Testing of RTI's Non-Aqueous Solvent CO_2 Capture Process at NCCC using the SSTU (DE-FE0026466)

Executive Summary

RTI International is developing a novel Non-Aqueous Solvent (RTI-NAS) based process for post-combustion CO_2 capture from coal-fired power plants. The process has the potential of substantially reducing the thermal energy requirement for the solvent regeneration compared to the NETL baseline Case 12. RTI has already shown the reduction of thermal energy using NAS in a Bench-scale Gas Absorption System (BsGAS) at RTI with simulated flue gas and a pilot-scale unit at SINTEF's Tiller facility in Trondheim, Norway with coal-derived flue gas. The objective of the current NAS testing at the National Carbon Capture Center (NCCC) is to investigate solvent degradation, corrosion, and emissions using the Slipstream Solvent Test Unit (SSTU) with long-term exposure to coal-derived flue gas from Alabama Power's Plant Gaston in Wilsonville, Alabama to reduce the scale-up risks for this technology. The test facilities at NCCC include the original Power System Development Facility (PSDF) which contains the gasification and pre-combustion CO_2 capture processes, and the Post-Combustion Carbon Capture Center (PC4) located beside the Alabama Power E.E. Gaston power plant. Gaston Unit 5 (an 880 MW supercritical pulverized coal unit) supplies the flue gas required for PC4 testing.

A series of tests were planned at the SSTU to evaluate operating conditions that may be effective in reducing the amine emissions and solvent losses from the CO_2 capture process. The RTI team prepared a test plan to address project objectives and to measure solvent degradation, and corrosion with long-term exposure of NAS to coal-fired flue gas for at least 400 hrs. Testing was conducted during May-August 2018, with 580 hours of time on stream with coal-derived flue gas from the power plant. In addition, SO_3 was injected into the flue gas at certain periods (39.4 hrs with 1-6 ppm) of testing to investigate the effect of aerosols on amine losses. The operating parameters of interest include higher CO_2-lean loading, flue gas velocity, reduced CO_2 rate (kg-CO_2/h) and capture efficiency (%), reducing the difference in the lean solvent and absorber bulge temperature, and the aerosols concentration. The emissions from the process were analyzed by collecting condensate and using selective sorbents from a slipstream of the water wash effluent. The aerosols exiting the system were also measured with ELPI+^{TM}.

Samples of the solvent were routinely taken at various points in the system during steady state operation to analyze the system operation and detect any changes in the solvent. Samples were analyzed for amine, water, and CO_2 content from both the absorber and desorber side of the system. In addition, the samples were analyzed for degradation species. Over the course of testing, excess water was added to the system multiple times from the wash section due to system operational issues. The water concentration was greater than 10 wt% for ~420 hours during the 580-hour test campaign, beyond the desired water

concentration range of 5 to 10 wt%. Due to the need to remove the excess amount of water from the system under non-standard conditions, there was a significant amount of solvent losses, about 150kg (15 % of the total weight of the active component), over the course of the test campaign. A few degradation species were identified from the solvent samples.

Corrosion coupons were inserted in the piping downstream of the absorber and reboiler that each included carbon steel and stainless steel as well as polypropylene at the absorber outlet. The coupons were removed from the system at the end of the testing and were analyzed for weight change and any surface defects.

The NCCC system was operated for 580 hours with flue gas with intermittent interruptions related to power plant outages, changes to the SSTU, and malfunctioning equipment on the SSTU which limited the number of test runs completed. This report outlines the results of test runs that were performed in the campaign, which are important tests to measure solvent degradation, corrosion, and amine emissions from RTI-NAS while operating on coal-derived flue gas at NCCC.

<u>Conclusions from the campaign:</u>

- Completed 580 hrs. of time on stream, more than the targeted 400 hrs. of testing with coal-fired flue gas and obtained baseline pilot scale testing hours in a conventional process arrangement.
- Solvent samples were taken periodically during the 580 hrs (3 samples per steady state operation; ~every 24 hrs; one from absorber, one from desorber and one from water wash) campaign to determine the CO_2 working capacities and solvent concentrations. The total number of samples collected were 69.
- Emission samples were collected to measure the size of the aerosols (4 sets of online measurements using Electric Low-Pressure Impactor (ELPI+^{TM}) instrument for 4 steady-state runs) and emission products (8 samples of condensates from flue gas & 40 sorbent tubes for emission products) by condensing flue gas in a chilled water bath. Gas and Liquid Chromatography Mass Spectrometry (GCMS and LCMS) and Integrated coupled plasma mass spectrometry (ICPMS) instruments were used at RTI to study the emission products from solvent degradation. Some of the emissions adsorbed on solid sorbents and condensate samples were sent to external labs such as SINTEF, Norway and Analytics Corporation, Virginia to analyze.
- The emissions products from the process were similar to those seen at SINTEF during small-pilot testing for the RTI-NAS solvent. That testing also showed that the use of intercooling reduces emissions by almost 10 times.

- RTI-NAS emitted more small/medium-sized aerosols from the wash tower outlet compared to MEA. This is likely due to the lower water content in the solvent preventing the aerosols from growing large enough to be removed in the water wash.
- Aerosol measurements were completed by Southern Research, Alabama using ELPI+^{TM} and that was also used in the past for the MEA baseline testing in the SSTU. Interpretations of the effect of size distributions and particle concentrations were done by both Southern Company and RTI.
- Solvent degradation products were measured and identified.
- Corrosion coupons made of different materials (polypropylene, carbon steel, and stainless steel) were placed in the system to determine the extent of corrosion caused by RTI-NAS. The RTI-NAS solvent exhibited extremely lower corrosion rates (~100 times lower) than aqueous solvents for carbon steel due to the low conductivity of the solvent. Similarly, the RTI-NAS solvent showed significantly lower metal concentrations compared to MEA baseline testing at SINTEF and NCCC.
- During the campaign, different concentrations of SO_3 (2.25 ppm for 16 hrs and 4 ppm for 6 hrs and 5 ppm for 2 hrs and 6 ppm for 7 hrs and ~9 hrs for calibrations) were injected to simulate the presence of aerosols at different concentrations. Condensates collected from the water wash off-gas were collected while varying the SO_3 level to evaluate the effect on amine emissions. SO_3 injections increased the emission of large-sized aerosols.
- CO_2 capture efficiency was varied from 60 to 90%. Absorber temperatures were maintained at the top from 40 to 63°C and at the bottom from 40 to 70°C. Solvent regeneration pressure was varied from 1 to 2 bar(g). Solvent lean loading was varied from 0.008 to 0.025 mol/mol. Solvent rich loading was varied from 0.14 to 0.25 mol/mol.

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1. Introduction

1.1. RTI's Non-Aqueous Solvent Technology

RTI is developing a CO_2 capture process based on novel, Non-Aqueous Solvents (RTI-NAS) under funding from the U.S. Department of Energy and industrial partners. RTI has been continually improving the process design and technology for full-scale power plant applications through research, development, and increasing scale demonstrations. Key technical advantages for RTI-NAS solvents are:

- CO_2 capture technology with substantially reduced energy consumption
- High net cycle CO_2 absorption capacity resulting in low solvent circulation flow
- Minimal changes to the conventional process to realize NAS-optimal performance
- Low corrosivity enabling the use of cheaper materials of construction

The development pathway for RTI-NAS technology is shown in Table A. The initial concept for RTI-NAS was developed using RTI internal funds, followed by several rounds of DOE funding (ARPA-E and NETL) where the technology progressed from solvent screening and lab-scale evaluation to bench scale evaluation using simulated flue gas at RTI and pilot scale testing at SINTEF's Tiller facility using coal-derived flue gas. The primary focus of the development work has been minimizing the solvent regeneration energy. With successful demonstration of the low regeneration energy at the small pilot scale, the current focus is toward further scale-up while controlling emissions. With recent project awards and additional DOE funding, future work will be focused on developing emissions control strategies for water-lean solvents and scale-up of NAS for pre-commercial demonstration at 12 MW scale at Technology Centre Mongstad (TCM) in Norway.

NCCC provided an opportunity for RTI to test its NAS solvent using actual coal-fired power plant flue gas. Our team believes it is important to gain as much exposure to coal flue gas as possible at small scale to reduce the deployment risk for the NAS technology and accelerate NAS technology development at lower cost. Test objectives of RTI's advanced RTI-NAS formulation at NCCC are to determine operating windows, solvent performance, water balance, degradation, corrosion, emissions, amine loss, and other operational issues.

Even though the NCCC SSTU setup is not optimized for RTI-NAS, it was a valuable opportunity for RTI to test its solvent against actual flue gas and gather data on solvent degradation, corrosion, and emissions. RTI-NAS performs optimally with the use of intercoolers to keep the absorber temperature low, increasing the working capacity of the solvent, resulting in lower liquid recirculation rates and lower reboiler duties. Since the SSTU does not have intercoolers, the RTI-NAS was not expected to perform optimally for solvent regeneration energy and this data has already been measured at SINTEF's Tiller plant with NAS-specific system modifications. Hence the focus of this test campaign was on studying solvent degradation, emissions, and corrosion during CO_2 capture using RTI-NAS solvent with actual coal-derived flue gas.

Table A. NAS technology pathway from lab scale to large demonstration through a series of projects

					
Lab-Scale & Evaluation (2010-2013)	**Large Bench-Scale System (RTI facility, 2014-2016)**	**Pilot Testing at Tiller Plant (Norway, 2015-2018)**	**Pilot Testing at SSTU (NCCC, 2018)**	**Emissions control (Tiller, 2018+)**	**Engineering-Scale Validation (TCM, Norway, 2018+)**
Solvent Screening	**Process modification**	**Process scalability**	**Degradation, emission & corrosion**	**Emission mitigation strategy**	**Engineering scale demonstration**
System size	**6 kW**	**60 kW**	**50 kW**	**60 kW**	**12 MW**

2. Description of NCCC-SSTU

The test facilities at NCCC include the original Power System Development Facility (PSDF) which contains the gasification and pre-combustion CO_2 capture processes, and the Post-Combustion Carbon Capture Center (PC4) located beside the Alabama Power E.E. Gaston power plant. Gaston Unit 5 (880 MW supercritical pulverized coal unit) supplies the flue gas required for PC4 testing. The flue gas prior to being discharged from the stack passes through Selective Catalytic Reduction (SCR) units for NO_x control, dry electrostatic precipitators for particulate control, and wet flue gas desulfurization (FGD) for SO_2 control to meet the emission control limits. The schematic arrangement of PC4 test units is given in Figure 1. Flue gas for the test equipment is derived from a slipstream from the FGD exit duct at 130°F. After the testing units, the spent flue gas is returned to the inlet of the FGD unit before being discharged into the stack to remove any contaminants gathered such as dust or solvent vapor from the processed flue gas. An excess amount of flue gas, about 35,000 lb/hr (3.5 MWe), is extracted from the power plant to maintain flue gas temperature and to avoid the condensation in the delivery header. 17,000 lb/hr flue gas (1.7 MWe) is fed into pre-scrubber 1 and 12,000 lb/hr flue gas (1.2 MWe) is fed into pre-scrubber 2. From pre-scrubber 1, 4000 lb/hr of flue gas goes to the Bench Scale Test Bays (B1-B5) and 5500 lb/hr is diverted into Pilot Bay 1 & 2 through a cooler. 10,000 lb/hr of desulfurized flue gas is used by two large pilot bays with 1 MWe for solvent and membrane pilot plants. The Pilot Solvent Test Unit (PSTU) receives 5000 lb/hr of flue gas (0.5 MWe) from the cooler. The Slipstream Solvent Test Unit (SSTU) gets 500 lb/hr of flue gas (0.05 MWe). Flue gas supplied to PC4 has compositions and conditions as shown in Table B (Topical Report for DE-FE0022596, 2017).

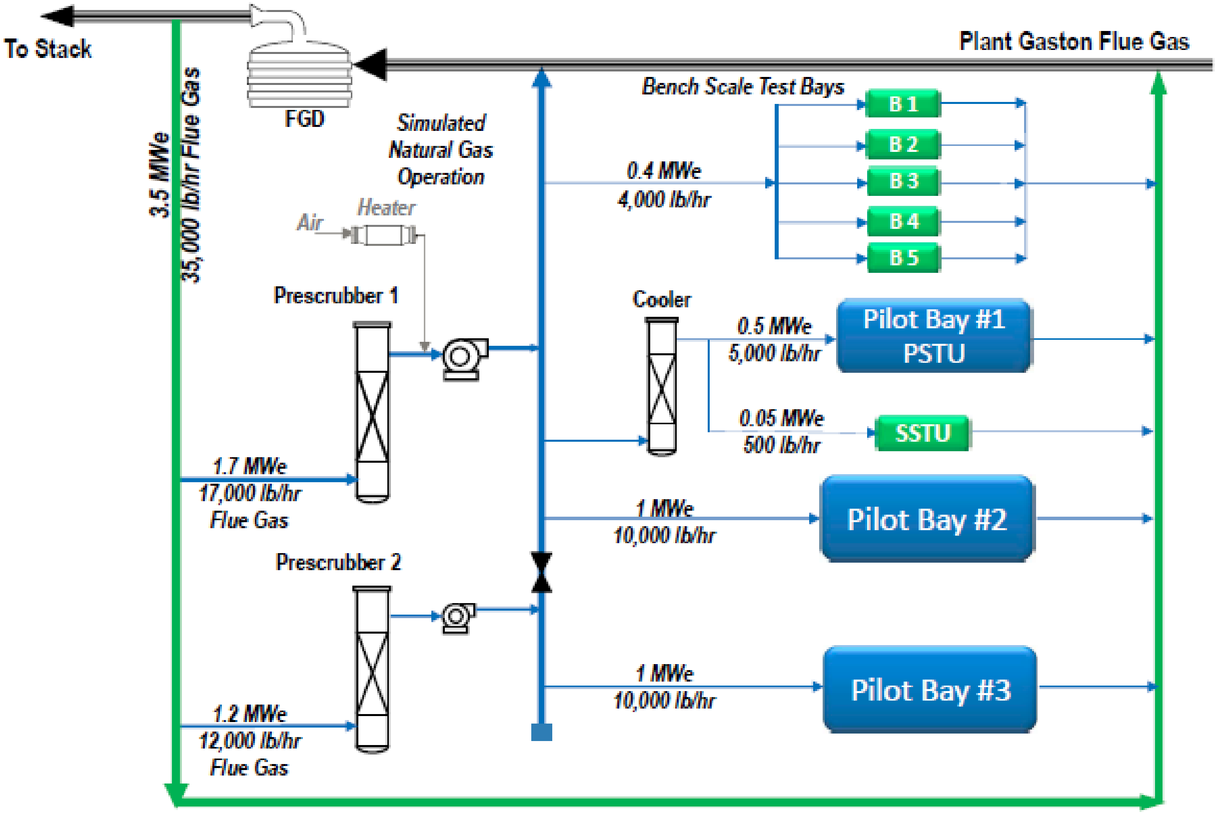

Figure 1. Flue Gas Slipstream Arrangement for PC4

Table B. PC4 flue gas compositions and conditions

Component	Unit	Design	Minimum	Maximum	Average
CO_2	vol%	12.14	12	16	14
O_2	vol%	5.2	3	6	4.5
N_2+Ar	vol%	69.36	65	72	68.5
H_2O	vol%	13.3	7	19	13
SO_2	ppmv	1	0,1	5	2.5
NO_x	ppmv	80	-	-	-
Temperature	°C	71	63	71	68
Pressure	mbarg	25.4	-25.4	76	50.8

Figure 2 shows a view of the SSTU in the NCCC facility. The schematic diagram of the SSTU is given in Figure 3. The SSTU provides a fully integrated system for comprehensive solvent characterization at the bench-scale for early stages of development and solvents that are only available in smaller amounts (~600 kg). In late 2015, monoethanolamine (MEA) baseline testing was done in the SSTU for future comparisons of solvent based technologies and used in this report for comparison. The flue gas from the PSTU cooler outlet is fed into the absorber through a non-operating pre-scrubber (C100) and a blower (BL101). It was found in the baseline test that the CO_2 recovery rate improved dramatically by the addition of the blower (BL101) upstream of the absorber (C200). After the blower, the treated gas is sent to the wash tower (C500) to control the amine emissions. Lean solvent (1-5 gpm) is fed at the top of the absorber and flows through 2 packing sections in the absorber and captures 70-90% CO_2 from flue gas. CO_2-rich solvent is collected at the bottom of the absorber in a tank (TK200) and fed to the regenerator (C300) by a pump (PU200) through a rich-lean heat exchanger (R/L HX301) to extract the heat from the hot lean solvent coming from the regenerator. The heated solvent flashes CO_2 into a flash tank (TK302) and the remaining CO_2-rich solvent is fed into the top of the stripper. Steam supplied at the bottom of the regenerator through a reboiler removes the CO_2 from the solvent and the lean solvent collected at the bottom of the regenerator is fed back to the lean tank (TK301) through a lean pump (PU300) and the rich-lean heat exchanger. A lean cooler (HX200) is used to control the solvent temperature fed into the absorber. The dimensions and types of packing used in the prescrubber, absorber, stripper, and wash tower are given in Table C.

