Large Bench-scale Development of a Non-Aqueous Solvent CO_2 Capture Process for Coal-fired Power Plants

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RTI at a Glance

Worldwide Presence and Financial Strength

$972 M
FY2017 Revenue

3,852
Projects
(fiscal year 2017)

1,198
Clients
(fiscal year 2017)

12 U.S. Offices

Research Triangle Park, NC
Ann Arbor, MI
Atlanta, GA
Berkeley, CA
Chicago, IL
Fort Collins, CO
Portland, OR
Rockville, MD
San Francisco, CA
Seattle, WA
Waltham, MA
Washington, DC

12 International Offices

Abu Dhabi, United Arab Emirates
Barcelona, Spain
Beijing, China
Belfast, Northern Ireland
Jakarta, Indonesia
Kuala Lumpur, Malaysia
Ljungskile, Sweden
Manchester, United Kingdom
Nairobi, Kenya
New Delhi, India
San Salvador, El Salvador
Toronto, Canada

ENERGY TECHNOLOGIES

Developing advanced process technologies for energy applications by partnering with industry leaders

Biomass Conversion	Industrial Water Treatment
Carbon Capture & Utilization, Gas Separations	Advanced Materials for Catalysis & Separations
Syngas Processing	Natural Gas

Presentation Overview

- Project Overview and Objectives
- Project Summary and Budget
- Budget Period 1 Review
  - Milestones and Accomplishments
  - NAS Solvent
  - Process Engineering and Design
  - Bench-Scale Testing
- Budget Period 2 Update
  - Overview, Tasks, and Objectives
  - BP2 Progress
- Next Steps

Project Overview

Total Funding: $4,532,652

Federal: $3,468,584

Cost Share: $1,064,068

Objective: Continue the advancement of the NAS CO_2 Capture Process

- Increase solvent performance
- Design and build unique process modifications for Tiller
- Perform pilot testing of NAS on coal-derived flue gas
- Techno-economic and EHS evaluation

Timeframe:

BP	Timeframe	Months	Proposed Budget	Actual Budget
1	10/01/15 – 12/31/2016	15 months	$1,670,000	$1,532,330
2	01/01/17 – 09/30/2018	21 months	$3,000,322	$3,000,322

BP1 Scope and Objectives

- NAS Process testing at Tiller using propane + coal-derived flue gas
- Reduce the parasitic energy penalty to < 2.0 GJ_t/tonne of CO_2 captured

Other goals and objectives:

- Conduct baseline testing of MEA
- Measure NAS solvent degradation and material compatibility
- Design Regenerator and Absorber wash section
- Improve the physical properties of NAS
- Improve NAS formulations and plan for Scale-up

Bench-Scale Testing of Refined Solvents

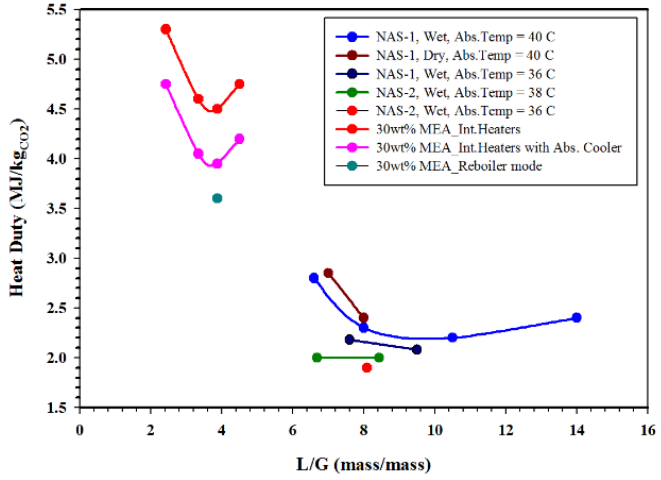
Absorber
3" Sch. 10 SS316 (8.5 m)
Mellapak 350X
Temp: 30-55° C
Pressure: Up to 200 kPa
Gas Vel: 0.33-1.5 m/s
L: 15-75 kg/h

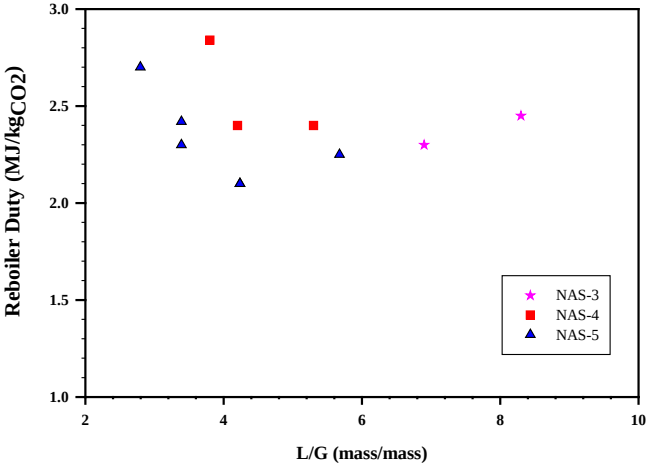
Regenerator
3" Sch. 10 SS316 (7.1 m)
Mellapak 350x
Temp: Up to 150° C
Pressure: Up to 1MPa

