Engineering Scale Testing of Transformational Non-Aqueous Solvent-Based CO_2 Capture Process at Technology Centre Mongstad

DE-FE0031590

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Acknowledgement and Disclaimer

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Project Summary

Objective: Testing and evaluation of the transformational Non-Aqueous Solvent (NAS)-based CO_2 capture technology at engineering scale at TCM

Key Metrics

- Solvent performance including capture rate, energy requirements, solvent losses
- Solvent degradation, corrosion, emissions
- Resolve remaining technical and process risks
- Technoeconomic and EHS evaluation

Specific Challenges

- Operate TCM plant within emission requirements
- Minimize rise in absorber temperature
- Maximize NAS performance with existing hardware limitations

Timeframe: 8/8/18 to 12/31/21*

Total Funding: $18,738,512*

*Pending DOE approval

Partners: CO_2 Technology Centre Mongstad, EPRI Electric Power Research Institute, CCSI² Carbon Capture Simulation for Industry Impact, SINTEF

Project Objectives

DOE Performance Goal:

- New coal-fired power plants with CO_2 capture at a cost of electricity 30% lower than the baseline cost of electricity from a supercritical PC plant with CO_2 capture, or approximately $30 per tonne of CO_2 captured by 2030.
  - Reducing the parasitic energy penalty is the most important factor

Project Objectives:

- Confirm the potential to reduce the parasitic energy penalty by 20 to 40% compared with the MEA process
- Demonstrate the long-term process operational reliability
- Verify solvent degradation rate, emissions, solvent loss, and corrosion characteristics
- Perform a NAS-specific revamp of the TCM unit to show lower energy penalty
- Demonstrate NAS in the modified TCM unit for at least two months

Development History for Novel, Non-Aqueous Solvents

Technology Status

- Cumulative DOE funding > $20 MM and ~$15 MM funding from RTI industrial partners
- Solvent development work finalized
- Pilot testing completed at SINTEF Tiller and National Carbon Capture Center (NCCC)
- Pre-commercial demonstration (12 MW) underway at Technology Center Mongstad (TCM), Norway (*current)*

Key Technical Advantages

- CO_2 Capture Technology with substantially reduced energy consumption
- Minimum changes to existing process to realize NAS optimal performance
- Commodity-scale production ready

Impact

- Long-term potential for large scale CO_2 capture applications
- Commercialization path via process technology licensing
- Application potential for high-efficiency acid gas separations

R&D Strategic Approach

Breakdown of the Thermal Regeneration Energy Load

$$q_R = \left[\frac{C_P(T_R - T_F)}{\Delta\alpha} \cdot \frac{M_{sol}}{M_{CO_2}} \cdot \frac{1}{x_{sol}}\right] + \left[\Delta H_{V,H_2O} \cdot \frac{p_{H_2O}}{p_{CO_2}} \cdot \frac{1}{M_{CO_2}}\right] + \left[\frac{\Delta H_{abs,CO_2}}{M_{CO_2}}\right]$$

Reboiler Heat Duty — Sensible Heat — Heat of Vaporization — Heat of Absorption

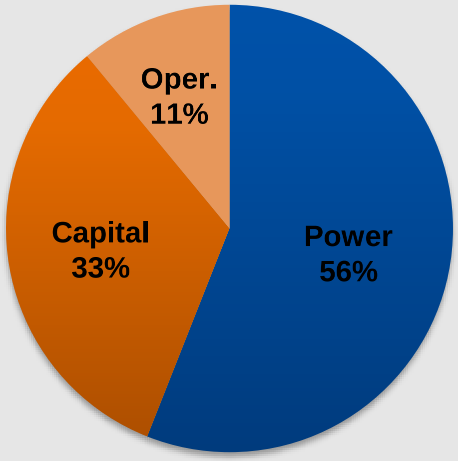
Solvent	C_p [J/g K]	ΔH_{abs} [kJ/mol]	ΔH_{vap} [kJ/mol]	x_{solv} [mol solvent/mol solution]	$\Delta\alpha$ [mol CO_2/ mol solvent]	Reboiler Heat Duty [GJ/t-CO_2]
30 wt% MEA-H_2O	3.8	85	40	0.11	0.34	3.75
RTI's NASs	2.0	85	negl.	0.47	0.45	2.40

For NAS, heat of vaporization of water becomes a negligible term to the heat duty

Process capable of achieving these criteria will have a lower energy penalty than SOTA processes

Path to Reducing ICOE and Cost of CO_2 Avoided

- Primarily focus on reducing energy consumption – reboiler duty
- Reduce capital expenditure
    - Simplify process arrangement
    - Materials of construction
- Limit operating cost increase



[1] Rochelle, G. T. Amine Scrubbing for CO_2 Capture. *Science* **2009,** 325, 1652-1654.

