CO$_2$ CAPTURE FROM IGCC GAS STREAMS USING THE AC-ABC PROCESS

2010 NETL CO$_2$ Capture Technology Meeting
September 16, 2010 Pittsburgh, PA.
Project Overview

- **Partners:**
  - SRI International, Menlo Park, CA
  - Great Point Energy, Cambridge, MA
  - DOE-National Energy Technology Center

- **Period of Performance:**
  - 10-1-2009 through 1-30-2012

- **Funding:**
  - U.S.: Department of Energy: $3.4 million
  - Cost share: $1.1 million
  - Total: $4.5 million
Project Objectives

- Overall objective:
  - To develop an innovative, low-cost CO₂ capture technology based on absorption on a high-capacity and low-cost aqueous ammoniated solution.

- Specific objectives:
  - Test the technology on a bench scale batch reactor to validate the concept,
  - To determine the optimum operating conditions for a small pilot-scale reactor,
  - Design and build a small pilot-scale reactor capable of continuous integrated operation,
  - Perform tests to evaluate the process in a coal gasifier environment,
  - Perform a technical and economic evaluation on the technology.
Process Block Diagram

From Gasifier

- **Water Gas Shift**
  - 30 to 50 bar
  - 230 – 285°C

- **Syngas Cooling**
  - 30 to 50 bar
  - 40 to 60°C

Gas & Steam Turbines

- **H₂(g)**
  - 30 to 50 bar

AC-ABC CO₂ Absorption

AC-ABC Regeneration & CO₂ Release

Pipeline

- **CO₂(g)**
  - 30 to 50 bar

Rich Solvent

temperature:

130 to 160°C

Lean Solvent

Pipeline

From Gasifier
Process Highlights

- Concentrated ammoniated solution is used to capture CO\(_2\) and H\(_2\)S from syngas at high pressure.
- Operates at or above ambient temperature; No refrigeration is needed.
- CO\(_2\) is released at a high pressure:
  - The size of CO\(_2\) stripper (regenerator) and the electric power consumption for compression of CO\(_2\) to the pipeline pressure is reduced.
- High net CO\(_2\) loading, up to 20\% by weight.
- H\(_2\)S is released at conditions suitable for sulfur recovery.
Process Advantages

- Low cost and readily available reagent.
- Very little solvent makeup is required
  - Reagent is chemically stable under the operating conditions.
- Low heat consumption for CO$_2$ stripping (<600 Btu/lb CO$_2$).
- Extremely low solubility of H$_2$, CO and CH$_4$ in absorber solution
  - Minimizes losses of fuel species.
- Absorber and regenerator can operate at similar pressure.
  - No need to pump solution cross pressure boundaries. Low energy consumption for pumping.
Chemical Reactions (Aqueous Phase)

- $\text{NH}_4\text{OH} + \text{CO}_2 \leftrightarrow \text{NH}_4\text{HCO}_3$
- $(\text{NH}_4)_2\text{CO}_3 + \text{CO}_2 + \text{H}_2\text{O} \leftrightarrow 2\text{NH}_4\text{HCO}_3$
- $\text{NH}_4(\text{NH}_2\text{CO}_2) + \text{CO}_2 + 2\text{H}_2\text{O} \leftrightarrow 2\text{NH}_4\text{HCO}_3$
- $\text{NH}_4\text{HCO}_3 \leftrightarrow \text{NH}_4\text{HCO}_3$ (precipitate)

All the reactions are reversible and they go from left to right in the absorber (lower temperature) and from right to left in the stripper regenerator (higher temperature).

Heat of reaction is in the 300-600 btu/lb of CO$_2$ range and it depends on temperature and the CO$_2$/NH$_3$ ratio of the solution.

- $2\text{NH}_4\text{OH} + \text{H}_2\text{S} \leftrightarrow 2\text{NH}_4\text{HS} + \text{H}_2\text{O}$
- $(\text{NH}_4)_2\text{CO}_3 + \text{H}_2\text{S} \leftrightarrow \text{NH}_4\text{HS} + \text{NH}_4\text{HCO}_3$
- $\text{NH}_4\text{HCO}_3 + \text{H}_2\text{S} \leftrightarrow \text{NH}_4\text{HS} + \text{H}_2\text{O} + \text{CO}_2$