Figure 2. View of SSTU in NCCC

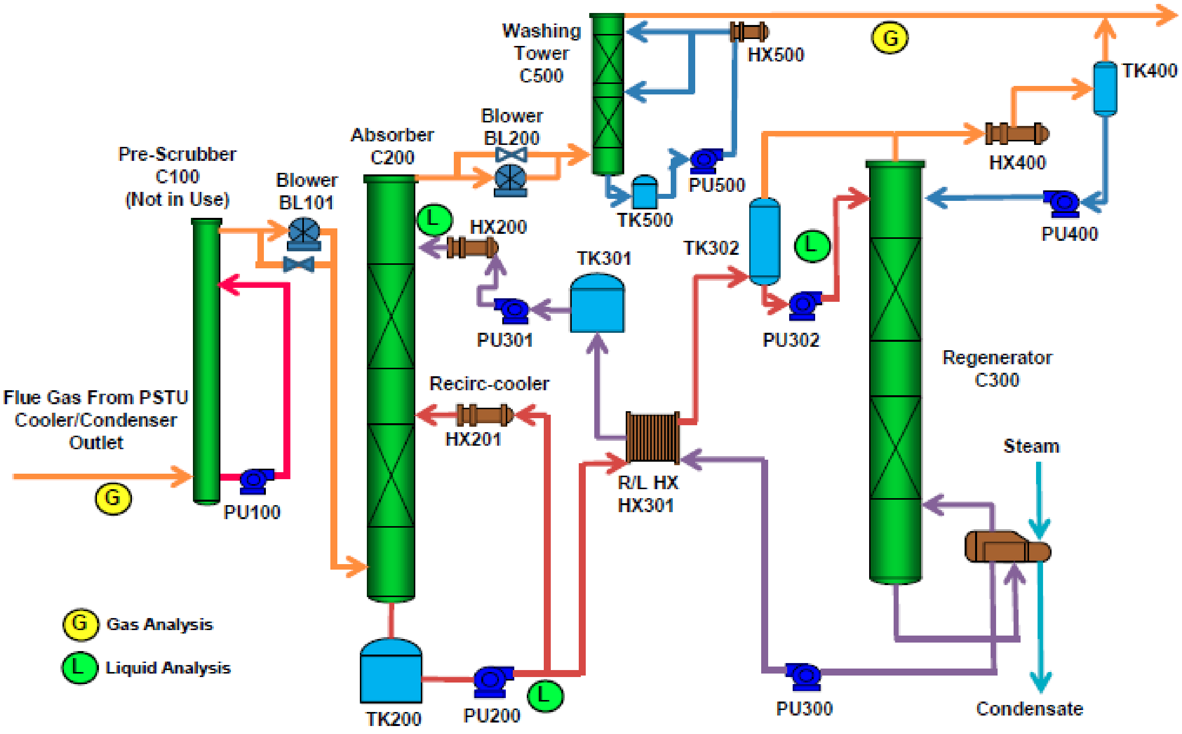

Figure 3. Schematic of the SSTU

Table C. Dimensions and packing used in SSTU Columns

Column	Height (ft)	Internal Diameter (in)	Number of Beds	Packing Height (in)		Packing Type
				Lower	Upper	
Pre-Scrubber	46	30	1			Random
Absorber	20	10.42	2	43.625	98.125	Flexipac 1YHC
Wash Tower	34.8	12.39	2	128.75	128.75	Flexipac 1YHC
Regenerator	15	6.065	2	32.688	109.125	Flexipac 1YHC

Screen shots of the distributed control system (DCS) showing typical control of the flue gas system (SSTU Flue Gas_CO_2 Overview), regenerator, solvent system, the overall system (SSTU Amine Overview) are given in Figure 4-Figure 7 with typical control parameters. Operators in the control room have access to control the process conditions and trouble shoot problems raised during the operation.

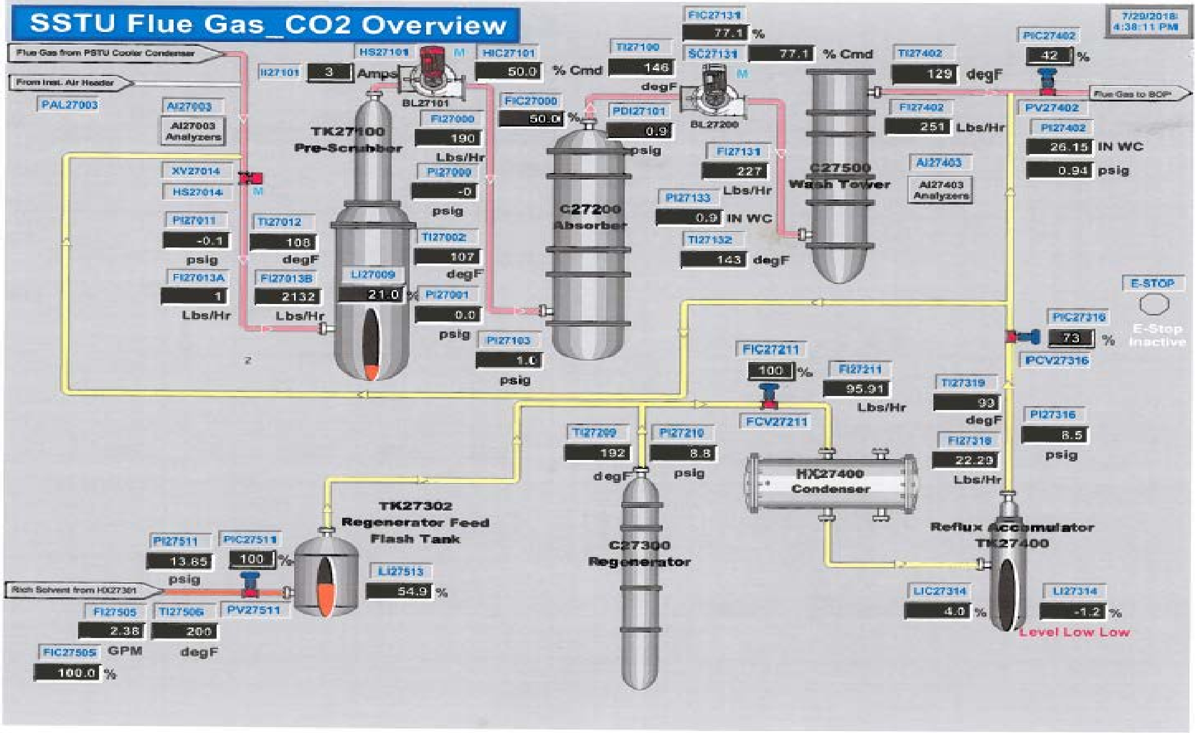

Figure 4. SSTU overview process control display

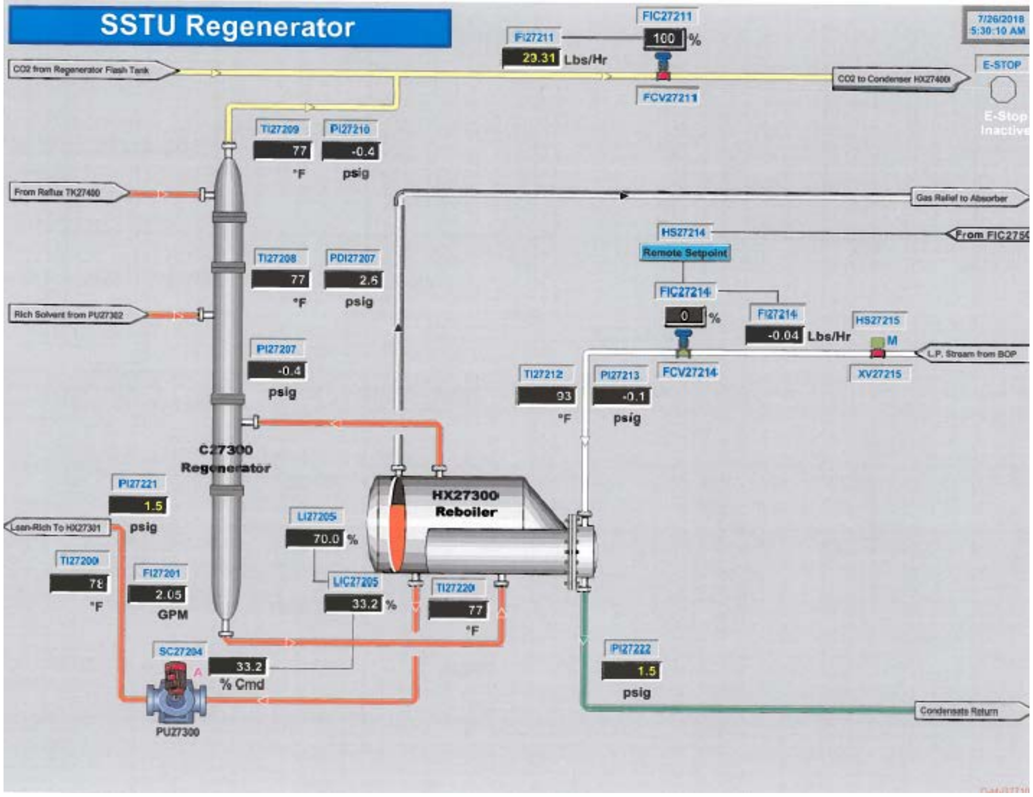

Figure 5. Regenerator process control display

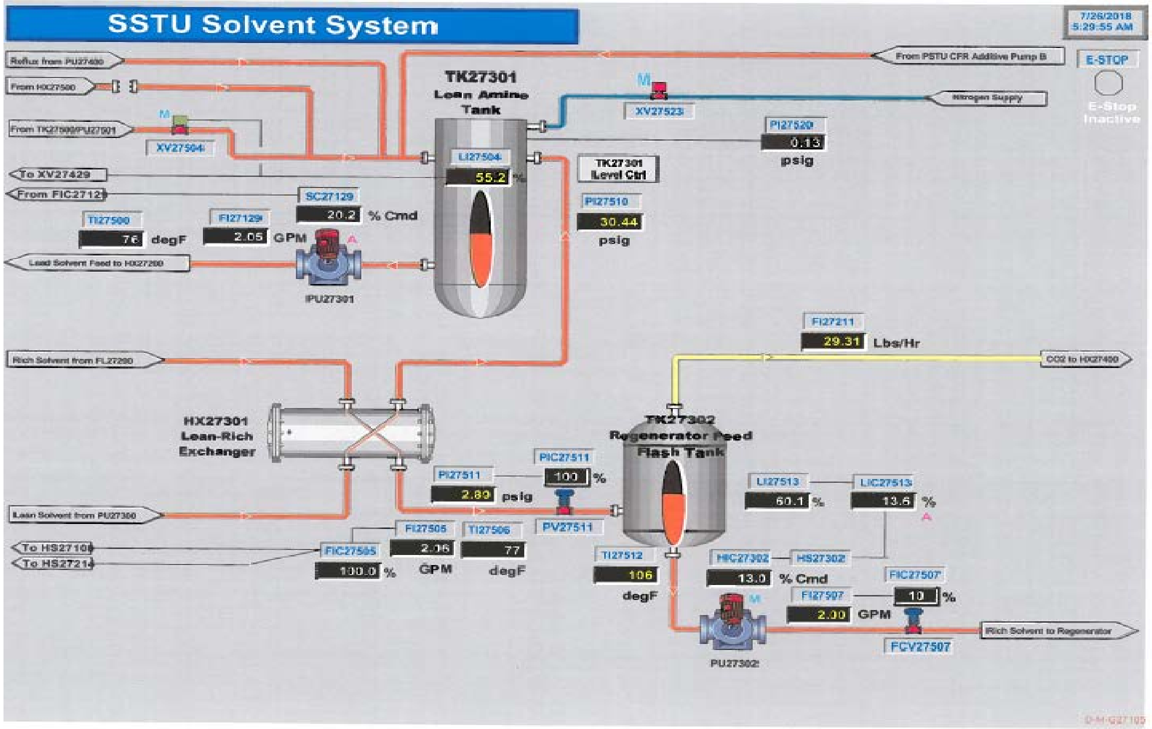

Figure 6. Solvent System process control display

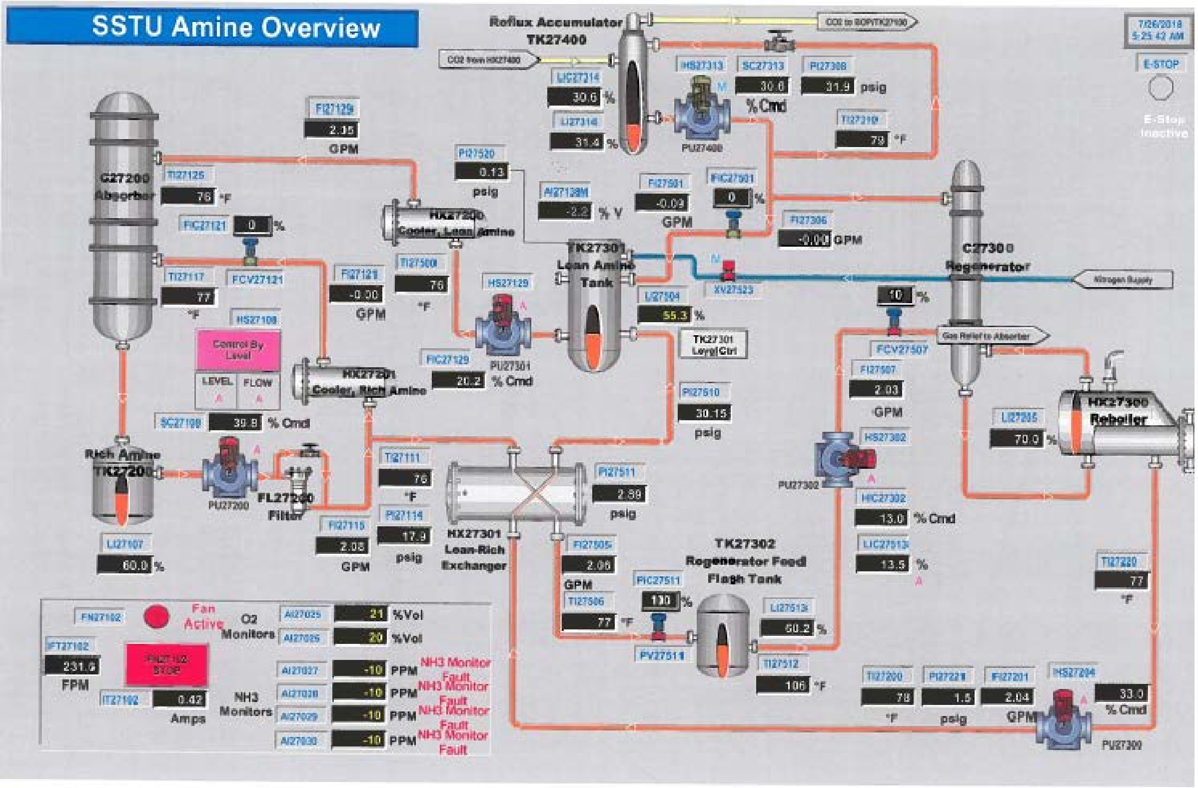

Figure 7. SSTU system overview process control display

2.1. Test Objectives

The objective for testing the RTI-NAS at NCCC using the SSTU is to gain as much exposure to coal-derived flue gas as possible at small scale to reduce the deployment risk for the RTI-NAS technology and accelerate RTI-NAS technology development at lower cost. The following work was performed:

- Test advanced RTI-NAS formulation at NCCC to determine operating windows, solvent performance, water balance, degradation, corrosion, emissions, amine loss, and other operational issues,
- Operate RTI-NAS with coal-derived flue gas for at least 400 hours

Testing RTI-NAS in an industrial setting is important and reduces the risk of committing the funding required to design and operate pilot-scale test units. Process-integrated testing at the NCCC exposes the RTI-NAS technology to the requirements and rigors of real plant operating conditions and allows it to be scaled-up with confidence for pilot-scale testing and commercial demonstration. In addition to obtaining performance data, this approach identifies areas of process design that require further development before pilot testing and commercial application.