NAS CO_2 Capture Technology Path to Market

Lab-Scale Development & Evaluation (2010-2013)

Solvent screening and Lab-scale evaluation

~$2.7MM

Large Bench-Scale System (RTI facility, 2014-2016)

Demonstration of key process features (≤ 2,000 kJ/kg CO_2)

~$3 MM
6kW

Pilot Testing at Tiller Plant (Norway, 2015-2018)

Demonstration of all process components at pilot scale

~$3MM
60 kW

Pilot Testing at SSTU (NCCC, 2018)

Degradation, emission, and corrosion characterizations under real flue gas

~$0.75MM
50 kW

Emissions control (Tiller, 2018+)

Effective emissions mitigation strategy for WLS at engineering-scale

~$3.5MM

Engineering-Scale Validation (2018+)

Pre-commercial Demonstration at Technology Centre Mongstad, Norway (~12 MWe)

~$18.75 MM
12 MW

From lab to large scale (12 MW) demonstration through series of projects

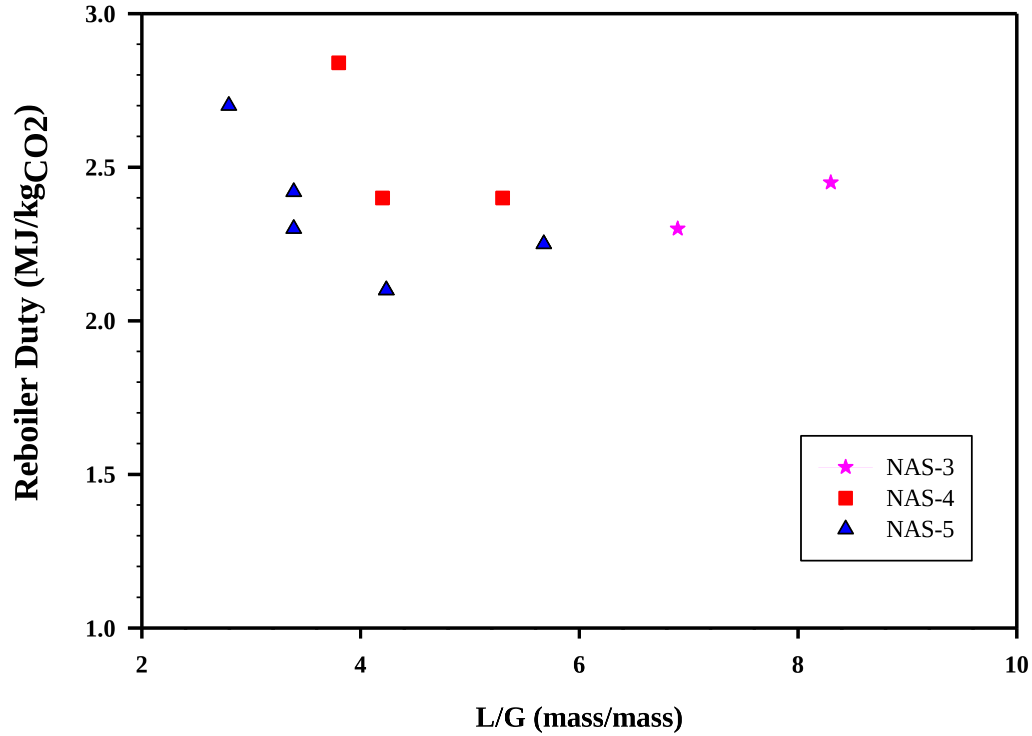
Bench-Scale Testing of Refined Solvents

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

6 kW ~120 kg CO_2/day

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

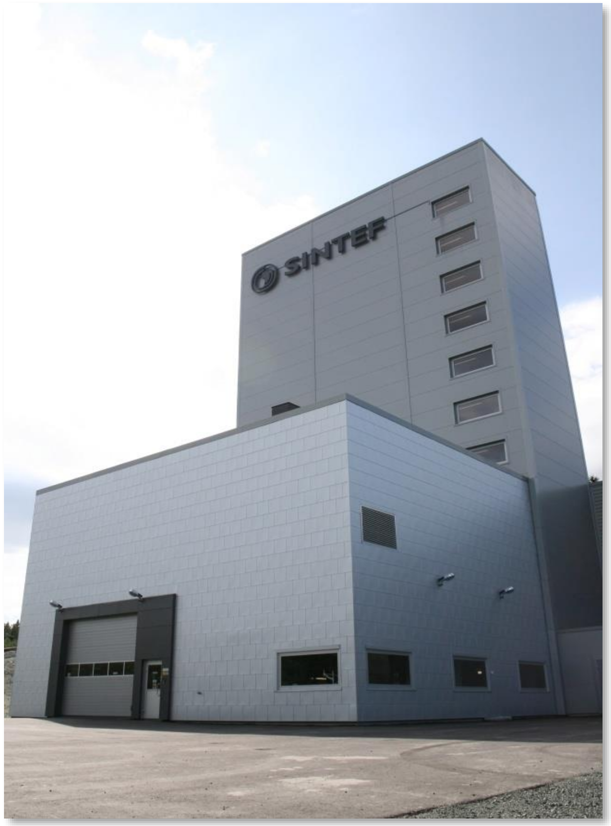


Simulated Flue Gas Properties	
FG Flow Rate:	100 to 485 SLPM
CO_2 Feed Rate:	1.8 to 8.6 kg/h
Feed Temp.:	30 to 50°C
Target Comp:	CO_2: 13.3%; H_2O: 6.1%; O_2: 2.35%; N_2: bal.
CO_2 Content:	up to 20 %vol
Water Content:	~0 to 12.3%vol

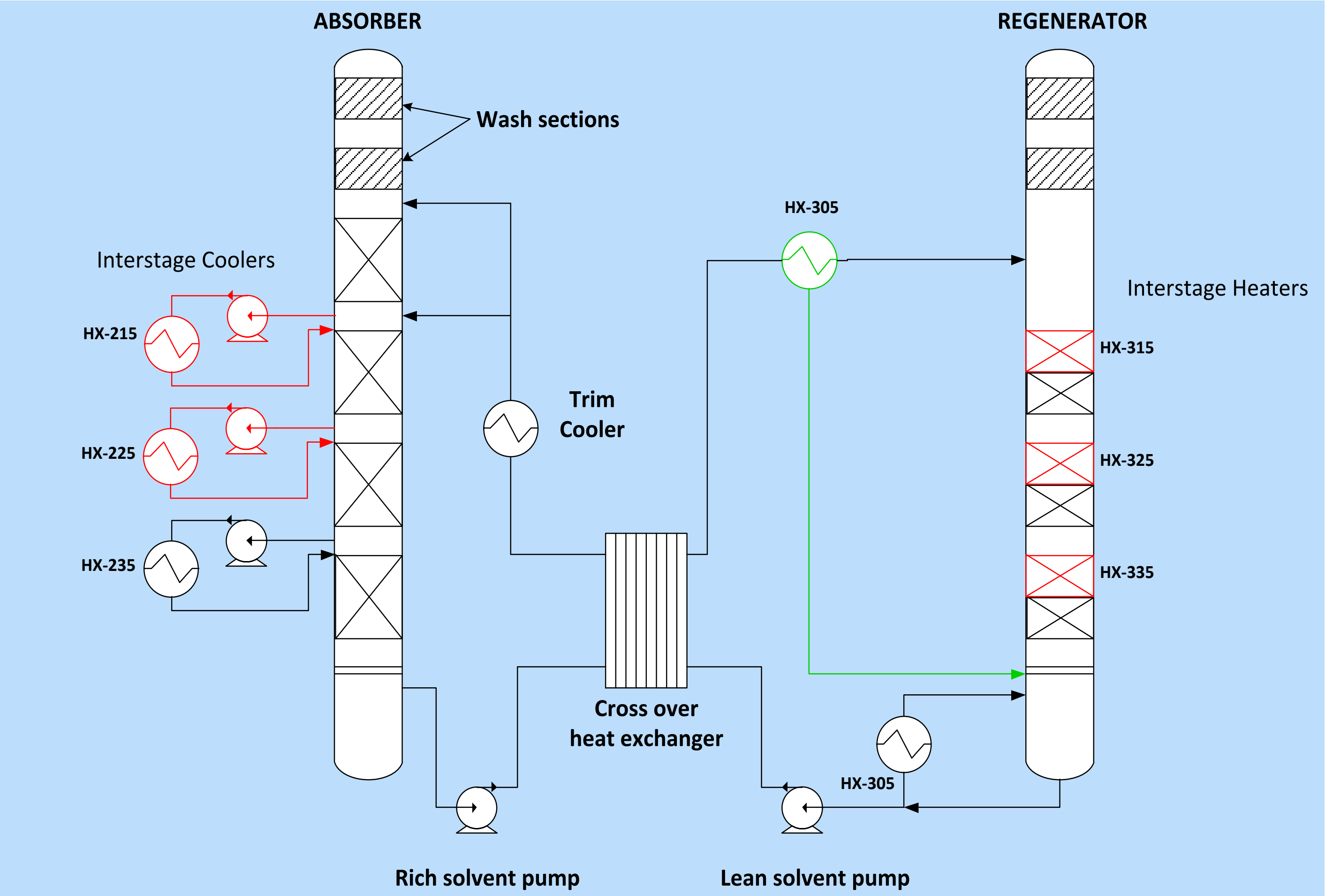
Testing of RTI NAS in Tiller Pilot Plant

