Engineering-scale testing of non-aqueous solvent for CO_2 capture at Technology Centre Mongstad

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RTI INTERNATIONAL

** Los Alamos National Laboratory, NM, USA

Evaluating technology options to mitigate greenhouse gas emissions
pccc-7
Post Combustion Capture Conference

Project Summary

U.S. DEPARTMENT OF ENERGY | NATIONAL ENERGY TECHNOLOGY LABORATORY

Description: Testing and evaluation of 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
- Technoeconomic and EHS evaluation

Specific Challenges

- Resolve remaining technical and process risks
- Operate TCM plant within emission requirements
- Minimize rise in absorber temperature
- Maximize NAS performance with existing hardware limitations

Timeframe: 8/8/18 to 06/30/23

Total Funding: $17,384,512

Partners: SINTEF; EPRI ELECTRIC POWER RESEARCH INSTITUTE; TECHNOLOGY CENTRE MONGSTAD; CCSI² Carbon Capture Simulation for Industry Impact

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

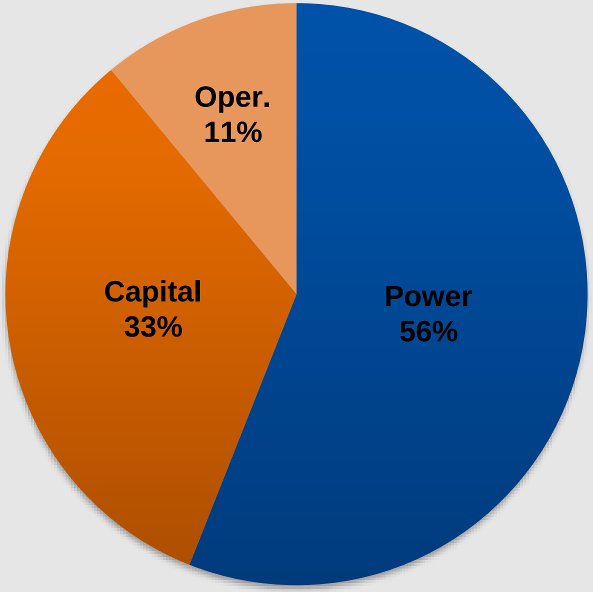
Solvent	C_p [J/g K]	ΔH_{abs} [kJ/mol]	ΔH_{vap} [kJ/mol]	x_{solv} [mol solvent/mol solution]	$\Delta\alpha$ [mol CO_2/ mol solvent]	Reboiler Heat Duty [GJ/t-CO_2]
30 wt% MEA-H_2O	3.8	85	40	0.11	0.34	3.75
RTI's NASs	2.0	85	negl.	0.47	0.45	2.40

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

Sensible heat term is decreased due to lower heat capacity, higher loadings, and higher amine concentration relative to baseline

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.

Technology Overview – NAS Technology Development Path

Lab-Scale Development & Evaluation

(2010-2013)

Solvent screening and lab-scale evaluation

0.0015 t-CO_2/day

TRL 1-2

Large Bench-Scale System (RTI facility)

(2014-2016)

Demonstration of key process features (≤ 2.3 GJ/t CO_2) at bench scale

0.11 t-CO_2/day

TRL 2-3

Pilot Testing at Tiller Plant Norway,

(2015-2018)

Demonstration of all process components at pilot scale

1.0 t-CO_2/day

TRL 3-5

Pilot Testing at SSTU, NCCC

(2018)

Degradation, emission, corrosion characterizations under real flue gas

1.0 t-CO_2/day

TRL 3-55

RTI Emissions Control

(2018-2021)

Effective emissions mitigation strategy for water-lean solvents

1.1 t-CO_2/day

TRL 2-3

Engineering-Scale Validation, TCM, Norway

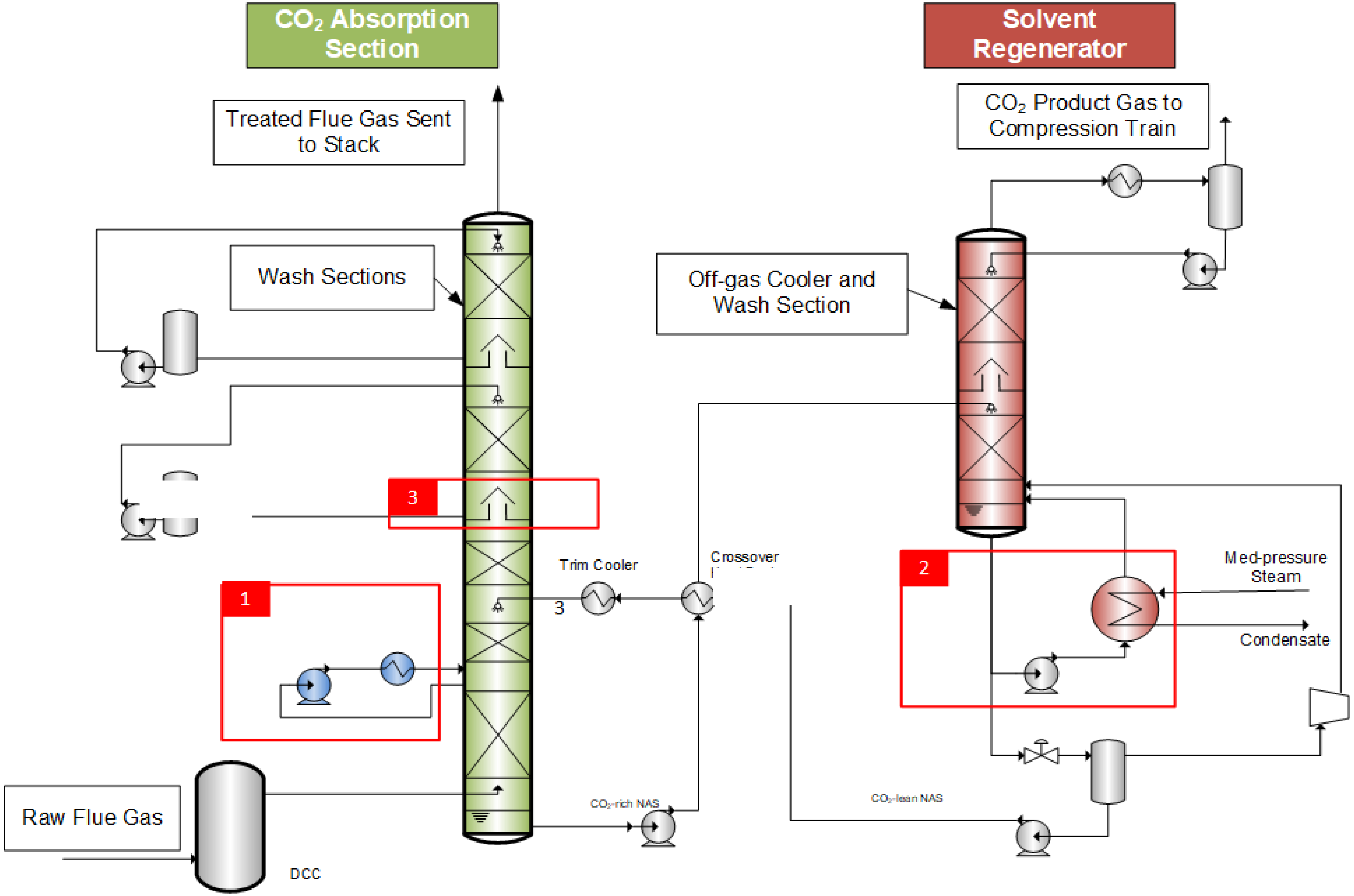
(2018-2023)

Pre-commercial demonstration at TCM, Norway (~12 MWe)

