

A COMPARISON OF THE LATEST DATA ON CESAR1 AND MEA FOR COMMERCIAL USE

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For Best Available Techniques (BAT) information for CCS
see <https://ukccsrc.ac.uk/best-available-technology-bat-information-for-ccs/>

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Sherman, TX NGCC Post Combustion Capture Plant

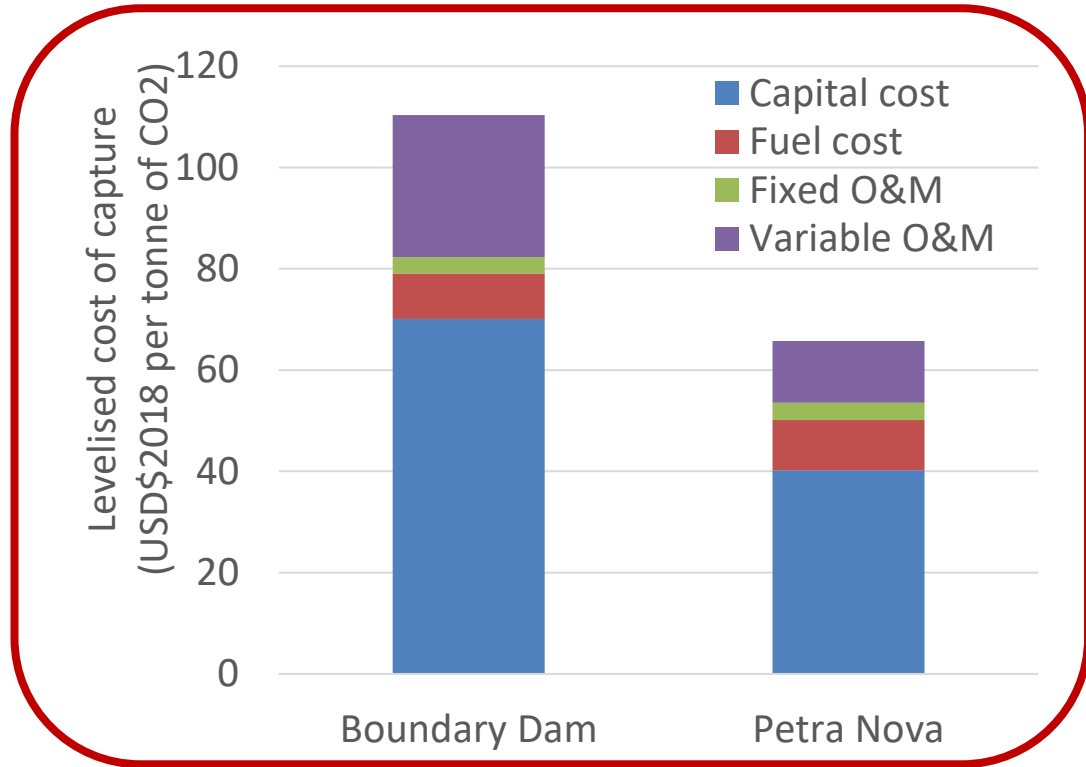
<https://ukccsrc.ac.uk/open-access-sherman-feed/>

Cost Sensitivities and Uncertainty Levels Tornado Diagram

% Range	\$/Tonne CO2 Captured		Base (\$/Tonne CO2 Captured)
Cap Cost ± 15%	12.5	12.5	83.10
Maintenance ± 50%	3.5	3.5	7.00
Energy ± 20%	2.6	2.6	13.00
Personnel ± 30%	1.9	1.9	6.20
Solvent ± 50%	1.2	1.2	2.30
Other Ops ± 50%	0.8	0.8	1.55
Waste Disposal ± 50%	0.7	0.7	1.35

Reported capture costs for BD3 and Petra Nova

(GCCSI (2019) *Global Status of CCS Report: 2019*. <https://www.globalccsinstitute.com/resources/publications-reports-research/global-status-of-ccs-report-2019/>)



- ‘Variable O&M’ costs are likely to be predominantly for solvent management and replacement.
- Cost data normalised to 2017 values.
- Stated accuracy range for Boundary Dam and Petra Nova: -10% to +15%.
- Proprietary solvents reported as being used in these projects:

Boundary Dam 3: Cansolv DC-103

<https://www.carboncapturejournal.com/news/saskpower-boundary-dam-project/2775.aspx?Category=all>

Petra Nova: MHI KS-1

<http://www.mhi.co.jp/technology/review/pdf/e551/e551032.pdf>

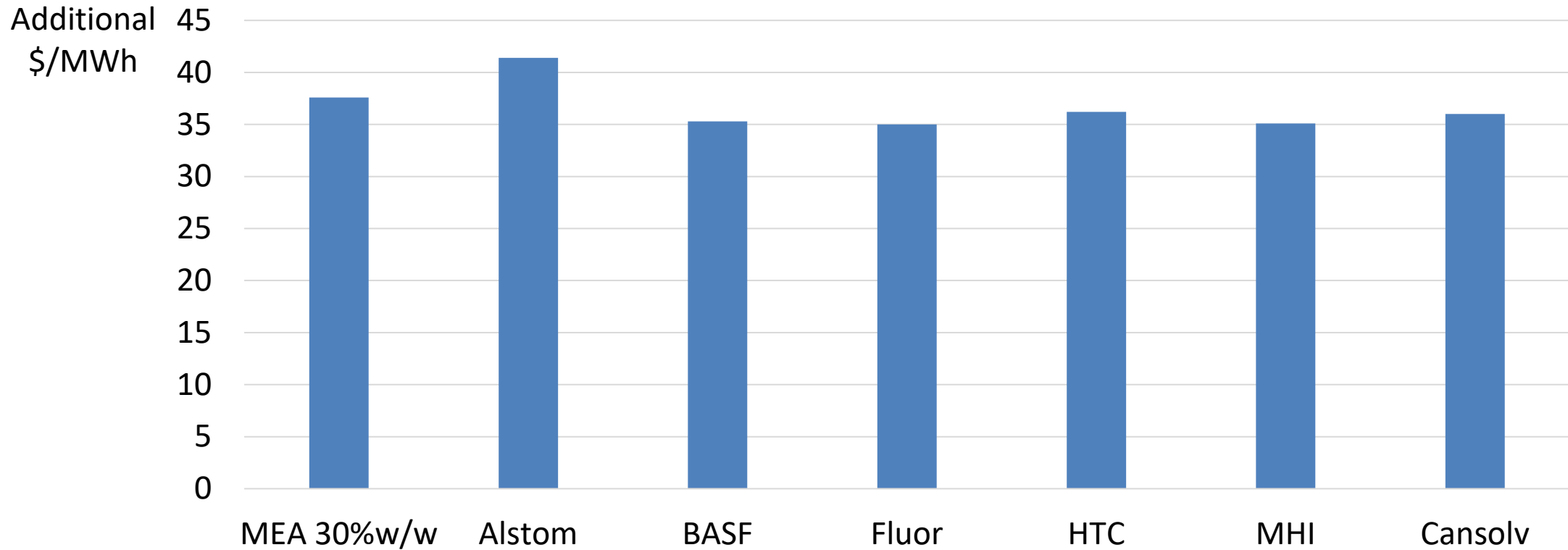
For Boundary Dam, which captures less than 1MtCO₂/yr, annual costs for solvent replacement alone were stated by the SaskPower chairman as \$17.3M in 2015, \$14.6M in 2016 (SaskPower, 2016) and reported to a government committee as \$13.6M in 2017 (SaskPower, 2018), against initially-predicted costs of \$5M. These solvent replacement costs would be consistent with the level of variable operation and maintenance (O&M) costs above.

SaskPower (2016) *A Word from the President on Smart Meters and Carbon Capture and Storage*, Blog on SaskPower web site, December 16, 2016.

SaskPower (2018) *Letter to Herb Cox, Chairman, Standing Committee on Crown and Central Agencies, Government of Saskatchewan*.