2.2. Success Criteria

After the campaign in the SSTU, RTI should be able to

- Determine solvent performance, water balance, emissions, amine loss and other operational issues
- Achieve time of stream for > 400 hours
- Estimate the performance advantages and benefits of the NAS process
- Perform cost/benefit analysis of the NAS process as compared with MEA based process

2.3. Test Plan

Based on the objectives and success criteria, a series of 22 test runs were planned to be carried out in the SSTU including:

1. Establishing L/G curve vs. SRD
2. Lower and higher lean solvent temperatures
3. Lower CO_2 capture rates
4. Lower and higher flue gas flow rates
5. Higher flue gas humidity
6. Lower CO_2 concentration testing
7. Aerosol formation with an SO_3 generator
8. Long-term testing at optimal L/G condition

2.4. Results and discussion

Unfortunately, due to several reasons as listed in Table D, only a few test conditions were executed in the SSTU. The time on stream over the course of the RTI-NAS test campaign (580 hrs.) in the SSTU is shown in Figure 8.

Table D. Reasons for NCCC-SSTU shutdowns during test campaign

No	Date	Reasons for plant shutdowns
1	5/29/2018	CompactLogix CPU was broken
2	5/31/2018	New CPU not compatible with PLC rack
3	6/4/2018	Large quantity of fresh DI water dumped into SSTU and the system was shutdown to drain it. Rich tank PDT transmitter also broken.
4	6/5/2018	Flue gas not available from Gaston power plant
5	6/7/2018	Leak in regenerator due to unnoticed vent without blind
6	6/12/2018	Gaston power plant off line
7	6/20/2018	System shutdown due to misbehavior of lean pump at the exit of the reboiler
8	6/21/2018	Ordered a replacement PEEK gear
9	7/13/2018	SSTU faulty temperature I/O card
10	7/17/2018	Gaston power plant offline
10	7/25/2018	Gaston power plant offline
11	7/29/2018	Gaston power plant offline

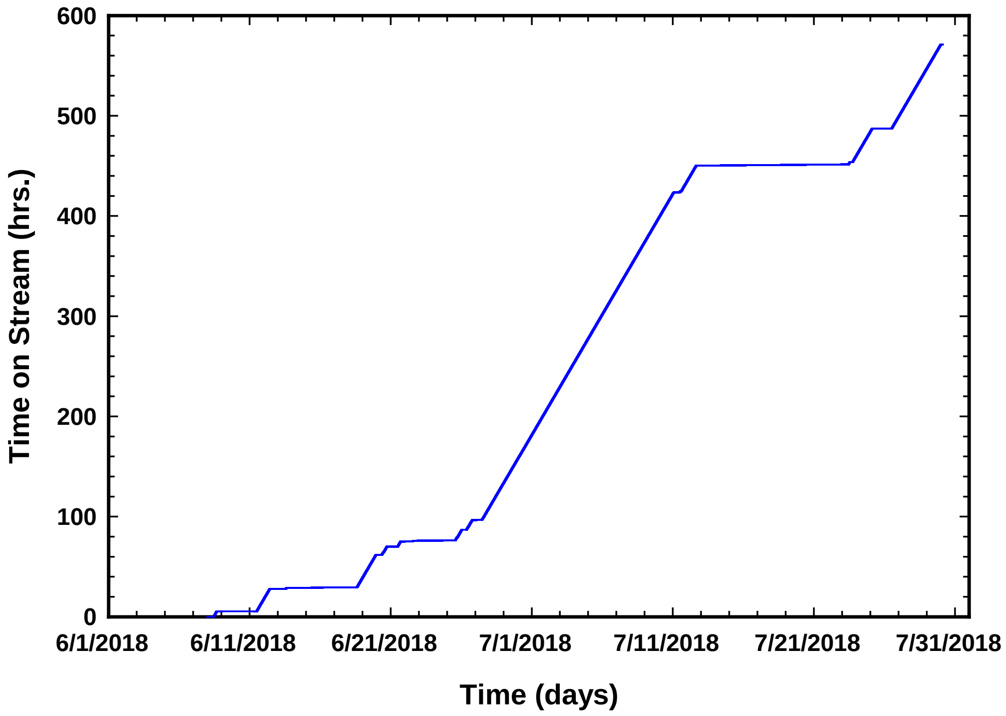

Figure 8. Time on stream for CO_2 capture using RTI-NAS obtained in the NCCC-SSTU Unit

2.4.1. Process control parameters

Figure 9 shows the liquid and gas flow rates maintained during the RTI-NAS test campaign in the SSTU. Liquid flow rate (L) varied from 10 to 15 kg/min and gas flow rate (G) was maintained at 1.11-3.8 kg/min translating to L/G ratios of 4.1-8.4. Emissions measurements were made during four SO_3 injections (2.25 to 6 ppm) during the campaign at L/G ratio at 5.2. Last two SO_3 injections were done at L/G 6.7 and 8.4. The CO_2 capture rate during the campaign varied between 60-90%.

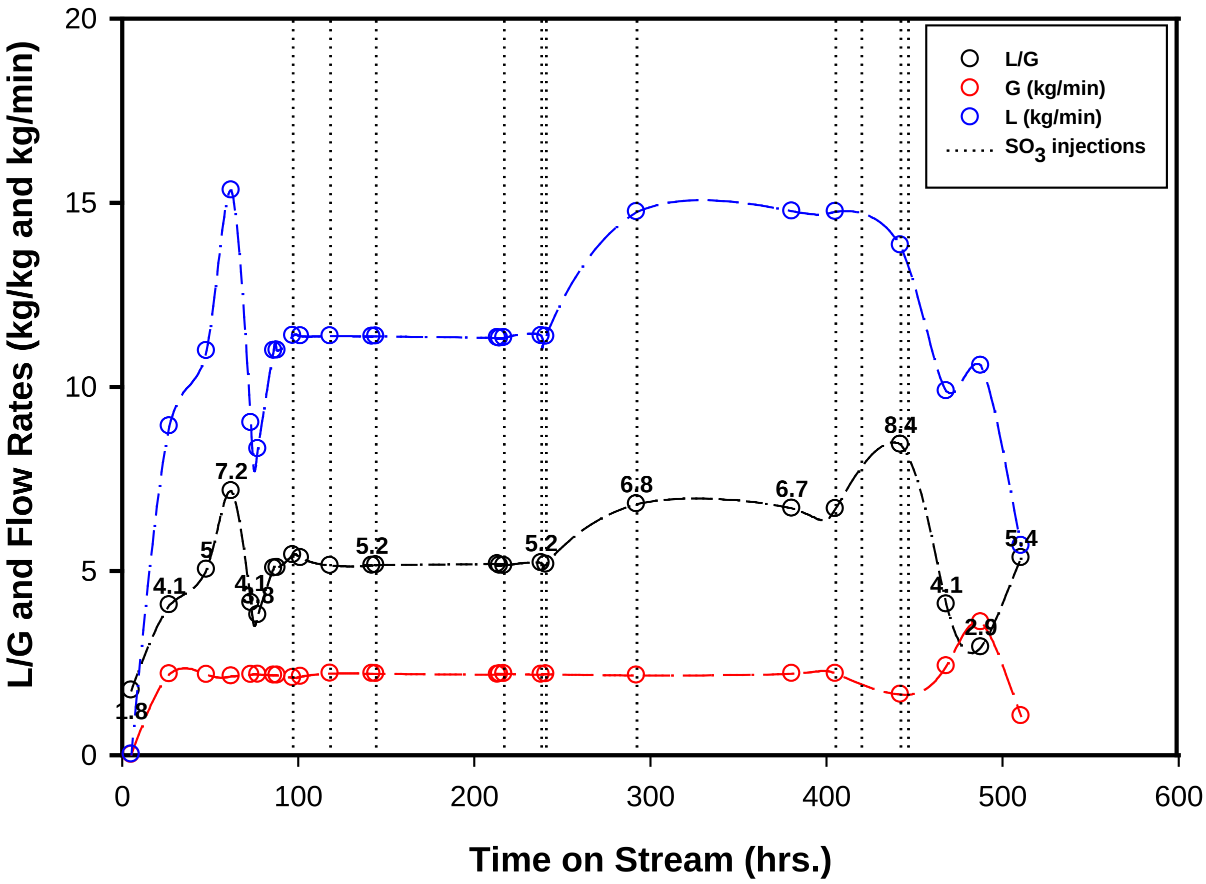

Figure 9. Sampling points during long-term exposure runs conducted in SSTU-NCCC with different liquid and gas flow rates. SO_3 injections were made on flue gas in a few runs (dotted lines in the graph)

Figure 10 shows the temperature profiles in the absorber obtained at steady state conditions. The temperatures throughout the campaign remained consistent between different conditions. The lean solvent temperature was maintained around 50-55°C. The absorber top bed temperature varied between 55-60°C and the bottom bed had temperature variations between 60-70°C. The wash water column temperature varied between 35-45°C.

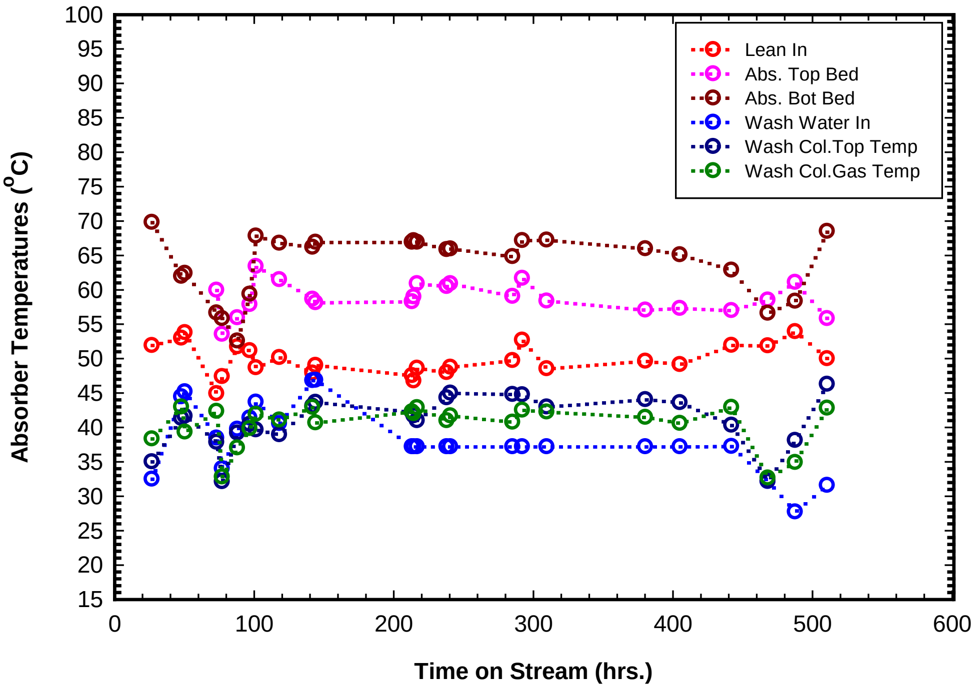

Figure 10. Absorber profile of NCCC-SSTU during RTI-NAS Campaign during steady state operation when samples were taken.

Temperature profiles in the absorber and desorber in the SSTU are similar to the temperature profiles obtained from other RTI-NAS testing without intercooling and interheating as shown in Figure 11 and Figure 12. Absorber profiles are included for reference of using intercooling in SINTEF's Tiller plant and RTI's BsGAS that show that the temperature profile can be shifted ~20°C lower with intercooling. The absorber column height in the SSTU is about 5 times lower than that of SINTEF's Tiller plant and 2 times lower than RTI's BsGAS. The desorber was operated between 90-115°C with a kettle-type reboiler with steam heating. Additional profiles are also shown in the desorber with interstage heating from SINTEF's Tiller plant and RTI's BsGAS. These profiles show the impact of using distributed heating on the RTI-NAS with the lack of a stripping agent to boil up the column.

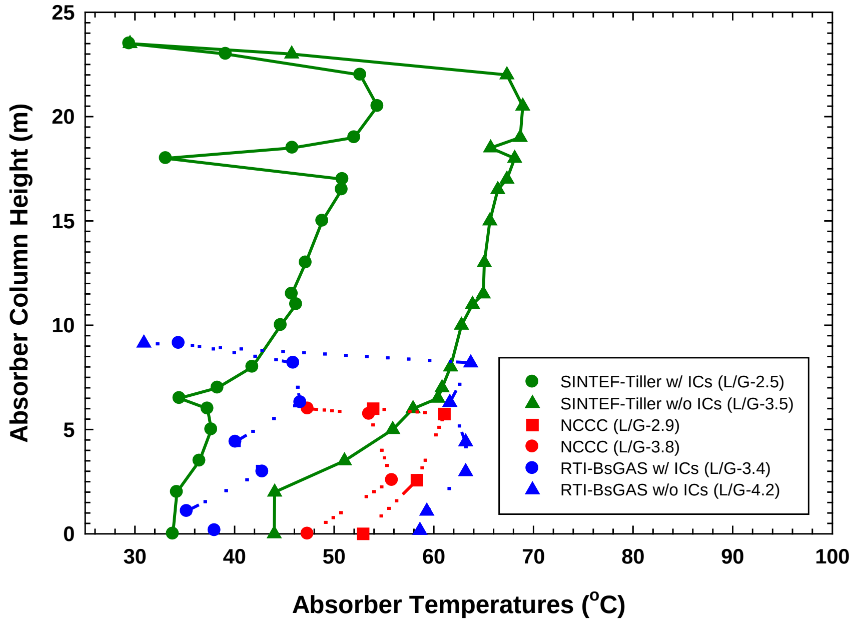

Figure 11. Comparison of absorber temperature profile of NCCC-SSTU with SINTEF-Tiller and RTI-BsGAS for CO_2 capture using RTI-NAS

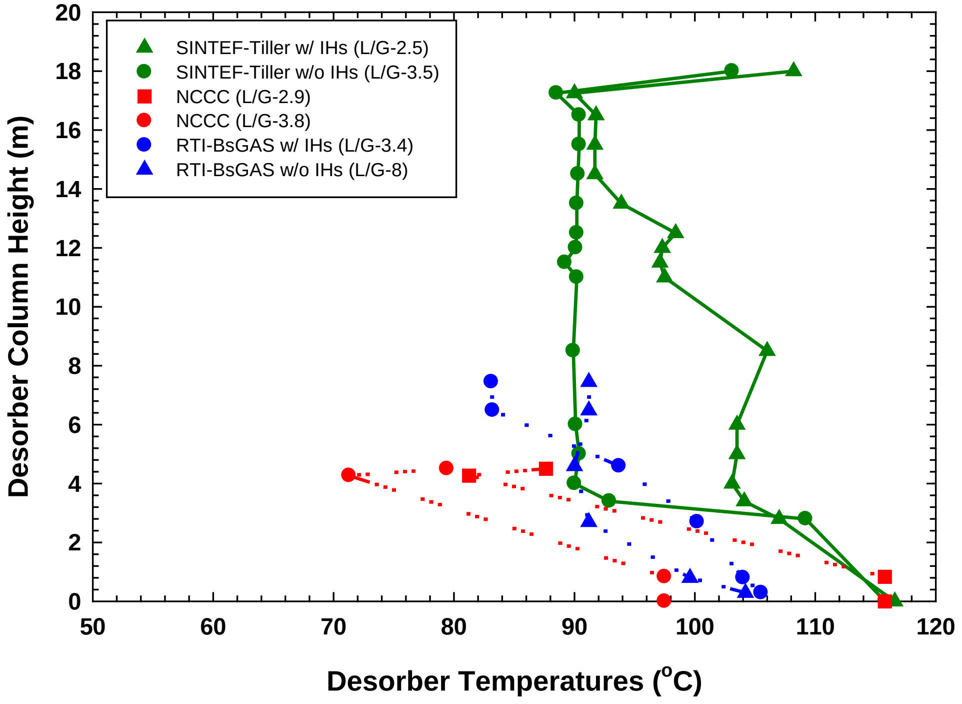

Figure 12. Comparison of desorber temperature profile of NCCC-SSTU with SINTEF-Tiller and RTI-BsGAS for CO_2 capture using RTI-NAS

During the test campaign, the SSTU was flooded with water on multiple occasions with excess water from the wash tower due to process control issues. Water concentrations in RTI-NAS were varied between 2-55 wt%. Figure 13 shows the variation of water concentration in the SSTU during the campaign and known times that excess water was added into the system from the wash tower return valve into the lean tank (at least 5 times). A second liquid phase will form in the NAS above ~14 wt% water, which was most of the campaign. To remove the excess water from the process, much of the test campaign required operating at process conditions that stripped water from the solvent.