3 kW ~185 kg CO_2/day

Simulated Flue Gas Properties	
FG Flow Rate:	100 to 485 SLPM
CO_2 Feed Rate:	1.8 to 8.6 kg/h
Feed Temp.:	30 to 50°C
Target Comp:	CO_2: 13.3%; H_2O: 6.1%; O_2: 2.35%; N_2: bal.
CO_2 Content:	up to 20% vol
Water Content:	~0 to 12.3% vol

Conditions for Experimental Data
- Absorber: 37-40° C
- Regenerator: 87-98° C
- Pressure: 2.5 bar
- Interstage Heater Regeneration





BP-1 Baseline Testing of NAS in Tiller Pilot Plant

Objectives:

- Compare MEA and NAS in conventional system
- Water balance
- Confirm reboiler heat duty
- Emission measurement

Results:

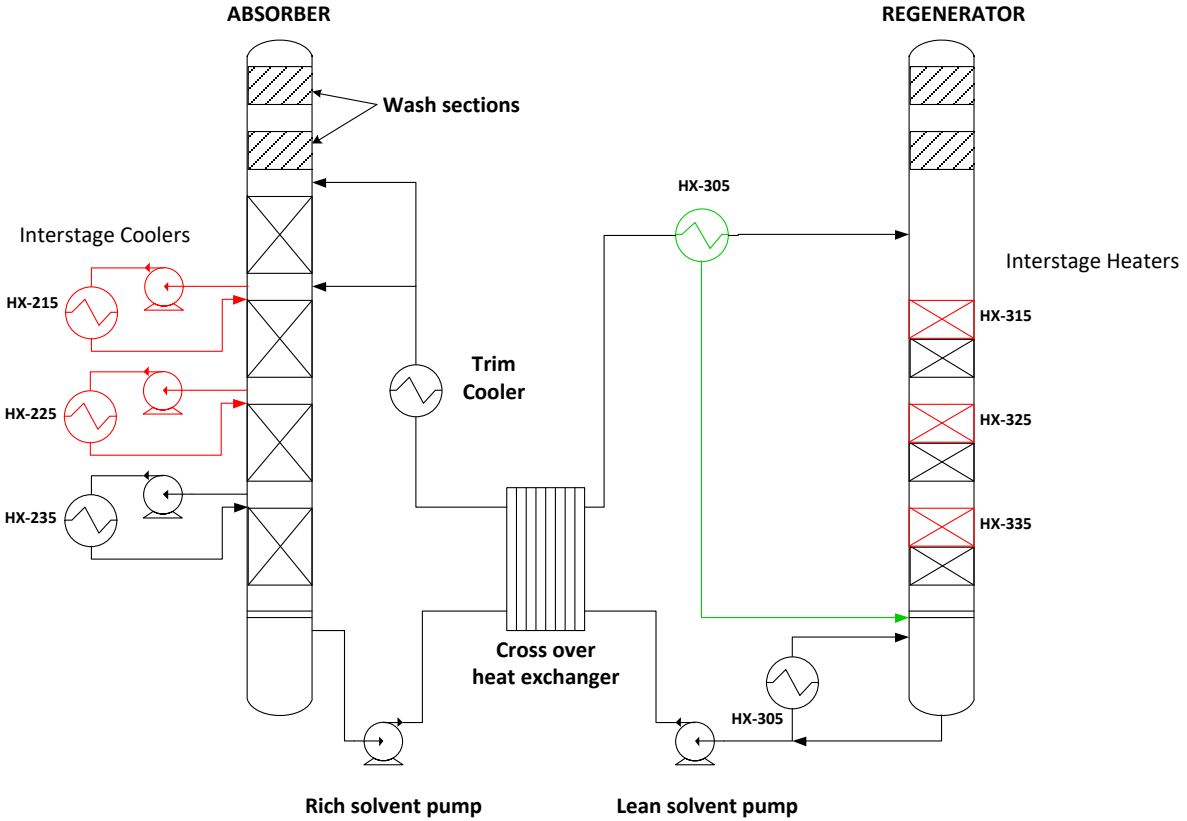
- MEA baseline testing completed at Tiller plant
- NAS baseline testing completed
  - 350 hours of testing with propane + 50 hours with coal flue gas
  - Confirmed the reduction in reboiler duty

Design Improvements for NAS-based Process

Design improvements (e.g. interstage coolers, new Regenerator packing section, rich solvent preheater) have been incorporated in the process engineering for a NAS-based CO_2 capture system