<http://docs.legassembly.sk.ca/legdocs/Legislative%20Committees/CCA/Tabladdocs/CCA%2061-28%20SaskPower%20Responses%20to%20questions%20raised%20at%20the%20June%2027,%202018%20meeting.pdf>

Estimated variation in additional electricity cost for retrofit to a natural gas combined cycle power plant using MEA and various proprietary solvents (Nexant, 2016)



Nexant (2016), *World Bank Pre-Feasibility Study for Establishing a Carbon Capture Pilot Plant in Mexico - Full-Scale Poza Rica NGCC PCC Retrofit Incremental Electricity Cost (\$/MWh) for 85% CO₂ Capture*, <https://www.gob.mx/sener/en/documentos/pre-feasibility-study-for-establishing-a-carbon-capture-pilot-plant-in-mexico?idiom=en>, download https://www.gob.mx/cms/uploads/attachment/file/107318/CCPP_Final_Report.pdf

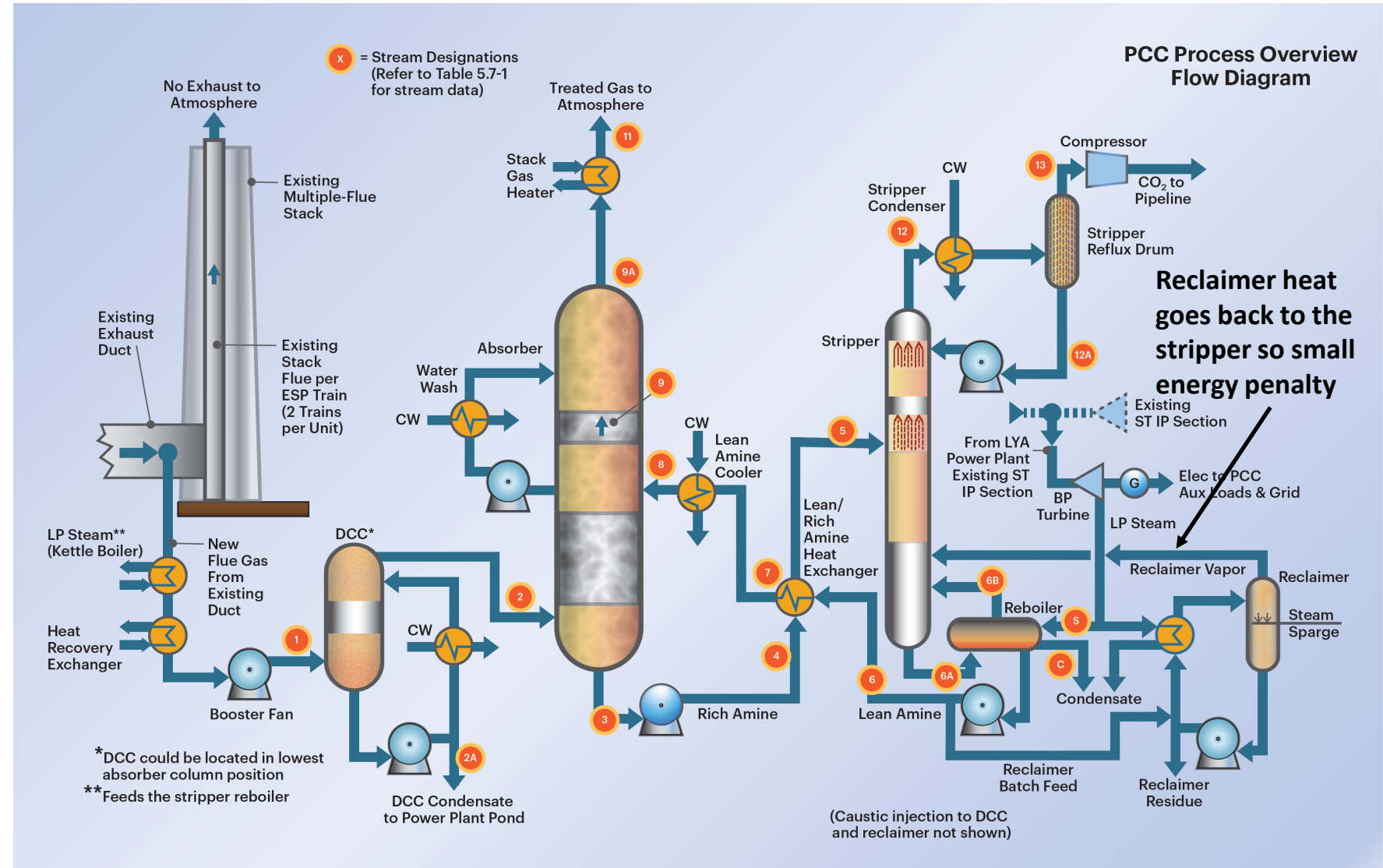
Desorber-coupled continuous thermal reclaimer

Retrofit study for a brown coal power plant in Australia

Bechtel (2018) for CO2CRC, Retrofitting an Australian Brown Coal Power Station with Post-Combustion Capture, <https://ukccsrc.ac.uk/wp-content/uploads/2022/10/Retrofit-Main-Report-Final-Final-in-CO2CRC-webpage.pdf>

Some special features are:

- a) 40% MEA open-access study
- b) SO_x removal in DCC;
- c) Stack gas heater at top of absorber;
- d) Continuous reclaimer



Reported TCM thermal reclaiming data and estimated selectivities for removal

		Degradation products	Metals	HSS
MEA reclaiming, R/V (number of solvent inventories reclaimed)	3			
Expected reduction for s=1	96.02%			
Oct-15 reclaiming run after 1843 hrs operation – reduction from reclaiming		~95%	>95%	>95%
Apparent selectivity for removal (for 95%)		0.9986	0.9986	0.9986
CESAR1 reclaiming, R/V, (number of solvent inventories reclaimed)	4.5			
Expected reduction for s=1	98.98%			
Apr-20 reclaiming run after ~1600 hrs operation – reduction from reclaiming		84%	95%	89%
Apparent selectivity for removal		0.4072	0.6657	0.4905
Unremovable fraction, x		15.1%	3.9%	10.0%
Oct-20 reclaiming run after ~2200 hrs operation		82%	93%	89%
Apparent selectivity for removal		0.3811	0.5909	0.4905
Unremovable fraction, x		17.1%	6.0%	10.0%

^[1] In (Flø, 2017) <https://doi.org/10.1016/j.egypro.2017.03.1899> it was incorrectly stated that “A total accumulated amount of 46 000 kg solvent was fed to the reclaimer during the whole period of 3 days. This corresponds to about 110 % of the total solvent inventory.” But this is inconsistent with the average flow shown in Figure 6, which averages around 2000 kg/h over 3 days, so roughly 3 x 24 x 2000 = 144 000 kg. After correspondence on the matter TCM confirmed by email that “the solvent flow to the reclaimer over the 3 days was 143 570 kg. This is 3 times the inventory.”

A. Tests on TCM CHP flue gas, ~3.5-3.7% v/v CO₂

(Shah 2018); (Shah, 2021); (Benquet, 2021); ([Hume, 2021](https://doi.org/10.2139/ssrn.3366149)) ; (Hume, 2022)

The minimum flue gas temperature was 40°C with CESAR1 solvent because of precipitation at lower temperature in the absorber, while it was 30°C in MEA case.