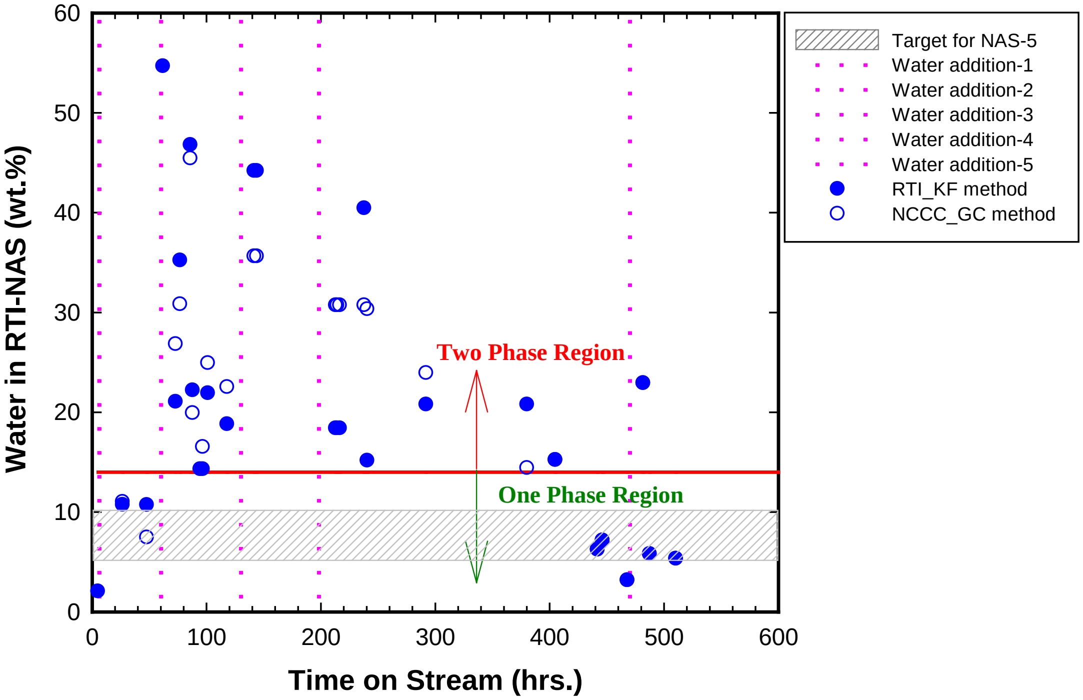

Figure 13. Measured water concentration and excess water additions during RTI-NAS Campaign in NCCC-SSTU

Figure 14 shows the working capacity of RTI-NAS compared to 30 wt% MEA in the SSTU. 0.3 mol_{CO2}/mol_{MEA} was shown during MEA baseline testing, whereas only 0.1-0.25 mol_{CO2}/mol_{amine} for RTI-NAS testing. This may be due to several reasons but most notably because of the lack of intercooling, which is very important for optimal performance of the NAS. Other reasons for low rich solvent CO_2 loadings may be unattainable equilibrium for CO_2 loading due to the short SSTU absorber column, insufficient cooling from undersized heat exchangers, and higher water content in the solvent. Actual working capacity of RTI-NAS measured in the RTI-BsGAS and at SINTEF-Tiller without intercooling was 0.3-0.35 mol_{CO2}/mol_{amine} and more than 0.4 mol_{CO2}/mol_{amine} with intercooling (SINTEF Report : Mejdell T., 2018). The lean loading measured for the NAS was lower than usual from other test campaigns. This low lean loading is likely due to the high water content in the solvent leading to a much higher water vapor concentration in the regenerator that provided deeper stripping of the solvent.

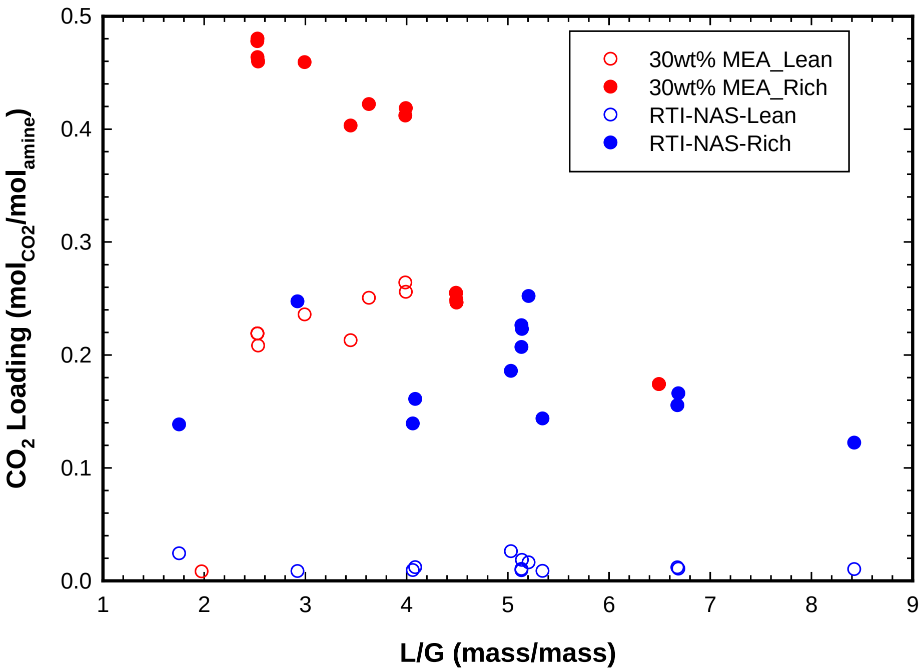

Figure 14. CO_2 working capacity of RTI-NAS in the NCCC-SSTU

2.4.2. Solvent Analysis: RTI-NAS Composition

Samples collected in the NCCC-SSTU campaign from the absorber, regenerator, and wash tower were analyzed at both RTI and NCCC. The amine and diluents content in the samples were analyzed by Gas Chromatography (GC) at NCCC and by Auto-titrator and Gas Chromatography Mass Spectrometry (GCMS) at RTI. The CO_2-rich and lean solvent samples obtained from NCCC were analyzed at RTI by GCMS using internal standard calibration methods to quantify the amine and diluent concentrations in the mixture. The water and CO_2 content of the solvent mixture was analyzed by a Karl-Fischer titrator and CO_2 acidic evolution method using 30 wt% H_2SO_4, respectively, and accounted for in the GCMS analysis.

- The results obtained from the GCMS study show a solvent composition of desired amine concentration at the early stages of the campaign. During the test campaign, the amine content showed a 16% decrease in the solvent after 580 hours of testing. The decrease in the amine content is presumably due to amine vapor and aerosol emissions at the top of the absorber and oxidative and byproduct decomposition pathways of the amine, whose products have been observed in final GCMS traces. Higher than normal amine emissions were expected from operating at process conditions required to strip excess water from the solvent. The mass balances of the solvent composition proposed through the GCMS analysis method shows close agreement to the solvent composition calculated by other analytical methods (GC and Auto-titrator). Three of the samples screened to analyze the compositions of the solvent were biphasic, causing the water content to be unaccounted for in the GCMS analysis, resulting in an overestimation of the mass balance for those samples. Late in the campaign, fresh amine was added to maintain the RTI-NAS formulation near the desired range. About 20 gallons of amine makeup was added after about 500 hrs. of time on stream into the system.

3. Solvent Degradation

3.1. Objectives

- Quantification of RTI-NAS solvent composition at various collection points at NCCC.
- Identification of byproducts formed from amine during NCCC run.

3.2. Experimental

All chemicals were purchased from commercial vendors and were used as received without further purification. Gas chromatography of the collected samples was conducted in an Agilent Technologies 6890 GC system equipped with a 5975C VL MSD. Samples were taken directly from the reaction solution or diluted with methanol and a micro syringe was used to inject 1.0 μL of sample directly into the cool-on-column inlet of the GC. An HP-5MS column (30 m × 0.25 mm, 0.25 μm film thickness with 5% phenyl-methyl-polysiloxane as the stationary phase) was used for the separation of the components. The standard method (with He as carrier gas) used for all runs involved an initial oven temperature of 35°C (held for 5 min) followed by a 20°C/min ramp to 300°C (held for 5 min). Quantification of amine, and diluent in the solvent was accomplished using a six-point calibration curve made with mesitylene as an internal standard. The correlation coefficient (R^2) was greater than 0.996 for all curves.

3.3. Results and Discussion

3.3.1. Identified Degradation Products

Samples obtained from NCCC were analyzed to determine the degradation products present in the solvent composition. The analysis identified aldehydes, amides, and oximes of amine. The emissions of degraded products are described in the next section and show that they are approximately 6% of the emissions of the primary amine near the end of the test campaign. This indicates that the degradation of the amine is relatively low throughout the campaign, but further development to mitigate amine degradation should be studied.

The concentration of other degradation products such as oxalate and formate were also identified as shown in Figure 15 by LC-MS and found to be lower than the MEA baseline campaigns in NCCC-SSTU in October 2010 (~24-96 ppm & ~90-140 ppm: (Brown, October1-September 30, 2013)) & in March 2012 (393 and 1820 ppm: (National Carbon Capture Center, 2012)). The formation of heat stable salts as sulfates in the solvent were also measured by analyzing the lean and rich solvent at various times on stream and plotted in Figure 16. It was found that concentration of sulphates in the solvent increased mainly due to SO_3 injections. The heat stable salts formation in the form of sulfates are much lower in NAS-5 than MEA baseline campaigns in October 2010 (~2000-8000: (Brown, October1-September 30, 2013)) & in March 2012 (~1010 ppm: : (National Carbon Capture Center, 2012)).

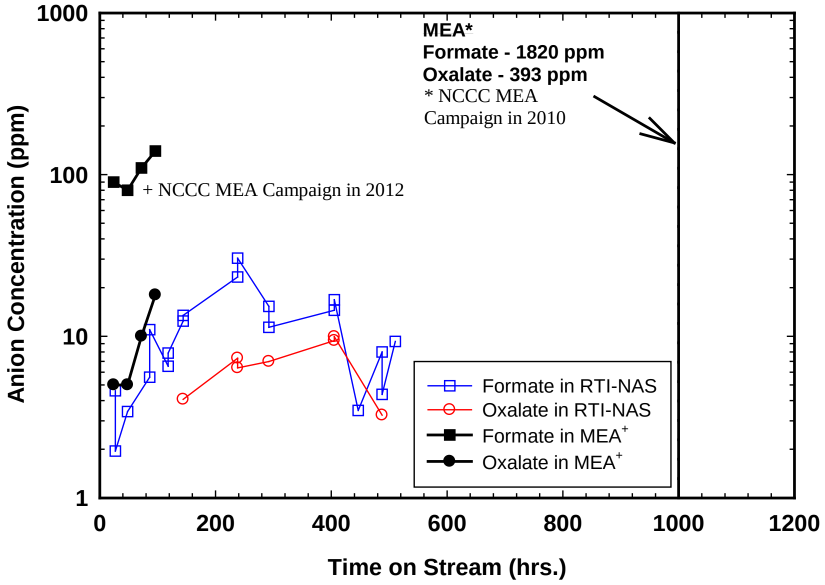

Figure 15. Other degradation products observed in NAS-5 during campaign in NCCC-SSTU

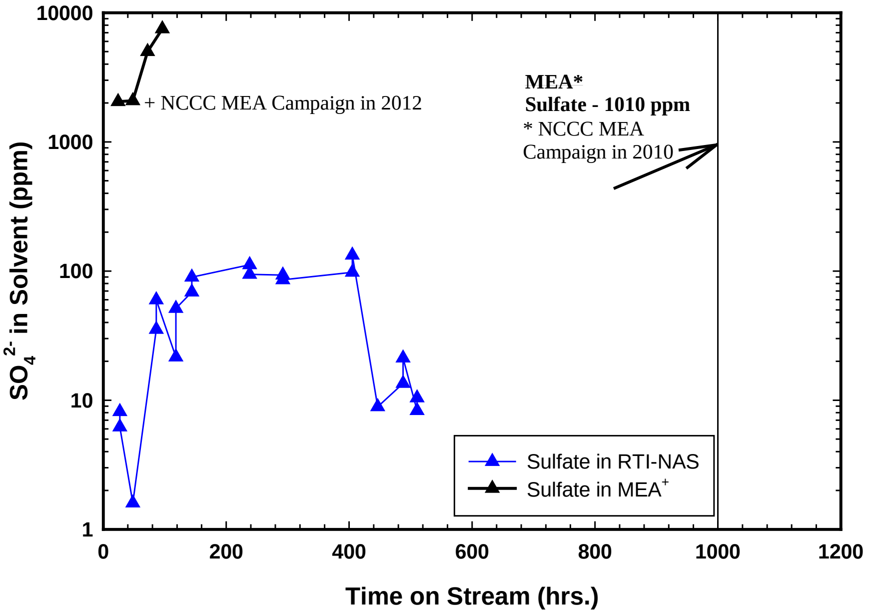

Figure 16. The formation of heat stable salts as sulfates in NAS-5 during NCCC-SSTU campaign

4. Emissions

4.1. Objectives

The vapor pressure of the amine for RTI-NAS dictates the amount of amine in the gas phase leaving the absorber at any given flue gas temperature which leads to the amine vapor loss. NOx, dust, and water droplets present in the flue gas serve as nucleation sites for amine coalescence and ultimately leads to amine loss via aerosol formation. Aerosol growth is largest at the top of the absorber column where the gas becomes supersaturated. The supersaturation is created by a sudden temperature change when warm gas from the exothermicity of CO_2 absorption in the absorber meets cold lean solvent entering the absorber top and causes the gas to quickly cool and become supersaturated with water vapor. The supersaturation leads to water and amine condensation on aerosol particles in the top section of the absorber and results in amine loss. Aerosol and vapor losses will be evaluated in this test campaign with and without the use of controlled SO_3 injection as aerosol nucleation sites.

4.2. Experimental

4.2.1. Emission Sample Collection Setup

To study the emissions from RTI-NAS during the campaign, amine carryover samples were taken periodically by collecting condensate samples from the outlet of the wash tower. Sampling of the flue gas for the amine and amine degradation products must be done isokinetically to ensure that a representative sample is obtained. The sampling system is a hybrid of a modified EPA Method 5 sampling system (as shown in Figure 17) on the front end coupled with a manifold of special sorbent tubes on the back end (as shown in Figure 18). The modified Method 5 portion of the system collects aerosols and any vapors that are condensable at ice-bath temperatures; while the sorbent-tube back end collects any remaining (non-condensable) vapors. The impinger train does not use any solvent to trap the carryover. The temperature of the “cold box” or “impinger train was kept at 40-45°F (4-7°C) during the time of collection following EPA standard [Modified method 5, section 6.6; <68°F (<20°C)].