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

Results:
- MEA baseline testing completed
- NAS baseline testing completed
  - 350 hours of testing with propane + 50 hours with coal flue gas
  - Confirmed reduction in reboiler duty



Design Improvements for NAS-based Process



Additional equipment:

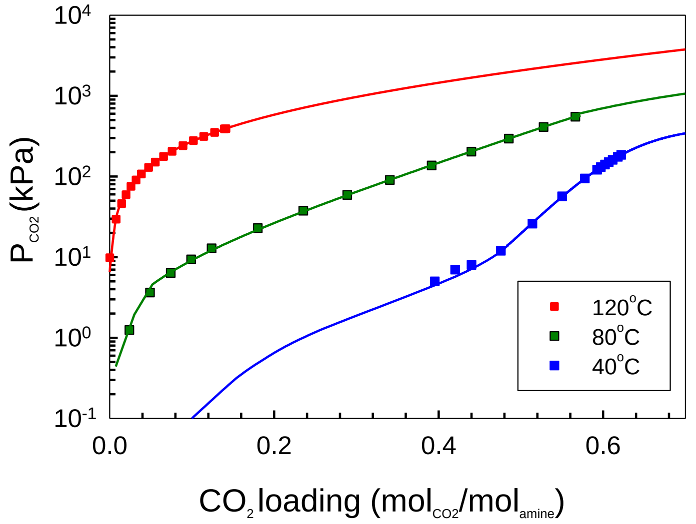
- Interstage coolers
- Interstage heaters
- Rich-solvent preheater

SRD Highlights:

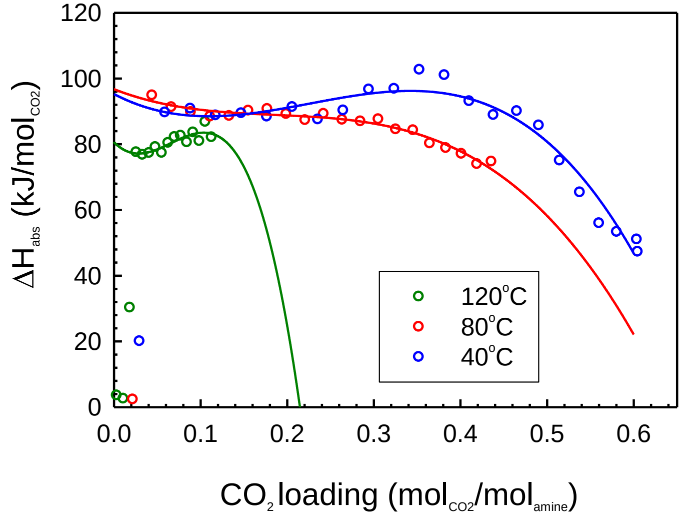
- Interstage coolers: 2.19 (all) to 3.23 (none)
- Interstage heaters: 2.19 (all) to 2.86 (none)
- The use of preheater (HX-305) appeared to lower the SRD

Process Model for Non-Aqueous Solvents

- Thermodynamic Model
  - VLE, Reaction kinetics and ΔH_{abs} measured at RTI
  - Electrolyte NRTL symmetric method for non-ideal liquids
  - RK equation of state for vapor
  - Concentration-based reaction kinetics
  - Rate-based models for absorber and stripper
- Hydrodynamic Model
  - Viscosity and heat capacity data measured at RTI
  - Other properties such as surface tension, thermal conductivity etc., estimated using Group contribution methods or using interaction parameters.
  - Electrolyte transport property models



Regressed VLE



Regressed Heat of absorption

Rigorous Aspen Plus rate-based model for CO_2 Capture using NAS

BP1 Key Tasks

Key Tasks	Milestone Number and Task	Approaches/ planned Activities	Planned Completion Date
Initial TMP	M3/T1	• Evaluation of technology potential	December 31, 2018
EH&S report as outlined in Appendix E of the FOA	M4/T2	• Evaluate environmental health and safety concerns of planned test campaign • Identify potential risks	January 31, 2019
Solvent qualification test results	M5/T3	• Perform qualifying tests at SINTEF-Tiller to show equivalent performance of vendor-prepared solvent	September 30, 2019
FEED study and cost estimate	M6/T4	• Perform FEED study with EPC at TCM to determine coarse cost estimate of plant modifications	December 31, 2019

BP1 Success Criteria : Completion of FEED study and favorable cost-benefit analysis justifying modifications to TCM to show improved performance of NAS (Task 4)

Process Emissions and Solvent Losses

Technical Issues:

