Mixed-Salt Process (MSP) for CO_2 Capture in NGCC Systems at ≥95% Capture:

Highly Efficient Regeneration Module for Carbon Capture Systems in Natural Gas Combined Cycle

Net-zero Flexible Power: High Capture Rate Project Review Meeting

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Presented by Elisabeth Perea, SRI

June 6, 2024 11:15-11:35 AM

DOE Contract # FE0032135

Outline

- MSP Background
- Project Objectives
- Technology Approach for ≥95% Capture
- Impacts of Operating at High Capture Rate
- Challenges and R&D Needs to Maintain High Capture Rate

Current SRI Carbon Capture Project Portfolio

Funding: 80% DOE, 20% Cost-share (~10% Cash, ~10% In-kind)

PBI-membrane for Hydrogen recovery

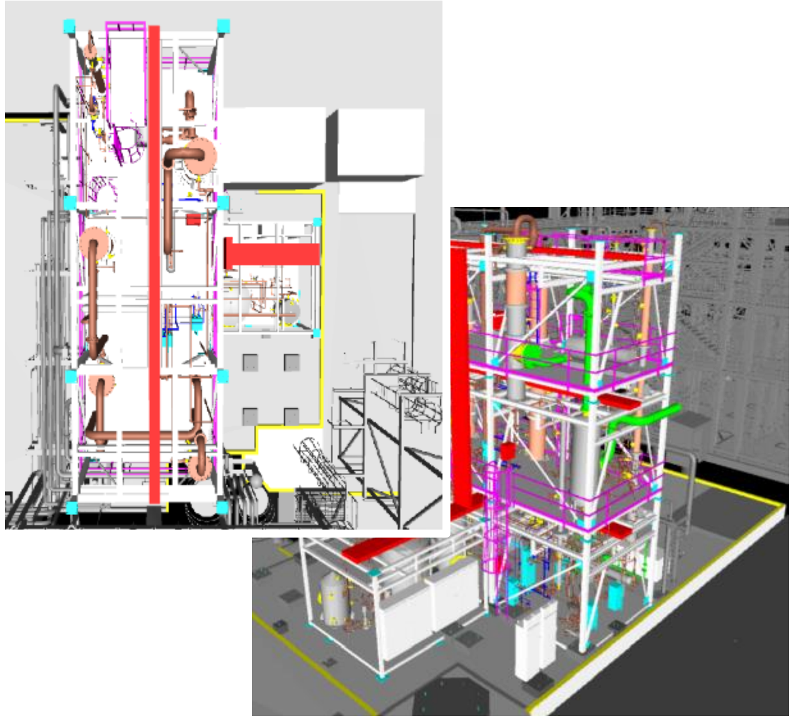
Development and Testing of a High-Temperature PBI Hollow-Fiber Membrane Technology for Pre-Combustion CO_2 Capture. DOE-NETL: DE-FE0031633
Team - PBI Performance Products, and Enerfex

Mini-pilot: (MSP Application for NG)

Highly Efficient Regeneration Module for Carbon Capture Systems in Natural Gas Combined Cycle Applications. DOE-NETL: DE-FE0032135
Team- BH, Trimeric, and OLI Systems

Mini-pilot: Advanced Solvent

Mixed-Salt Based Transformational Solvent Technology for CO_2 Capture. DOE-NETL: DE-FE0031597
Team - OLI Systems, Technical University of Denmark, SINTEF, and BH



Engineering Demonstration of MSP at 0.5 MWe scale

Engineering-Scale Demonstration of the Mixed-Salt Process (MSP) for CO_2 Capture. DOE-NETL: DE-FE0031588
Team - BH, NCCC, Trimeric, OLI Systems, Epic Systems

CO_2 Utilization: Microbial processes for CO_2 to food

pbi PERFORMANCE PRODUCTS · EPIC · OLI systems, Inc. · Trimeric Corporation · NC National Carbon Capture Center · Illinois · Baker Hughes · NETL National Energy Technology Laboratory

Current MSP Project Objectives

- **Demonstrate the Mixed-salt process (MSP) for capturing CO_2 from dilute sources such as natural gas (NG) power plants at 95% or better efficiency.**
- **Project scope includes:**
  - Design and fabrication of a highly efficient regeneration module capable of providing a deep-lean absorption solution.
  - Integration of the advanced stripper with the existing absorption modules of the large-bench scale MSP system.
  - Testing of the integrated system at SRI site using a simulated flue gas stream equivalent to about 10 kWe.
  - Data collection for detailed techno-economic analysis (TEA)

Mixed-Salt Process (MSP)

Process Summary

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

Demonstrated Benefits (by testing and modeling)

- Enhanced CO_2 capture efficiency
- High CO_2-loading capacity
- High-pressure release of CO_2 (10-12 bar)
- Reduced energy consumption (For 90% capture, 1.9-2.2 MJ/kg-CO_2 for PC-based applications, 2.9 MJ/kg-CO_2 for NG-based applications)

Expected Additional Benefits

- Capture from low-concentration CO_2 sources
- > 95% capture possible
- Removes common acid pollutants and particulates