TCM run series	%w/w MEA in water	Capture rate	Packing height (m)	SRD (GJ/tCO ₂)
MEA-3	43%	86%	18	3.6
F2	36%	90%	18	3.8
B3-rep	37%	91%	18	3.6
D3-rep	36%	97%	24	3.7
CESAR1: K		85%	18	3.5
C		90%	18	3.4
D		98%	18	3.9
K		85%	24	3.3
AA		90%	24	3.5
BB		98%	24	3.75
Hume (2021)		~96%	24	~3.45 minimum*

B. Tests on TCM RFCC flue gas, 13-14% v/v CO₂

TCM run series	%w/w MEA in water	Capture rate	Packing height (m)	SRD (GJ/tCO ₂)
MEA (Shah, 2018)				
1A-1	30%	90.5%	18	3.5
1A-2	30%	89.4%	18	3.54
CESAR1 (Hume, 2022)				
EPRI Baseline		91%	18	3.23
B4REP2		89.6%	18	3.06
B1		89.5%	18	3.13

C. RWE Niederaussem tests, ~15% v/v CO₂

Tests results at Niederaussem were summarised into expected plant performance by Weir (2023) as:

* Including dry bed for amine emission reduction

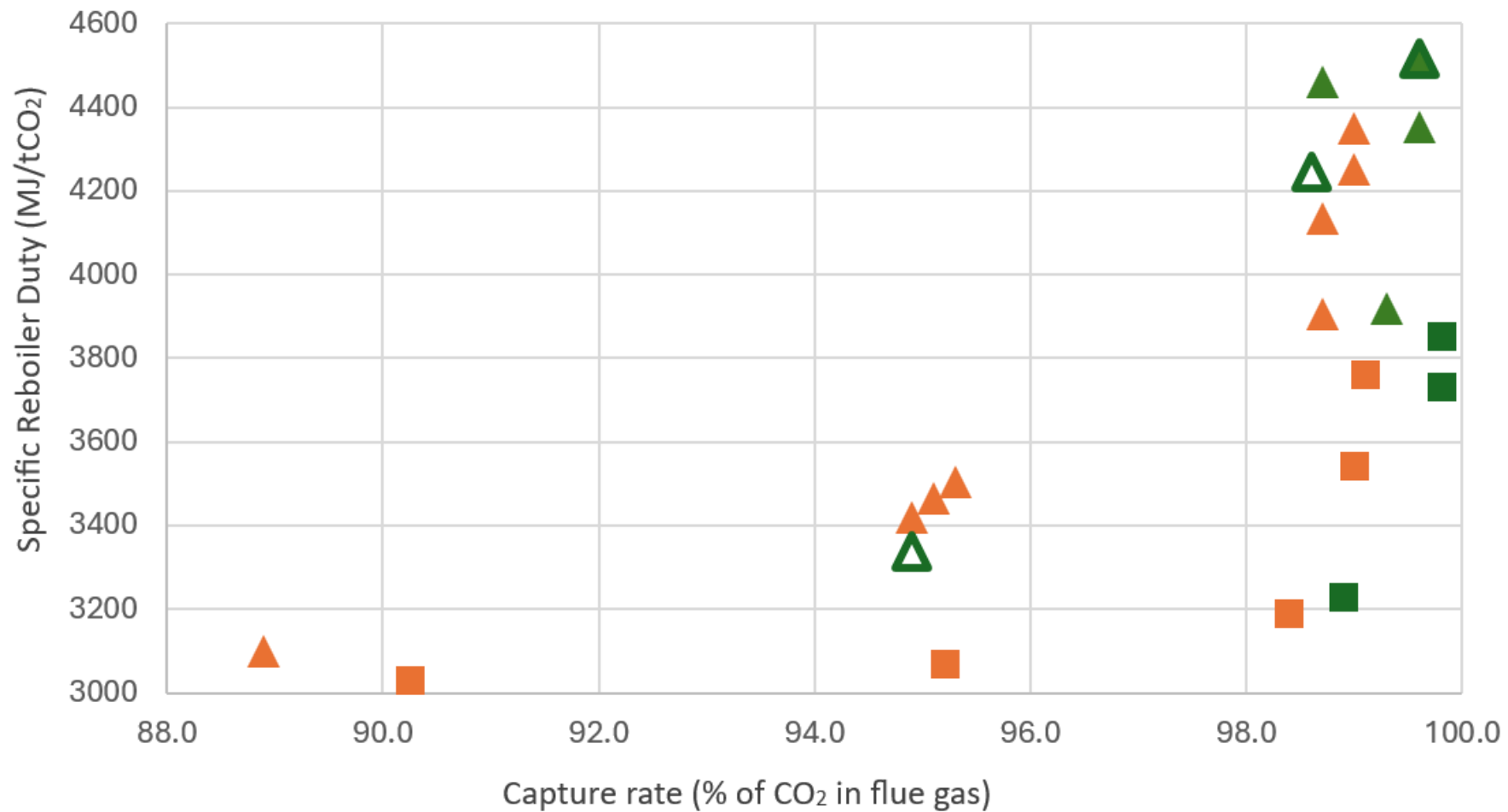
Run series	%w/w MEA in water	Capture rate	Packing height (m)	SRD (GJ/tCO ₂)
MEA 90%	30%	90%	18	3.6
CESAR1, 90%		90%	28*	3.0
CESAR1, 95%		95%	28*	3.0
CESAR1, 98%		98%	28*	3.24

D. National Carbon Capture Center tests – ~30%w/w MEA, ~10.3% v/v CO₂*

(Morgan, 2017) <https://researchrepository.wvu.edu/etd/6262/>

* These tests were undertaken as part of generated a pre-determined matrix of conditions for model calibration, i.e. they were not optimised high capture rate tests, as suggested by the relatively high lean loadings and low rich loadings

Case No.	Capture rate (gas data)	L/G (w/w)	Lean loading (mole CO ₂ /MolMEA) A)	Rich loading (mole CO ₂ /MolMEA)	SRD (GJ/tCO ₂)	Number of beds (Inter-coolers)
K15	99.4%	3.042	0.224	0.413	3.81	3 (2)
K14	98.3%	3.055	0.224	0.42	3.86	3 (2)



▲ 3 beds, 1.75 bar, IC low ■ 4 beds, 1.75 bar, IC low ▲ 3 beds, 2.4 bar, IC low
■ 4 beds, 2.4 bar, IC low △ 3 beds, 2.4 bar, IC high

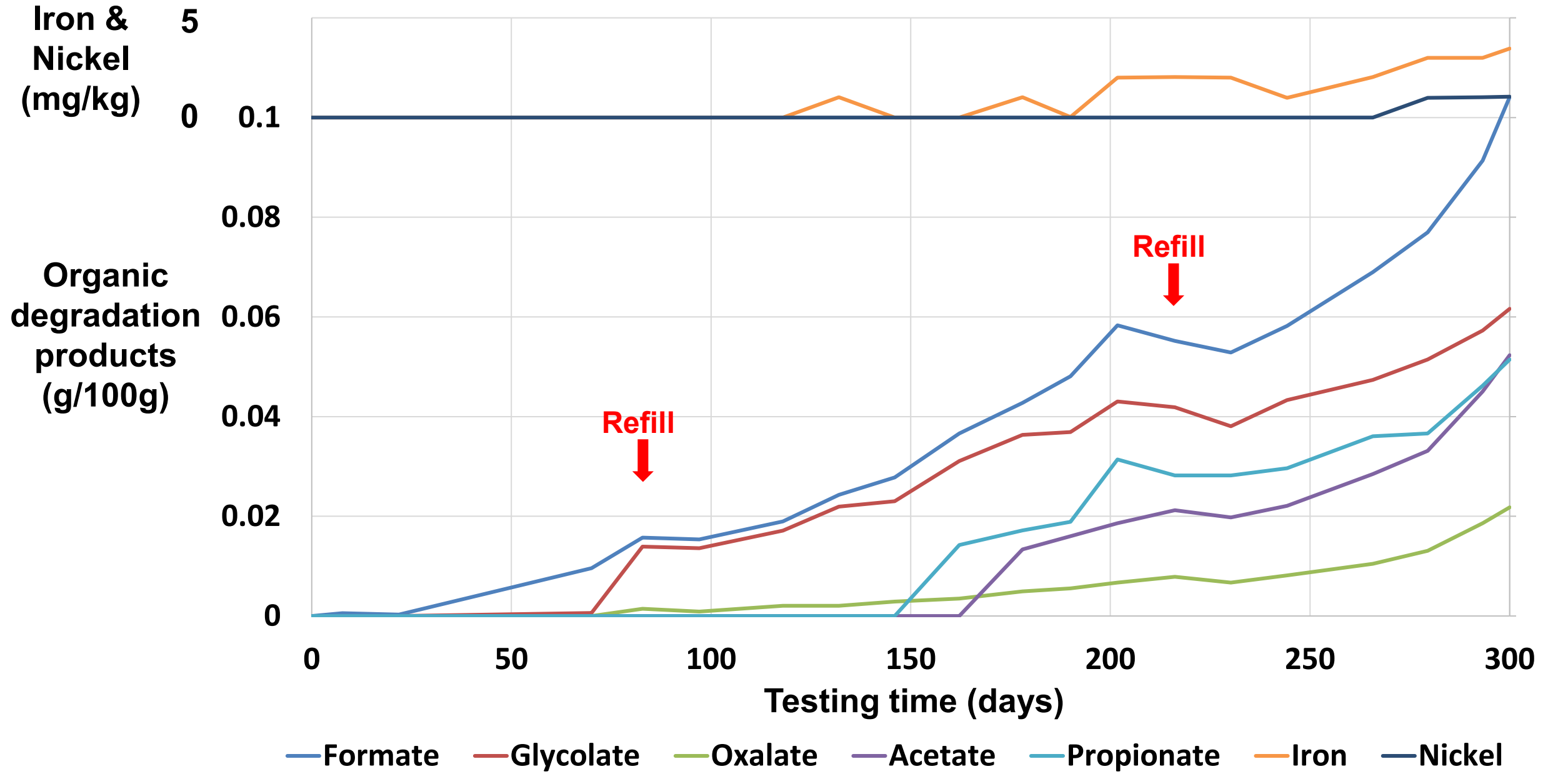
CESAR1 Niederaussem test data, including at high capture rates
(Selected data from Moser, 2024a and Weinfeld, 2024)