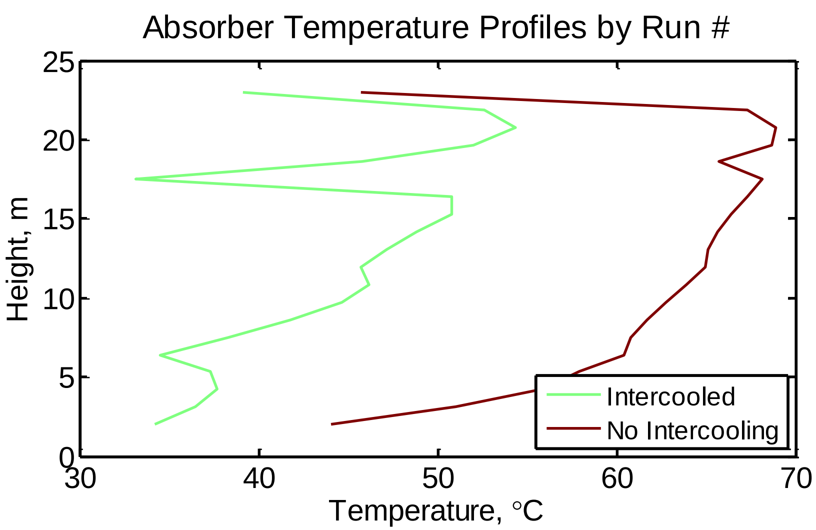
- TCM emissions limit of 1 ppmv
- Emission challenges from aerosols
  - significant impact on amine emissions from aerosols observed at SINTEF and NCCC
  - Significant impact on amine emissions from coal particulates entrained at higher flue gas flow rates
- Emission challenges from TCM set-up and NAS system operations
  - Increase in amine emissions w/o intercooling at TCM

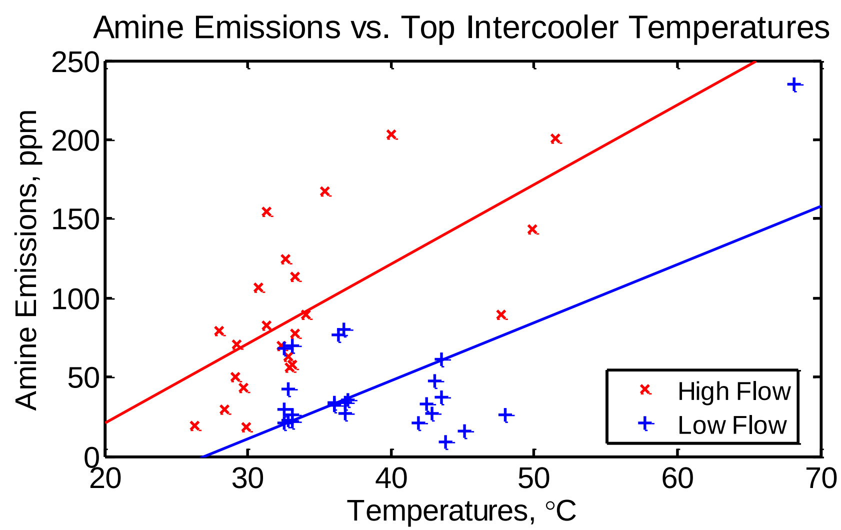
Solutions:

- Control emissions by mitigating impact of aerosols
  - Begin by testing on CHP flue gas with no particulates to refine emission control strategies
  - Utilize Brownian diffusion unit (BDU) to reduce particulates from RFCC
- Control emissions by altering NAS system operations
- Control emissions with intercooler
- Control emissions with water wash
  - Reduce water wash temperature
- Control emissions with acid wash
  - Utilize acid wash to reach < 1 ppm emissions

Control Emissions by Altering NAS System Operations

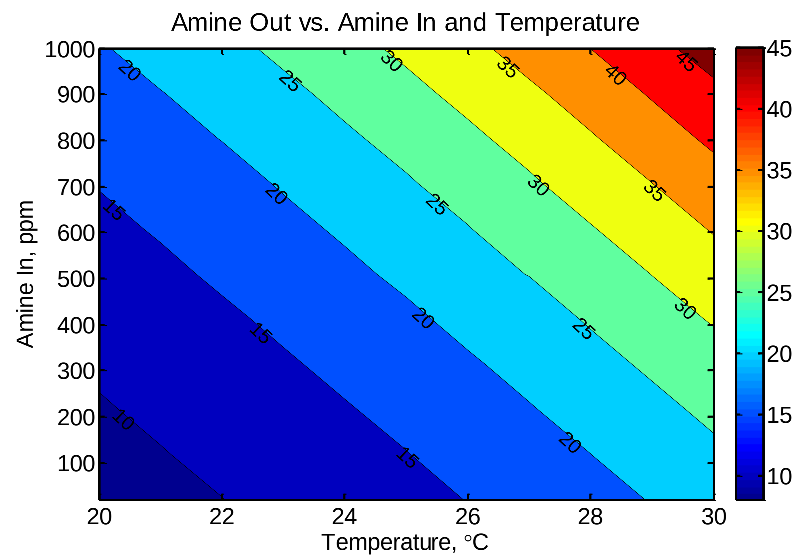
Higher amine emissions due to absence of an intercooler at TCM





