Improvement of GE Power’s Chilled Ammonia Process using Membrane Technology

Large Pilot Scale Post Combustion CO$_2$ Capture
No. FE0026589
National Energy Technology Laboratory \ Department of Energy
August 9, 2016
Acknowledgement

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Project Overview: Team

- **Host Site and Funding Partner**
  Technology Centre Mongstad (TCM)
  Bjorn-Erik Haugan

- **US. DOE NETL**
  Program Manager
  Steve Mascaro

- **Project Director**
  Barath Baburao

- **GE Power**
  Principal Investigator
  Dave Muraskin

- **GE Power**
  Technology Manager
  Sanjay Dube

- **Technical Consultants**
  - ElectroSep, Dr. Paul Parisi, Todd Larson
  - General Electric Power & Water, Alexander Gorman
  - OSMO: Jurgen Muller
  - Georgia Institute of Technology, Dr. Sankar Nair, Dr. Ryan Lively, Nikita Kevlich

- **GE Power**
  Project Manager
  Robert Harvey

- **GE Power**
  Procurement
  Bill Hubbard

- **TCM Site Operations Manager**
  Gerard Lombardo

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Project Review Meeting Agenda

- Project Overview
  - Funding (DOE and Cost Share)
  - Overall Project Performance Dates
  - Project Participants
  - Overall Objectives
- Technology Background
- Technical Approach / Project Scope
- Progress and Current Status
  - Budget Period (length and cost)
  - Accomplishments
  - Performance levels achieved
- Future Testing / Development
## Discussion Topics

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Project Background

- Utilize liquid-liquid membrane technology to improve General Electric’s Chilled Ammonia Process (CAP) CO₂ capture technology
  - Elimination of CAP liquid ammonium sulfate effluent stream
  - Reduction of CAP energy demand
  - Initial laboratory testing of concepts performed in a development program outside the scope of this work

Project Overview

- Perform Technical Economic Analysis of concepts and compare with DOE Baseline
- Perform Gap Analysis to assess development needs
- Provide Final Report to summarize findings
Project Overview

• Original Project Funding (DOE and Cost Share)

<table>
<thead>
<tr>
<th>Budget Period No.</th>
<th>Budget Period Start</th>
<th>Government Share $/$%</th>
<th>Recipient Share $/$%</th>
<th>Total Estimated Cost</th>
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<tbody>
<tr>
<td>1</td>
<td>10/01/2015</td>
<td>$922,709 (74.1%)</td>
<td>$322,933 (25.9%)</td>
<td>$1,245,642</td>
</tr>
<tr>
<td>Total Project</td>
<td></td>
<td>$922,709 (74.1%)</td>
<td>$322,933 (25.9%)</td>
<td>$1,245,642</td>
</tr>
</tbody>
</table>

• Overall Project Performance Dates
  – GAP Analysis 9/1/2016
  – Final Report 9/30/2016
Project Overview

• Phase I Overall Objectives (original)
  – Complete a preliminary techno-economic analysis (TEA) and technology gap analysis of membrane concepts for the Chilled Ammonia Process at a full scale 550 MW power generation facility to show the concepts have the potential to meet DOE’s desired cost and performance goals.
  – Complete a firm estimate of the costs and schedule needed to modify the existing large pilot facility at the host site.
  – Develop key project success criteria values and risks.

• Modification of membrane development program due to laboratory test results
  – Decision not to proceed with the Large Pilot Modifications and application for Phase II funding

• Phase I Overall Objectives (revised)
  – Complete a final Techno-Economic Analysis (TEA) and Technology Gap Analysis (TGA) of membrane concepts for the Chilled Ammonia Process at a full scale 550 MW power generation facility to show the concepts have the potential to meet DOE’s desired cost and performance goals.
  – Develop key project risks.
Discussion Topics

- Project Overview
- Technology Background
- Technical Approach / Project Scope
- Progress / Current Status
- Future Development / Testing
CAP Technology Background