<https://dx.doi.org/10.2139/ssrn.5016144>

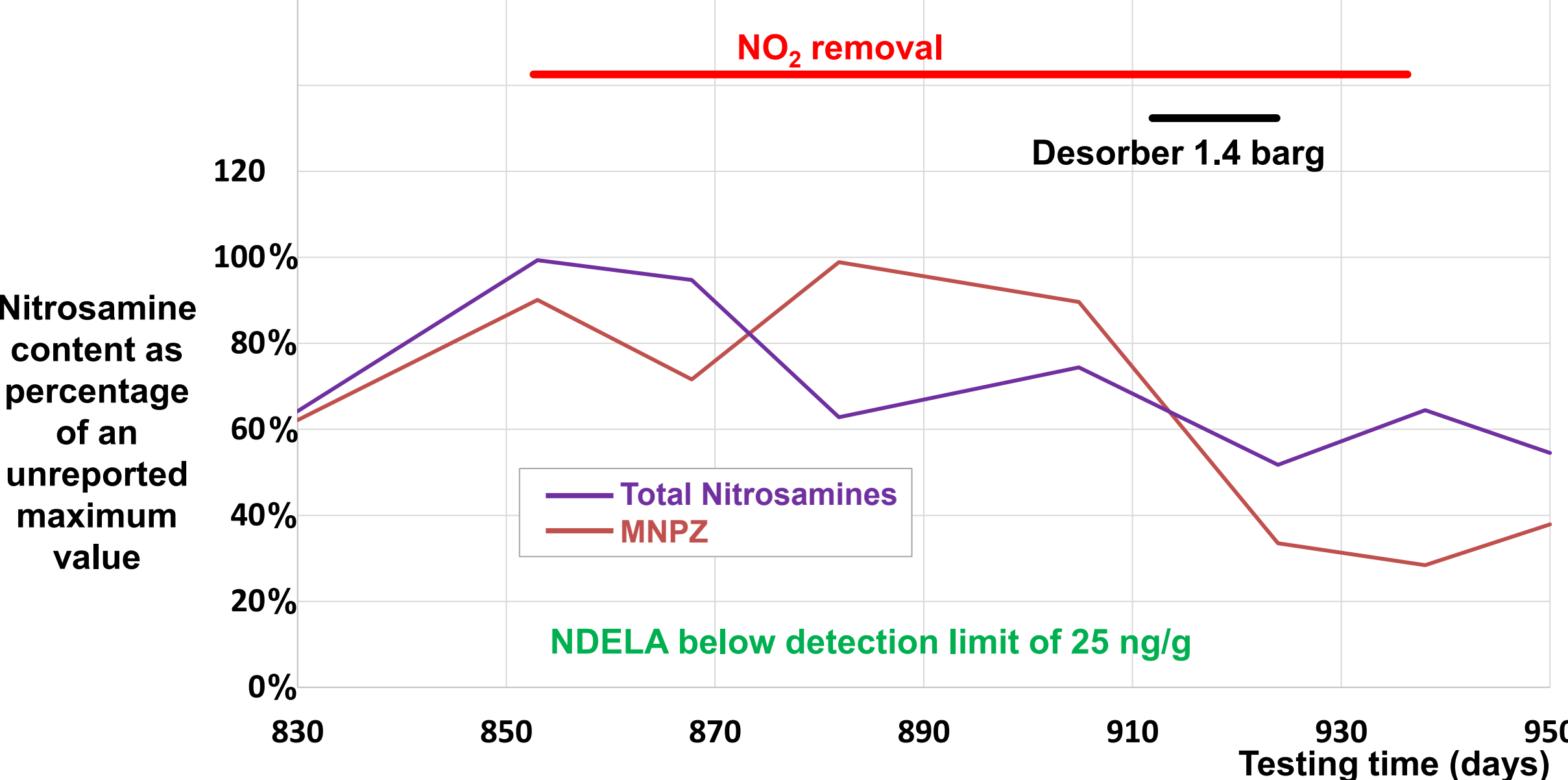
<http://dx.doi.org/10.2139/ssrn.5017300>

CESAR1 at Niederaussem with no solvent management (except sampling bleed and feed?)

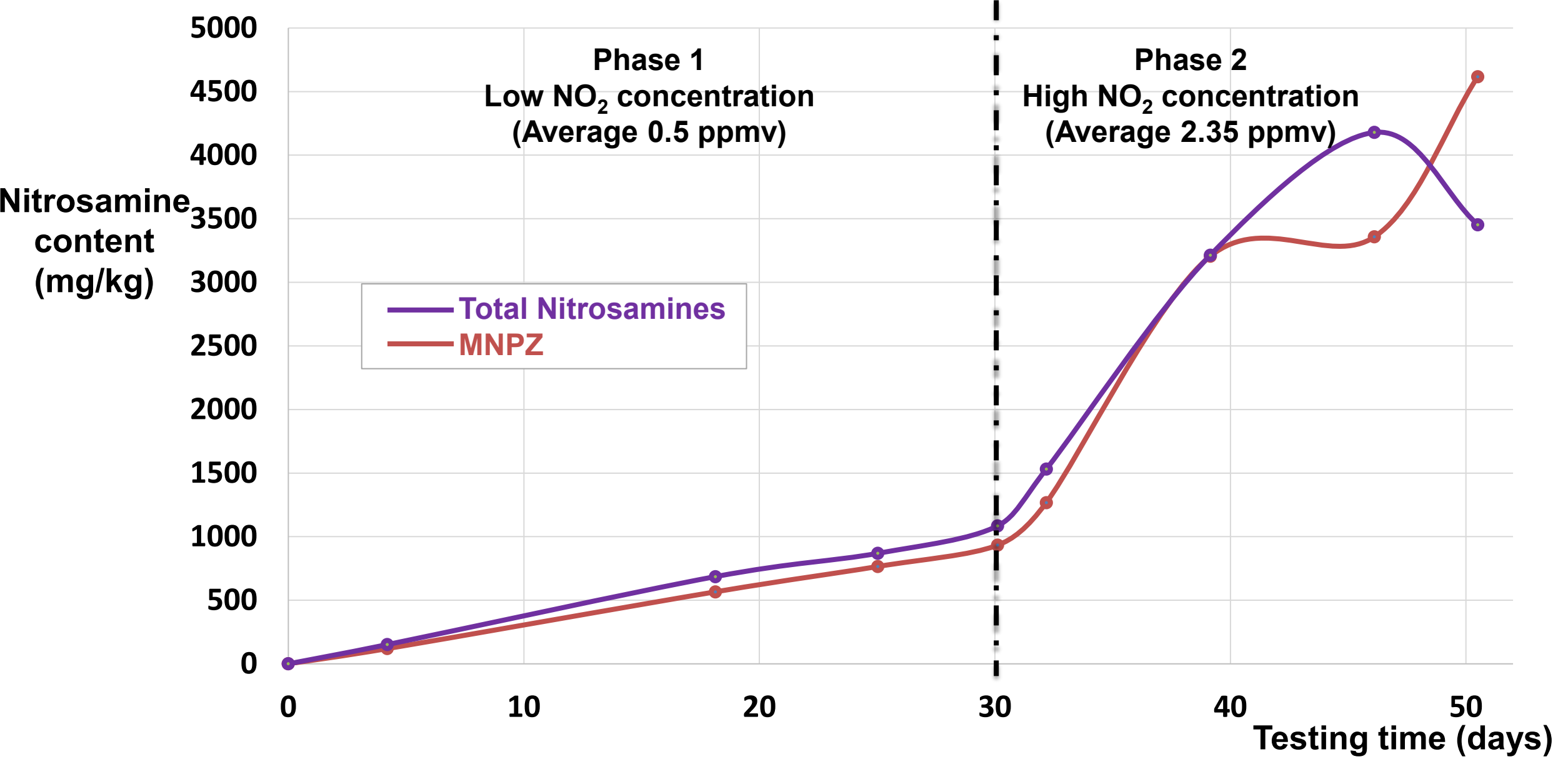
(Moser, 2024) <https://doi.org/10.1016/j.cej.2024.155928>