Result Highlights:

- Interstage heaters: 2.19 (all) to 2.86 (none) GJ/tonne-CO_2
- Interstage coolers: 2.19 (all) to 3.23 (none) GJ/tonne-CO_2
- The use of preheater (HX-305) lowers the SRD



BP1 Milestones

Milestone	Description	Completion	Status
A	Kick-off Meeting	12/31/15	***Milestone Achieved.*** Kick-off meeting held at DOE/NETL site on 12/17/2015.
B	Updated project management plan	5/5/16	***Milestone Achieved.*** Revision 1 of PMP was approved by DOE/NETL on 6/27/2016.
C	Completion of 250 hours baseline testing at SINTEF Tiller plant	3/20/17	***Milestone Achieved.*** Performed MEA baseline testing at SINTEF and verified 3.6 GJ/tonne-CO_2 reboiler heat duty consistent with values reported in literature. NAS testing is planned for November 2016.
D	Engineering design package for Regenerator delivered to SINTEF	10/31/16	***Milestone Achieved.*** A final design and engineering package has been delivered and included updated P&IDs, stream tables, and bill of materials for modification recommendations to SINTEF for their CO_2 capture unit at the Tiller plant.
E	Experimental data from formulation improvement confirming that the NAS solvents absorb less than 5 wt% water	12/31/16	***Milestone Achieved.*** Some NAS formulations are able to achieve the < 5 wt% target, however, the optimal formulations have a preferred water absorption target between 5 to 10 wt%.

Success Criteria Description	Status / BP1 Achievement
Completion of 250 hours baseline testing at Tiller plant on coal-derived flue gas	***Completed.*** NAS testing in the Tiller plant facility followed SINTEF's testing of the NAS in their lab pilot system. NAS testing was conducted on propane-fired flue gas, and coal-fired boiler. A total of 405 hours of testing was completed.
Regenerator design package completed and agreed upon by project team	***Completed.*** See "Milestone D" description. RTI and SINTEF have agreed on Tiller plant design modifications. These recommended design changes will be implemented in BP2.

BP-2 Progress and Accomplishments Summary

- Modifications at Tiller led to NAS-optimized absorption process, capturing 90% of CO_2 with the SRD < 2.4 GJ/tonne-CO_2 under realistic process conditions (coal-fired and NG FG)
- Completed – Comprehensive parametric testing with 40+ trial conditions
- Completed – 1,500+ hours of testing under coal-fired flue gas
- Ongoing – Update process simulation based on Tiller data
- Ongoing – Update techno-economic assessment with solvent reclaimer
- Completed – NAS testing at NCCC

Task	Milestone Description	Planned Completion	Verification
5	**F.** NAS-specific components installed and commissioned at SINTEF Tiller plant	**Completed**	Quarterly Report #8
6	**G.** Completion of 1,200 hours cumulative testing at SINTEF Tiller plant	**Completed**	Quarterly Report #9
7	**H.** Detailed techno-economic analysis report delivered to DOE	9/30/18	Quarterly Report #11

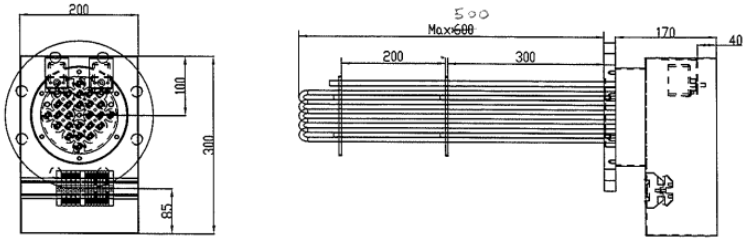
Task 7 - Modifications at Tiller

Coal-fired Burner

Additional Water Wash column

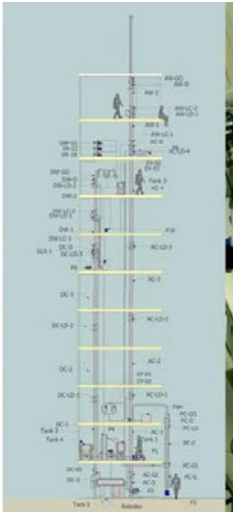
Realizing the NAS optimal performance through process modifications:

- Addition of:
  - 1 x regenerator preheater
  - 2 x interstage heaters
  - 2 x interstage cooler
  - 1 x water wash column
- Enlarge lean-rich heat exchanger
- Addition of coal-fired burner
- Timeline:
  - Sizing, Design, and Approval: 01/2017-03/2017
  - Procurement and site prep: 03/2017-07/2017
  - Installation and Shakedown: 08/2017-11/2017
  - Parametric and long-term test: 12/2017-03/2018



Regenerator's Interstage Heaters

Task 8 - Parametric and Long-term Testing of NAS at Tiller



Research Interests:

Scalability

Can the minimal SRD and continuous, water-balanced operation demonstrated at RTI's BsTU be realized at the system about 10x larger?