K_2CO_3–NH_3–CO_2–H_2O system

$CO_2(g) \leftrightarrow CO_2(aq)$

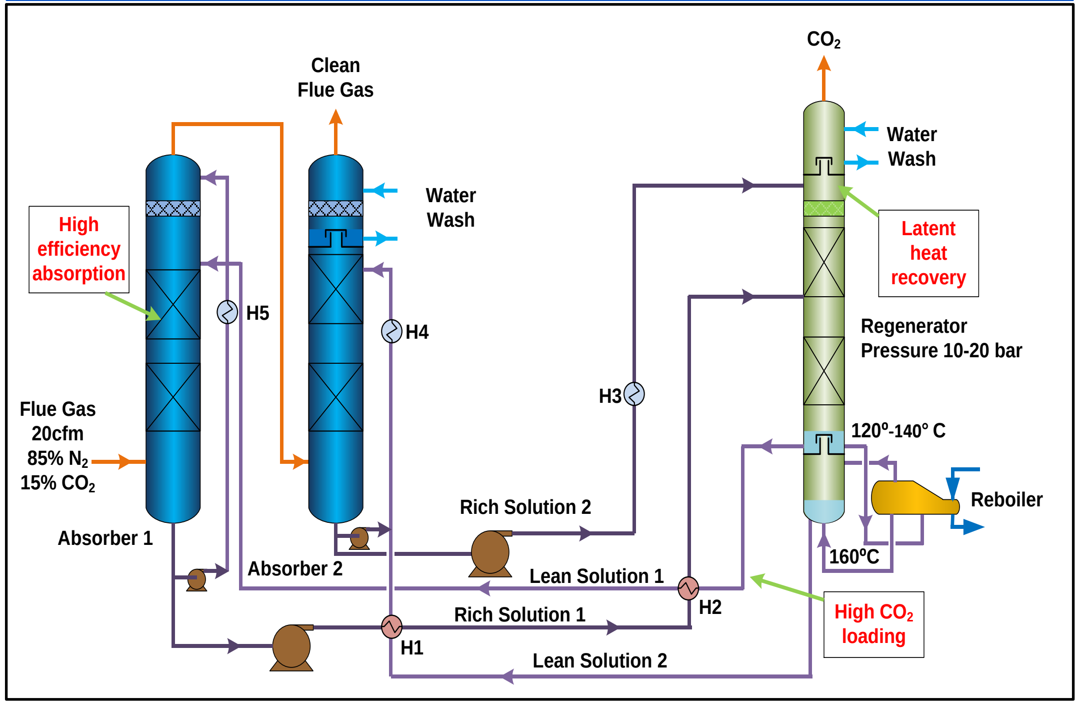
$NH_3(aq) + CO_2(aq) + H_2O(liq) \leftrightarrow (NH_4)HCO_3(aq)$

$(NH_4)_2CO_3 + CO_2(aq) + H_2O\ (liq) \leftrightarrow 2(NH_4)HCO_3(aq)$

$2NH_3(aq) + CO_2(aq) \leftrightarrow (NH_4)NH_2CO_2$

$(NH_4)NH_2CO_2(aq) + CO_2(aq) + 2\ H_2O(liq) \leftrightarrow 2(NH_4)HCO_3(aq)$

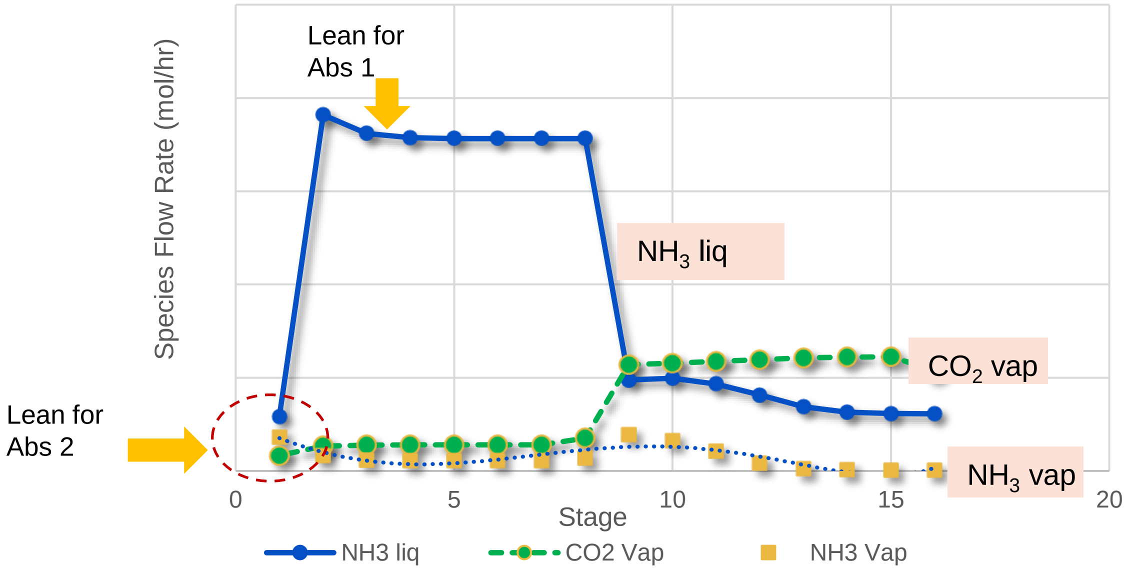
$K_2CO_3(aq) + CO_2(aq) + H_2O(liq) + Catalyst \leftrightarrow 2KHCO_3(aq)$