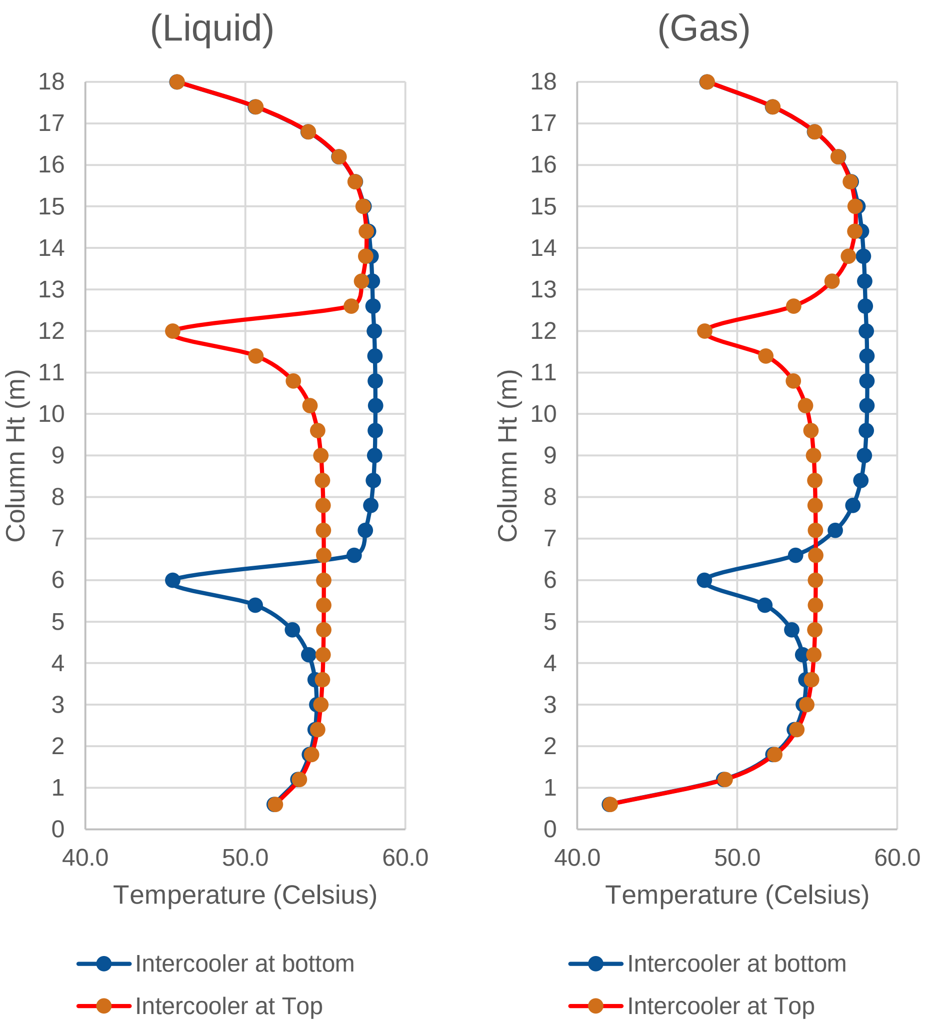
Emission reduction strategies based on testing at Tiller and RTI:

- Operating the water wash column at lower temperatures
- Lowering the gas flow-rate
- Adding an intercooler to the absorber



