **steam usage** measurement
- Continuous **energy consumption** measurement
- Comprehensive liquid sampling ports for **solvent quality analyses**
- Comprehensive **gas sampling** ports for emissions and degradation analyses
- Liquid/gas **column profile** sample ports for absorber profile validation
- **Corrosion coupon** testing locations for material evaluation
- On-site **analytical laboratory** for routine liquid sample analysis

Phase 2 Modifications: Install CO$_2$ pre-concentration membrane and emission reduction systems
Technology Description

Conditions at Top of Absorber
T ~ 100 °F, P ~ 15 psia

Conditions at Top of Primary Stripper
T ~ 200-230 °F, P ~ 22-50 psia

Conditions at Top of Secondary Air Stripper
T ~ 180 °F, P ~ 15 psia
The UKY-CAER Transformational CO$_2$ Capture technology has the ability to reduce regeneration energy with a variety of different solvents.
Emissions and Solvent Degradation

Full Environmental Study:
- Amine Degradation
- Heavy Metal Accumulation
- Nitrosamines
- Amine Emissions
- NH₃, Formaldehyde
- All Other Waste Streams
- 3rd party Emission and EH&S Assessment
NH$_3$ Emissions and Iron Correlation

NH₃ Emissions and Copper Correlation

Ammonia Emissions vs. Cu Concentration (ppm) over Operating Hours (0-1500)

Reclaiming

Corrosion

An amine strainer was removed due to frequent leakage and was found to have brass internals. It was severely corroded and the likely source of the high copper levels observed during the MEA campaign.

In addition to Fe and Cu, elevated levels of Cr, Ni were also observed –

This may be related to system commissioning as NCCC observed similar results in their initial MEA testing campaign, with significantly lower levels observed in subsequent solvent testing campaigns

Se will need to be constantly monitored to verify it remains below RCRA limits

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### Metal Accumulation

<table>
<thead>
<tr>
<th>Elements</th>
<th>UKy-CAER (mg/L)</th>
<th>NCCC (mg/kg)</th>
<th>CSIRO (mg/kg)</th>
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<tbody>
<tr>
<td>Cr</td>
<td>29.382</td>
<td>45.90</td>
<td>4.20</td>
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<tr>
<td>Fe</td>
<td>265.248</td>
<td>137.20</td>
<td>199</td>
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<tr>
<td>Ni</td>
<td>28.024</td>
<td>28.77</td>
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<tr>
<td>Cu</td>
<td>33.898</td>
<td>&lt; LOD</td>
<td>3.54</td>
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<tr>
<td>As</td>
<td>0.290</td>
<td>0.219</td>
<td></td>
</tr>
<tr>
<td>Se</td>
<td>0.769</td>
<td>1.950</td>
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<tr>
<td>Ba</td>
<td>0.982</td>
<td>0.265</td>
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<tr>
<td>Pb</td>
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<td>Ag</td>
<td>&lt; LOD</td>
<td>&lt; 0.50</td>
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</tr>
<tr>
<td>Cd</td>
<td>&lt; LOD</td>
<td>&lt; 0.01</td>
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</tr>
<tr>
<td>Be</td>
<td>&lt; LOD</td>
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<tr>
<td>Mg</td>
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<td>Al</td>
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<tr>
<td>Zn</td>
<td>0.940</td>
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<tr>
<td>Mn</td>
<td>5.620</td>
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<tr>
<td>V</td>
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</tr>
<tr>
<td>Mo</td>
<td>0.49</td>
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<td></td>
</tr>
<tr>
<td>Co</td>
<td>1.020</td>
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<tr>
<td>Flue Gas Source</td>
<td>Coal</td>
<td>Coal</td>
<td>Brown coal</td>
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<tr>
<td>Operating Hours</td>
<td>880$^a$</td>
<td>1140</td>
<td>1476$^b$</td>
</tr>
</tbody>
</table>

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$a$ Values reported before reclaiming.