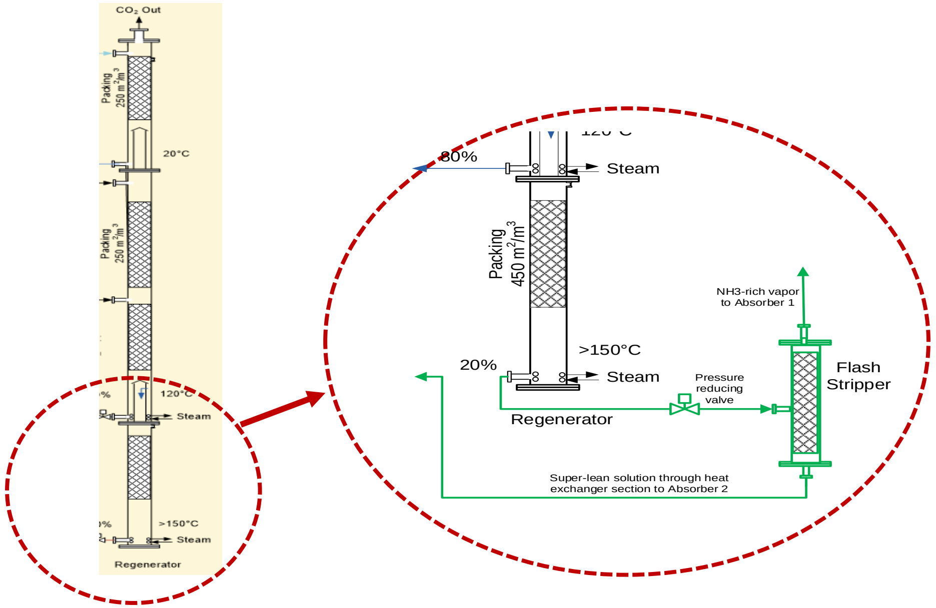
Simplified Process Flow Diagram

Approach for Generating Lean Solutions for high Efficiency CO_2 Capture in NG Flue Gas

Regenerator vapor and liquid composition of selected species



Regenerator modification to include the flash-stripper



- In the modified system, partially ammonia-lean lean solvent is extracted from the bottom of the regenerator and sent through the flash-stripper to recover more ammonia for efficient absorber 1 operation.
- Potassium-rich lean solvent is directed to absorber 2.

Current Status

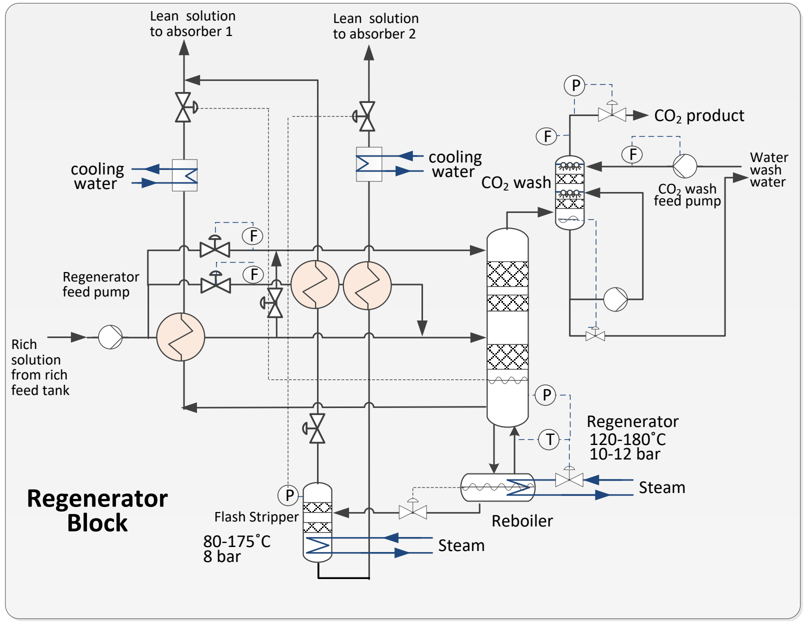
- We have completed parametric and steady state data collection and steam use measurements for operation at a high capture rate in the large bench system at SRI (pictured below)
- OLI Systems optimized the flowsheet model to generate a heat and mass balance (H&MB) for comparison to DOE case 31B Rev. 4.
- Trimeric is currently finalizing the techno-economic analysis (TEA)

Analytical and Control Systems

Absorbers

Regenerator

Regenerator block of the SRI large bench scale system with new flash stripper



Modeling the flash stripper performance to determine optimal operating conditions

Series 1: Pressure variation at fixed NH_3 evaporation)

Case	10-2	10-4	10-6	10-8	10-10	10-11.5
*Column Calculation Method	Equil	Equil	Equil	Equil	Equil	Equil
Regenerator Duty, MJ/KgCO2	1.96	1.96	1.95	1.95	1.95	1.95
NH3 Stripper Duty, MJ/KgCO2	1.02	1.02	1.01	1.01	1.01	1.01
Flash Stripper Duty, MJ/KgCO2	0.25	0.34	0.40	0.43	0.31	0.22
Total Duty, MJ/KgCO2	3.23	3.31	3.36	3.39	3.27	3.18
*Flash Stripper Pressure, atm	2	4	6	8	10	11.5
Flash Stripper Bottom T, C	96	114	126	136	142	145
*Flash Stripper Gas NH3, % of Feed	10	10	10	10	10	10

Series 2: Pressure variation at fixed temperature

Case	140-4	140-6	140-8	140-10	140-11.5
*Column Calculation Method	Equil	Equil	Equil	Equil	Equil
Regenerator Duty, MJ/KgCO2	1.97	1.96	1.95	1.95	1.95
NH3 Stripper Duty, MJ/KgCO2	0.75	0.89	0.99	1.02	1.03
Flash Stripper Duty, MJ/KgCO2	1.41	0.90	0.51	0.30	0.20
Total Duty, MJ/KgCO2	4.13	3.75	3.44	3.27	3.18
*Flash Stripper Pressure, atm	4	6	8	10	11.5
*Flash Stripper Bottom T, C	140	140	140	140	140
Flash Stripper Gas NH3, % of Feed	89	48	16	8	4

Series 3: NH_3 evaporation variation at fixed pressure

Case	10	19	29	34	39	41	43	48	58
*Column Calculation Method	Equil	Equil	Equil	Equil	Equil	Equil	Equil	Equil	Equil
Regenerator Duty, MJ/KgCO2	1.95	1.95	1.95	1.956	1.95	1.95	1.95	1.96	1.96
NH3 Stripper Duty, MJ/KgCO2	1.01	0.98	0.95	0.93	0.92	0.91	0.91	0.89	0.87
Flash Stripper Duty, MJ/KgCO2	0.22	0.22	0.21	0.21	0.22	0.22	0.23	0.25	0.30
Total Duty, MJ/KgCO2	3.18	3.15	3.11	3.096	3.089	3.088	3.090	3.10	3.13
*Flash Stripper Pressure, atm	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5
Flash Stripper Bottom T, C	145	151	157	160	162	163	164	166	170
*Flash Stripper Gas NH3, % of Feed	10	19	29	34	39	41	43	48	58