No precipitation of Sulfide salts.
Technical Challenges

Precipitation of solids

- Benefit: Increases the CO$_2$ loading of solution flowing to the regenerator.
- Risk: Potential fouling of packing and heat exchanger surfaces.
- Solutions:
  - Operate at elevated temperatures under non-precipitation conditions.
  - Use open, smooth structural packing.
  - Use slurry pumps to transfer from absorber to regenerator
Technical Challenges (continued)

- Excessive residual ammonia in the fuel gas stream leaving the absorber
  - Source of Risk:
    - Absorber operation at an elevated temperatures
  - Solutions:
    - Install a small absorber (wash) column to capture the residual ammonia
    - The wash water will be reclaimed in a stripper and the ammonia is cycled back to the absorber.
    - Tests at SRI has shown that ammonia levels can be reduced to ppm levels.
Project Tasks

1. Bench-scale Batch Tests

2. Pilot-Scale Integrated, Continuous Tests

3. Project Management
Bench-Scale Absorber Testing

- Determination of solubility:
  - Shifted-gas components (H₂, CO, N₂, Ar)

- Determination of reactivity of CO₂ and H₂S:
  - Function of composition, pressure, and temperature.

- Mixed-gas testing to determine the relative reaction kinetics.
Schematic Diagram of the Absorber System

FEED SOLUTION RESERVOIR

INJECTION PUMP

OUTLET FLOW

TO ANALYZER

SPENT SOLUTION RESERVOIR

HEAT EXCHANGER

CIRCULATION PUMP

PRESSURE GAUGE

LIQUID LEVEL INDICATOR

ABSORPTION COLUMN

MASS FLOW CONTROLLERS

H₂, CO₂, H₂S GAS CYLINDERS

SCRUBBER AND GAS ANALYZER
Photograph of the Absorber System

Reactor ID: 4-in
Low pressure drop
Koch structural packing:
  Specific area: 425 m²/m³
Packing height: 2-ft
### Solubility of Non-Reacting Gases in the Solution

<table>
<thead>
<tr>
<th>Gas</th>
<th>Gas Component Concentration (%v/v)</th>
<th>Dissolved Gas (g/kg Solution) at 40 atm Total Pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td>H2</td>
<td>50.0</td>
<td>6.53E-03</td>
</tr>
<tr>
<td>CO</td>
<td>2.0</td>
<td>3.62E-04</td>
</tr>
<tr>
<td>CH4</td>
<td>2.0</td>
<td>4.67E-04</td>
</tr>
<tr>
<td>N2</td>
<td>1.0</td>
<td>1.11E-04</td>
</tr>
</tbody>
</table>
CO₂ Capture Efficiency vs Solution Composition

Absorber Pressure: 265 psia
% CO₂ = 25
Effect of Temperature on Absorption Rate

Absorber Pressure: 265 psia
% CO₂ = 25

R’ = CO₂/NH₃ Mole Ratio

Run 17 (50 C)
Run 16 (33 C)
Run 13 (45 C)
Run 11 (45 C)
Run 18 (45 C)
Run 19 (60 C)
Run 20 (43 C)
Temperature Raise on Absorption

CO$_2$ Absorption Rate x10$^3$ (mole/min) vs Delta-T (°C)

- Run 17 (50 C)
- Run 16 (33 C)
- Run 18 (44 C)
- Run 19 (60 C)
- Run 20 (43 C)
- Run 21 (55 C)

57 kJ/mole ($R' \sim 0.43$) @ 8M NH$_3$
Absorber Operating Pressure = 265 psia
4 M and 8M Ammonia, Temperature: 35 to 60 C
Feed CO2: 25 %v/v
H$_2$S and CO$_2$ Absorption Efficiencies

Pressure: 265 psia
Temperature: 55 C
1% H$_2$S and 25% CO$_2$
CO₂ Capacity: Function of Solution Composition

**CO₂ loading in ammoniated solutions**

- **10M NH₃ in solution**
- **8M NH₃ in solution**

**Operating Range**

Solubility of NH₄HCO₃ at 50°C: 70 wt%
Bench-Scale Regenerator Testing

- Determination of CO$_2$ release characteristics
  - Function of temperature, pressure and solution composition
- Determination of H$_2$S release characteristics
  - Function of temperature, pressure and solution composition
- Relative kinetics of CO$_2$ and H$_2$S release
CO$_2$ Attainable Pressure Function of Temperature
Photograph of the Regenerator System
High Pressure Regeneration of CO₂

8 M NH₃ Solution, 300 psig
Feed NH₃/CO₂= 1.6
Release of H$_2$S During Regeneration

8M NH$_3$; 0.6 M sulfide; Feed NH$_3$/CO$_2$ = 1.6
Technical and Economic Analysis

- Aspen and GT-Pro modeling were used to generate the equipment sizing and heat and material flows.