Emission

What is the best solution to recover and minimize amine emission? Can the use of built-in water wash be an effective approach?

Degradation

How does the presence of contaminants in coal-fired flue gas affect the NAS's performance, emission, and formation of the degraded products?

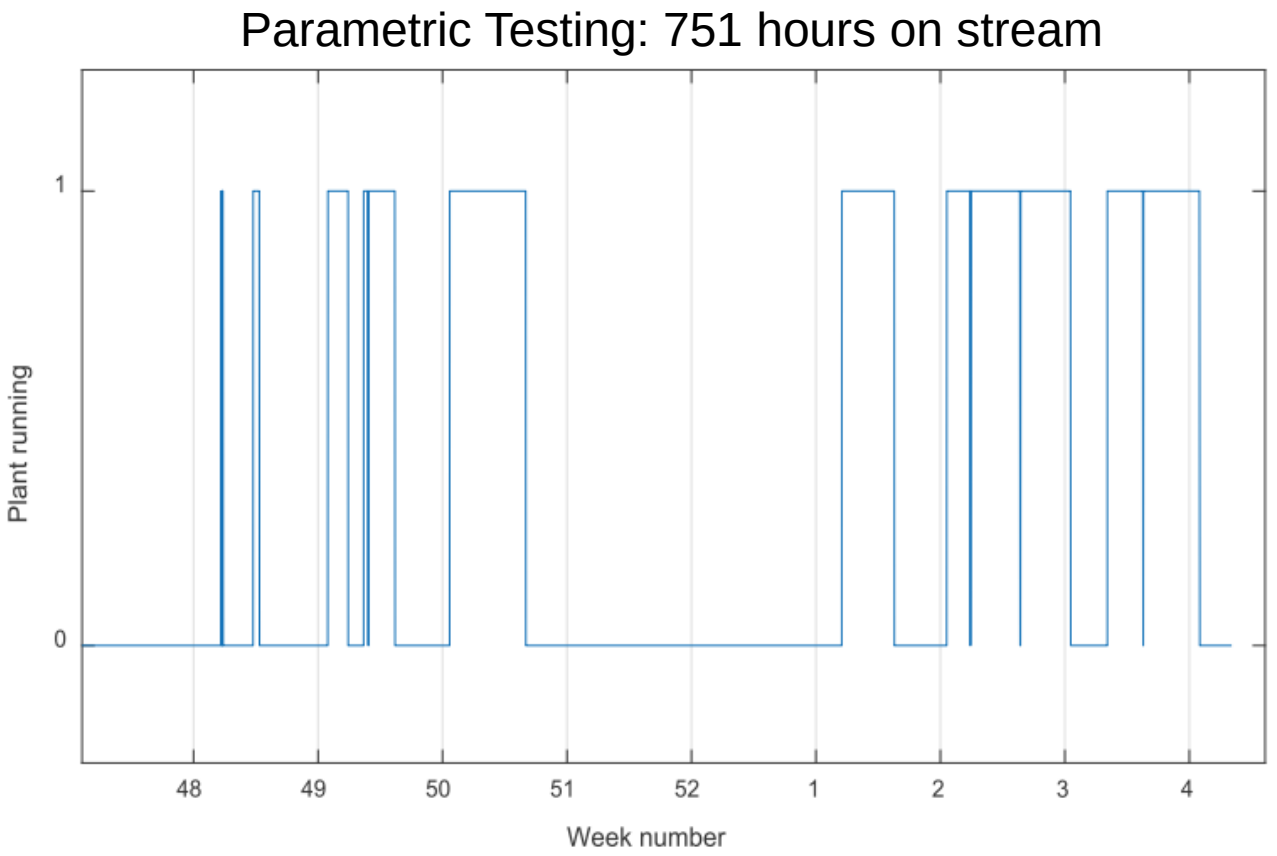
Long-term Performance

What is the CO_2 capture performance under long-term coal flue gas conditions?