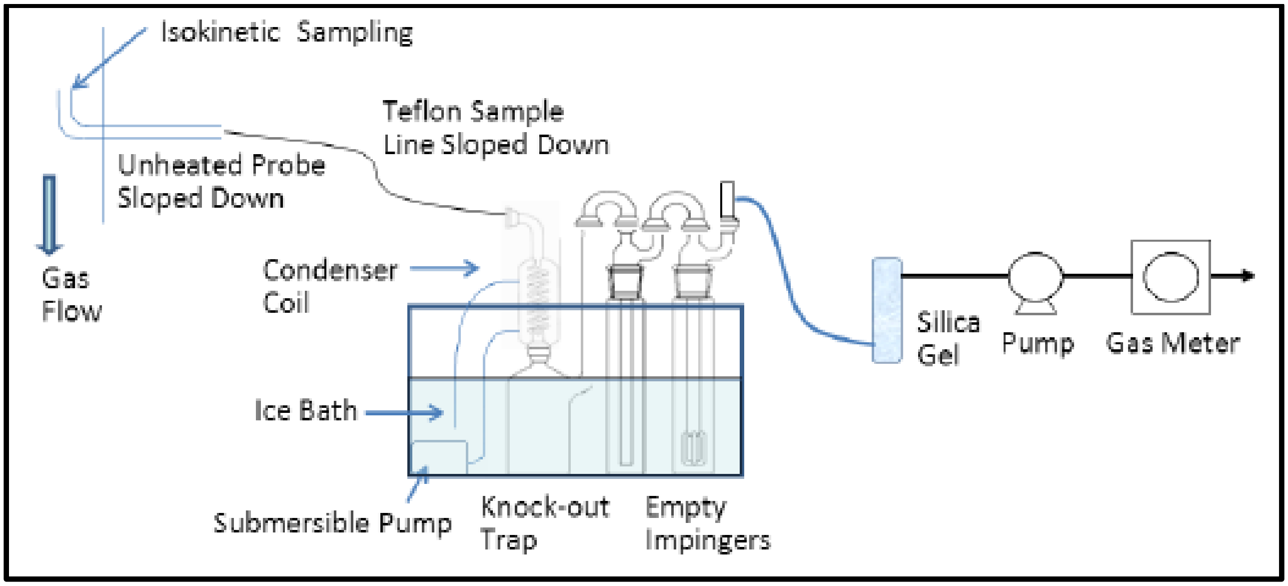

Figure 17. Gas sampling method for amine carry over using the modified EPA method (National Carbon Capture Center, 2012)

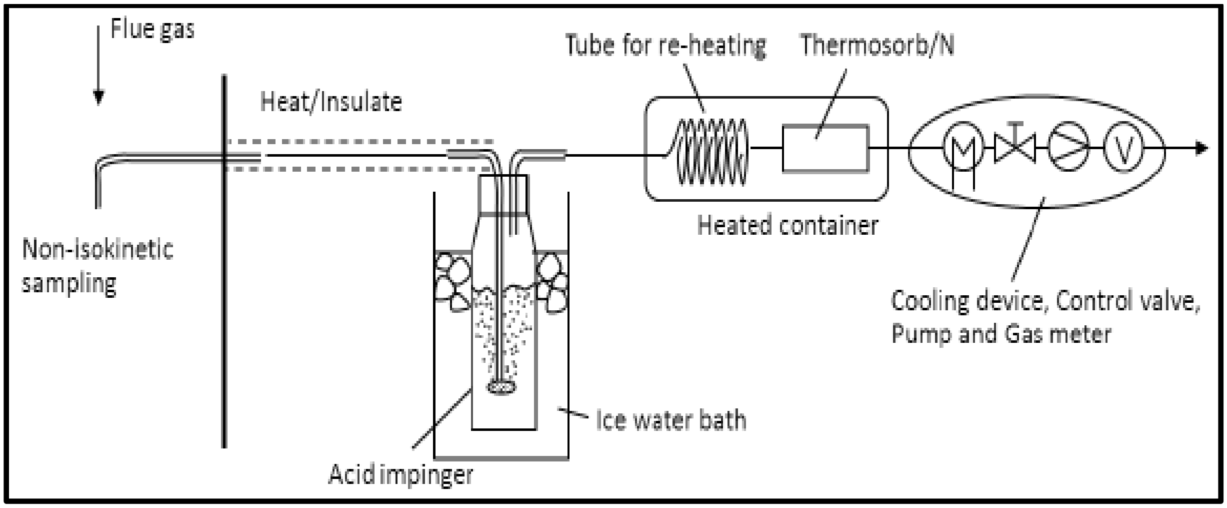

Figure 18. Gas sampling method for non-condensable emissions (National Carbon Capture Center, 2012)

4.2.2. Results and Discussions

The compounds emitted from the NCCC-SSTU absorber wash tower during the RTI-NAS campaign were analyzed by GCMS. The amine vapors not trapped by knock-out trap and adsorbed by the sorbent tubes were analyzed by an external lab (Analytics Corporation, Virginia).

- As the amine concentration in the wash water increases, the capacity of the wash water to scrub the gases leaving the amine decreases, resulting in an increase in the amine concentration leaving the wash tower (Figure 19). Reducing the amine concentration in the wash water could lead to reduction in the amine emissions. This could be achieved by operating the wash tower in a multi-stage fashion. The higher amine emissions occurred during the SO_3 aerosol injection testing described below. These conditions lead to a larger amount of amine being captured in the wash water, but also still a large amount being emitted. RTI-NAS emissions are similar in levels and species as seen in the SINTEF-Tiller testing for the RTI-NAS solvent when the intercooler was not used at roughly 240 ppm. The emissions observed during SINTEF-Tiller testing were significantly lowered by almost 10 times to 37 ppm upon the use of intercooling.

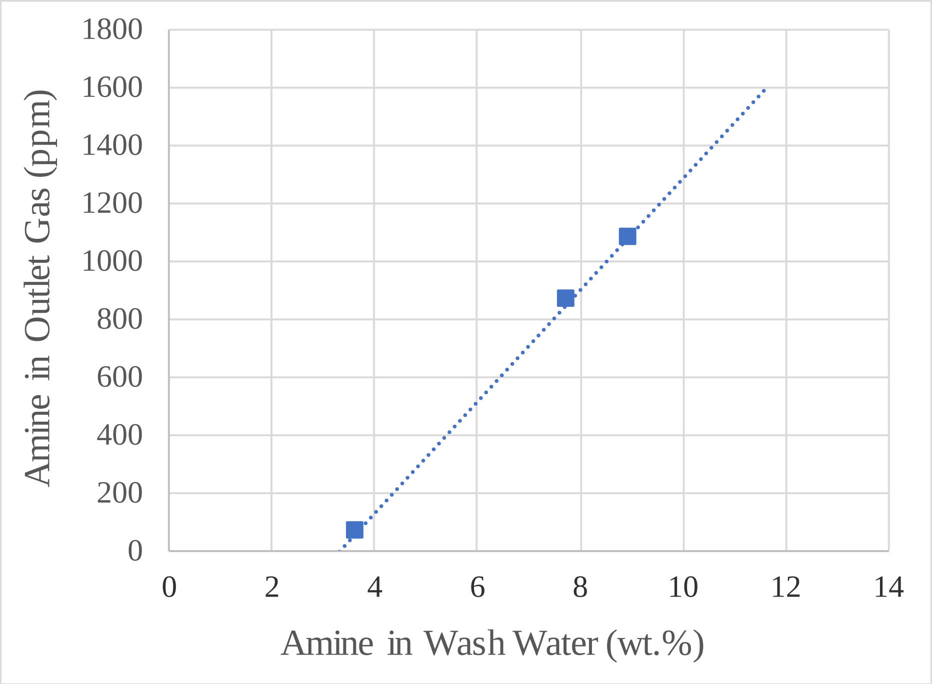

Figure 19. Correlation between amine in wash water and gas phase amine emissions

4.3. Aerosol Characterization at NCCC

In this campaign, isokinetic samples of aerosol measurements using an Electric Low-Pressure Impactor (ELPI+^{TM} as shown in Figure 20) were extracted from the absorber inlet and the wash tower outlet to study aerosol growth from the CO_2 capture process. The schematic of the ELPI+^{TM} measurement system is given in Figure 21. The sample stream from the flue gas is expected to be saturated with water, so dilution of the sample with heated air is necessary to avoid condensation on the impactor plates of the ELPI+^{TM} stages. Condensation can cause electrical short circuiting of the plates and inaccurate measurements of aerosol size distribution and concentrations. The dilution air is passed through a moisture trap, filtered to remove any particles, and then through an ejector type dilutor. After dilution, the dry air is heated and drawn to an ELPI+^{TM} head unit for aerosol characterization. The dilution ratio is defined in volume ratios of sample volume and air flow volume as:

$$N = \frac{V_{sample} + V_{air}}{V_{sample}}$$

The flow ratio of dilution air and the gas sample is kept constant if the sample pressure is constant. The diluted sample concentration should be multiplied by the dilution ratio (N) to get the initial concentration of the gas sample. The same setup was used during the MEA baseline testing to measure the amine emissions due to aerosols.

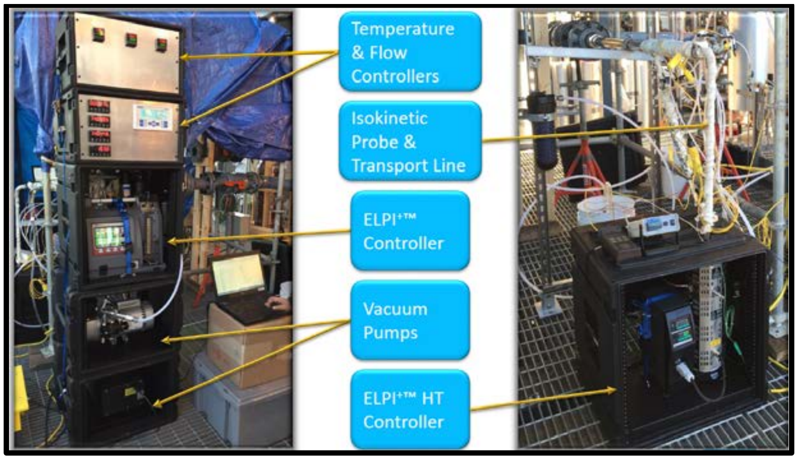

Figure 20. ELPI+^{TM} measurement (Photos taken during one of the test campaigns (Saha & Anthony, 2018))

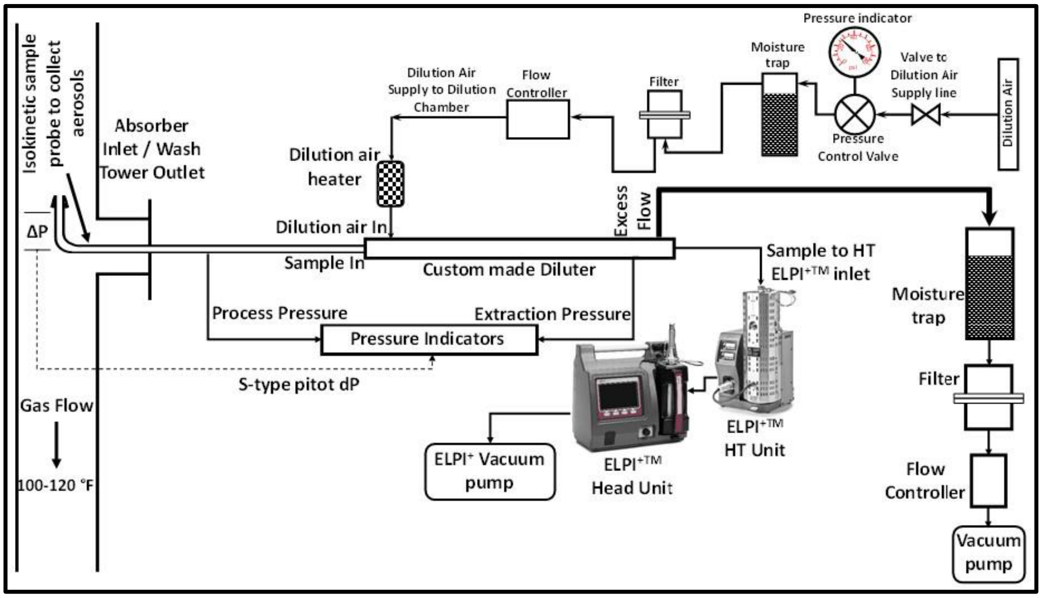

Figure 21. Schematic of the isokinetic sample extraction system for HT ELPI+ measurements at absorber inlet/wash tower outlet of SSTU (Saha & Anthony, 2018)

4.3.1. Baseline Testing

The amine emissions were found to be high during the MEA baseline testing at NCCC, but after installing a baghouse, the amine emissions due to aerosols were brought down from 110 ppm to 10 ppm with a substantial reduction in particulates. All aerosol measurements in this campaign were collected after the baghouse installation at NCCC using ELPI+ ^{TM} at 2 process locations and 3 different conditions: 1) aerosol concentrations in the inlet flue gas to the SSTU with relatively lower dilution and higher dilution ratios; 2) aerosol concentrations after the water wash section with relatively lower and higher dilution ratios to establish a baseline; 3) aerosol concentrations after the water wash section with SO_3 injections at 6 ppm with relatively lower and higher dilution ratios; and 4) repeat of condition 3 for aerosol concentrations for repeatability and reliability.

Figure 22 shows the ELPI+^{TM} measurements performed at the absorber inlet on June 6th, 2018 with different dilution ratios. It can be seen from the figure that tests are highly repeatable. Dilution of the incoming samples helps to not condense the aerosols and it is expected that it will not alter the flue gas or aerosol properties. The different dilution ratios produced similar particle concentrations with minimal effect on aerosol number (particle number per cm^3) and size distributions (D_p - diameter of particles, μm) as an indication that the dilution air is not affecting the aerosols. Figure 23 shows a comparison of typical aerosol particle distributions and concentrations from coal-fired flue gas and measurements made in the NCCC-SSTU in the past. The concentration of large-sized aerosols (>10^6 particles/cm^3) was reduced by approximately two orders of magnitude after installing the baghouse at NCCC as shown in Figure 23.

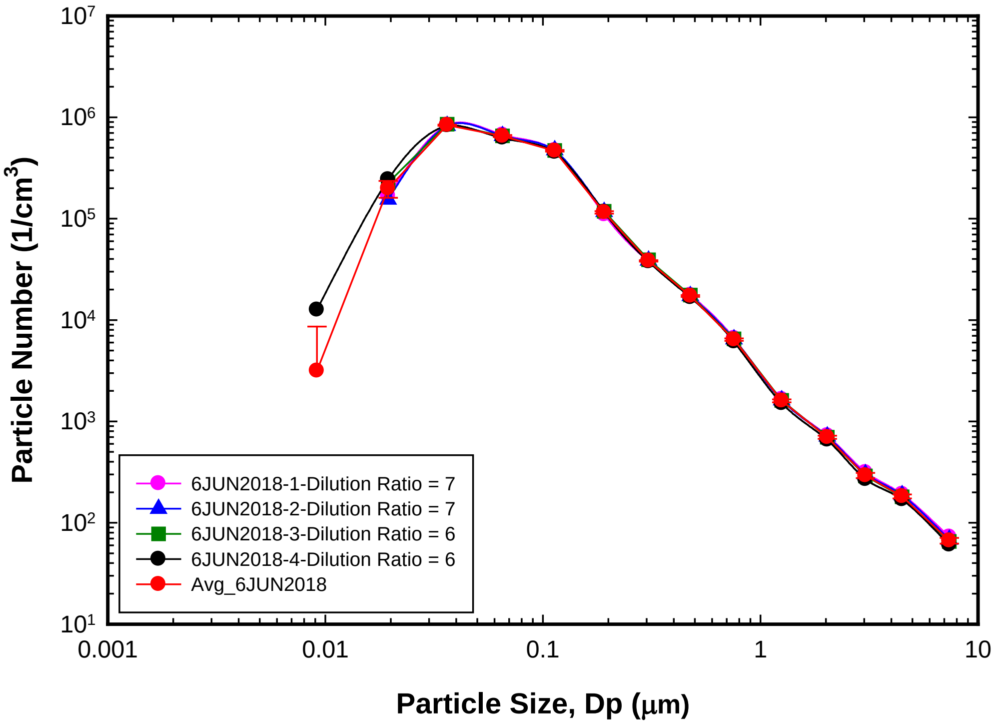

Figure 22. Comparison of particle number concentration at different dilution ratios

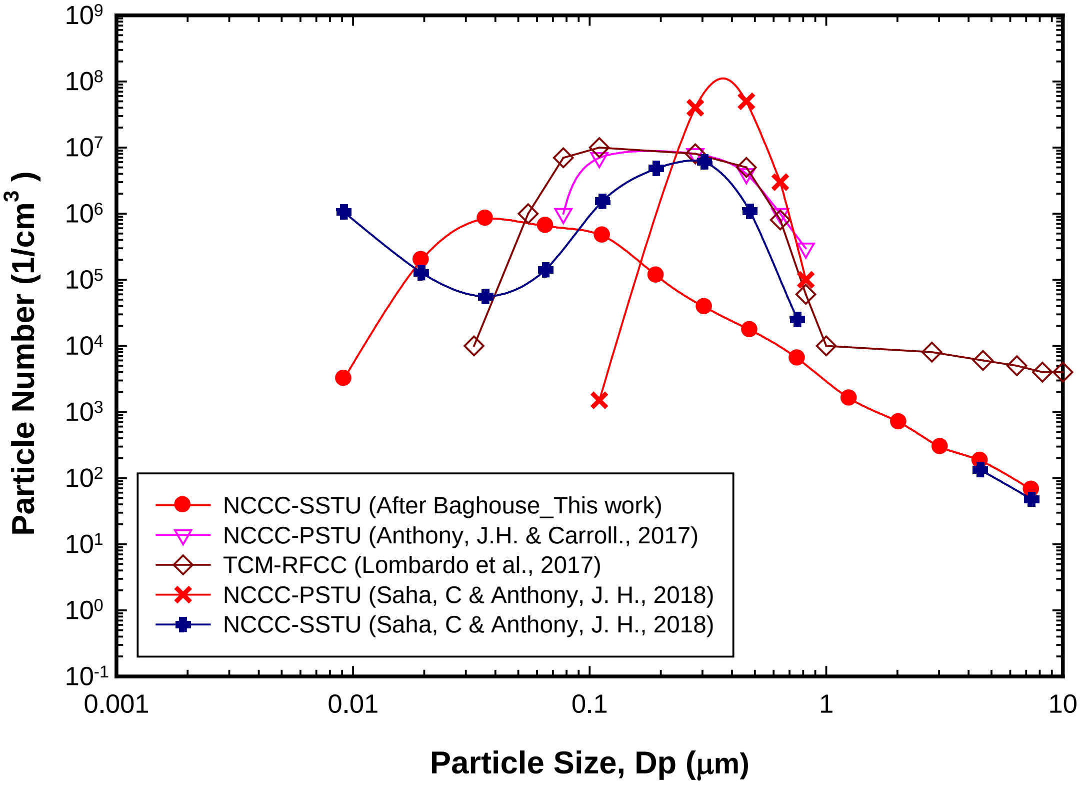

Figure 23. Comparison of NCCC-SSTU flue gas inlet with others from literature from before the baghouse installation [(Saha & Anthony, 2018), (Lombardo et al., 2017), (Anthony, 2017)]

Figure 24 shows the baseline ELPI+™ measurements done at the wash tower outlet (WTO) on June 19th, 2018. The concentration of aerosols varied from 10^3 for larger particle sizes to 10^8 for smaller particles. The high concentrations for the lowest size aerosols were said to be typical after the Unit 5 baghouse started its operation. The particle concentrations of larger size aerosols are lower due to the installation of baghouse as seen with the previously available data for MEA in the NCCC-SSTU unit and shown in Figure 25. But smaller and medium size particles increased for the RTI-NAS solvent compared to MEA after the baghouse installation. This may occur because the lower amount of water in the solvent may limit aerosol growth to the point that the aerosols do not grow large enough to be captured in the water wash. The cause will be investigated further in our current emission mitigation project for water-lean solvents.