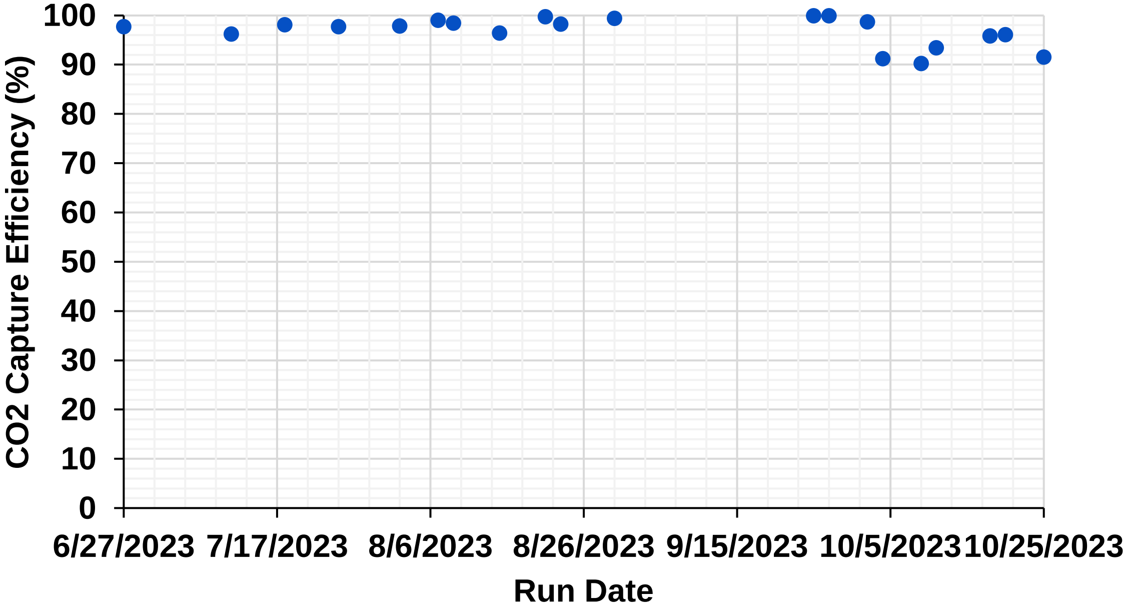
Varied the flash stripper pressure and the % of NH3 vaporized from the flash stripper feed stream within the process model to observe the effect on the total system reboiler duty

Parametric Testing at Large Bench Scale

Key Test Parameters

- Regenerator and Flash stripper T,P
- Flash stripper on/off
- Liquid recycle rate (L/G: 2.5 to 8 range)
- Gas flow rate (300 to 600 LPM)

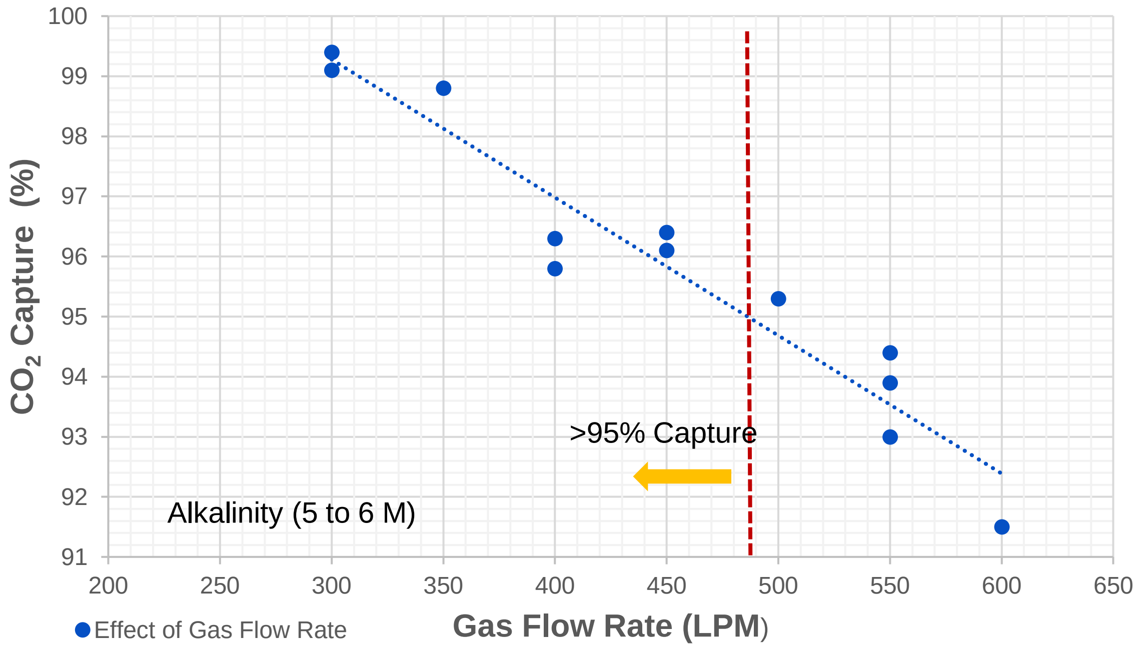
95% or greater CO_2 capture rate achieved with and without a flash stripper