220 t-CO_2/day

TRL 5-6

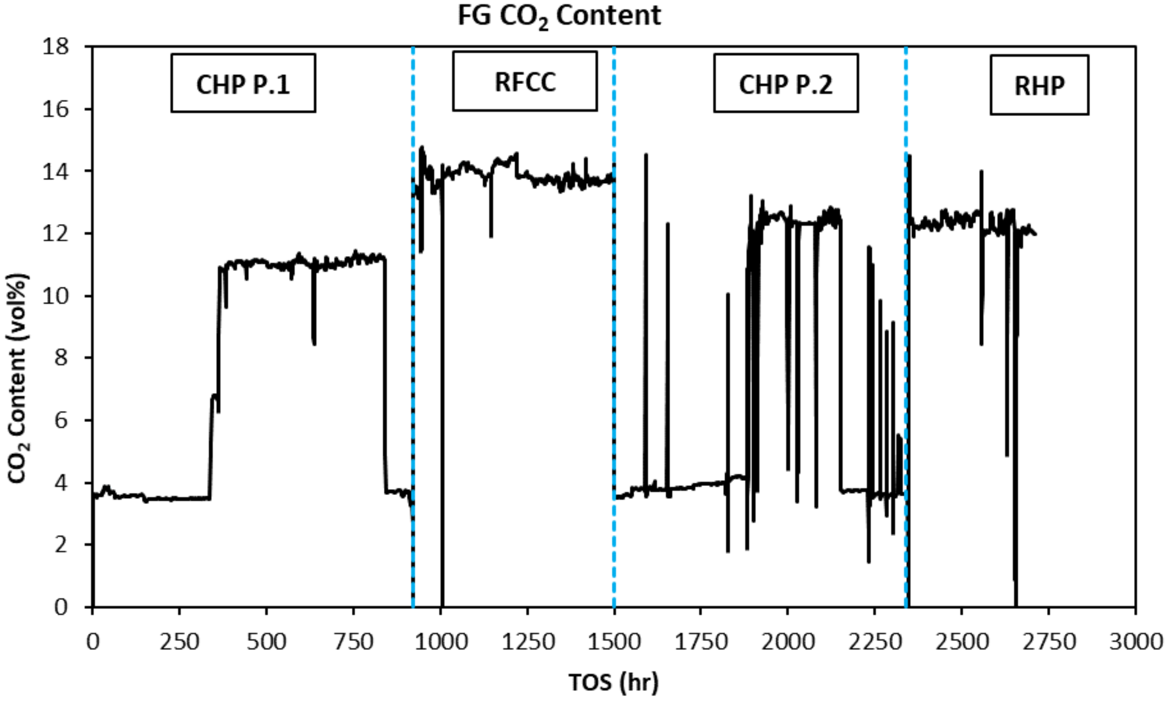
TCM Amine Plant Modifications

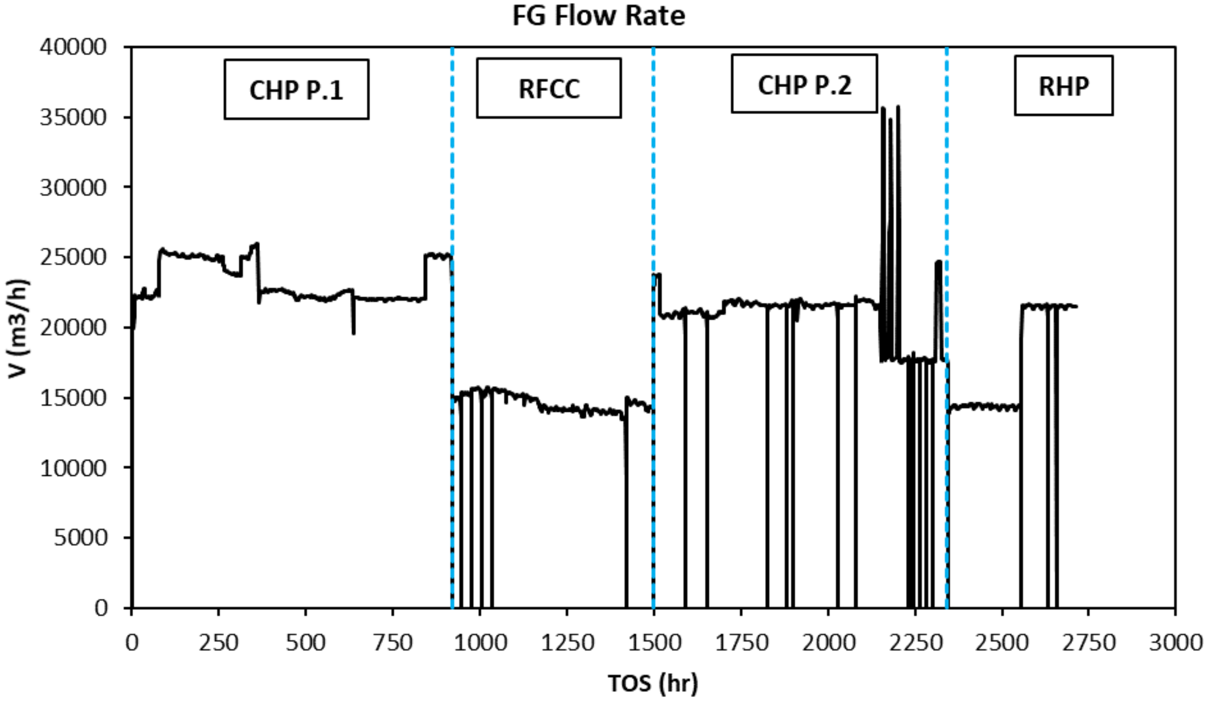


Modifications:

1. Addition of absorber interstage cooler.
2. Forced recirculation pump
3. Chimney tray tightening to reduce leakage of water from lower water wash to absorber for water control.

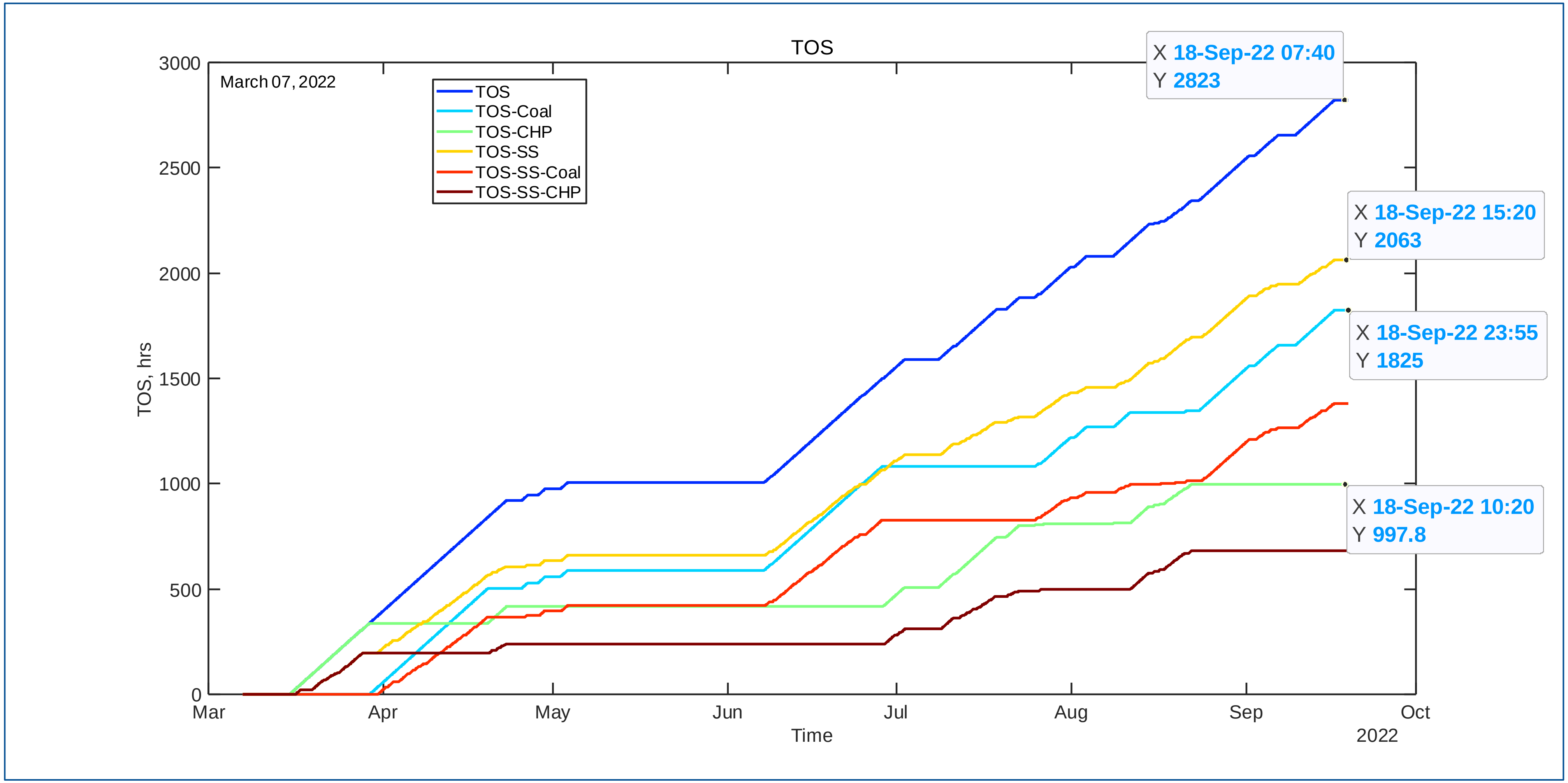
Test Campaign Segments and Flue Gas Characteristics