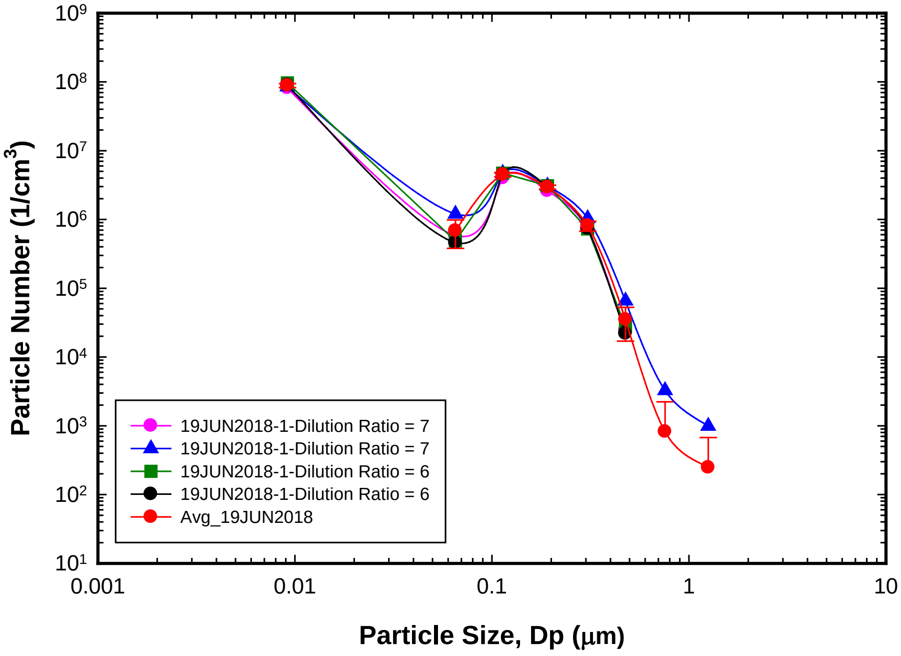

Figure 24. Comparison of total particle concentration of aerosols on NCCC-SSTU WTO at different dilution ratios

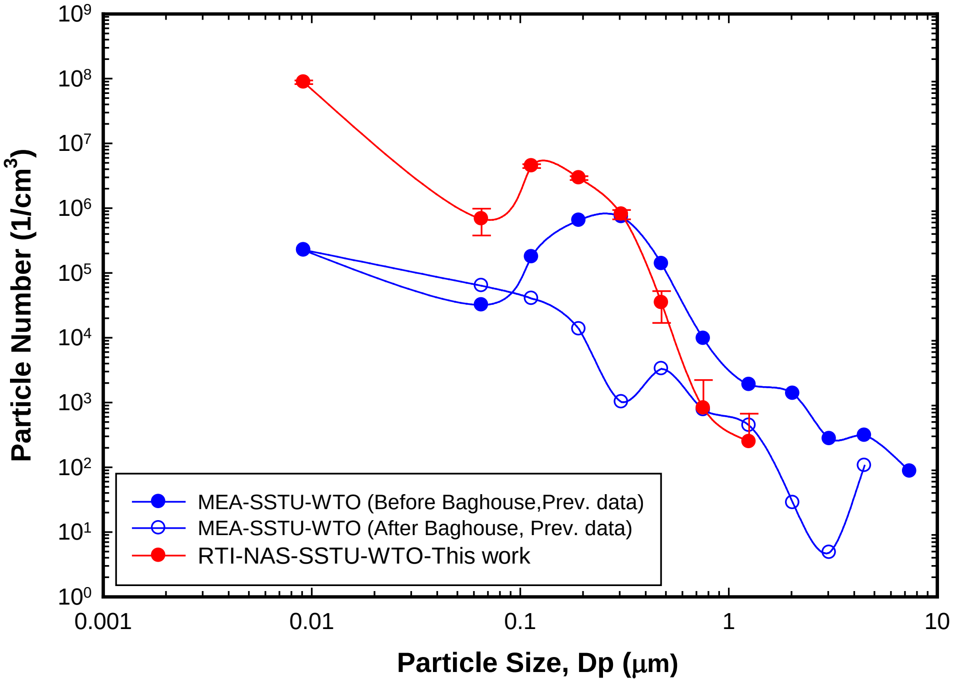

Figure 25. Comparison of aerosol measurements at the NCCC-SSTU wash tower outlet to previous data from MEA runs (Saha & Irvin, 2017)

4.3.2. SO_3 Injection Testing

During the test campaign, a parallel effort by the University of Texas at Austin (UT-Austin) was taking place in the PSTU. Their tests included the use of an SO_3 generator to study the impact of aerosol nucleation sites on the process emissions in a controlled manner. The flue gas to the PSTU and SSTU share a common inlet after the SO_3 generator, so testing with SO_3 injection was also completed in the NAS SSTU campaign. A schedule of the SO_3 injections completed during the campaign are included in Table E.

Table E. SO_3 injection schedule during the test campaign

Run	Date	Time of Injection (hr:min)	Start Time	Stop Time	SO_2 Setpoint (SCFH)	ppm
1	27-Jun	3:15	11:45	12:30	12	6
			12:30	13:00	10	5
			13:00	13:30	8	4
			13:30	14:00	6	3
			14:00	14:30	4	2

			14:30	15:00	2	1
2	28-Jun	2:38	12:22	13:15	12	6
			13:15	13:45	10	5
			13:45	14:15	8	4
			14:15	14:45	6	3
			14:45	15:00	4	2
3	29-Jun	2:44	10:35	13:19	4.5	2.25
4	2-Jul	3:00	12:30	15:30	4.5	2.25
5	3-Jul	3:20	9:40	13:00	12	6
6	5-Jul	6:11	9:00	14:11	4.5	2.25
			14:11	14:40	7	3.5
			14:40	14:59	10	5
			14:59	15:11	12	6
7	6-Jul	4:35	10:00	14:05	12	6
			14:05	14:35	4.5	2.25
8	10-Jul	2:55	11:00	12:39	4.5	2.25
			12:39	13:55	10	5
9	11-Jul	3:37	12:23	13:56	4.5	2.25
			13:56	14:31	7	3.5
			14:31	15:25	10	5
			15:25	15:49	12	6
			15:49	16:00	10	5
10	12-Jul	2:37	10:38	11:59	4.5	2.25
			11:59	12:45	7	3.5
			12:45	13:15	10	5
11	13-Jul	4:32	11:28	15:28	7	3.5
			15:28	16:00	4.5	2.25

The concentration of aerosol particles increased from 10^3-10^5 to 10^5-10^7 as the 6 ppm SO_3 injection began. Negative currents were recorded during SO_3 injection tests due to the accumulation of particles on lower stages that caused some aerosols to bounce and blow-off from particular stages to other stages. Therefore, the currents carried out by those aerosols/particulates were either lost or recorded negatively due to collection of the aerosols in improper stages. Figure 26 shows the increased smaller size aerosols as well as larger size aerosols during SO_3 injections.

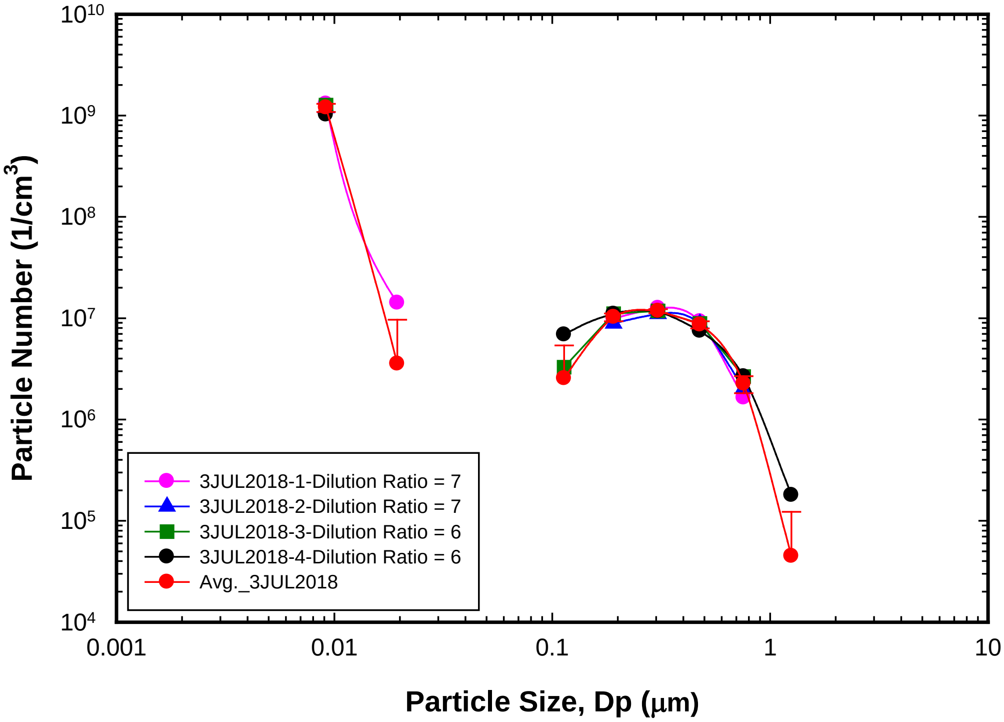

Figure 26. Comparison of particle concentration of aerosols at the NCCC-SSTU wash tower outlet at different dilution ratios during the first SO_3 injection (6 ppm)

Figure 27 shows the ELPI+™ measurements repeated for SO_3 injection at 6 ppm from the NCCC-SSTU wash tower outlet on July 6th, 2018. The repeatability of particle size and concentrations are slightly lower than during the first SO_3 test. The trends of the results for different dilution ratios are similar but the actual particle concentrations vary by 11-30% depending on the size of aerosols. This may be due to increased variability from particulate formation and bounce and blow off during the SO_3 injection tests. The effect of particulate formation on the ELPI+™ stages was enhanced during the repeat SO_3 injection test. This effect could be inferred from Figure 28 showing microscopic images at different stages of ELPI+™ with accumulated particulates.

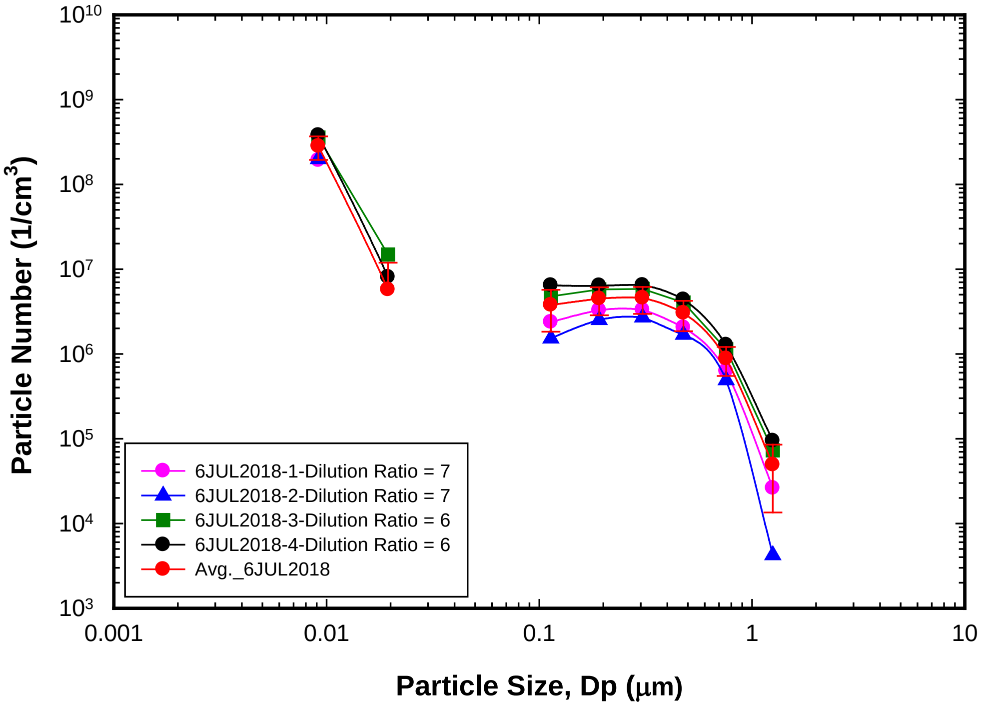

Figure 27. Comparison of total number concentration of aerosols on NCCC-SSTU WTO at different dilution ratio during second SO_3 injections (6 ppm)

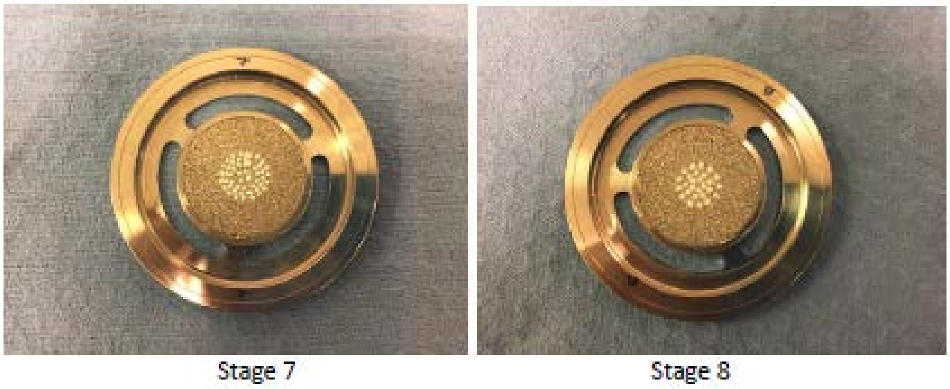

Figure 28. Microscopic pictures showing the particulate collections in ELPI+^{TM} during the campaign (Report to RTI international by Southern Company Inc., 2018)

Figure 29 shows the effect of the SO_3 injection on the aerosol emissions by comparing the average distributions from the four different tests. Large size aerosols (> 0.1 μm) increased in concentration from 10^5 to 10^6 from the flue gas inlet to the wash tower outlet due to accumulation of water, amines, and degradation products from RTI-NAS. During the SO_3 injections, the smallest size aerosols (0.006 μm) increased from 10^8 number concentration to 10^9, whereas larger size aerosols (0.35 μm) increased from 10^6

to 10^7 due to an increased number of nucleation sites. The tests with SO_3 injections were repeatable even with the particulate accumulation within the ELPI+^{TM} instrument.