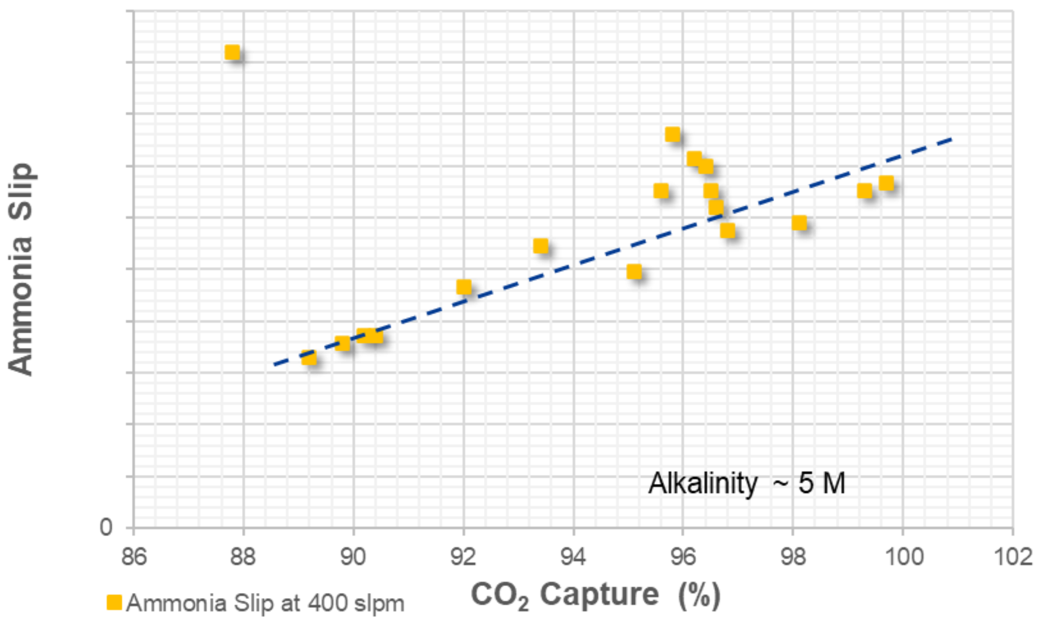


Run #	Total gas flow rate (LPM)	Regenerator P (bar)	Regenerator T (°C)	Flash stripper (On/Off)	Flash T (°C)	Flash P (bar)	CO_2 capture % ABS 1 + ABS 2
4	400	7.8	125 to 140	Off	NA	NA	89.8
6				On	113	3.2	95.8
8				Off	NA	NA	95.6
9				On	105	2.1	96.2
10		8.9		Off	NA	NA	96.8
11				On	114	3.3	98.1
14		8.2		Off	NA	NA	95.1
15		8.9		On	94	1.6	96.6
22		8		Off	NA	NA	96.5
23		7.6		On	95	12	96.4
25		7.3		Off	NA	NA	99.3
27		7		On	101	2	99.7
30	300	8		Off	NA	NA	99.1
31		6.9		On	92	1.8	99.4
38		9.9		Off	NA	NA	97.3
40		9.7		On	102	2.4	98.4
41	350	9.9			97	2	95.2
42		10.1			114	3.3	91.2
43	400	9.8			96	2.8	90.2
44		9.7			126	4.6	89.2
45		9.7			116	3	87.8
46		9.8			103	3.2	90.4
47		9.7			79	1.8	92
48		9.7		Off	NA	NA	93.4
49		9.8		On	102	2.6	94.8
50		9.7			111	3.7	96.3
51*		9.7			109	3.6	95.8
52	450	9.9			103	2.7	96.1
53		9.8			103	2.7	96.4
54	500	9.8			105	2.9	95.3
55	550	10.7			102	3	94.4
56		10			102	3	93.9

CO_2 Capture Rate, Gas Flow Rate and Ammonia Slip

- Ammonia slip = ammonia exiting the top of Absorber 2. This ammonia is re-absorbed in the water wash and then recovered in an ammonia stripper column and recycled back to the absorbers.
- A higher ammonia slip results in a higher reboiler duty for the ammonia stripper.