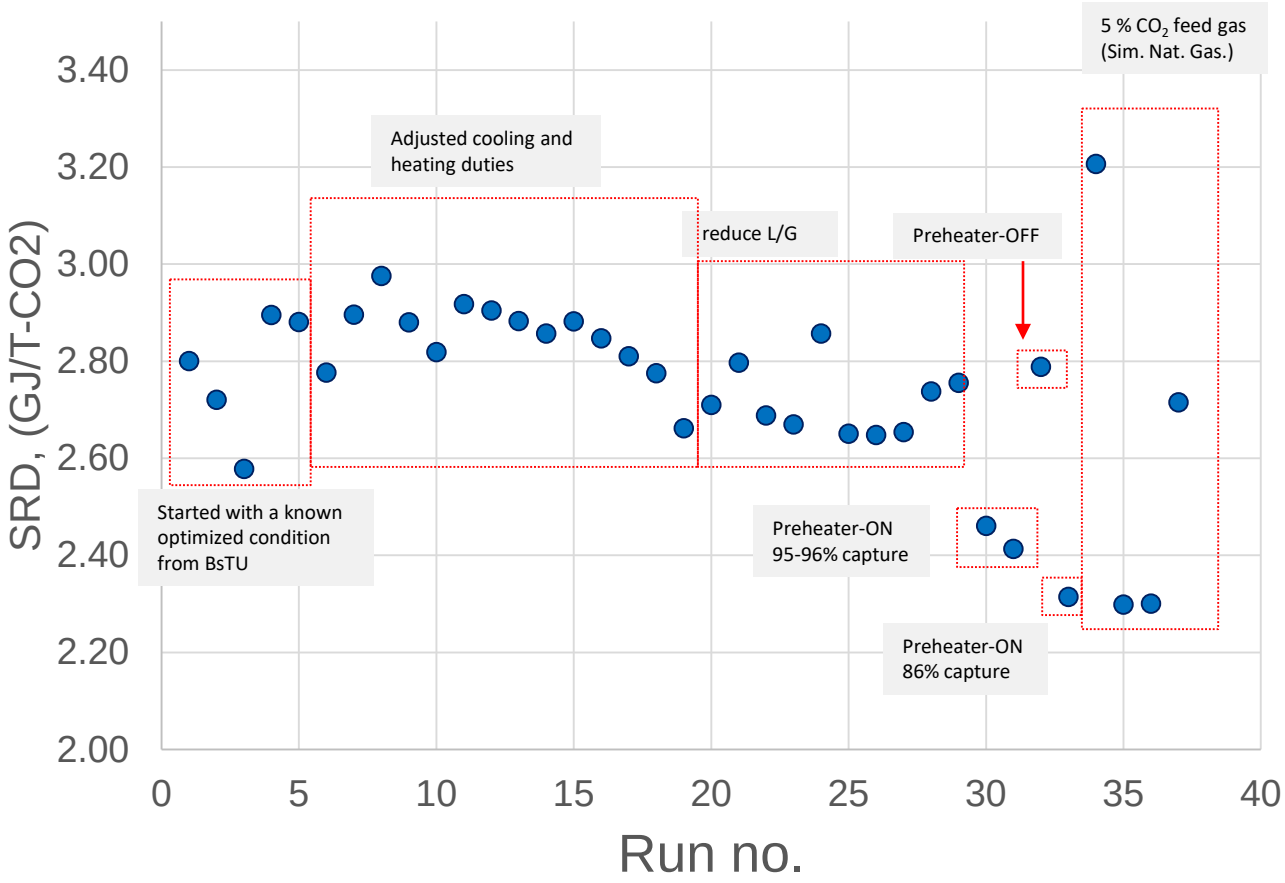
Parametric testing of NAS-5 – Testing Condition

19 steady-state runs performed with varied parameters:

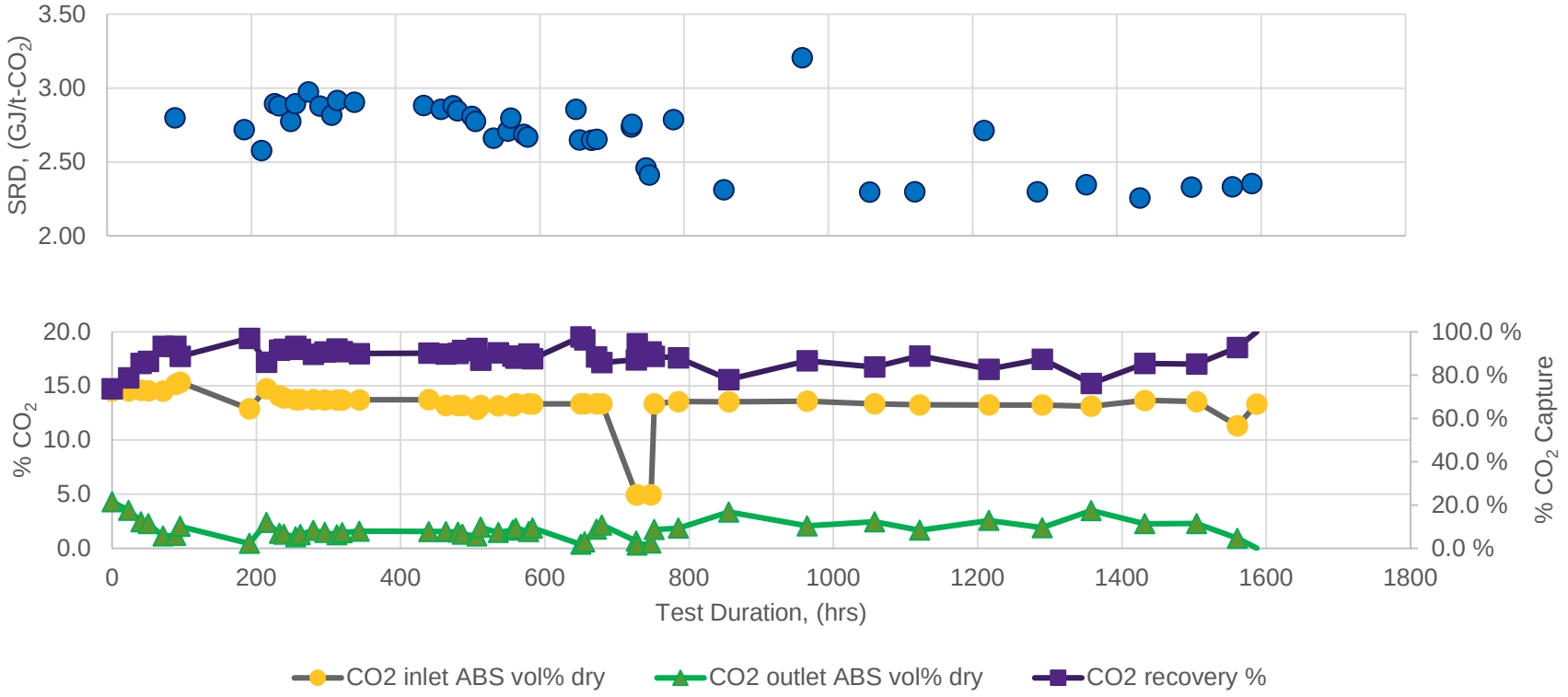
- Flue gas velocity
- FG humidity
- Liquid circulation rate
- Heating duty and its distribution
- Cooling duty and its distribution
- Coal-fired vs. Natural Gas
- Water wash operating conditions
- Acid wash operating conditions