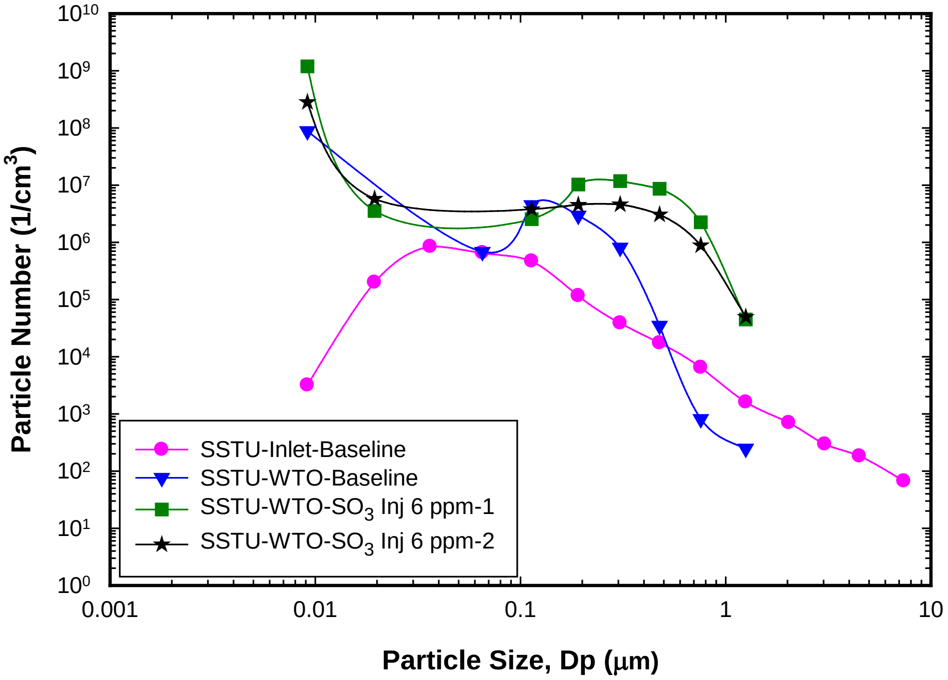

Figure 29. Comparison of particle number concentrations during baseline and SO_3 injection tests

5. Corrosion

5.1. Objectives

The capital cost of CO_2 capture plants is one of the largest drivers in the cost of CO_2 captured. As a result, efforts to reduce the capital costs are one of the most effective ways to bring down the cost of a technology. Most capture systems are currently built with stainless steel due to the corrosive nature of MEA, but cheaper alternatives including carbon steel or plastic liners may be suitable for other solvents like RTI-NAS. The corrosion rate on coupon discs was measured in the SSTU to get a better estimate of the suitability of these materials for the NAS technology.

5.2. Experimental

During the RTI-NAS campaign in the NCCC-SSTU, polypropylene discs and metal corrosion coupons (carbon steel and SS304) were placed in the piping after the absorber and regenerator sumps in the SSTU and corresponding locations are shown in Figure 30. A53-Grade B carbon steel was used as representative of carbon steel commonly used in piping. The polypropylene discs were only inserted in the absorber location as a possible absorber liner for a concrete column. The arrangement of coupons on the pipe plug holder is shown in Figure 31. Two coupons of each material were placed on each coupon holder in mirror order. This would allow for any local effects to be measured and accounted for as the coupons were further removed from the fluid flowing in the pipe. At the end of the campaign, the coupons were removed, cleaned, weighed, and analyzed. Microscopic images of Carbon Steel coupons observed pits as shown in Figure 32, whereas in SS304 pits were not observed. Coupons were cleaned via the ASTM G1 standard method (ASTM, 2017). Corrosion rates were calculated from the surface area of the coupon, the hours exposed at relevant conditions, and the mass lost during the test.

Corrosion Coupons Before and After **Coupon Location in Abs.** **Coupon Location in Regen.**

Figure 30. Corrosion coupons used in NCCC-SSTU unit before and after the RTI-NAS Campaign

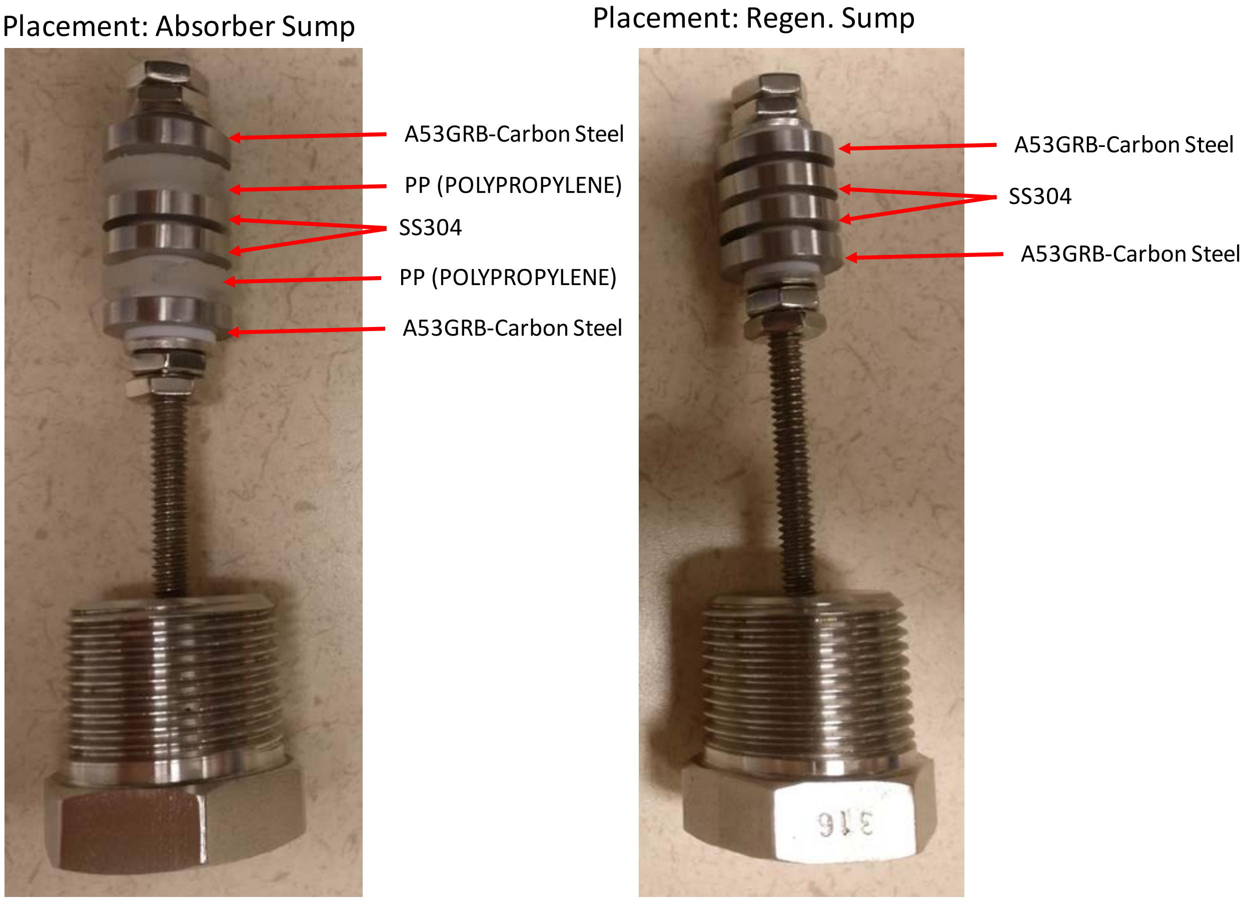

Figure 31. Arrangement of coupons on the coupon holders on both the absorber and desorber side

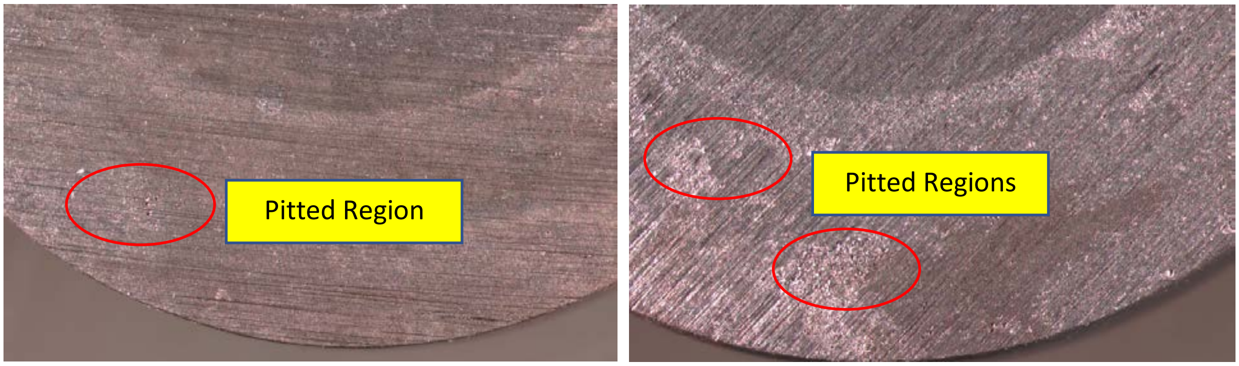

Figure 32. Microscopic images of carbon steel coupons highlighted with pits in the absorber (left) and reboiler (right)

5.3. Results and Discussion

The initial and final weights of the coupons are shown in Table F. It was observed that polypropylene discs absorbed some NAS (~4% weight gain). The weight change for the metal coupons was very small and an average corrosion rate was calculated for each coupon.

Table F. Initial and final weights of the coupons

Coupon	#	Initial Mass (g)	Final Mass (g)	Weight Change (g)	Weight Change (%)
SS304	1	3.8664	3.8643	-0.0021	-0.054
	2	3.8707	3.8687	-0.002	-0.052
	3	3.8554	3.8543	-0.0011	-0.029
	4	3.8608	3.8596	-0.0012	-0.031
A53GRB	1	4.1677	4.1613	-0.0064	-0.154
	2	4.2076	4.1999	-0.0077	-0.183
	3	4.0727	4.0655	-0.0072	-0.177
	4	4.3500	4.3349	-0.0151	-0.347
PP	1	0.4549	0.4732	0.0183	4.023
	2	0.4588	0.4789	0.0201	4.381

The average corrosion rate was calculated as follows (ASTM, 2017):

$$Corrosion\ Rate\ \left(\frac{\mu m}{yr}\right) = \frac{8.76 \times 10^{7} \times Mass\ Loss\ (g)}{Area\ (cm^{2}) \times Time\ Exposure\ (hrs) \times Density\ of\ Coupon(\frac{g}{cm^{3}})}$$

The exposed time used in the calculation for each coupon on the absorber side was the total installed time with solvent in the system because the ambient temperatures during any down time were not very different from the actual process. The exposed time on the regenerator side considered all time where the solvent was circulating and above 90°C. The SS304 coupons in both locations showed a corrosion rate in the outstanding range (2.1-3.8 µm/yr), whereas carbon steel lay in the excellent range (25.8-40.5 µm/yr). The conductivity of CO_2 capture solvents could be used as a corrosion indicator for monitoring and prediction purposes, since it exhibits a linear relationship with the corrosion rates (Gunasekaran, Veawab, & Aroonwilas, 2013). Therefore, the conductivity of the solvent (µS/cm) for both CO_2 lean and rich solvent samples collected in the NCCC-SSTU were measured using a conductivity probe (Mettler Toledo in Lab®710, 0-500000 µS/cm) and listed in Table G along with process conditions and parameters. The conductivity of lean solvent varied from 0.51-912 µS/cm and rich solvent from 1.95-4010 µS/cm and was strongly correlated with the water concentration. Figure 35 shows the power law relationship that exists between water concentration and conductivity of both lean and rich solvent in these samples. The typical conductivity of aqueous amine solvents are in the range of 1000-5000 µS/cm (Gunasekaran et al., 2013), comparable to NAS with a large amount of water. Distilled water has a conductivity in the range of 0.6 to

3.1 μS/cm (Dalmas, 2000). This leads to the conclusion that increasing amine in aqueous solvents increases the conductivity of the solvent and increasing the water in the RTI-NAS increases the conductivity.

Table G. Summary of conductance of RTI-NAS during the Campaign

L/G	Time (hr)	CO_2 loading		Water (wt%)		Conductance (μS/cm)	
		Lean	**Rich**	**Lean**	**Rich**	**Lean**	**Rich**
4.10	26.93	0.01	0.14	10.71	11.78	7.34	103.20
5.00	48.08	0.03	0.19	10.69	8.33	14.67	59.20
3.80	86.18	0.02	0.22	54.64	54.64	912.00	4010.00
3.80	118.20	0.02	0.22	18.78	22.29	48.60	738.00
5.20	144.17	0.01	0.23	44.15	31.53	42.40	1360.00
5.20	238.18	0.02	0.25	40.41	26.41	91.90	1221.00
6.80	292.27	0.01	0.15	15.13	25.25	20.90	165.40
6.70	405.18	0.01	0.17	12.99	15.29	23.90	191.70
8.40	446.42	0.01	0.12	6.04	6.99	15.80	1.95
4.10	468.15	0.01	0.16	4.16	2.97	0.51	2.19
2.90	487.77	0.01	0.25	7.28	5.95	3.17	22.40
5.40	510.60	0.01	0.14	8.92	5.62	1.35	11.79

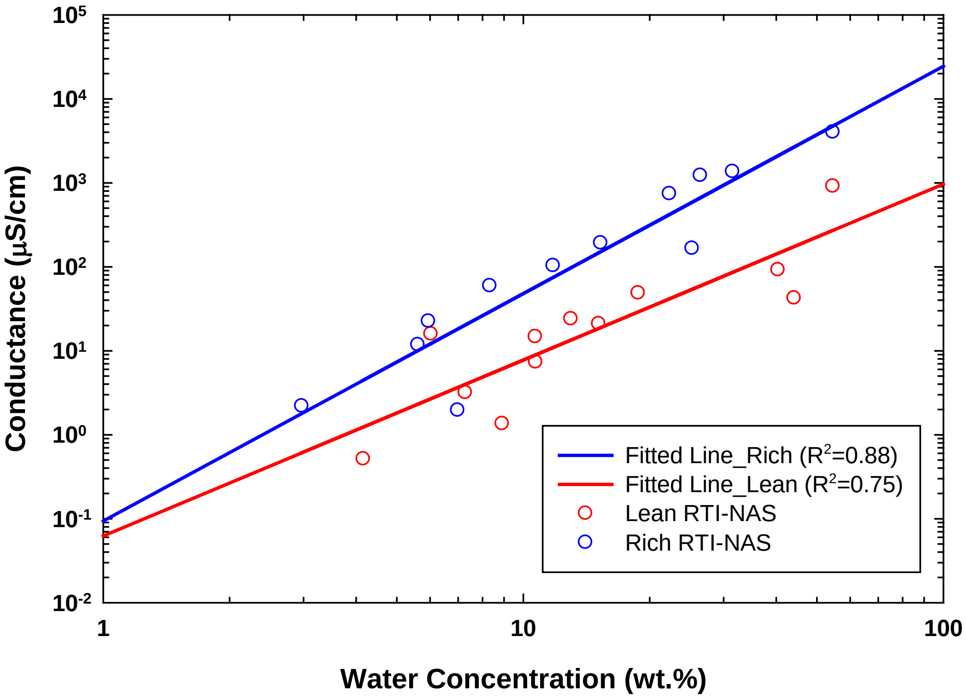

Figure 33. Change in conductivity of solvent with concentration of water in the RTI-NAS solvent from NCCC Campaign

The time-averaged water content in the SSTU campaign was used with the correlation seen in Figure 33 to determine an average conductivity of RTI-NAS solvent throughout the campaign. The corrosion rates for each coupon placed in the absorber and desorber piping in the NCCC-SSTU are plotted with the average conductivity in Figure 34. The experimental data from Gunasekaran et al., 2013 were used along with the data obtained in this work to plot the power law relationship between conductivity (mS/cm) and corrosion rate (mm/yr) in Figure 34. The corrosion rate of the CO_2 capture solvents generally increases with an increase in conductivity of the solvent. The corrosion rate of coupons in the regenerator were greater than the coupons placed in absorber. As expected, the corrosion rate of the SS304 coupons are lower than carbon steel coupons due to the protective layer of chromium and nickel present is SS304. The corrosion rates of different types of amines were also presented as comparison. It was observed that RTI-NAS solvent (0.015 mm/yr) exhibited extremely lower corrosion rates, ~100x less than aqueous solvents (MEA – 50 mm/yr, Gunasekaran et al., 2013) for carbon steel due to the low conductivity of the solvent as shown in Figure 34.

The corrosion rate decreased in the following order: aqueous amines > non-aqueous amines due to the low conductivity. In aqueous amines, from the corrosion rate data obtained from literature (Gunasekaran et al., 2013) primary amine (MEA) > sterically hindered primary amine (1-amino-2-propanol, AMP) > secondary amine (Diethanolamine, DEA & Piperazine, PZ) > tertiary amine (Methyl diethanolamine, MDEA).