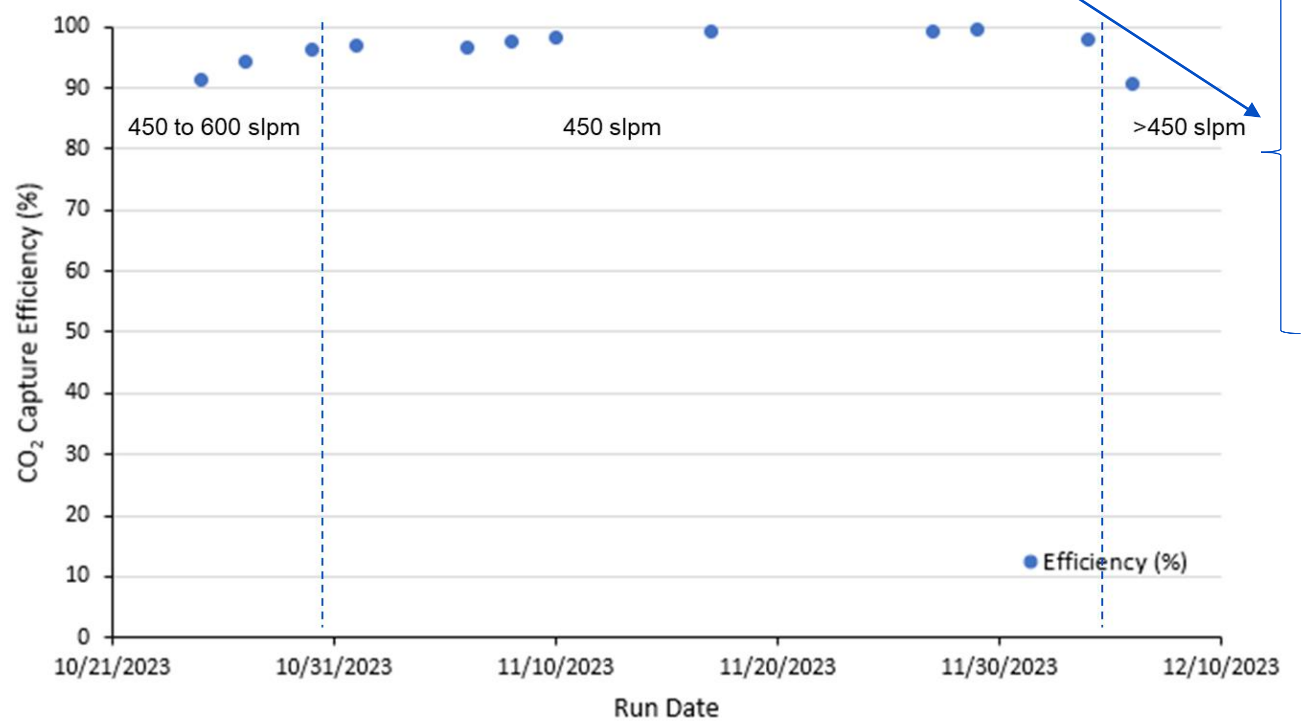


- 95% - 99% CO_2 capture (for NG flue gas simulating feed streams) was easily achieved during the initial testing of the integrated system.
- Ammonia slip from Absorber 2 at 400 slpm flow rate is below 14,000 ppm for 95% CO_2 capture for 5 M (> 6 molal) alkalinity MSP solutions
- Ammonia slip from Absorber 2 at 400 slpm flow rate is around 20,000 ppm for 95-96% CO_2 capture for 6 M (>7 molal) alkalinity MSP solutions
- We selected 450 slpm for the first series of steady state testing

Steady State Operation at >95% Capture

- Flash stripper operating for these runs
- Cumulative run time to date: 280 hrs.
- Test runs 68 to 75: 450 LPM and at L/G ratio of 3.5 for steady-state testing.

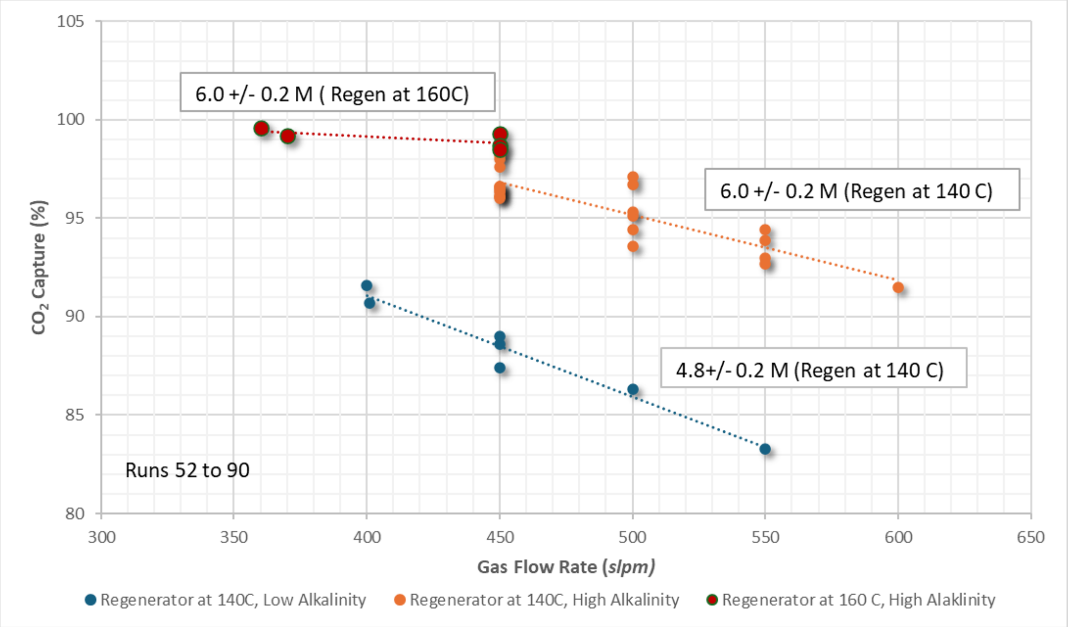
95% or greater CO_2 capture rate achieved with flash stripper for ~200/280 hours