Chilled Ammonia CO₂ capture

Flue Gas Cooling/conditioning

CO₂ Storage

CO₂ Compression

CO₂ Absorption

CO₂ Regeneration

CO₂

Heat exchangers Pumps Cooling

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Technology Background

• Membrane Concepts for Development in the Chilled Ammonia Process
  – Concept 1: Elimination of CAP Ammonium Sulfate Byproduct and Reduction of Reagent Consumption
  – Concept 2: Reduction of CAP Ammonia Stripper Energy Using Membrane Technology
  – Utilize commercially available membrane systems
Technology Background

Concept Advantages

Membrane technology improvements include:

- Concept 1 Bipolar membrane electrodialysis
  - Elimination of CAP ammonium sulfate byproduct stream, costs for disposal or crystallization, concentration
- Concept 2 Membrane technology to reduce stripper energy using reverse osmosis
  - Reduction in CAP energy demand
  - Stripper duty can be reduced significantly.
  - Stripper and associated heat exchanger sizes can be reduced
- Overall reduction in cost of electricity as compared to DOE Baseline
Electrodialysis for Ammonium Sulfate Dissociation

- Benefits
  - Use of electrodialysis bipolar membrane to convert ammonium sulfate byproduct to process reagents
  - Reduction in sulfuric acid and ammonia reagent consumption
  - Elimination of ammonium sulfate byproduct stream (beneficial for locations where off-taker is not available).
  - Reduction in operating costs
  - Reduction in reagent (typical: anhydrous ammonia) storage on site
Benefits:

- Stripper feed ammonia levels are concentrated with reverse osmosis membrane separator resulting in reduced feed flow rate.
- Higher ammonia slip from the absorber is allowable.
- Absorber chiller duty can be minimized significantly.
- Stripper duty can be minimized significantly or eliminated resulting in specific steam energy.
- Stripper and associated heat exchanger sizes can be reduced by ~50%.
Technology Background
Membrane Improvement Concept 2

CO₂ Wash Bottoms using Reverse Osmosis

**Benefits:**
- Utilize reverse osmosis membrane technology to concentrate CO₂ wash bottoms stream
- Allows operation of the regenerator at lower pressure and higher ammonia emissions
- Allows lower pressure steam to regenerator

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Technology Background

Research Leading to Award
Chilled Ammonia Process
Update on GE Power roadmap

GE Power
Vaxjö Sweden
0.25 MWth

We Energies Pleasant Prairie
USA - 5 MWth, Coal

EoN Karlshamn
Sweden - 5 MWth, Oil

AEP Mountaineer
USA - 58 MWth, Coal

TCM Mongstad
Norway - 40 MWth, Gas

Roadmap to commercialization, 90% CO₂ capture demonstrated
Technology Background
Bench Scale Electrodiagnosis Testing

- Bench-scale Testing
  - Bipolar membrane electrodiagnosis by ElectroSep
  - Membrane systems
    - Anode exchange membrane
    - Cathode exchange membrane
    - Bipolar membrane
  - Test program completed
    - Parametric test program using synthetic solutions
    - Results indicate initial membrane selection is feasible
  - Additional experience provided by GE Power & Water

Electrodialysis Test Unit
ElectroSep Test Facilities
Saint Lambert, Quebec
Technology Background
Preliminary Results Reverse Osmosis Testing

• Bench-scale testing at Georgia Institute of Technology
• High rejection, seawater membrane samples tested from multiple suppliers
• Cellulose acetate, polyamide membranes
• Synthetic feed solution (stripper feed)
  – Ammonia-CO₂ solution: 1.5 M NH₃ using ammonium bicarbonate.
• Higher osmotic pressure needed to achieve desired ammonia rejection performance, flux
• Further testing with high pressure membranes is required
Technology Background
Membrane Development Challenges

Concept 2

• Higher pressure Reverse Osmosis membranes required
  – Increase in power consumption, operating costs
  – Increased capital cost
  – Increased membrane replacement costs
  – Decreased economic attractiveness

• New Reverse Osmosis concept considered to utilize lower pressure membranes
  – Laboratory testing of concept is needed
  – Economic assessment of concept needed
  – Development program to be revised
Discussion Topics