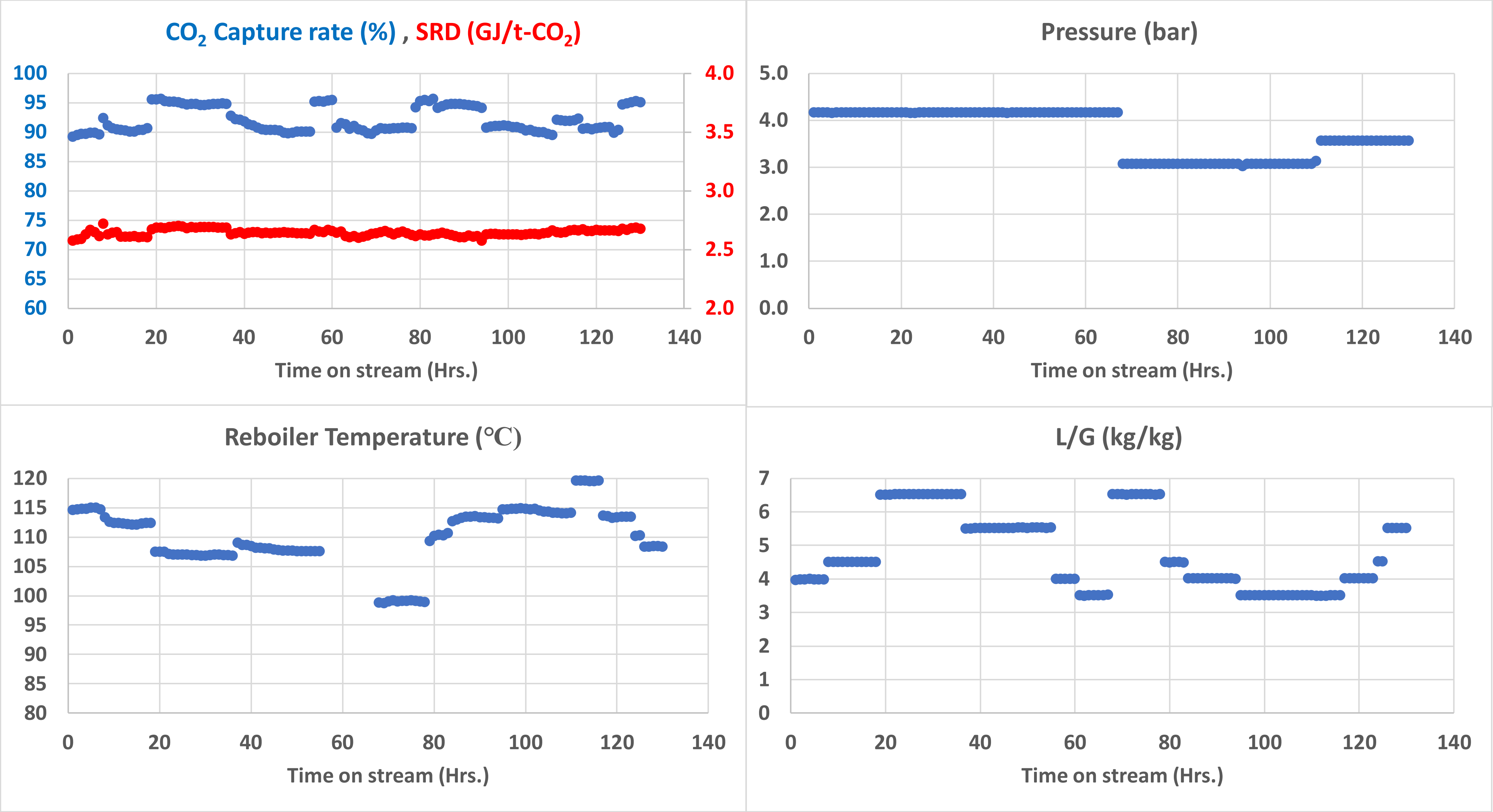
Flue Gas	CO_2 (vol %)	O_2 (vol%)	NO_2 (ppm)	NO (ppm)	SO_2 (ppm)
CHP	3.9	12.9	3.2	23.9	1.0
RFCC	14.7	2.4	1.2	66.5	0.0
CHP w/ Recycle (RFCC Mimic)	12.6	6.1	3.0	45.4	0.8
RHP (aka MHP)	13.7	4.6	4.6	50.9	0.4
RHP w/ Recycle (Cement Mimic)	18.0	4.6	5.0	3.4	0.0

