Engineering-scale Demonstration of Mixed-Salt Process (MSP) for CO$_2$ Capture (FE0031588)

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Technology Background
Mixed-salt Process (MSP)

How it works:
Selected composition of potassium carbonate and ammonium salts
- Overall heat of reaction 35 to 60 kJ/mol (tunable)
Absorber operation at 20° - 40°C at 1 atm with 30-40 wt.% mixture of salts
Regenerator operation at 120° - 160°C at 10-20 atm
- Produces high-pressure CO₂ stream

K₂CO₃-NH₃-CO₂-H₂O system

High CO₂ cycling capacity

Process Highlights:
- Reduced ammonia emissions
- Enhanced efficiency
- Reduced reboiler duty
- Reduced CO₂ compression energy

A SIGNIFICANT PARASITIC POWER REDUCTION COMPARED TO MEA!
MSP Summary and Benefits

Process Summary

- Uses inexpensive, industrially available material (potassium and ammonium salts)
- No chemical degradation
- Has the potential for easy permitting in many localities
- Uses known process engineering
- Accelerated development possible

Demonstrated Benefits (by testing and/or modeling)

- Enhanced CO$_2$ capture efficiency
- High CO$_2$-loading capacity
- High-pressure release of CO$_2$ (10-20 bar)
- Reduced reboiler energy consumption (~ 2 MJ/kg-CO$_2$)
- Reduced auxiliary electricity loads
Recently Completed Project (FE0012959)
Large Bench-scale Mixed-salt System at SRI
0.25 t-CO₂/day capacity - operational since January 2016

Absorbers

Regenerator pictures from different angles

System built under FE0012959

Continuous smooth operation of the integrated system over 1.5 years of operation

A : Rich solution inlet locations.
B : Discharge location for high NH₃/K ratio solution
C : Discharge location for low NH₃/K ratio solution
D : Heat exchangers (Cold rich ↔ Hot lean)
Data from Integrated System Testing in 2016

Excellent Performance

Observed 90% capture efficiency and regeneration with cyclic loading of ~0.7 mole of CO$_2$/mole of ammonia at 10 bar.

Alkalinity of rich and lean solutions circulating in the integrated system

Results from FE0012959

Absorber: 20-35°C
Regenerator stage 1: 140°C
Regenerator stage 2: 160°C
L/G = 2 to 6 (kg/kg)
Solvent composition: 5 to 8 m
## Techno-Economic Data

### Comparison Between Mixed-salt Technology and DOE Baseline Case

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<tr>
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<tbody>
<tr>
<td>Coal feed rate [kg/hr]</td>
<td>179193</td>
<td>224791</td>
<td>220576</td>
</tr>
<tr>
<td>CO2 removal</td>
<td>n/a</td>
<td>Cansolv</td>
<td>Mixed-Salt Technology</td>
</tr>
<tr>
<td>CO2 purification</td>
<td>n/a</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td>Sulfur removal</td>
<td>FGD</td>
<td>FGD</td>
<td>FGD</td>
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**Performance and Economic Summary**

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<tr>
<td>CO2 capture</td>
<td>n/a</td>
<td>90.0%</td>
<td>90.0%</td>
</tr>
<tr>
<td>CO2 purity</td>
<td>n/a</td>
<td>&gt;99%</td>
<td>&gt;99%</td>
</tr>
<tr>
<td>H2 recovery</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>HHV plant efficiency</td>
<td>40.7%</td>
<td>32.5%</td>
<td>32.7%</td>
</tr>
<tr>
<td>COE w/o T&amp;S [$/MWh]</td>
<td>82.3</td>
<td>133.2</td>
<td>117.5</td>
</tr>
<tr>
<td>COE w/ T&amp;S [$/MWh]</td>
<td>82.3</td>
<td>142.8</td>
<td>127.0</td>
</tr>
<tr>
<td>Increase in COE comparing the case w/o capture with the case w/ CC&amp;T&amp;S</td>
<td>0%</td>
<td>88%</td>
<td>67%</td>
</tr>
</tbody>
</table>

Reference: NETL, «Cost and Performance Baseline for Fossil Energy Plants Volume 1a: Bituminous Coal (PC) and Natural Gas to Electricity Revision 3,» pp. 137-166; 2015

### Process Modeling: OLI, IHI, and POLIMI

- Cyclic loading: 0.18 to 0.58; Reboiler duty: 2.0 (OLI); 2.3 MJ/kg-CO2 (POLIMI); 2.1 to 2.3 MJ/kg-CO2 (IHI-measured)
- Ammonia emission < 10 ppm
- Cost of CO₂ Capture at <$40/t CO₂; Cost Of CO₂ avoided (excluding T&S) ~ $51/t CO₂
- Cost analysis was performed by POLIMI
Current Project  (FE0031588)
**Project Budget, Team, and Work Organization**

DE-FE0031588
Two Budget Periods (BP1 and BP2)
BP1: 7/12/2018 to 10/31/2018
BP1 DOE Funding: $566,135
TCM: In-kind cost-share

Project Manager: Mr. Andrew Jones, NETL
Prime Contractor: SRI International
Project Team: US and International Partners

**Work Organization**

- SRI International
  - Technology provider
- Technology Center Mongstad (TCM), Norway
  - Host site and cost-share partner
- OLI Systems, USA
  - Process modeling (energy and mass balance)
- Aqueous Systems Aps, Denmark
  - Thermodynamic modeling
- POLIMI, Italy
  - Techno-economic analysis
BP1 Work Update

- Workshop at TCM on June 28, 29: Discussions on the program details, TCM requirements, TCM-CAP system P&IDs and modification requirements, and current status of the TCM-CAP system.
- TCM-CAP system inspection meeting at TCM (August 28, 29): Project progress evaluation and information exchange.

### Task Overview

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<td>DOE Project review and Decision to move to BP2</td>
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<td>BP2 Mixed-Salt Testing at TCM</td>
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![Gantt Chart](chart.png)
BP2 Tasks

Task 1. Project Management

Task 2. CAP System Re-commissioning and Modification

Task 3. Dynamic Testing of MSP

Task 4. Steady-state Testing of MSP

Task 5. Process Economics, Technology Gap Analysis, and Technology Maturation Plan

Task 6. Environmental, Health & Safety Assessment

Task 7. Pilot Shutdown and Project Closure

The planned system inspection and modification period is about 12 - 18 months and the planned technology testing period is about 9 -12 months. BP2 Tasks will be finalized after completing the BP1 work.
Technology Maturation: MSP Developments

Small bench to mini pilot to large pilot

Ammonia technology development started at SRI in 2004

Chilled Ammonia Process (CAP)

- 2004
- 2006
- 2008-2016

GE Facility, Vaxjo

Mixed-salt Process (MSP)

- 2012
- 2014
- 2016
- 2013-2017

IHI Corp., Japan

· MSP Testing in TCM-CAP System (DOE-FE0031588)
· CAP Validation at TCM
· Transformational Technology Development
· Next Generation MSP

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Technology Maturation: Testing MSP at TCM and Beyond

- Prof Of Concept
- TD model and kinetic model
- Testing/Data collection
- Process reliability
- Model validation
- TEA
- Water management
- TEA validation
- Technology gap analysis for large scale applications
- Technology Readiness Analysis
- Pilot scale testing in TCM-CAP system
- Large bench/mini-pilot scale testing
- Lab and small bench scale testing

*SRI has the patent coverage for MSP in US, Japan and Europe*

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DOE-FE003158

IHI Funded

DOE Funded

Commercial Opportunities
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Host Site

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Other Collaborators and Contributors

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Thank You

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