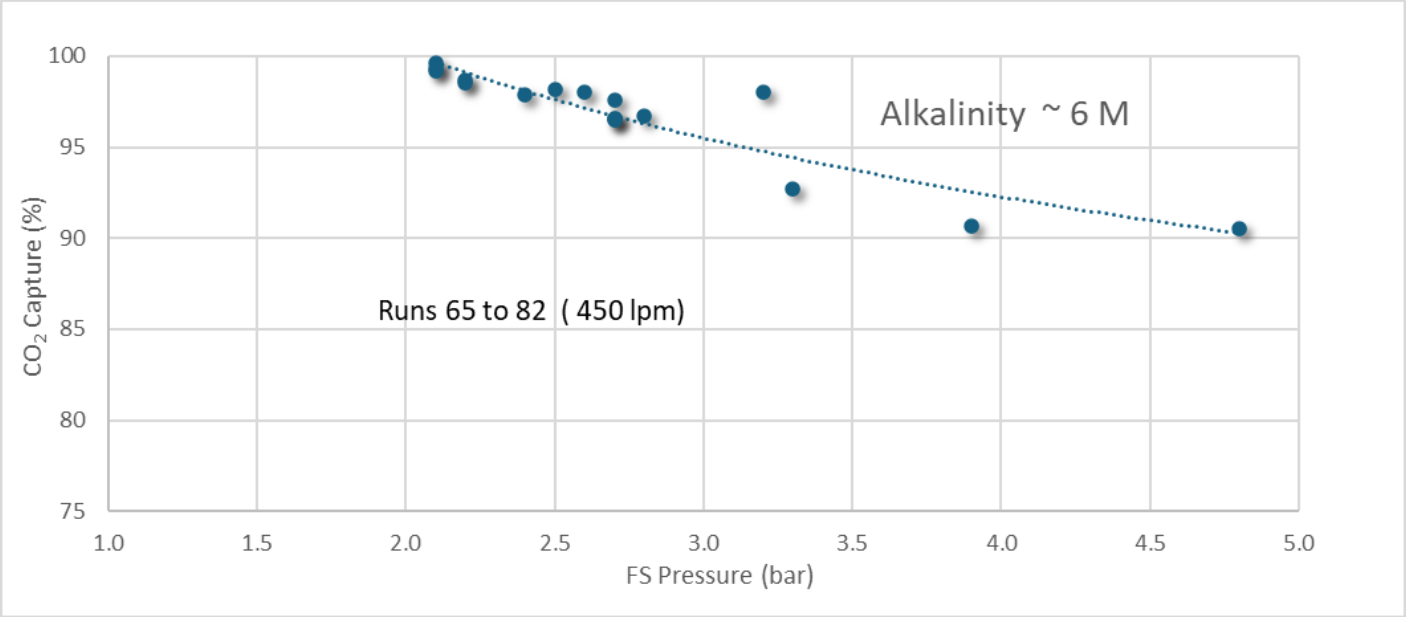
Run #	Gas Flow rate (LPM)	L/G	Regenerator conditions		Flash stripper conditions		ABS 1 + ABS 2
			P (bar)	Bottom T(°C)	T (°C)	P (bar)	
58	600	2.5			102	2.5	91.5
59					104	2.7	95.1
60	500	3.2			113	3.9	94.4
61					91	1.7	93.6
62					102	2.6	96
63	450	3.5			114	4.0	96.1
64					93	1.8	96.3
65	550	3		125-140	102	3.3	92.7
66	500	2.5			102	2.8	96.7
67		3.2			92	1.8	97.1
68					102	2.7	96.6
69					102	2.7	96.6
70			9.7		101	2.7	96.5
71					103	2.7	97.6
72	450	3.5			101	2.5	98.2
73					103	2.6	98
74					102	2.1	99.3
75					102	2.2	98.7
76*	370	4.2		140-160	103	2.1	99.2
77	450	3			103	2.2	98.5
78**	360	4			102	2.1	99.6
79		4.5			102	3.2	98
80	450			130-140	99	2.4	97.9
81		3			102	3.9	90.7
82					101	4.8	90.5

**CO2 feed concentration ~20%* ***CO2 feed concentration ~ 18%*

Achievement of >95% Capture at Large Bench Scale



The effect of gas flow rate and regenerator temperature on the capture rate. FS pressure range (2 to 3 bar at 103 ℃)



A plot illustrating the effect of FS pressure on the capture rate at the FS operating temperature of 103°C.

- 95% - 97% CO_2 capture (for NG flue gas simulating feed streams) was easily achieved by regenerating at temperatures between 130 to 140 ℃.
- >98% can be achieved by using high alkalinity solution or by increasing the regeneration temperature to 160℃.
- Identified the FS operation conditions to achieve >95%:
  - 2 to 3 bar at 103 ℃ /5-6 bar 120 ℃/ ~11 bar at 160 ℃ (40% ammonia evaporation)

Result of Flowsheet Modeling for the TEA

>95% capture rate from natural gas flue gas is achievable with the Mixed-Salt Process with 3.14 MJ/kgCO_2 total reboiler duty.

Summary of conditions:

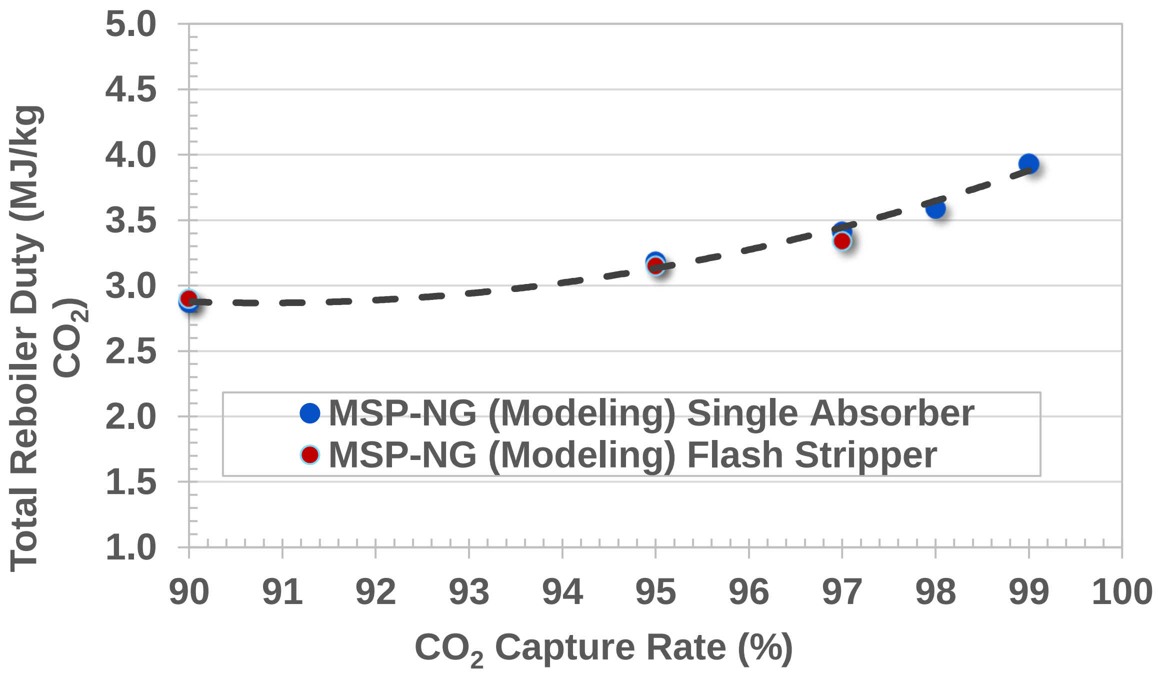
CO_2 Feed: 4%
CO_2 Capture: 95.4%
CO_2 Purity: 99.1%