Time on Stream Highlights

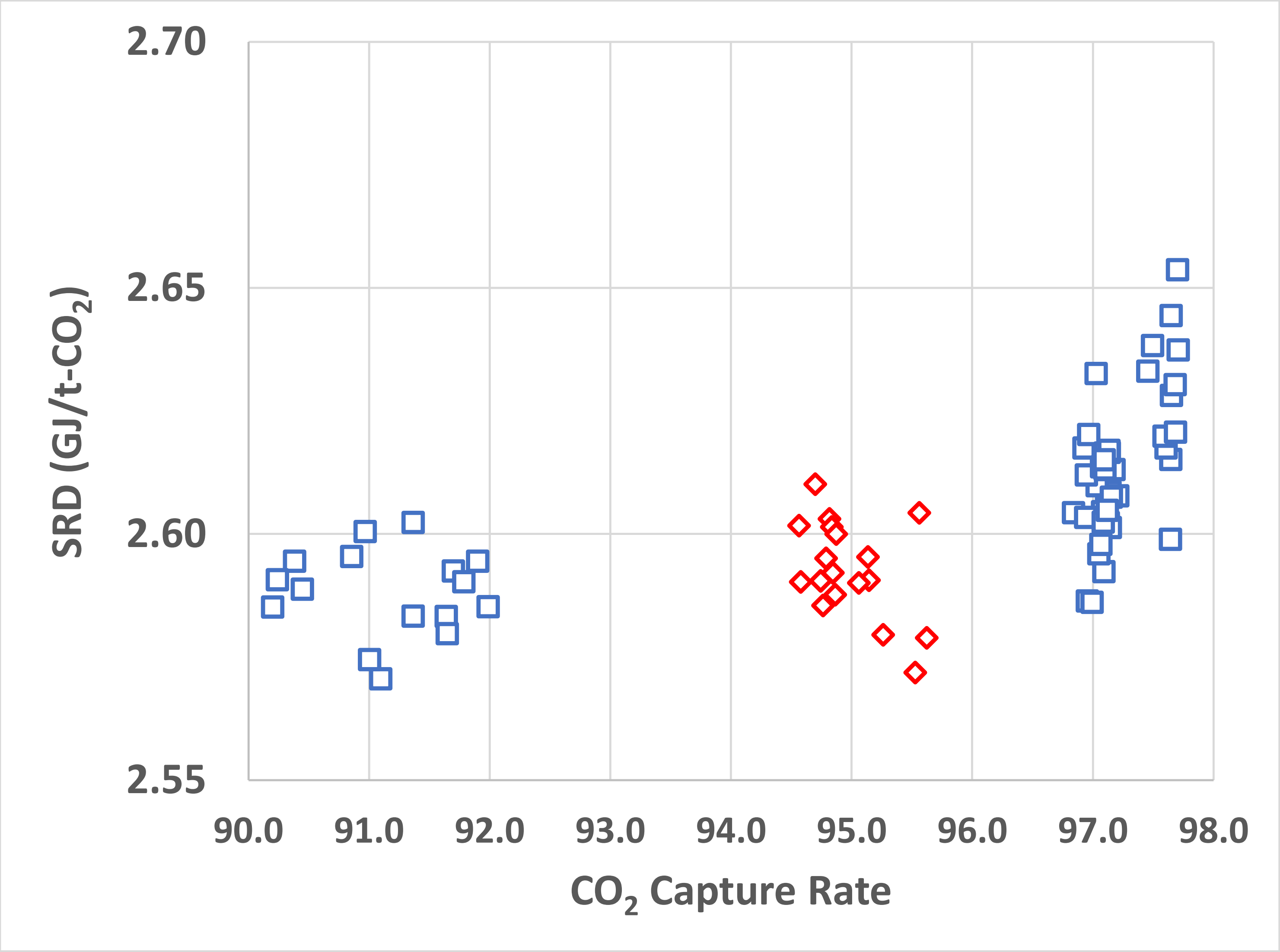


Time on stream:
2823 hours
Coal (RFCC):
1825 hours
NGCC (CHP):
998 hours
Steady state:
2063 hours