- Project Overview
- Technology Background
- Technical Approach / Project Scope
- Progress / Current Status
- Future Development / Testing
## Technical Approach / Scope

### Project Deliverables

<table>
<thead>
<tr>
<th>Deliverable</th>
<th>Date</th>
<th>Status</th>
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<tbody>
<tr>
<td>Phase 1 Technology Gap Analysis</td>
<td>September 1, 2016</td>
<td>September 1, 2016</td>
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<tr>
<td>Phase 1 Final Report</td>
<td>September 30, 2016</td>
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</table>
Discussion Topics

- Project Overview
- Technology Background
- Technical Approach / Project Scope
- Progress / Current Status
- Future Development / Testing
Progress of Project
Project Schedule & Key Milestones

- Large Pilot Accomplishments
  - Heat and Material Balances
  - Membrane estimates
  - Initial plant layout developed
  - Project discontinued

- Technical economic analysis
  - Submitted for review
  - Cost of electricity improvement from Baseline
  - Improvement not sufficient to proceed with existing design at large pilot

<table>
<thead>
<tr>
<th>Milestone Description</th>
<th>Planned Start Date</th>
<th>Actual Start Date</th>
<th>Completion Date</th>
<th>Verification Method</th>
<th>Commitment (progress toward achieving milestone, explanation for deviation from plan, etc.)</th>
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<tbody>
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<td>Kick-Off Meeting</td>
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<td>11/20/2015</td>
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<td>12/17/2015</td>
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</table>
Progress of Project Techno-Economic Analysis

- Plant layout
- Capital cost estimate
- Construction costs
- Power generation facility costs
- Steam cycle and steam / water integration
- TEA submitted for review
Techno-Economic Analysis Results

• Comparison to DOE Baseline (Case 12)
  – Improvement in power plant steam cycle efficiency
  – Decrease in total overnight costs
  – Reduction in cost of electricity (CoE) from the DOE baseline
  – **Performance**: degree of CoE improvement not sufficient to justify further development of the original Concept 2 Reverse Osmosis
  – New Reverse Osmosis membrane concept developed using low pressure membranes: expected to improve capital and operating costs, CoE
# Technology Gap Analysis

Technology areas considered in this project and the respective gaps are listed below

<table>
<thead>
<tr>
<th>Technology area</th>
<th>Current R&amp;D status</th>
<th>Technology Gap and R&amp;D plan</th>
</tr>
</thead>
</table>
| Chilled Ammonia Process without membranes   | Tested at different pilot scales and ready for large scale testing | • Ammonium sulphate removal where no market takers  
• Stripper energy consumption optimization  
• NH$_3$ volatility reduction in absorber  |
| Electro-dialysis unit                        | Tested at pilot scale in batch mode and ready for large pilot scale testing | • Potential for impurity interferences: test using power plant solutions  
• Scale-up to full scale sizes |
| Reverse osmosis membrane separation         | Tested at bench scale and ready for pilot scale testing       | • Low pressure membranes can only be used with modified process flow scheme  
• New process flow scheme with low pressure membranes has to be validated at bench and pilot scale  
• High pressure membranes are not cost effective and are currently with low lifetime |

- Technology Gap Analysis Report is due September 1$^{st}$, 2016
- Initial Gap Analysis draft completed: internal review
Progress Summary

• Techno-Economic Analysis Submitted on June 30, 2016
• Gap Analysis to be submitted September 1, 2016
• Final Report (summary of TEA & Gap Analysis) to be submitted September 30, 2016
Discussion Topics

- Project Overview
- Technology Background
- Technical Approach / Project Scope
- Progress / Current Status
- Future Development / Testing
Future Development & Testing

• New membrane improvement concept development
  – Lower pressure membrane design
  – Conduct laboratory testing at supplier facilities
  – Conduct laboratory testing at GE test facilities
  – Economic assessment to be performed to determine feasibility
  – Research and development budget to be determined in January, 2017