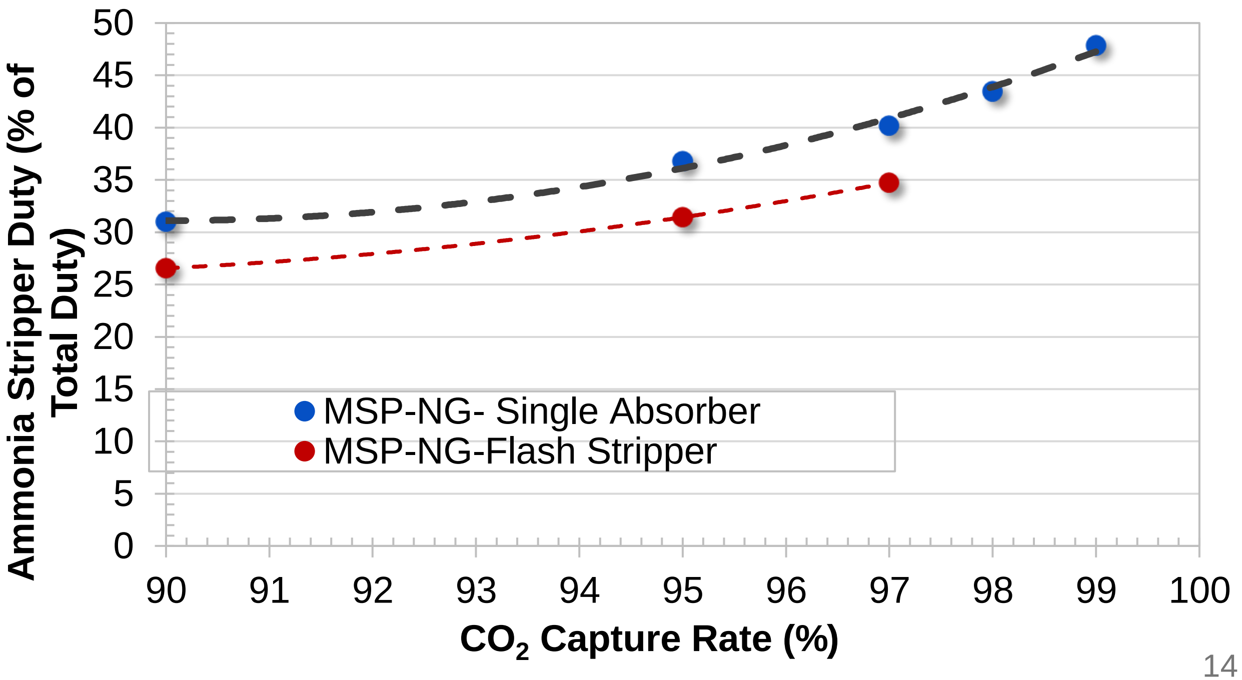
Flash-Stripper: 11.5 atm
Flash-stripper T: 160 ℃
Flash-Stripper NH3 recovery: 34%

Regenerator T: 133 ℃
Regenerator P: 12 atm
Total Reboiler Duty: 3.14 MJ/kg CO_2

(Energy) Cost Impact of Increased Capture Rate: Total Heat Duty vs. Capture Rate

MSP-NG-Flash Stripper: Case including the flash stripper to strip ammonia from the ammonia-rich lean stream, minimizing the ammonia stripper duty.
MSP-NG-Single Absorber: Case where there is no flash stripper and only one lean stream removed from the regenerator. This case has CAPEX benefits because only one absorber column is required.





Challenges/Benefits for High Capture Rate Operation

- Impacts of operation at higher capture rate are concentrated in the ammonia stripper.
  - Ammonia stripper reboiler duty increases with increased capture rate
  - Improvements to ammonia/water separation would be a major enabling breakthrough.
- However, the base MSP process (absorbers/regenerator) is robust and easily capable of operation at high capture rates.

Challenges/Benefits for Flexible Operation

- The response of plant operating parameters to dynamic scenarios would be necessary to fully characterize the MSP under flexible operating conditions
  - Cold and warm start-ups to assess the performance and ramp-up time of the MSP
  - Simple reboiler steam decoupling and reintroduction to assess the minimum capture rates achieved during turndown
- Promising intrinsic benefits of MSP:
  - High-pressure MSP regenerator is small and would heat up quickly
  - Solvent flow rates in the MSP can easily be adjusted and MSP has been demonstrated at a wide range of L/G ratios

Schedule for Completion

Task Name	Start	Finish
Task 6.0 – Final System Modeling and Techno-Economic Analysis (TEA)	Mon 10/2/23	Mon 9/30/24
Subtask 6.1 –Modeling and Test Data Comparison	Mon 10/2/23	Fri 5/31/24
Subtask 6.2 –Optimized CC Unit Integration with the Power Pant and TEA	Mon 10/2/23	Mon 9/30/24
TEA Preparation- on going (Trimeric)	Tue 2/6/24	Thu 6/6/24
TEA Information Review- ongoing (SRI)	Tue 2/6/24	Thu 6/13/24
TEA Review/Comments (DOE)	Fri 6/14/24	Fri 9/13/24
Final TEA Update (SRI and Trimeric)	Mon 9/16/24	Mon 9/30/24
Subtask 6.3 –Technology Maturation Plan (TMP)	Mon 7/1/24	Wed 7/31/24
Final Report	Mon 7/1/24	Mon 9/30/24

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Thank you!

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