$b$ Combined hours from 2 campaigns (640 h and 836 h) using the same solvent batch

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Comparative NH$_3$ Emissions

![NH$_3$ Emissions Bar Chart]

- **UKy-CAER**
- **TNO Maasvlakte**
- **TCM**
- **Niederaussem**
- **NCCC**

**Ammonia Emissions (ppmV or mg/Nm3)**

0 100 200 300 400

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Thompson et.al., Int J Greenhouse Gas Control 2017, 64, 22-33.
Morkin et.al., Energy Procedia 2014, 63, 6023-6038.
Carter, National Carbon Capture Center: Post-Combustion. Presented at the NETL CO2 Capture Technology Meeting, 9-12 July 2012, Pittsburgh, PA, USA.
Comparative MEA Emissions

Pilot results from coal combustion

MEA Emissions (ppmV or mg/Nm3)

0 100 200 300 400 500 600

UKy-CAER

Long-term operation

NCCC

TNO Maasvlakte

Some MEA emission observed over 1300 ppmV during parametric testing
Baghouse installed at Brown Station after MEA campaign

Wheeldon, J., National Carbon Capture Center: Post-Combustion CO2 Capture Program. Presented at the NETL CO2 Capture Technology Meeting, 8-11 July 2013, Pittsburgh, PA, USA.
Wheeldon, J., National Carbon Capture Center: Post-Combustion testing. Presented at the NETL CO2 Capture Technology Meeting, 29 July - 1 August 2014, Pittsburgh, PA, USA.
da Silva et al., Energy Procedia, 2013, 37, 778-783
Additional Solvent Considerations

Cost needs to be addressed by 3rd generation solvents
Additional Highlights

- Heat Stable Salt (HSS) accumulation from flue gas as expected
  - Sulfate and nitrate are major species

- Service water usage did not lead to any operational problems

- MEA thermal and oxidative degradation very similar to other campaigns
  - Formate and HEI major oxidative species
  - HEIA major thermal degradation product

- Aldehyde emissions were also comparable to other MEA testing campaigns

- Nitrosamines emissions were not observed above the ~1 ppbV detection limit
Large amount of degradation and many degradation products identified

Lab scale experiments under harsh conditions; high temperatures, high CO$_2$ loading, high contaminant levels (metals)

Bench scale experiments; less harsh and closer to actual process conditions

Less degradation and fewer degradation products

Pilot scale experiments; close to actual process conditions

Fewest degradation products identified with lowest overall degradation
Key Knowledge Gained

- Liquid/gas distribution can significantly reduce the absorber efficiency.

- It is important to consider the L/R exchanger performance when reporting and comparing solvent regeneration values.

- Thermal reclaiming may be needed for RCRA element management.
Hybrid 0.7 MWe CCS Flow Diagram
Pre-Concentration Membrane

Major Achievements
- 2x increase in vol% CO₂
  14% → 28%
- Engineered solution to utilize the increased driving force and realize energy savings – pump around

Major Challenges
- Pressure drop across membrane giving low gas flow rates
- Not straightforward integration/installation to realize benefit from higher vol% CO₂

Funded in part through DE-FE0012926
Modified WaterWash (WW)

Sorbent properties that can maximize N-nitrosamine adsorption while minimizing amine adsorption

Technology Development Pathway

Time


Scale

Proof of Concept
Fundamental Thermodynamic and Kinetic Studies

0.7 MWe Process Design Package (P&ID etc.)

0.7 MWe Process Flow Diagram

0.7 MWe Fabrication and Installation

10 MWe Design, Fabrication, Installation and Testing

150 - 550 MWe Deployment

0.7 MWe Operation

Testing on 0.03 MWe (0.1 MWth) Lab-scale Unit

Process Simulation/Steam Tables

Concept
Acknowledgements

José Figueroa and Lynn Brickett, DOE NETL
CMRG Members
Donnie Duncan, David Link, Michael Manahan, Mahyar Ghorbanian, and Jeff Fraley, LG&E and KU
UKy-CAER Slipstream Team