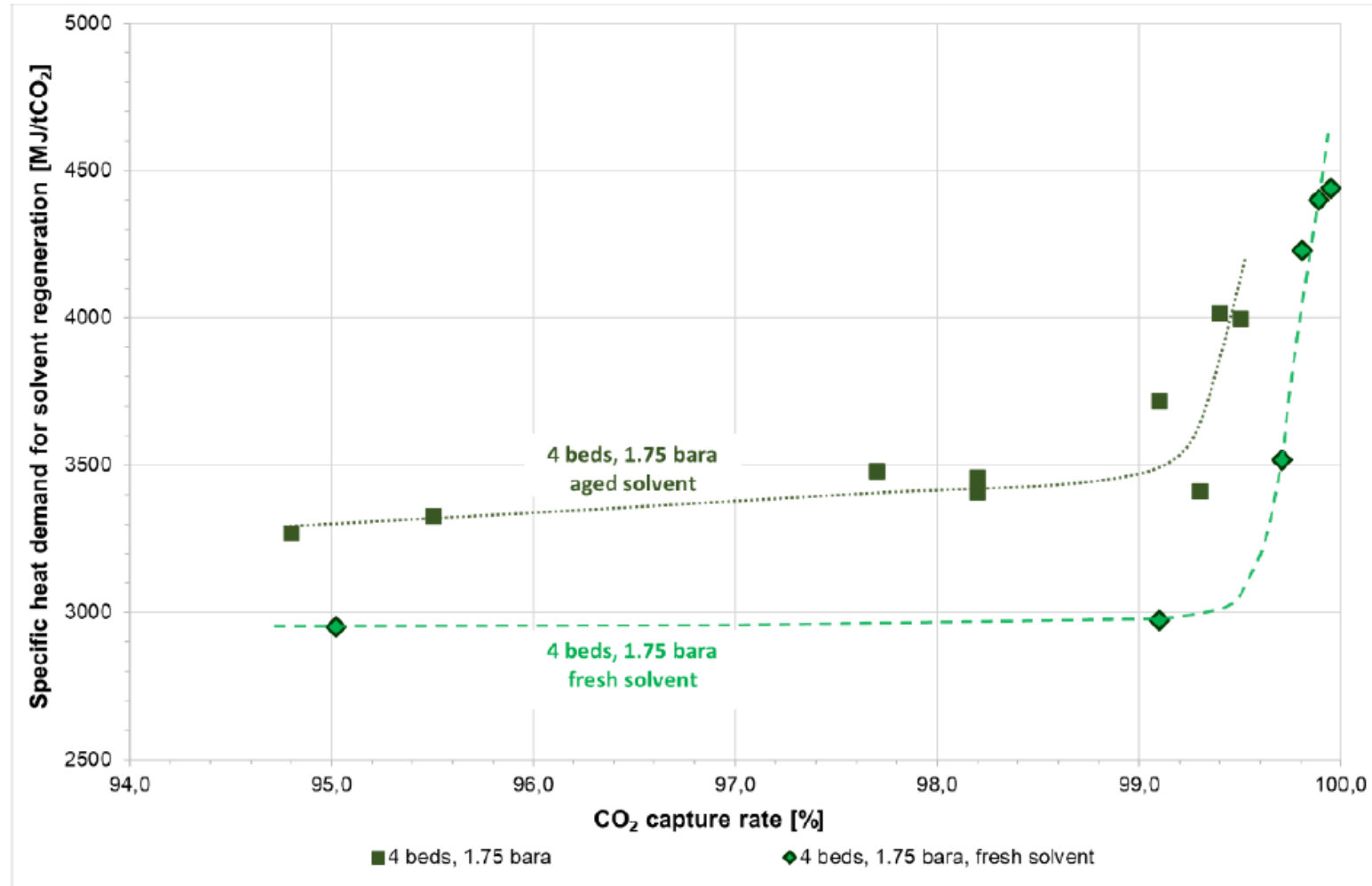


Solvent nitrosamine content measurements during a 3-year CESAR1 test campaign at Niederaussem (Moser, 2024) <https://doi.org/10.1016/j.cej.2024.155928>



Solvent nitrosamine content measurements for a CESAR1 test campaign on CCGT flue gas at TCM (Benquet, 2021) <https://dx.doi.org/10.2139/ssrn.3814712>





Specific heat demand for the regeneration of the CESAR1 solvent depending on the CO₂ capture rate and solvent aging for capture plant operation with full absorber height (four active beds with structured packings) and a solvent regeneration temperature of 120°C.

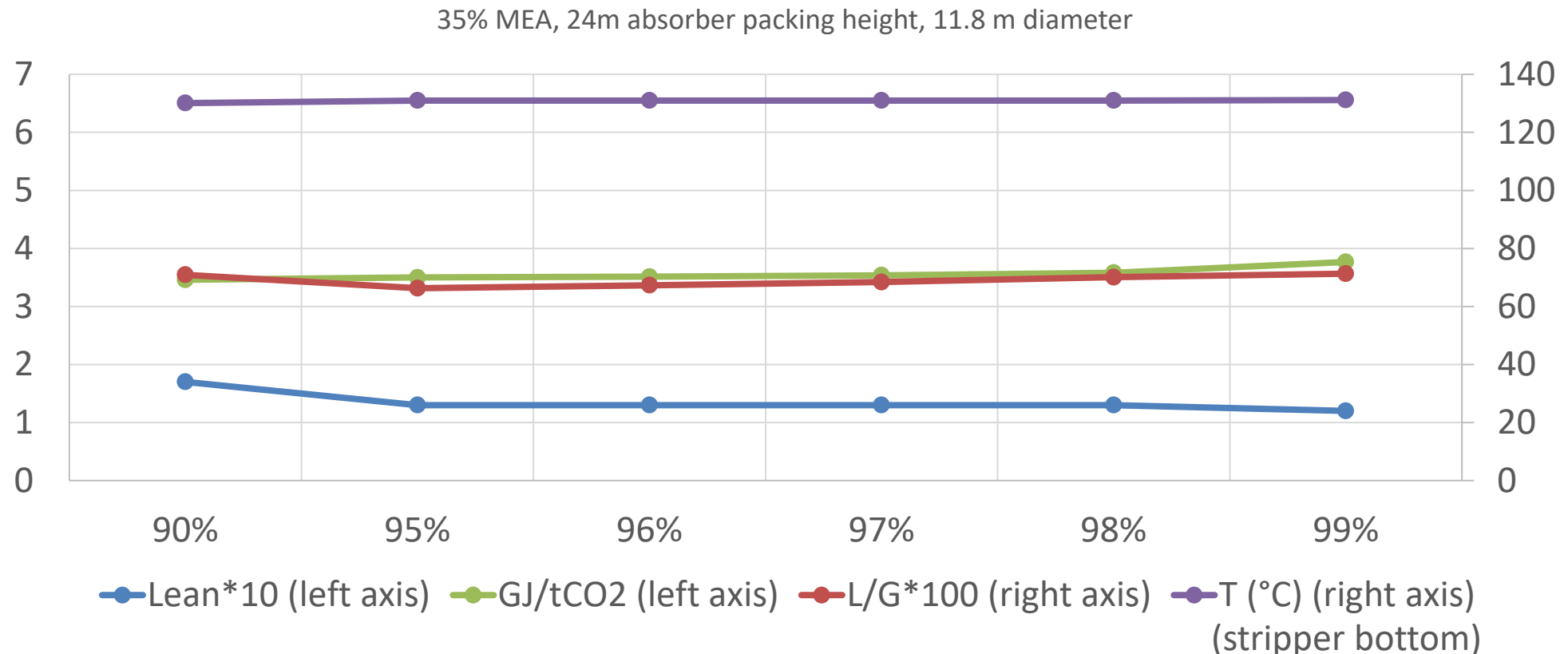
High levels of capture appear feasible with MEA