Performance at coal flue gas conditions

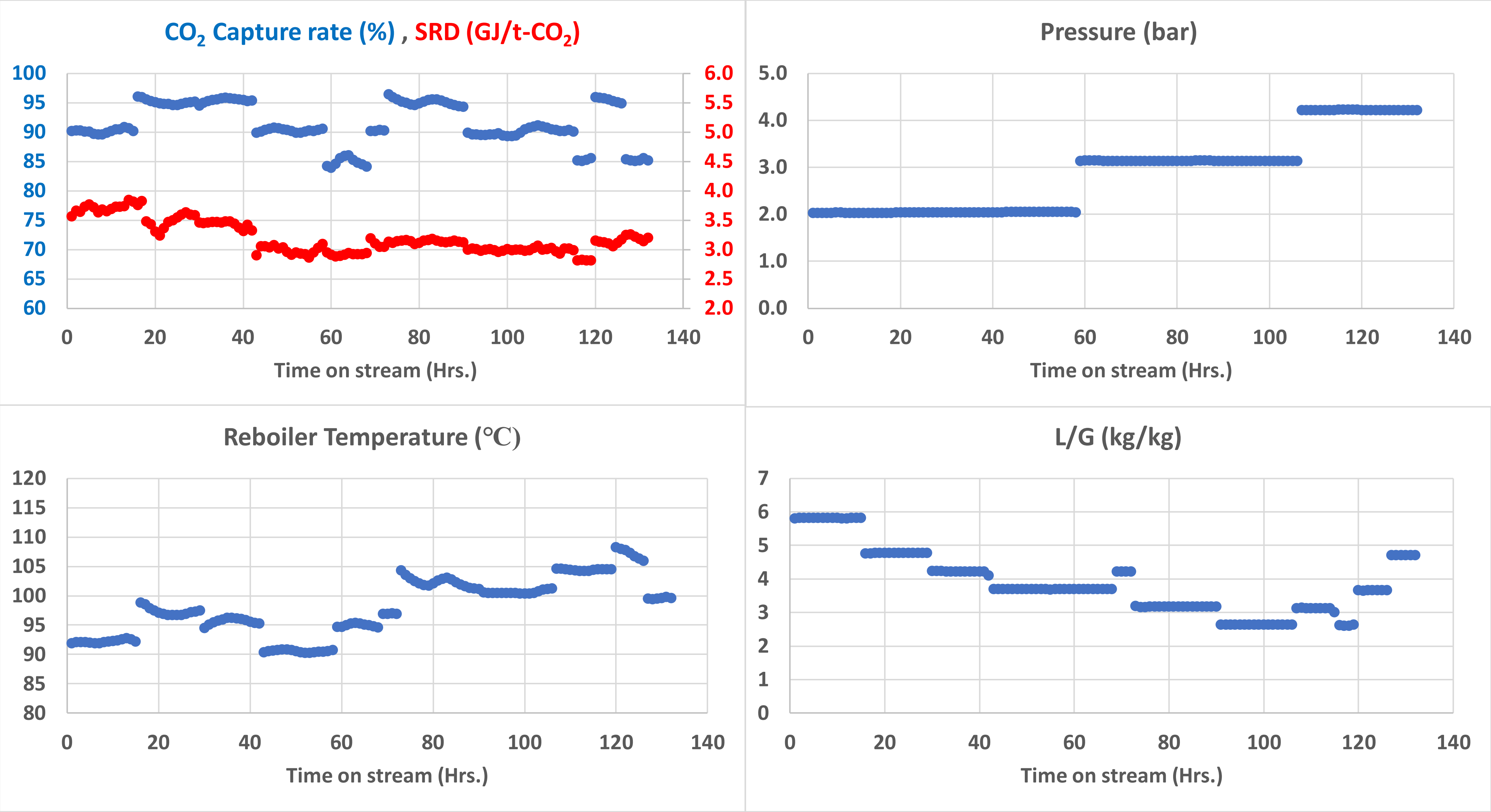


Coal High Capture Rates

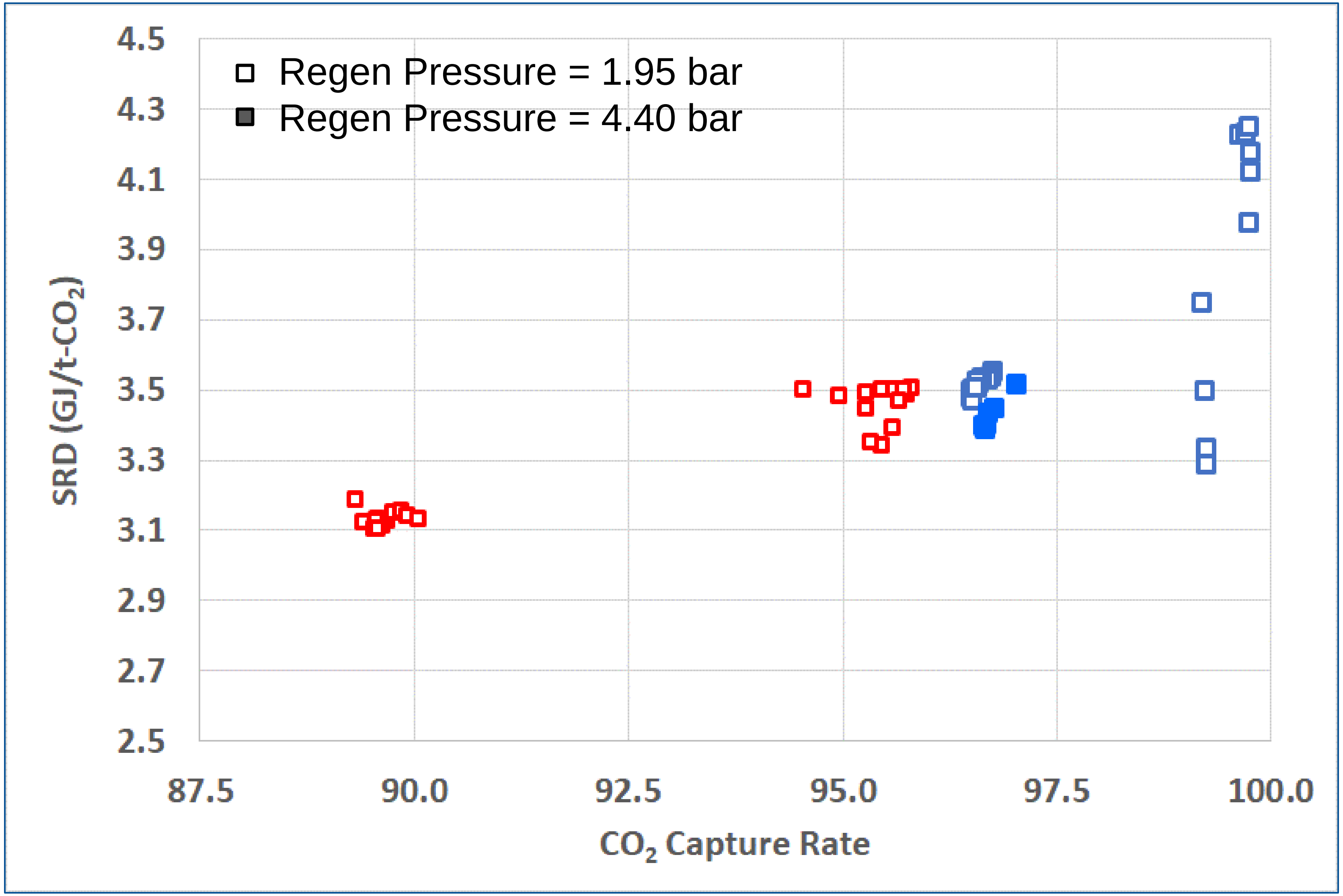


- Regenerator Pressure at 4.2 bar
- Reboiler Temperature 106 – 114 ℃.
- CO_2 concentration in flue gas at 13.5%