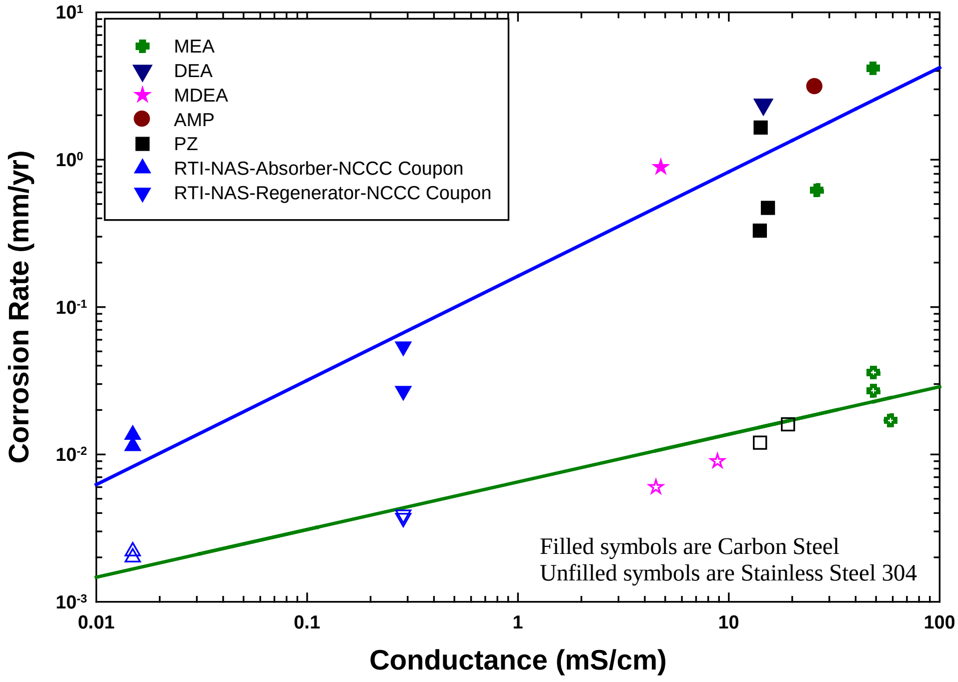

Figure 34. Comparison of corrosion rates of carbon steel and stainless steel 304 in RTI-NAS and with other solvents

The concentrations of metals in the samples collected from NCCC-SSTU were analyzed in RTI's labs using inductively coupled plasma mass spectrometry (ICPMS) for metal content. The results are shown in Table H along with the results obtained from MEA baseline testing in NCCC in March, 2012 (National Carbon Capture Center, 2012). Chromium (Cr), iron (Fe), nickel (Ni), manganese (Mn), and cobalt (Co) metals are present in the SSTU materials of construction and are not present in the flue gas in significant quantities. The presence of these metal ions shows that the occurrence of corrosion in the process equipment. As shown in Table H, the amounts of these metals are significantly lower than the MEA baseline testing. This is another indication that the corrosivity of RTI-NAS solvent is very low.

Table H. Concentration of metals in solvent and the RCRA limits

Metal	MEA from NCCC, mg/L (1000 hr)	RCRA Limit, mg/L	RTI-NAS data from NCCC, mg/L (511 hr)
Fe	137.2	-	0.7
Cr	45.09	5	0.32
Ni	28.77	-	1.2
Mn	5.62	-	0.04
Se	1.95	1	0.45
Co	1.02		0.03
Ba	0.27	100	<5e-3
As	0.22	5	<5e-3

Ag	<0.5	5	<5e-3
Cd	<0.01	1	0.03
Pb	<0.01	5	0.14
Hg	<0.005	0.2	<5e-3

The limits set by U.S. Environmental Protection Agency Resource Conservation and Recovery Act (RCRA) are also listed in Table H. Metals such as barium (Ba), selenium (Se), arsenic (As), cadmium (Cd), lead (Pb), and silver (Ag) typically exist in the flue gas and are observed in the NAS samples lower than or similar to the values obtained in the MEA campaign and the RCRA limits. The change in their concentrations during the testing is shown in Figure 35. Concentrations of nickel (Ni), chromium (Cr), and iron (Fe) generally showed an increasing value with respect to time, indicating that metals in the SSTU were corroding.

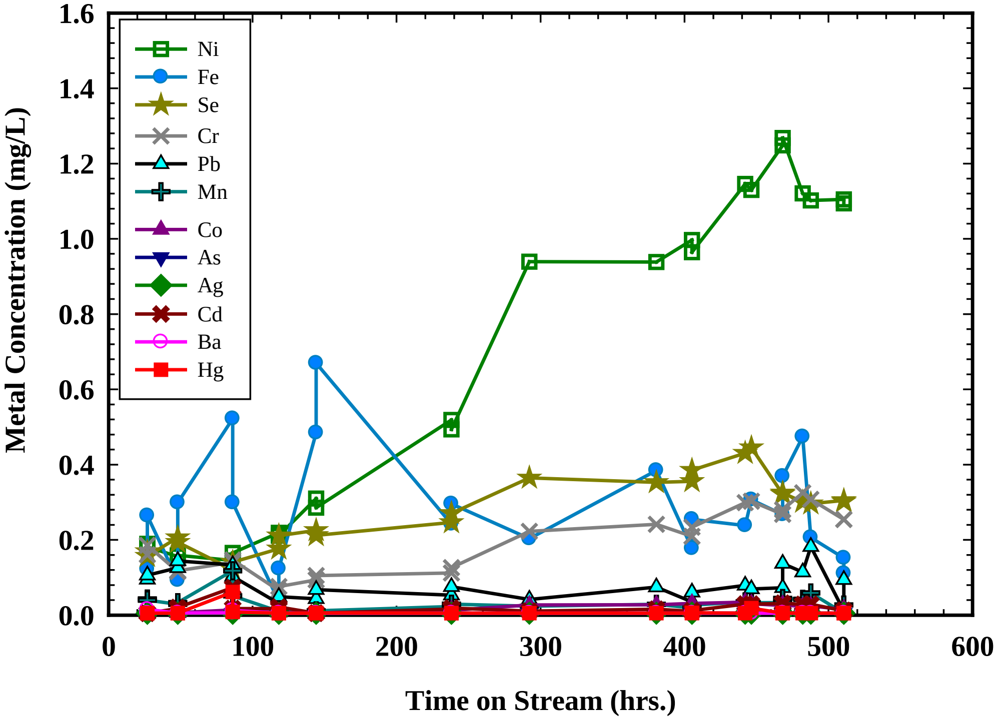

Figure 35. Metal ions dissolved in solvent during RTI-NAS Campaign in NCCC-SSTU

Figure 36 shows the values and relative distribution of the different metals from the two different solvents. The values and relative share of Fe, Cr, and Ni is much larger for MEA compared to RTI-NAS. Figure 37 shows that the Fe, Cr, and Ni ions are significantly lower than MEA in the testing both at NCCC and SINTEF. The major metal components present in MEA are two orders of magnitude higher than the metals measured in RTI-NAS. For instance, a maximum of ~100 ppm Fe was seen in the MEA campaign, whereas ~1 ppm Fe was observed in RTI-NAS campaign.

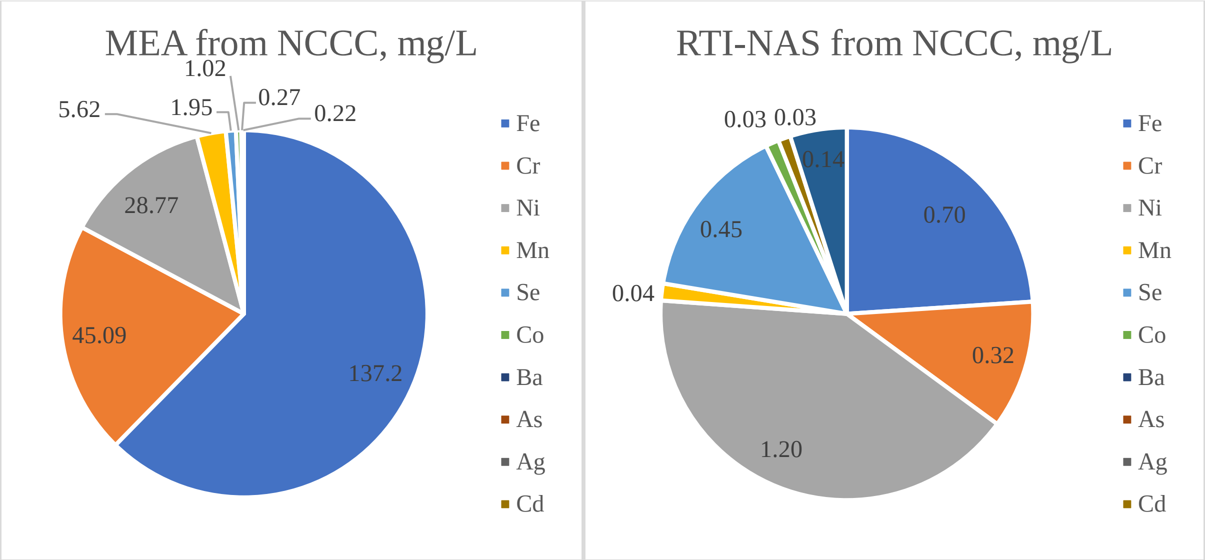

Figure 36. Distribution of metal concentration in RTI-NAS compared to 30 wt% MEA

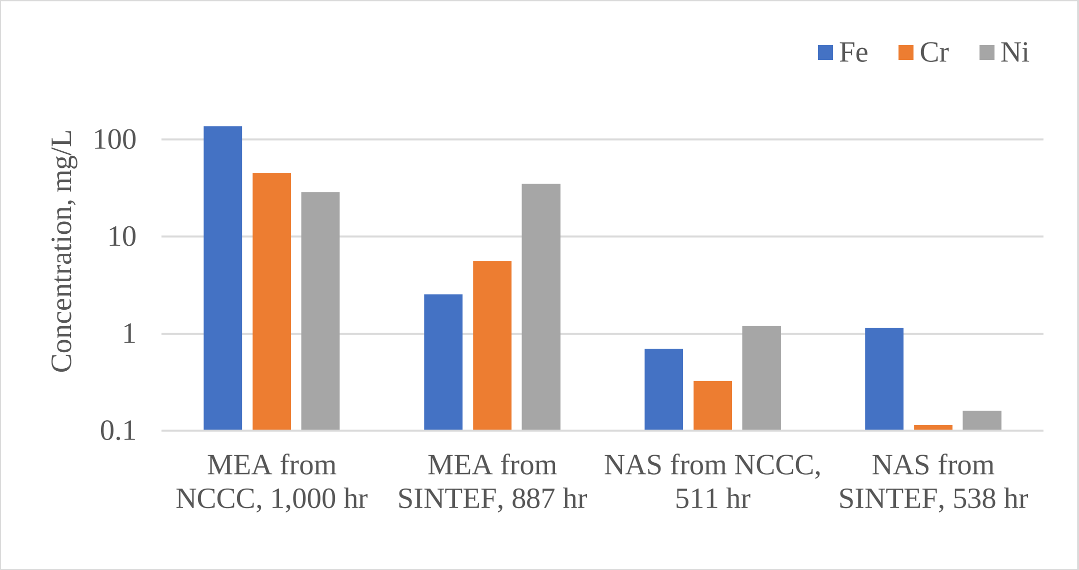

Figure 37. Comparison of major metal components in RTI-NAS CO_2 capture process with 30 wt% MEA

Fischer et al. (2017) suggested that a linear correlation exists between the rate of corrosion and the rate of formate ion production. The corrosion rate increases with an increase in formate ion concentration. The measured corrosion rates of RTI-NAS solvent and others from literature are shown in Figure 38. Comparing the literature values of other solvents, the formation of formate ions are lower in the case of the

RTI-NAS solvent. It appeared that a power law correlation was a better fit for the corrosion data and correlations for both carbon steel and stainless steel are included in the Figure 38

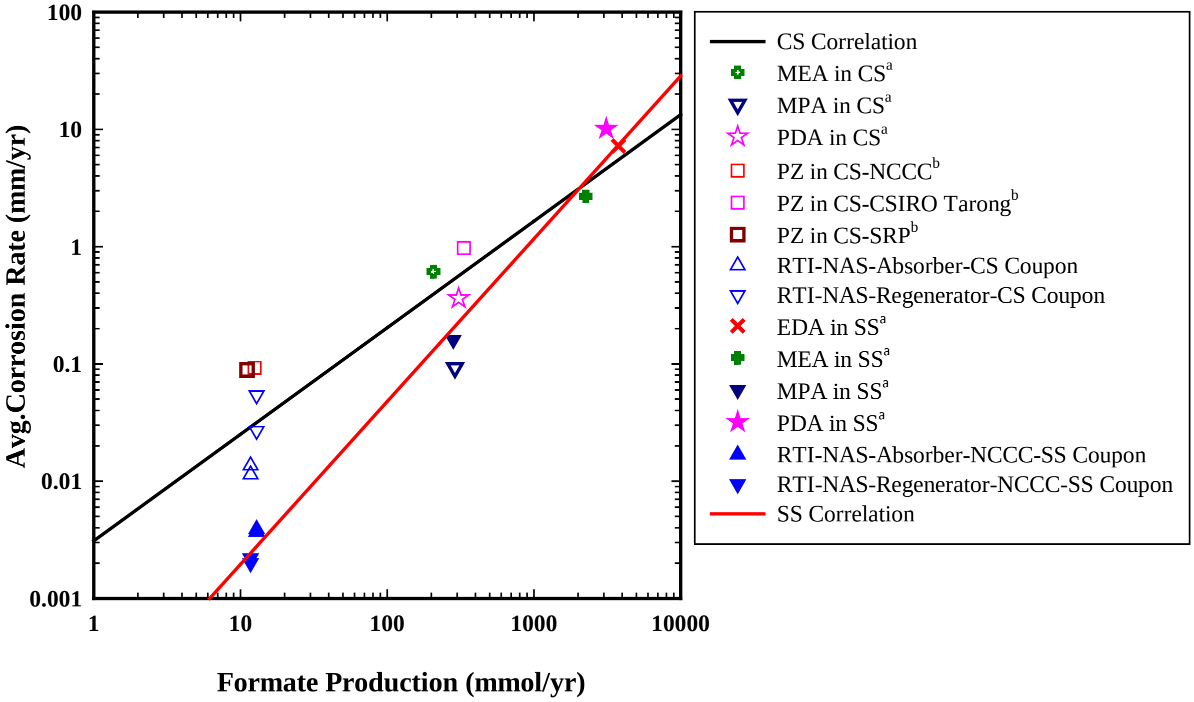

Figure 38. Formate production and average corrosion rate in. corrosion coupons compared with literature. [a] (Fischer, Daga, Hatchell, & Rochelle, 2017); [b] (Rochelle, 2018)

6. Summary and Conclusions

The RTI-NAS solvent was tested in the NCCC-SSTU from May-August 2018 using a slipstream from Plant Gaston’s Unit 5. The solvent was supplied by RTI International and the plant was operated by NCCC. Small modifications were made to the SSTU before the test campaign to address any EH&S concerns of the operation using the NAS. RTI personnel were on-site during the test period to observe testing and coordinate process conditions and sample collection for analysis.

The solvent was operated with coal-fired flue gas in the SSTU for about ~580 hrs. under various process conditions. SO_3 injections in the shared flue gas inlet were tested during the campaign by other technology developers. Nearly constant process conditions were used during this time for ~300 hrs. as a long-term campaign. The CO_2 capture over the duration of testing was ~60-90% under various process conditions. MEA baseline testing conducted by NCCC in the SSTU in March 2012 was used to compare the process parameters and results in this work. The principle findings from this work are listed below:

- RTI-NAS solvent with higher water content (15-60 wt%) will not be an efficient CO_2 capture process. Two-phase solvent operation should be avoided with proper system design and operation.
- RTI-NAS emissions are similar in levels and species as seen in the SINTEF-Tiller testing for the RTI-NAS solvent, and comparison showed that the intercooling reduces emissions by almost 10 times.
- RTI-NAS emitted more small/medium-sized aerosols from the wash tower outlet compared to MEA. The solvent emissions should be addressed in the future with emission mitigation strategies specific for the NAS technology and other water-lean solvents.
- During SO_3 injections, the emission of large-sized aerosols increased as expected.
- RTI-NAS solvent exhibited extremely lower corrosion rates (~100 times) than aqueous solvents for carbon steel due to the low conductivity of the solvent.
- RTI-NAS solvent showed significantly lower metal concentrations compared to MEA baseline testing at both SINTEF and NCCC, another indication of very low corrosion.

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