- UKCCSRC/TERC research^a suggests even 99% capture may be possible with 35% MEA – this is all the fossil CO₂
- >95% capture levels also demonstrated recently with ~35% MEA at Test Centre Mongstad^b
- 95% likely to become the design level for power PCC in the UK
- Dispatchable Power Agreement (DPA)^c incentivises higher capture levels

a) <https://terc.ac.uk/news-events/register-here-a-webinar-on-delivering-ultra-high-post-combustion-co2-capture/>

b) https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3821061

c) <https://www.gov.uk/government/publications/carbon-capture-usage-and-storage-ccus-business-models>

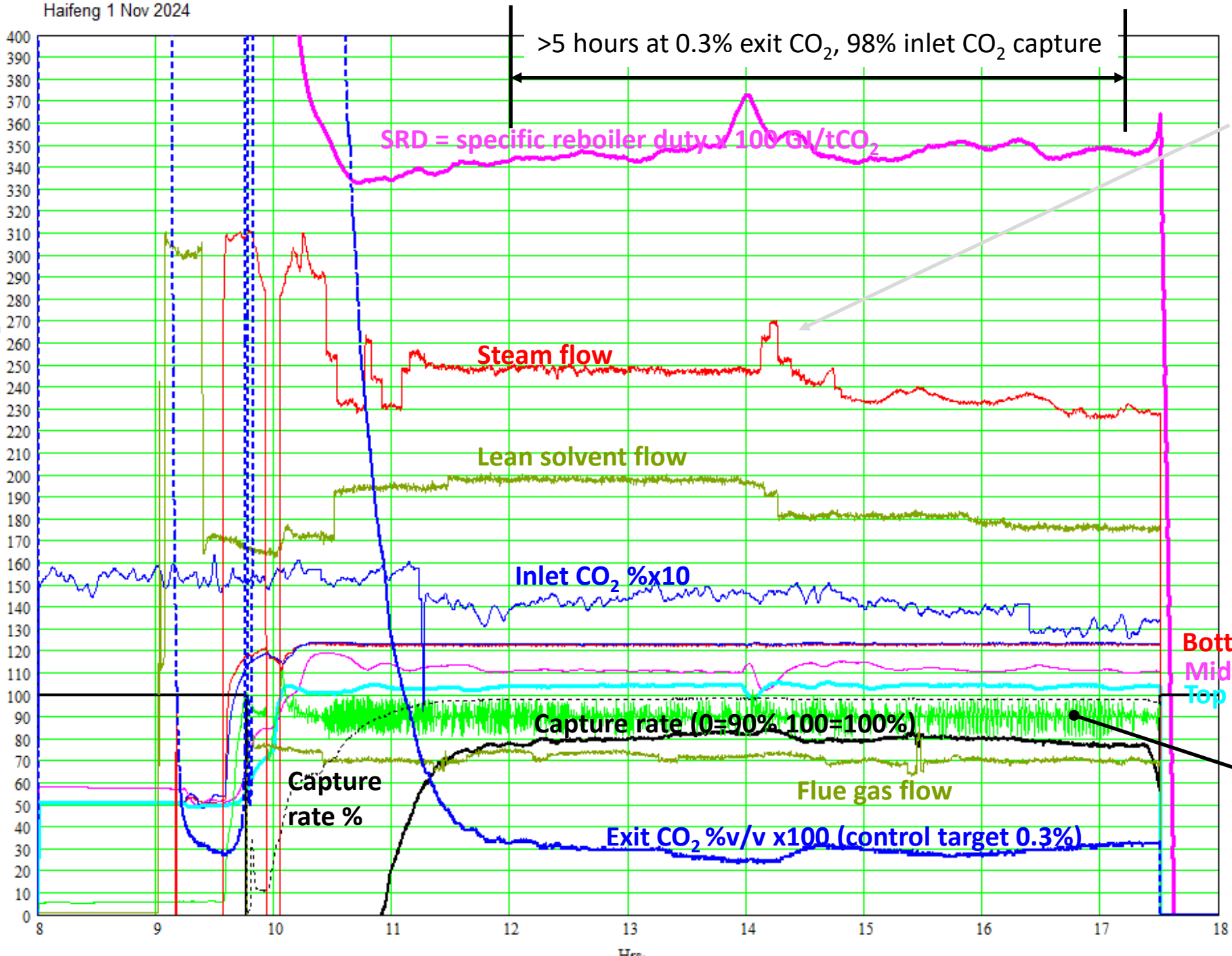


Haifeng 1 Nov 2024

Haifeng Pilot Plant,
~40t/day scale,
~35% MEA.

Final run on 1 Nov
shows sustained
capture rate of 98%
of the total
incoming CO₂ with
no significant
increase in energy
consumption, due
to careful real time
control based on
desorber packing
temperature
distribution.

FCDO CLEEN Project:
 COGENT – Capture Operation with
 Greater Economy for Net-zero Targets
 GD UK-China CCUS Centre
 Guangdong Carbon Capture Test Platform
 – ~ 40tCO₂/day in tests
 University of Sheffield/UKCCSRC
 Project report here:
<https://ukccsrc.ac.uk/research/flexible-funding/flexible-funding-2021/prof-jon-gibbins-university-of-sheffield>



>5 hours at 0.3% exit CO₂, 98% inlet CO₂ capture

SRD = specific reboiler duty x 100 GJ/tCO₂

Steam flow

Lean solvent flow

Inlet CO₂ %x10

Capture rate (0=90% 100=100%)

Flue gas flow

Exit CO₂ %v/v x100 (control target 0.3%)