Performance at NGCC Flue Gas conditions

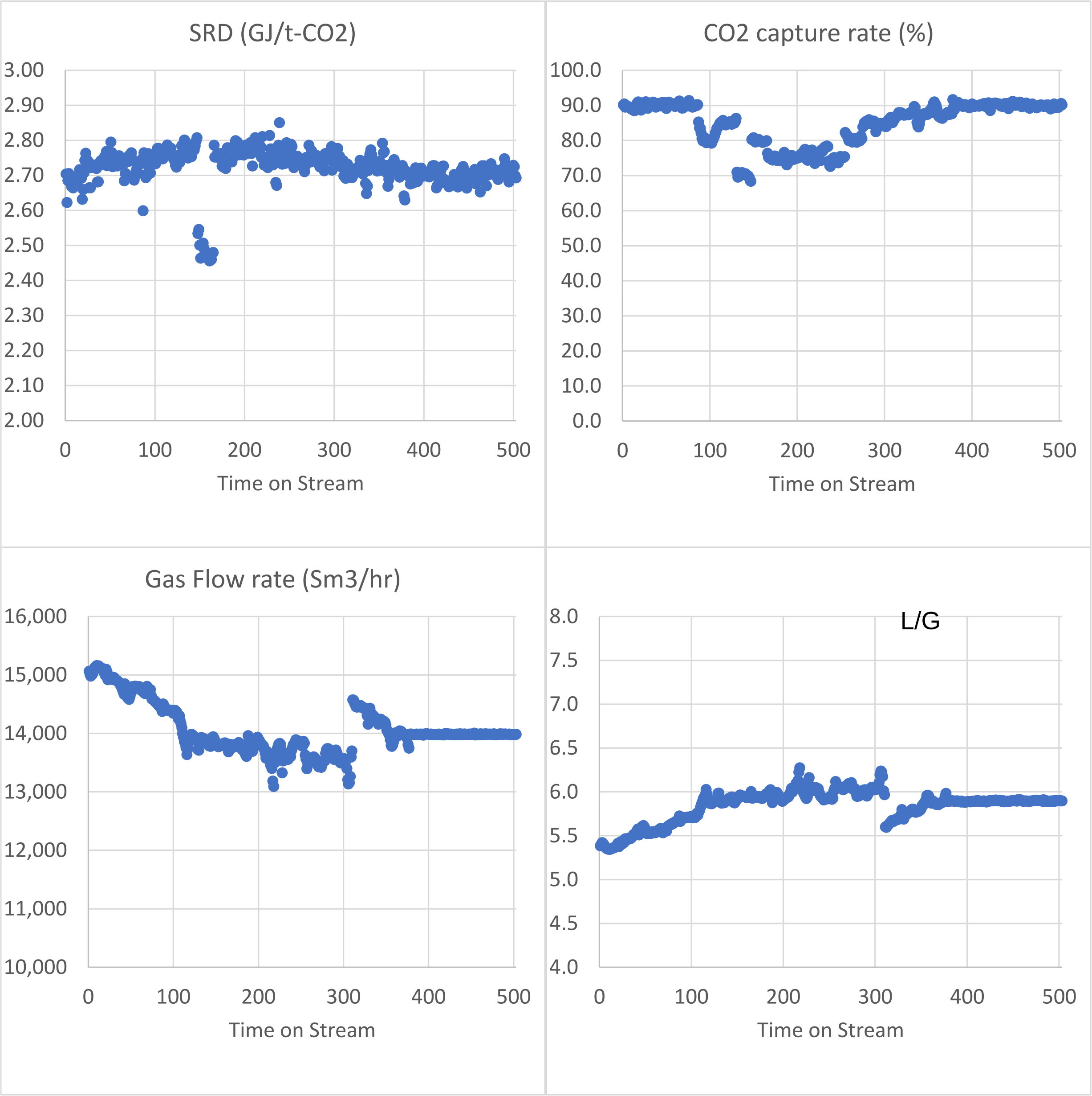


NGCC conditions - High Capture Rates

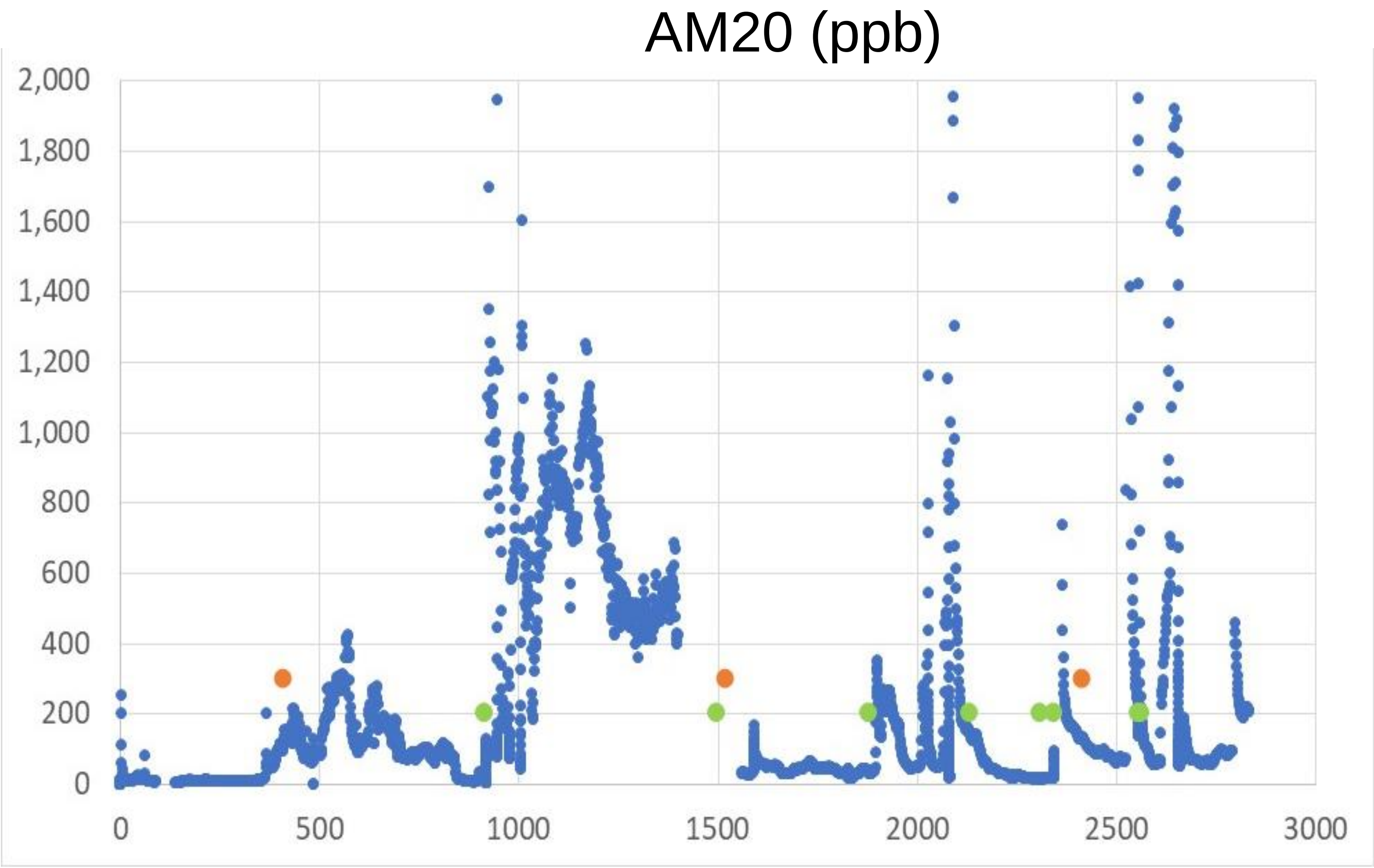


- Regenerator Pressure at 1.95 – 4.41 bar.
- Reboiler Temperature 88.4 – 113.5 ℃.
- CO_2 concentration in flue gas at 4%

Long term testing at coal flue gas conditions



Emission measurements by TCM/UiO using PTR-TOF-MS



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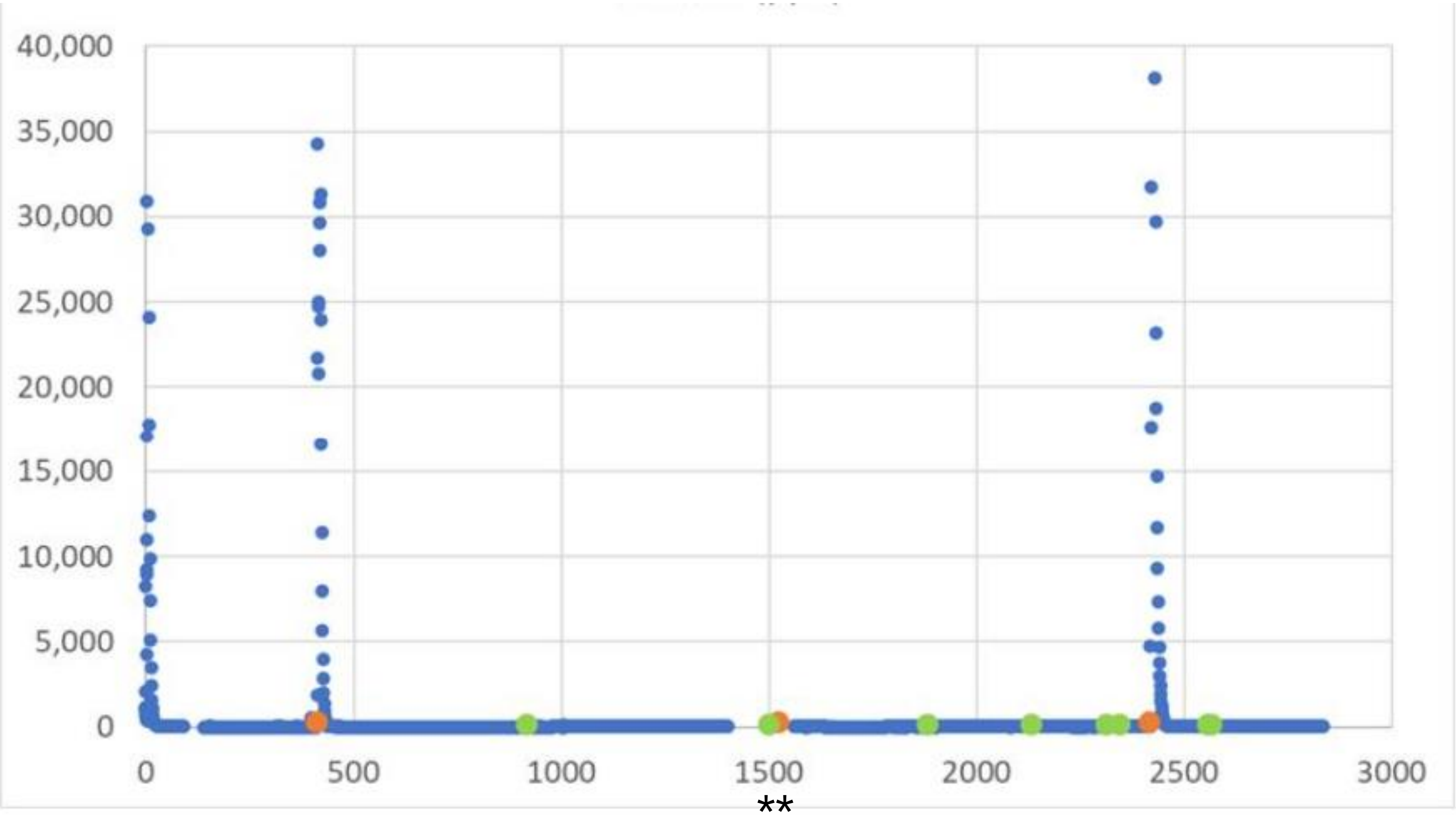
TOS (h)	Event (Green dots)
916	CHP ended, RFCC began
1499	RFCC ended, NGCC sDOE on CHP began
1881	NGCC sDOE ended, Coal sDOE began
2131	Coal sDOE ended, dynamic testing began
2331	Dynamic testing ended, deep capture NGCC began
2343	Deep capture NGCC ended, EF test began
2555	EF test ended, RHP test began

Emission measurements by TCM/UiO using PTR-TOF-MS

AM53 (ppb)