Parametric testing of NAS-5 – SRD

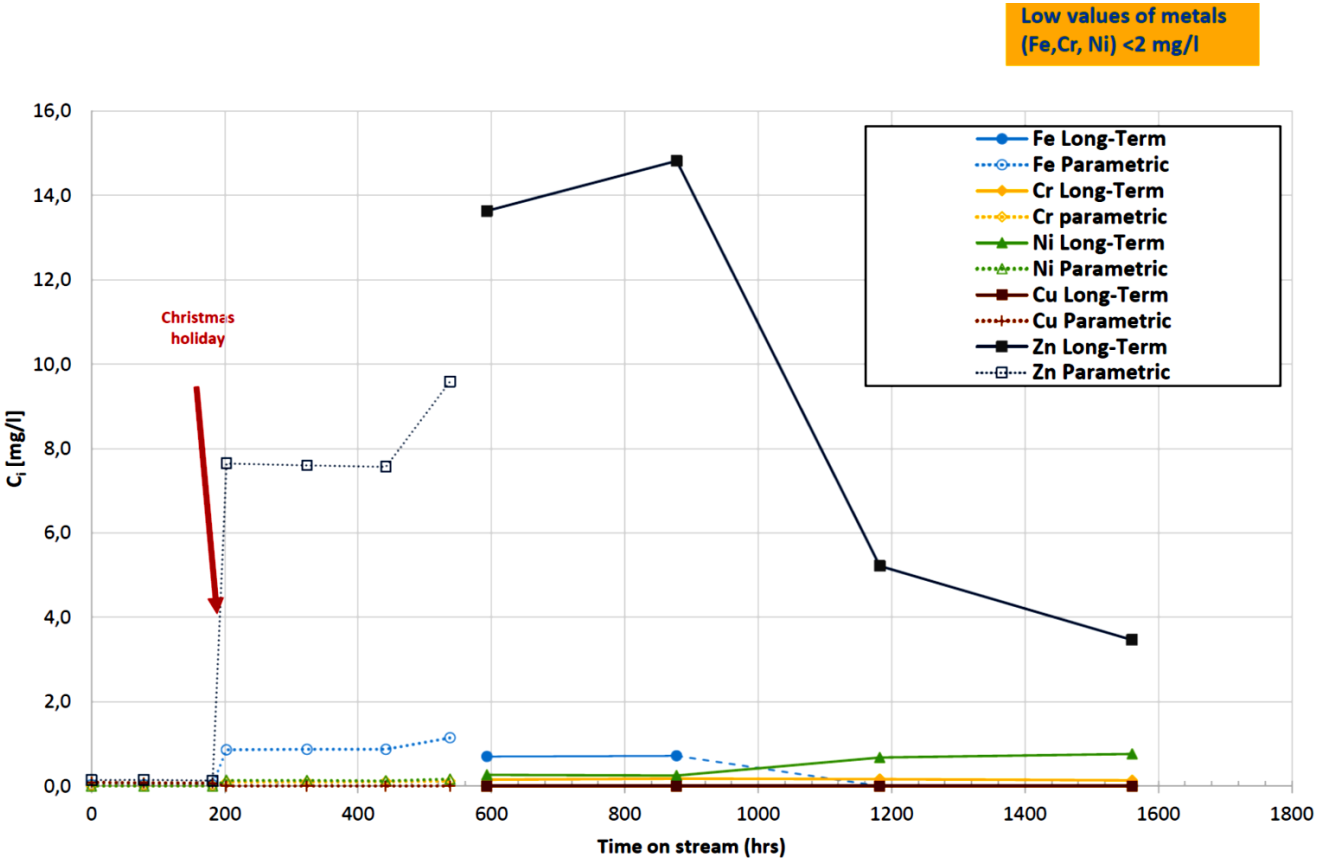


Long-term test of NAS-5



543 h on parametric testing and 1,043 h on stream for long-term testing, total of 1,587 h

Parametric and long-term testing of NAS-5 – Corrosion



- **Corrosion at Tiller**
  - No corrosion issues encountered at Tiller
  - PP liner evaluated at Tiller and result shows good compatibility
- **Material Compatibility**
  - Excellent compatibility
    - SS316
    - PTFE
  - Good compatibility
    - EPDM
  - Corrosion coupon testing being undertaken at National Carbon Capture Center (NCCC) in June-August
    - Carbon steel
    - SS304
    - PP

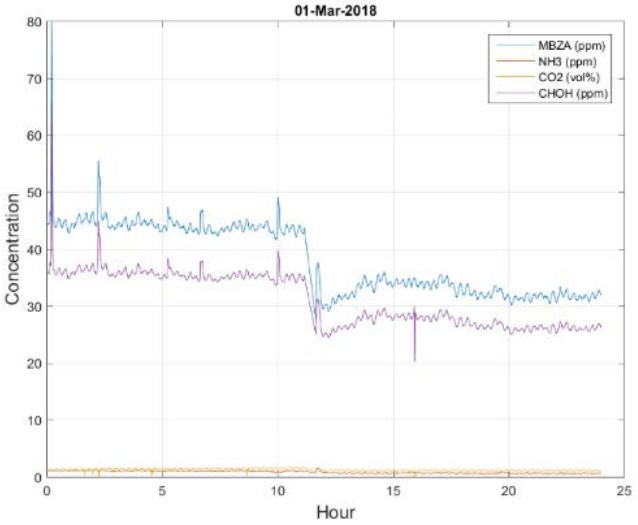
Parametric testing of NAS-5 - Degradation

- Ammonia
  - Controlled well by water wash and acid wash
- Methylamine
  - Manual samples taken near the end of the campaign before and after the water and acid washes to evaluate the mitigation approach
- Nitrosamine
  - Larger increase in nitrosamine seen during this campaign compared to the baseline campaign

- Risk Mitigation
  - Methylamine
    - Awaiting results of measurements after acid wash
  - Nitrosamine
    - Currently studying nitrosamine destruction using thermal degradation
    - Reclaimer at 150°C of a slipstream of lean solvent at the reboiler outlet can reduce nitrosamine levels
    - HSS reclaimer could be used for this purpose

Table 4.2 Determined alkylamines by LC-MS in Lean NAS solvent samples.

Journal no	RUN No	Time on stream [hrs]	NH_3 [mg/L]	Dimethyl-amine [µg/L]	Diethyl-amine [µg/L]	Methyl-amine [µg/L]	Ethyl-amine [µg/L]	Ethylmethyl-amine [µg/L]	Propyl-amine [µg/L]	Dipropyl-amine [µg/L]
P161252	0	**0**	109	130	< 100	64300	< 100	< 100	< 100	< 100
P161293	6	**24**	202	352	111	104114	< 100	< 100	< 100	< 100
P161365	12	**124**	33	700	165	83577	< 100	< 100	< 100	< 100
P17010	13	**151**	< 10	324	106	93767	< 100	< 100	< 100	< 100
P17046	17	**245**	25	208	< 100	81761	< 100	< 100	< 100	< 100



Parametric testing of NAS-5 – Heat-Stable Salts (HSS)

- HSS formation
  - Low levels of HSS measured in baseline campaign
- Phase separation
  - No issues or indication of phase separation during baseline or modified test campaign
  - A second liquid phase will form when the water content is raised above 16%

HSS Formation vs. Time

Run No.	Time on Stream, hrs	HSS, ppm
0	0	0.25
6	24	0.38
12	124	0.32
13	151	0.32
17	245	0.32
22	381	0.45