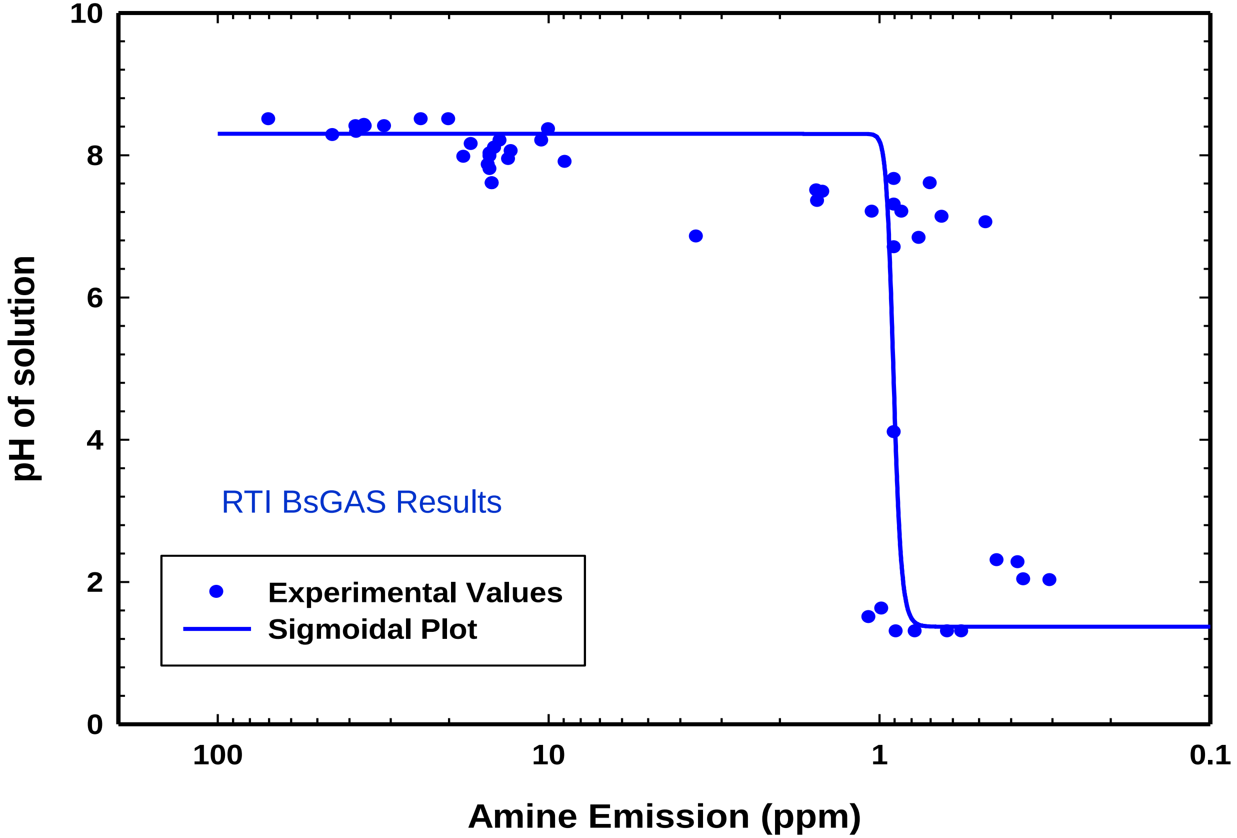
Use of Process Models to aid TCM modifications work

- Evaluate impact of intercooler placement (top or bottom of the absorber column)
  - RCC25-50 case (inlet at 25 ° C, 50% flow) chosen for evaluation
  - Model shows low sensitivity to intercooler location for SRD and heat removal.
  - For both cases
    - SRD = 2.71 GJ/t-CO_2
    - Heat Removal in intercooler = 2.72 MW
- Estimate amine emissions out of water wash and acid wash
  - Model emissions after absorber at 400 ppm, reduced to < 1 ppm after water wash and acid wash



Predicted temperature profile across absorber

Control Emissions with Acid Wash



Key finding:

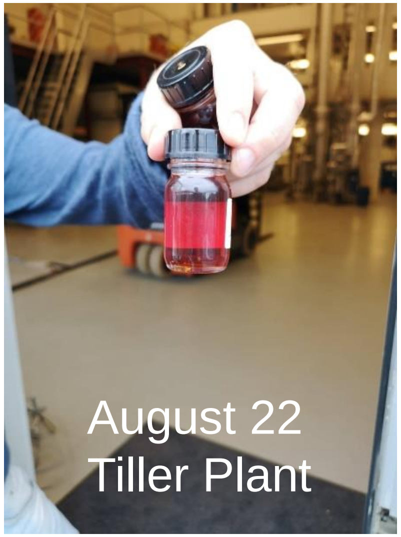
- Testing at RTI show outlet amine emissions < 1 ppm when pH was below 7

Strategies for TCM:

- Operate at lower gas flow rates to lengthen residence time in wash-section
- Lower gas flow-rates will also reduce aerosol formation due to lower particle entrainment

Solvent Qualification at SINTEF Tiller Plant

- 700-liter solvent batch produced by Clariant
- Delivered to SINTEF Tiller in June 2019
- Solvent loaded into the plant
- Tiller functional testing underway
- Qualification testing underway September 2