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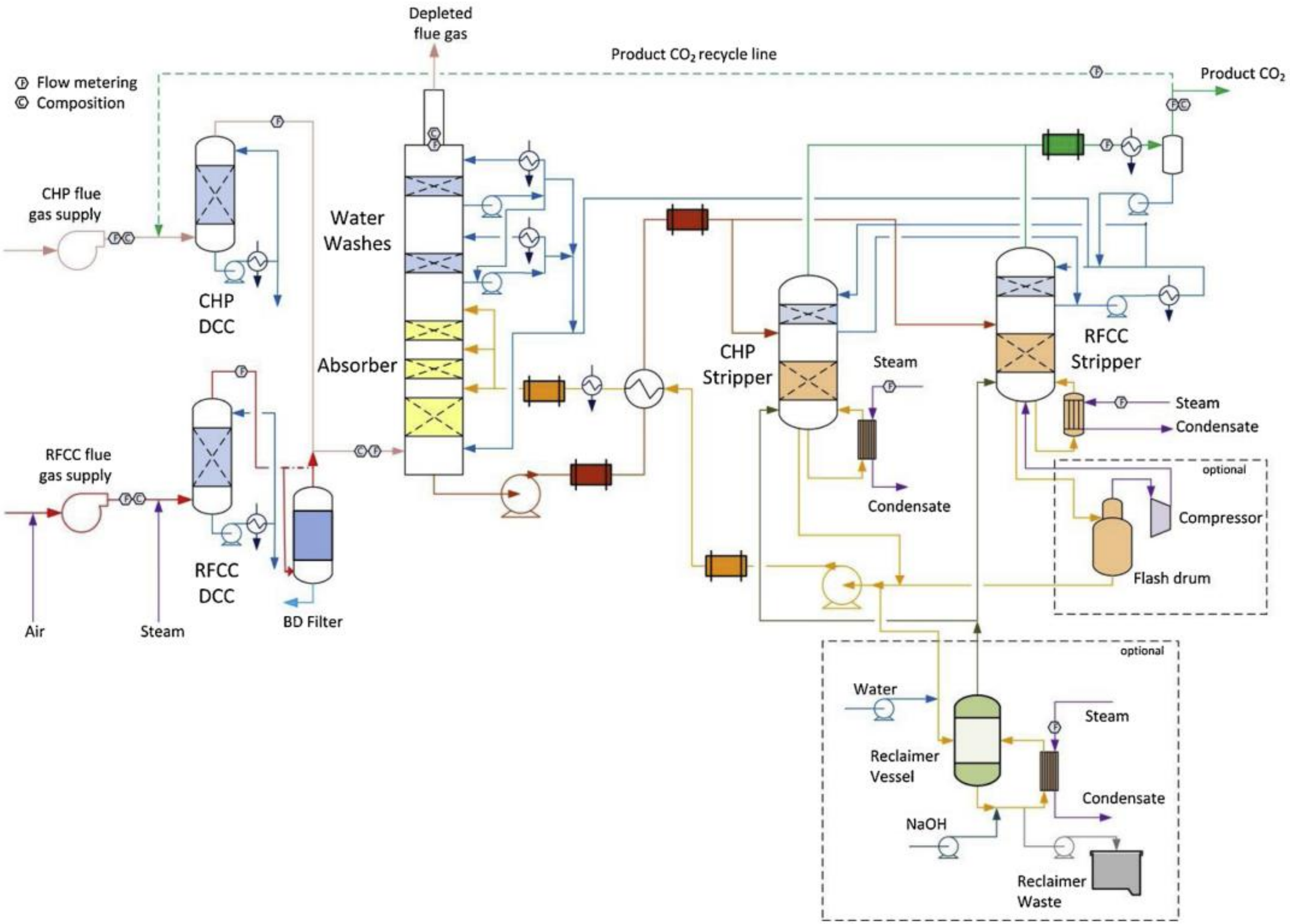
TOS (h)	Event (Orange dots)
409	Addition of fresh amine
1520	Addition of fresh amine
2414	Addition of fresh amine

** PTR-TOF-MS was down at this time.

- Trace emissions from solvent production may be present at start-up unless steps are taken during manufacturing to remove them.

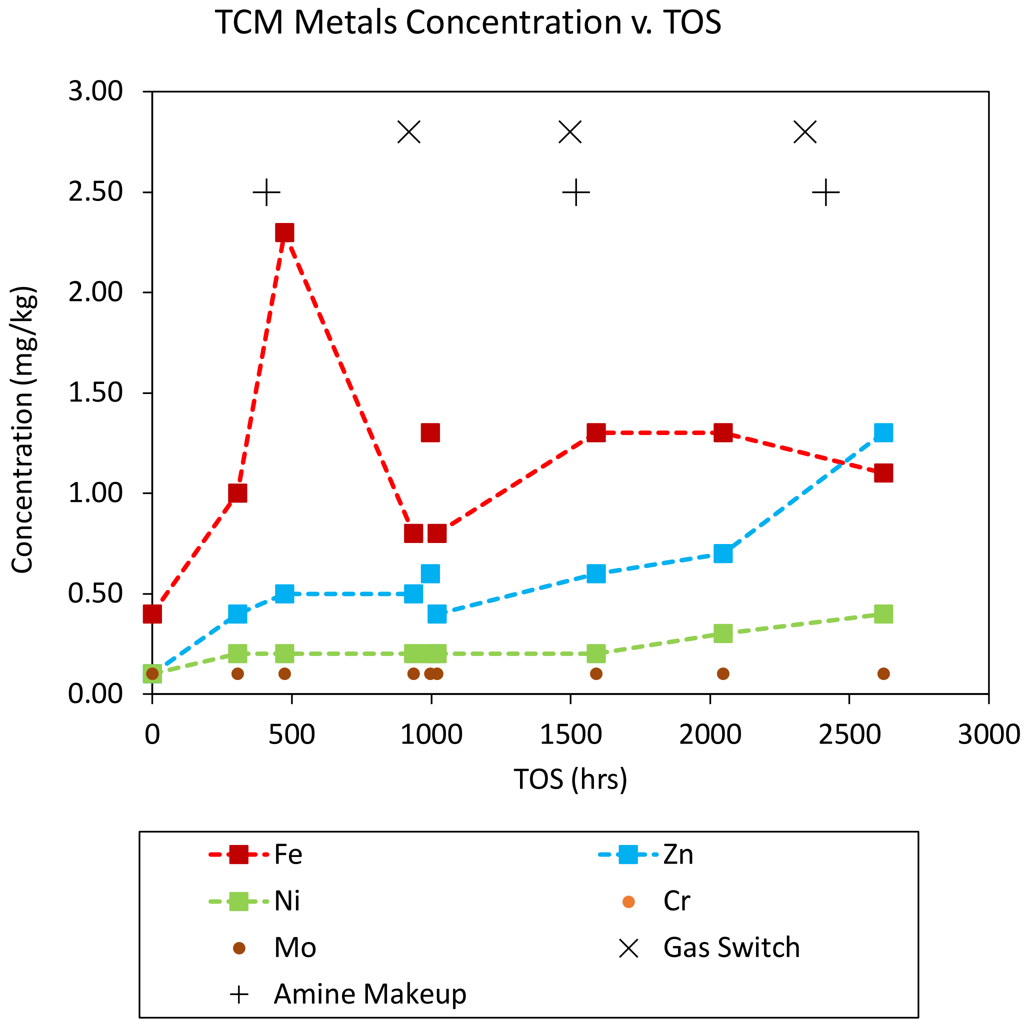
Corrosion Testing

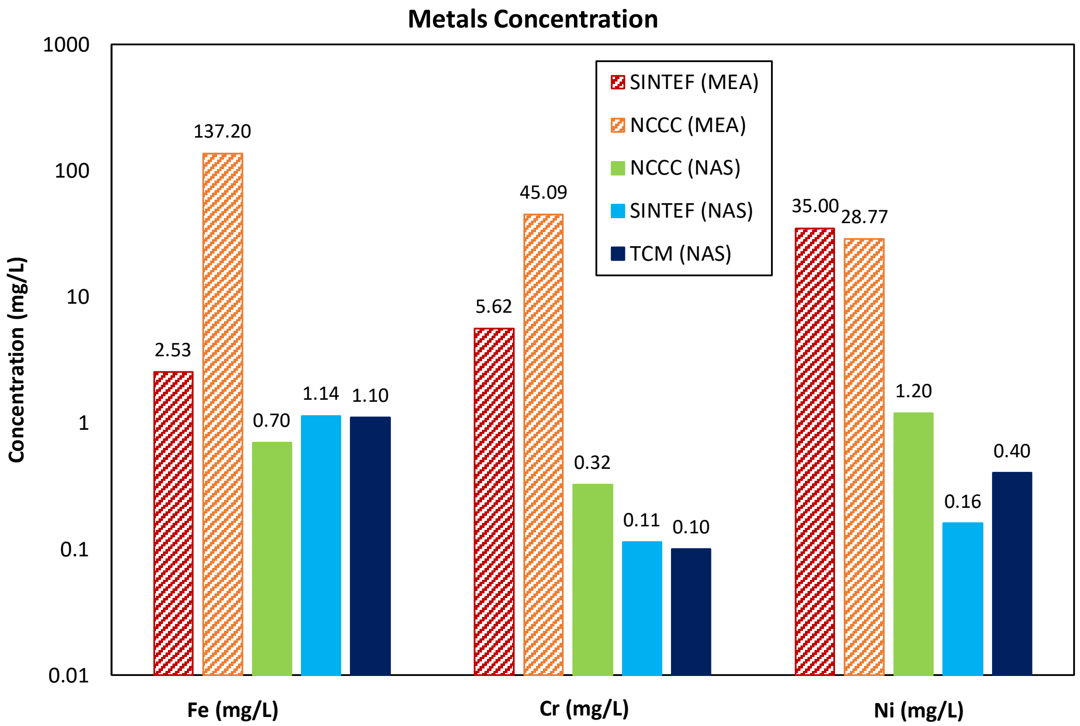


Rating	Corrosion Rate (µm/yr)
Outstanding	<25
Excellent	25—100
Good	100—500
Fair	500—1000
Poor	1000—5000
Unacceptable	>5000