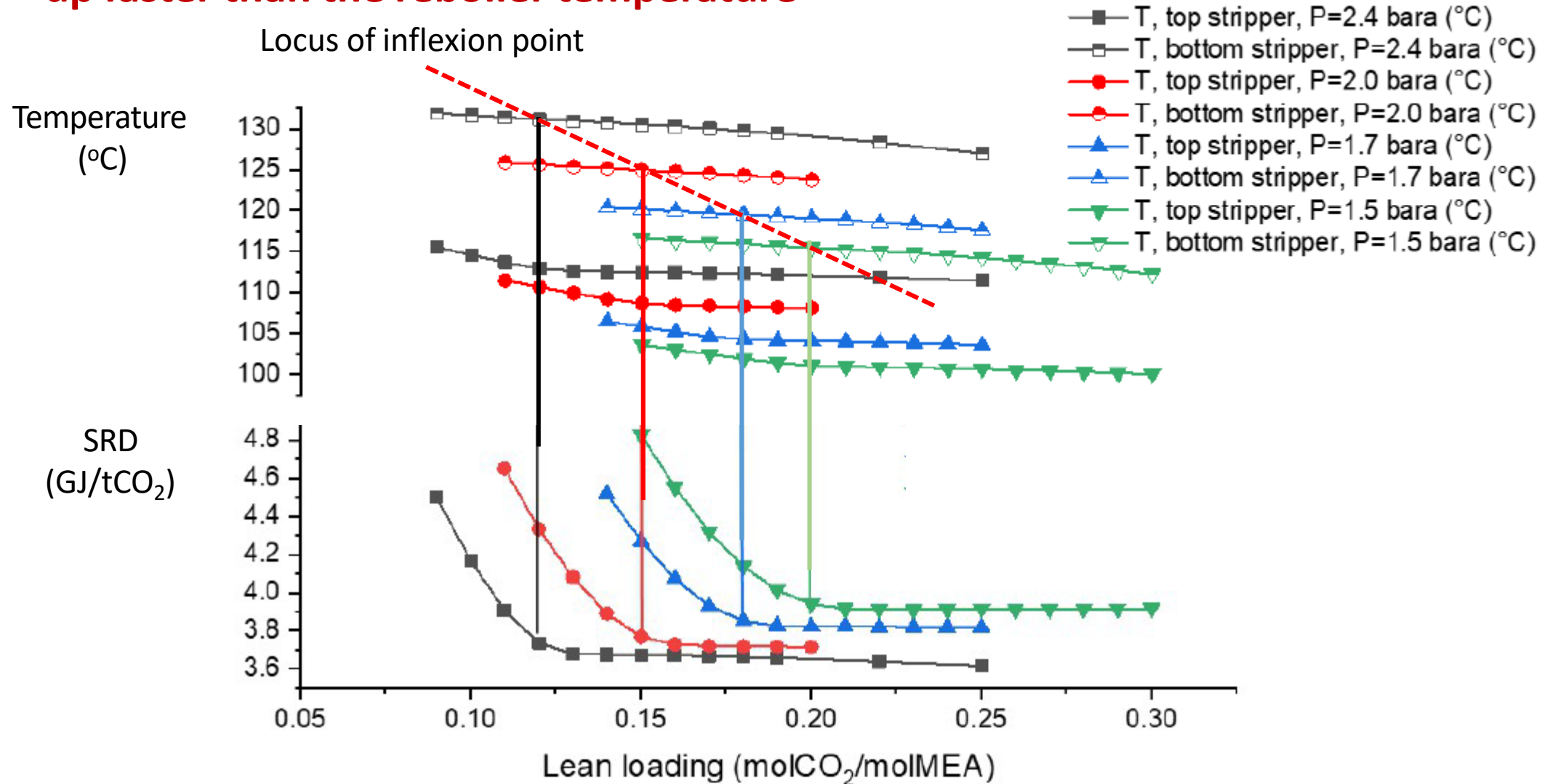
Sump level alarm disturbance

Desorber temperatures used for optimisation.
 Bottom T
 Middle T
 Top T

Desorber press. kPa

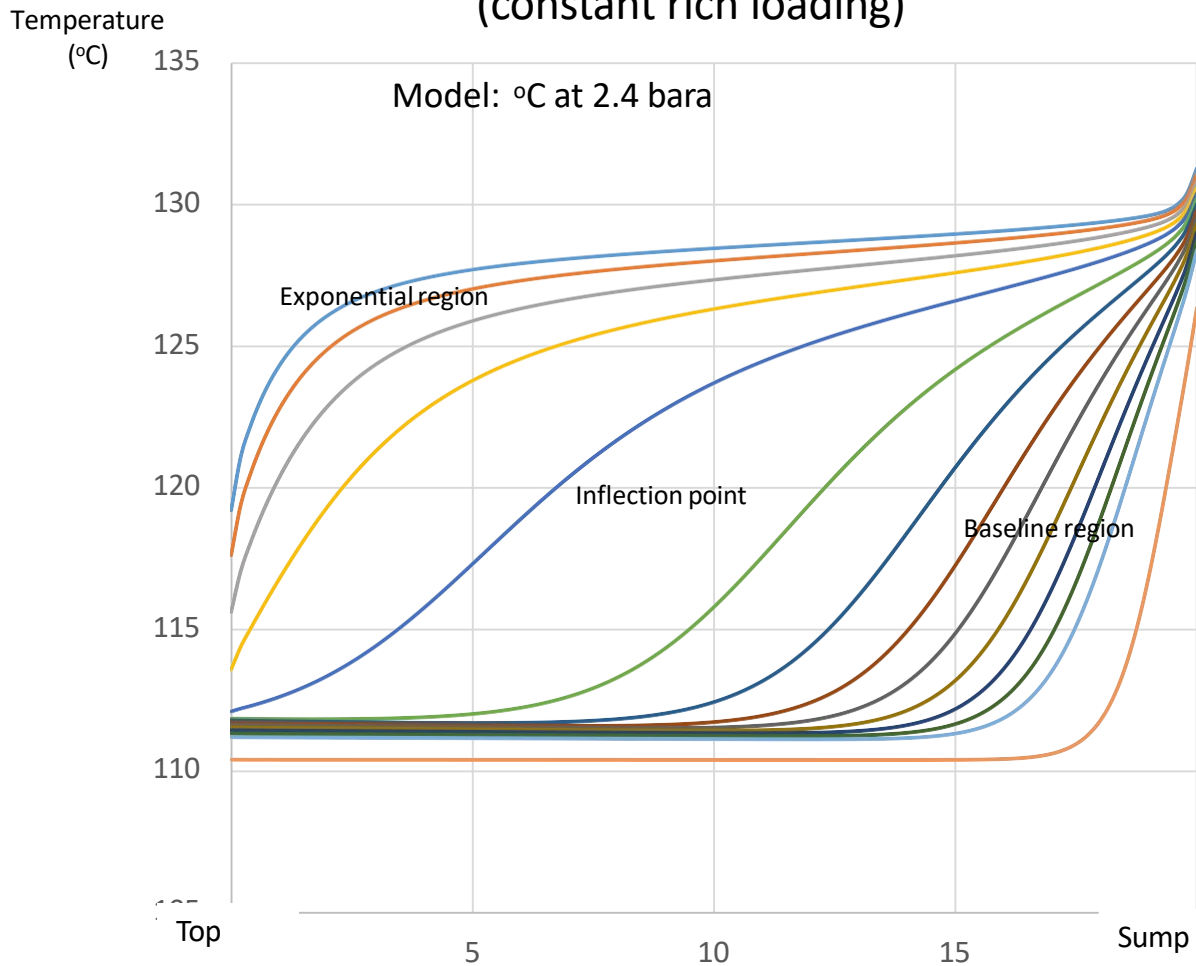
Capture rate %

Inflection point occurs when the specific reboiler duty (SRD) starts to increase rapidly is due to water vapour 'breakthrough'. The stripper column exit temperature starts to go up faster than the reboiler temperature