NAS Process Testing at NCCC and Cost/Benefit Analysis

- Scheduled for 3 months of testing, starting in late May through August
- Expose NAS with power plant's flue gas
- Further reduce the deployment risk, particularly on fugitive emissions and solvent degradation
- Tested NAS at NCCC using the SSTU
- Test advanced NAS-5 formulation at NCCC to determine:
  - operating windows
  - solvent degradation
  - water balance
  - emissions
  - amine loss
  - other operational issues
- Continuous run of NAS-5 using coal-derived flue gas for at least two months
- Recently completed with 570 hours on stream, data is being analyzed

Next Steps: Project Closeout/Pilot-scale Testing/Emission Mitigation

- Update process simulation with Tiller data to predict emission and waste generation
- Refine TEA with the additional solvent reclaimer unit
- EHS assessment
- Site preparation and solvent manufacturing for TCM testing

- Large pilot testing for non-aqueous solvent technology at Technology Center Mongstad (TCM) under DE-FE0031590
  - Under contract negotiation, project starts in May 2018
  - 10 MW equivalent
  - Range of flue gas compositions (including coal, NGCC, etc.)
  - Extended operation with finalized NAS formulation and process design
- Ongoing discussion with TCM on testing schedule, site preparation, operational experience from BsTU and Tiller

CO_2 Technology Centre Mongstad (TCM), Mongstad, Norway

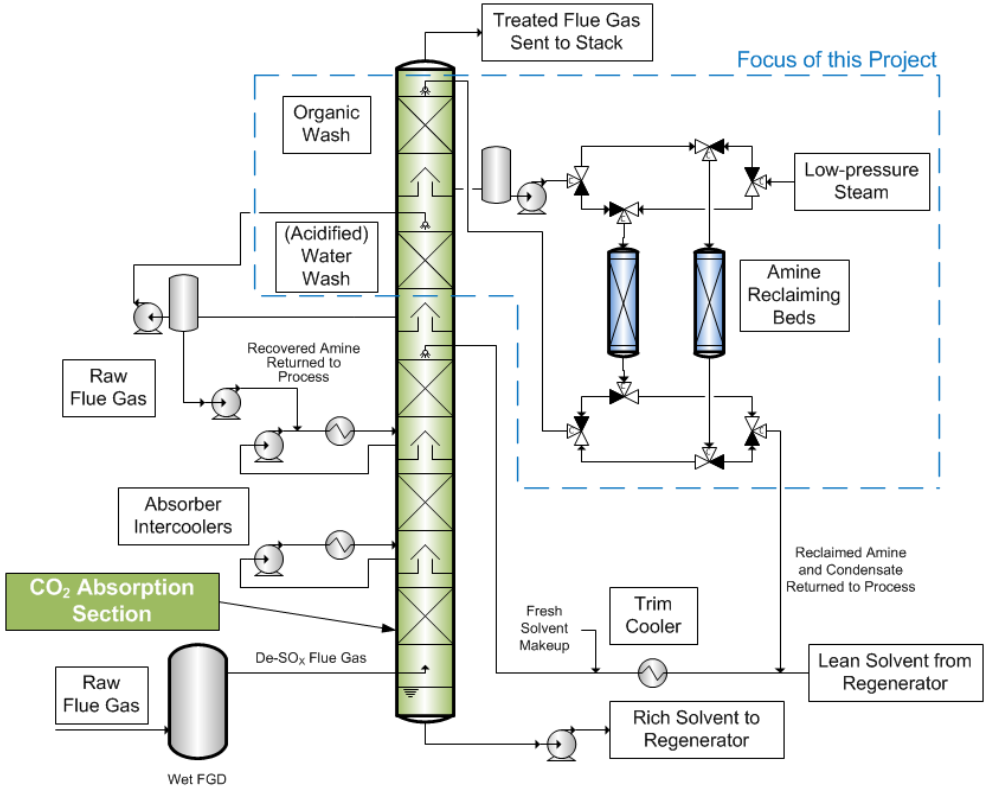
Next Steps: Project Closeout/Pilot-scale Testing/Emission Mitigation

- Bench-scale testing for Water-Lean Solvent systems (WLSs) at RTI and SINTEF's Tiller under DE-FE0031660

The specific goals of this project are to:

- Characterize and understand the emission produced by water-lean solvent
- Develop a empirically derived emission model based on the solvent physical properties and on critical operating parameters from the absorber and wash section
- Evaluate suitable process arrangement for emission reduction BACT devices
- Demonstrate the effectiveness of these emission mitigation devices on the bench-scale system optimized for water-lean solvent

More Detail: Poster Presentation



Potential emissions control technologies for WLS systems to be incorporated at the CO_2 capture plant

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- DOE Project Manager: Steve Mascaro

- RTI cost share and project partner SINTEF