		Cold Lean (8" Line)	Cold Rich (6" Line)	Hot Lean (8" Line)	Hot Rich (6" Line)	Stripper Overhead (12" Line)
Carbon Steels	CS 1010	-0.03 ± 0.06	-0.07 ± 0.08	383.02 ± 46.83	Lost	-0.51 ± 0.07
	CS 1018	-0.01 ± 0.14	0.01 ± 0.21	376.00 ± 10.84	956.22 ± 33.07	-0.27 ± 0.14
	SA 516	0.18 ± 0.14	0.06 ± 0.21	343.21 ± 9.90	1167.12 ± 40.36	-0.37 ± 0.14
	SA 516 Bent	0.12 ± 0.07	-0.08 ± 0.08	414.97 ± 64.57	Lost	-0.09 ± 0.04
Stainless Steels	Duplex 2205	-0.18 ± 0.14	-0.21 ± 0.21	-0.12 ± 0.14	-0.10 ± 0.21	-0.08 ± 0.14
	Duplex 2205 Bent	-0.07 ± 0.06	-0.07 ± 0.08	-0.03 ± 0.06	-0.06 ± 0.08	0.00 ± 0.04
	SS 304	-0.02 ± 0.14	-0.01 ± 0.20	0.00 ± 0.14	0.03 ± 0.20	0.00 ± 0.14
	SS 304 Bent	-0.04 ± 0.06	-0.03 ± 0.08	-0.02 ± 0.06	-0.01 ± 0.08	-0.02 ± 0.04
	SS 316	-0.03 ± 0.14	-0.01 ± 0.20	0.00 ± 0.14	0.02 ± 0.20	0.00 ± 0.14
Resin	Ultem Resin	-33.24 ± 5.73	20.85 ± 4.30	Lost	Lost	22.37 ± 3.89

Build-up of Metal Ions in the Solvent





Solvent Campaign	TOS
SINTEF (MEA)	887
NCCC (MEA)	1000
NCCC (NAS)	511
SINTEF (NAS)	538
TCM (NAS)	2500

Comparison of Cost and Performance against DOE Baseline Reference Cases

	DOE B12B.95	RTI B12B.95	DOE B31B.95	RTI B31B.95
Description	SCPC	SCPC	NGCC Class-F	NGCC Class-F
Solvent	Cansolv	RTI-NAS	Cansolv	RTI-NAS
SRD (GJ/t-CO_2)	2.50	2.55	2.70	3.10
Regenerator pressure (bar)	1.7	4.4	1.7	4.4
Coal flow rate (kg/hr)	276,574	271,356		
Natural gas flow rate (kg/hr)			93,272	93,272
Gross power output (MWe)	763	756	689	689
Aux. power req. (MWe)	113	108	49	48
Net power output (MWe)	650	648	640	641
Net plant HHV efficiency (%)	68.7	69.8	47.3	47.3
Power plant cost ($MM)	1643	1648	611	546
CO_2 capture cost ($MM)	549	363	432	410
CO_2 compression cost ($MM)	94	81	63	44
TPC ($MM)	2285	2092	1106	1001
TOC ($MM)	2802	2567	1344	1246
TASC($MM)	3235	2963	1469	1362
Total OPEX ($MM)	256	247	208	202
COE, excl CO_2 TS&M, mills/kWh	100.1	94.6	65.4	62.5
Cost of CO_2 Capture, ($/t-CO2)	37.3	30.5	59.9	52.0

All costs are on 2018 US$ basis

NexantECA

EPRI ELECTRIC POWER RESEARCH INSTITUTE

Independent TEA by Nexant and EPRI.

Design Basis as per DOE Baseline report**

- NOAK plant with single train.
- CWS at 60 ℉ (15.6 ℃)
- CWR at 80 ℉ (26.7 ℃)

** Bituminous Coal And Natural Gas To Electricity, Rev 4a Baseline Report (DOE/NETL - 2023/4320)

Continuation of the Technology Development Path

FLECCS – Dynamic Capture from NGCC

(2021-2024)

Process intensification to enable flexible capture, reduce capital expense

100 t-CO_2/day

TRL 3-5

Large Pilot Testing for Cement Flue Gas

(2021-2024)

Process intensified absorbers to reduce capital expense from cement flue gas capture

1.0 t-CO_2/day

TRL 4-5

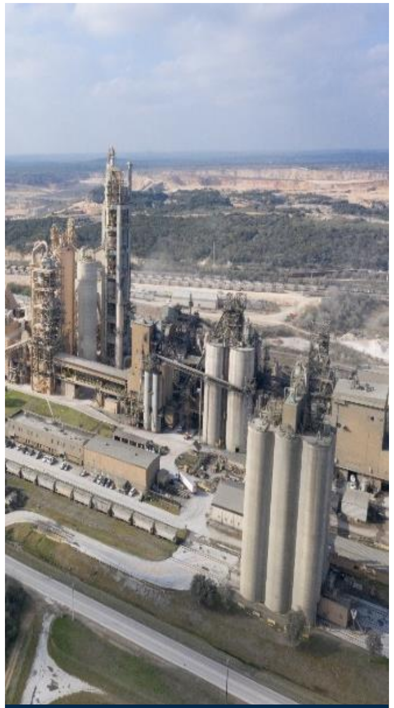
Gen2NAS

(2023-2024)

Improved Solvent chemistry with process intensification for higher capture rates at lower cost.

0.1 t-CO_2/day

TRL 2-3



FEED

(2023-2024)

Carbon capture plant FEED study for cement manufacturing

4000 -CO_2/day

TRL 6

News Release

Schlumberger and RTI International Partner to Accelerate the Industrialization of Innovative Carbon Capture Technology

Published: 10/17/2022

Commercialization with SLB

News Release

Schlumberger and RTI International Partner to Accelerate the Industrialization of Innovative Carbon Capture Technology

Published: 10/17/2022

A unique, versatile nonaqueous solvent

SLB and RTI International have partnered to industrialize and scale up an absorption-based carbon capture technology. The proprietary nonaqueous solvent (NAS) can be applied across a broad range of industrial sectors—from cement and steel manufacturing, coal and gas power generation, chemicals, and hydrogen.

With low energy consumption, simple process configuration, low corrosion chemistry, and fast reaction rates, NAS technology reduces energy consumption by up to 40% during CO_2 capture and minimizes both capex and opex compared with traditional solvents.

Read press release →

Summary

- Performed >2,800 hours testing of NAS at coal and NGCC flue gas conditions.
- Demonstrated NAS operations at TCM below emission limits.
- Achieved SRD of 2.6 GJ/t-CO_2 captured at coal flue gas conditions with sub-optimal TCM absorber configuration (had only one intercooler).
- Demonstrated NAS with CO_2 regeneration at 4.4 bar with minimal increase in SRD.
- Demonstrated high efficiency CO_2 capture from NGCC with NAS, though at higher SRD and cost.
- Observed low corrosion rates on carbon steel at absorber conditions.
- Found PTR-TOF-MS to be an effective tool for quickly identifying volatiles and monitoring at low levels of emission.

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