August 22
Tiller Plant

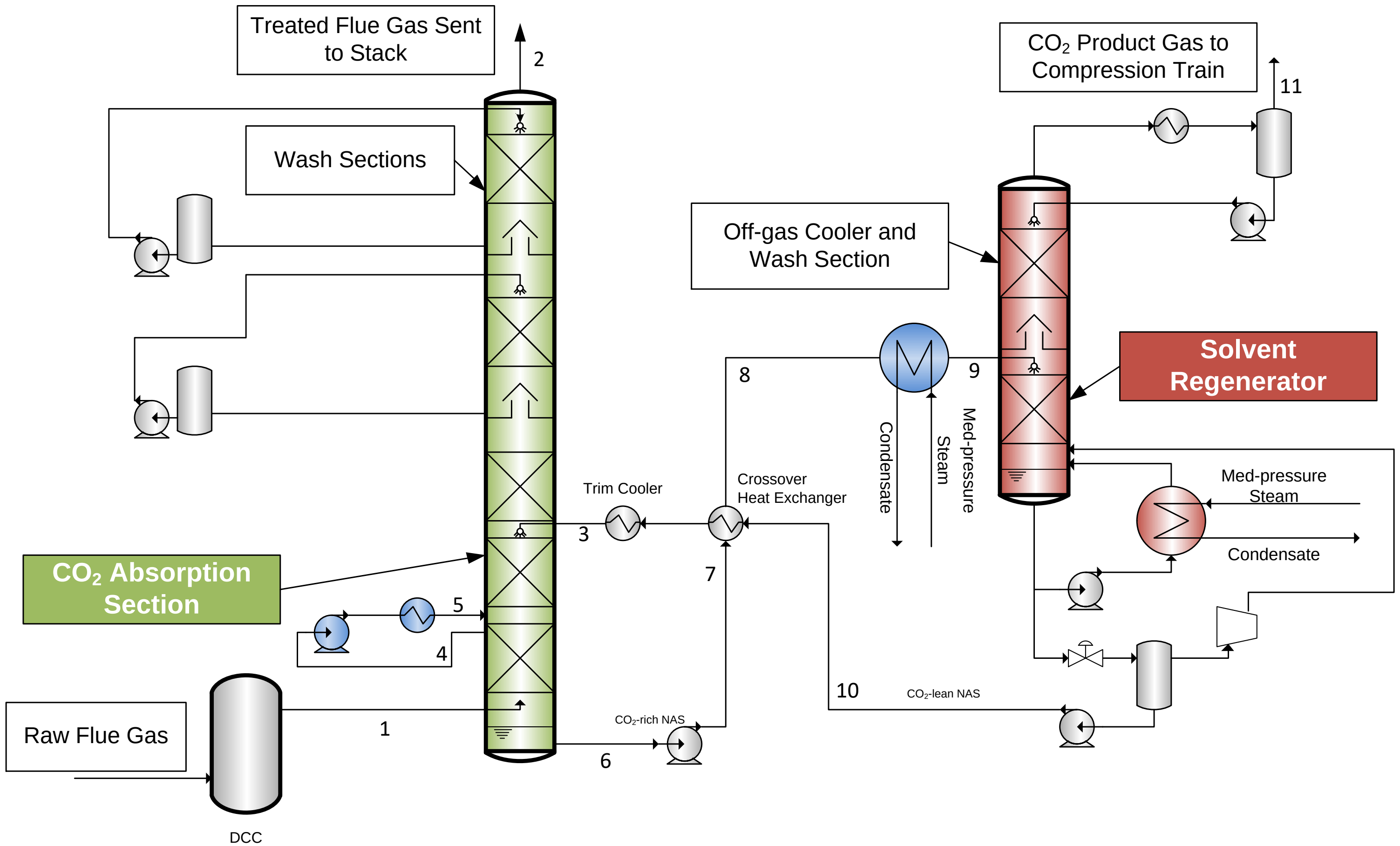
Day	Night	Priority	No	Activity description
1	1	1	1	NAS-Optimal (Prev. Cond.)
2		2	2	TCM Modified (Bot IC and Preheater)
	2	2	2a	TCM Modified (Bot IC and Preheater, Higher L/G)
3		2	3	TCM Modified (Top IC and Preheater)
	3	2	3a	TCM Modified (Top IC and Preheater, Higher L/G)
4		2	4	TCM Modified (2 ICs and Preheater)
	4	2	5	TCM Modified (2 ICs, 2 IHs, and Preheater)
5		3	6	TCM Baseline (No Intercooling, Higher L/G)
	5	3	7	TCM Baseline (No Intercooling, Higher L/G, Lower CR)
6	6	4	8	TCM Modified (Top IC and Preheater, Higher L/G, Demister)

SINTEF

FEED Study

- Selected EPC Pressura to perform FEED study
- Commenced August 19th, 2019
- Determine coarse cost estimate for modifications +/- 20%
- Absorber intercooler
- Regenerator pre-heater

PRESSURA



Summary

- Methods identified and demonstrated for reducing amine emissions <1ppm at TCM
- Solvent qualification underway at SINTEF to demonstrate performance of manufactured solvent
- EPC company selected for to perform FEED study at TCM
- FEED study underway to determine cost of TCM modifications

Thanks for your attention!

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