- Use DOE spread sheet to generate cost

- Base case will be an IGCC plant (750 MW nominal) with no CO₂ capture.

- Compare the AC-ABC process with a similar-size plant using CO₂ capture with Selexol subsystem.
Block Flow Diagram of the CO₂ and H₂S Capture System
## Preliminary Cost Comparison

<table>
<thead>
<tr>
<th>Units</th>
<th>Base Case: No CO\textsubscript{2} Capture</th>
<th>Base Case: Selexol CO\textsubscript{2} Capture</th>
<th>AC-ABC: 600 BTU/lb</th>
<th>AC-ABC: H\textsubscript{2}S Removal as Gypsum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power Production @ 100% Capacity</td>
<td>GWh/yr</td>
<td>5,445</td>
<td>4,461</td>
<td>4,888</td>
</tr>
<tr>
<td>Power Plant Capital</td>
<td>c/kWh</td>
<td>4.48</td>
<td>6.21</td>
<td>5.44</td>
</tr>
<tr>
<td>Power Plant Fuel</td>
<td>c/kWh</td>
<td>1.90</td>
<td>2.46</td>
<td>2.22</td>
</tr>
<tr>
<td>Variable Plant O&amp;M</td>
<td>c/kWh</td>
<td>0.78</td>
<td>1.00</td>
<td>0.93</td>
</tr>
<tr>
<td>Fixed Plant O&amp;M</td>
<td>c/kWh</td>
<td>0.60</td>
<td>0.79</td>
<td>0.72</td>
</tr>
<tr>
<td>Cost of Electricity (COE)*</td>
<td>c/kWh</td>
<td>7.76</td>
<td>10.46</td>
<td>9.31</td>
</tr>
<tr>
<td>Cost of Electricity (COE)</td>
<td>c/kWh</td>
<td>7.76</td>
<td>10.88</td>
<td>9.69</td>
</tr>
<tr>
<td>Increase in COE*</td>
<td>%</td>
<td>0.0%</td>
<td>34.8%</td>
<td>20.0%</td>
</tr>
<tr>
<td>Increase in COE</td>
<td>%</td>
<td>0.0%</td>
<td>40.2%</td>
<td>24.9%</td>
</tr>
<tr>
<td>Net Efficiency (HHV)</td>
<td>%</td>
<td>39.2%</td>
<td>30.3%</td>
<td>33.2%</td>
</tr>
</tbody>
</table>

* Excludes transportation, storage, and monitoring costs

CO\textsubscript{2} capture: 3.3 million tons/year; Plant operating life: 30 years; Capacity factor: 80%; Capital charge factor: 17.5%
Accomplishments

- Operation of bench-scale system:
  - High pressure (20 bar) and
  - Elevated temperatures (up to 160 °C).

- Demonstration of very high levels (>90%) of CO$_2$ and H$_2$S capture efficiency.

- Regeneration of solution and release of CO$_2$ and H$_2$S at high pressures.

- Preliminary analysis shows a significant cost improvement over the Selexol case.
Future Plans: Pilot-Scale Continuous Integrated Tests

- Design of a pilot-scale continuous, integrated test system
- Construction of the pilot-scale system
- Development of pilot-scale test plans
- Performance of pilot-scale tests
- Process modeling
- Economic analysis
- Technology transfer to commercial sector
Pilot-Scale Testing with a Gasifier Stream

- Use the gas stream from the Great Point Energy’s 1 ton/day gasifier
  - The stability of integrated operation will be evident in the field test more readily because not all variables are closely controlled as in the simulated tests.
  - Long test duration: The field tests will provide about 10 times longer total test time than with the simulated tests (up to 600 h total).
  - Effect of trace contaminants: The field test will use a gas stream from an operating gasifier that has undergone minimum cleanup and the gas stream will contain trace contaminants.
Team

- SRI International
  - Dr. Gopala Krishnan – Associate Director (MRL) and PI
  - Dr. Angel Sanjurjo – Materials Research Laboratory Director and Project Supervisor
  - Dr. Indira Jayaweera, Dr. Jordi Perez, and Mr. Anoop Nagar

- Great Point Energy, Inc,
  - Dr. Pat Raman

- DOE-NETL
  - Ms. Susan Maley, Ms. Jenny Tennant