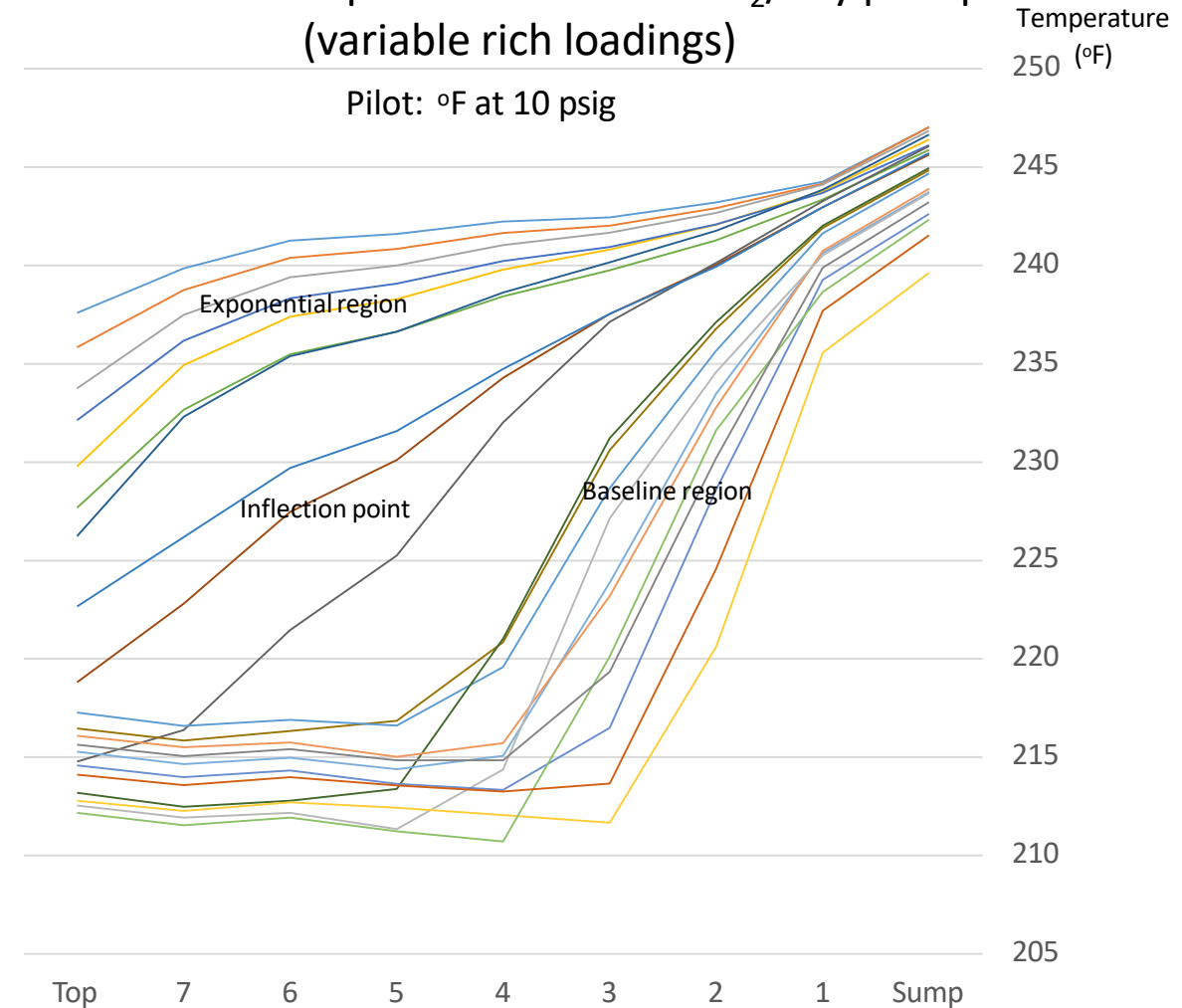


The phenomena that cause the inflection point are visible in the stripper column temperature profile

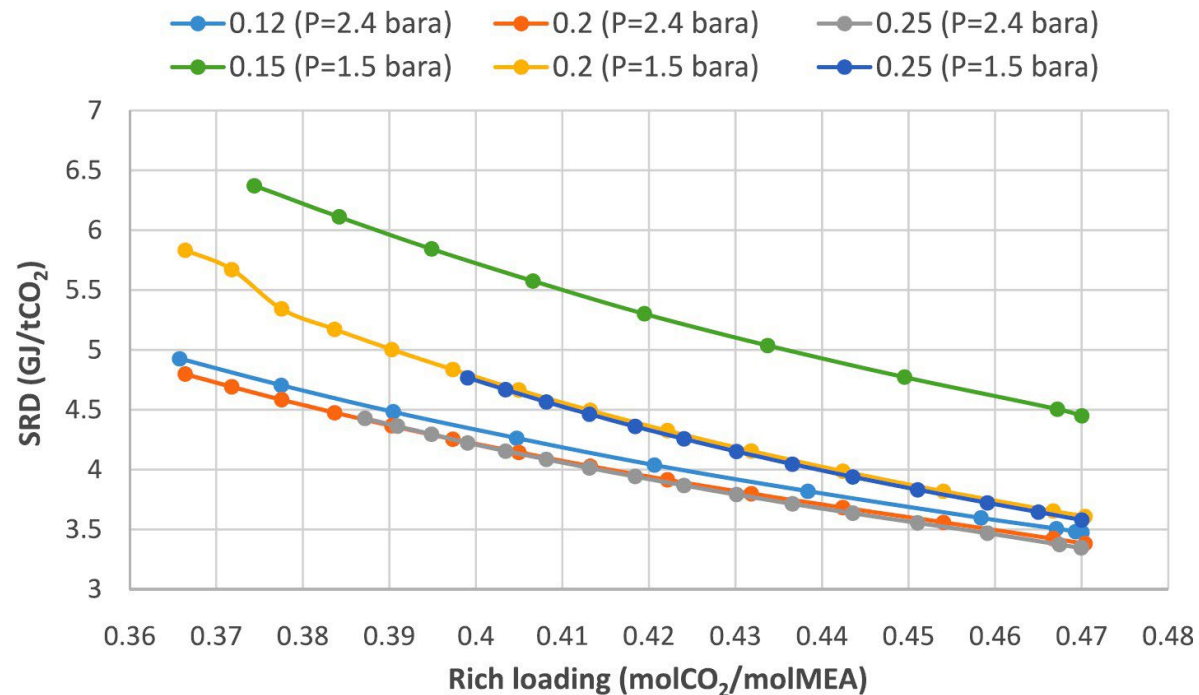
Modelled stripper internal temperature trends
(constant rich loading)



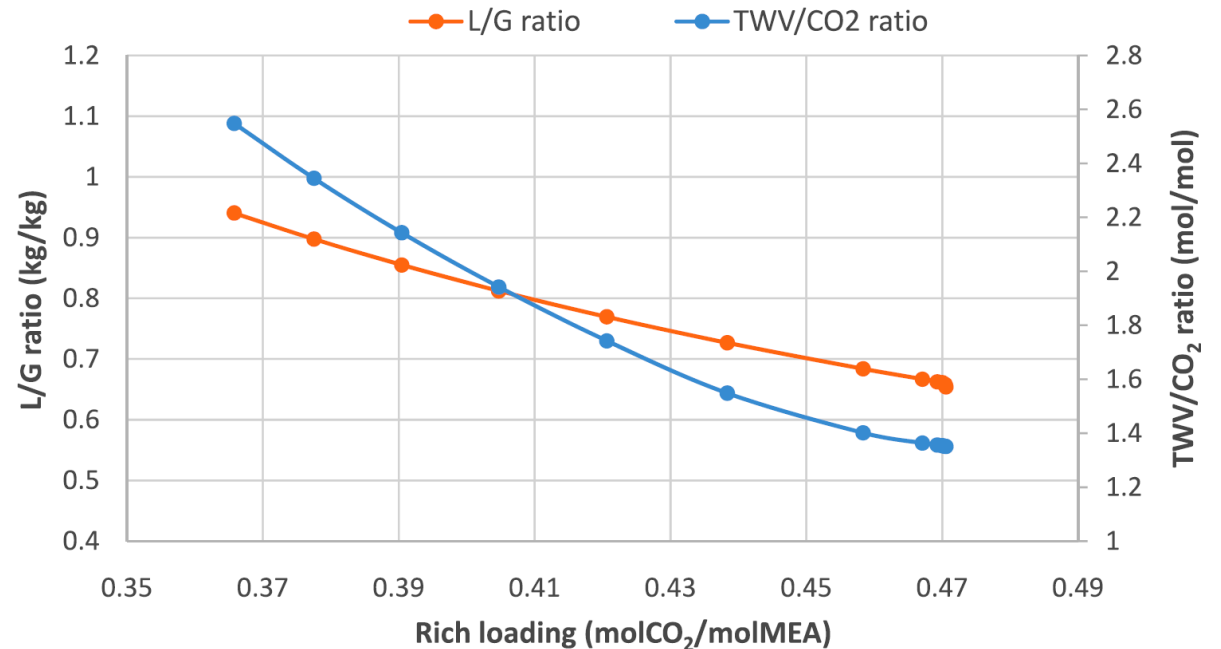
Stripper internal temperature trends observed on the
National Carbon Capture Center's 10tCO₂/day pilot plant
(variable rich loadings)



**SRD is insensitive to lean loadings down to the inflection point,
And SRD is insensitive to rich temperature (and then also rich flow rate) at the inflection point (STRETCHER, PCCC8)
But SRD is always sensitive to rich loading, higher CO₂ partial pressure means lower water vapour at exit**



Effect of rich loading and stripper pressure on the specific reboiler duty for different lean loadings of 0.12 (only for stripper pressure of 2.4 bara), 0.15 (only for stripper pressure of 1.5 bara), 0.2 and 0.25 molCO₂/molMEA.



Liquid/Gas L/G ratio and top water vapour TWV/CO₂ ratio as a function of rich loading. Lean loading is 0.12 molCO₂/molMEA and stripper pressure is 2.4 bara.

https://aurora-heu.eu/wp-content/uploads/2025/05/TCCS-13_DiegoM-1.pdf

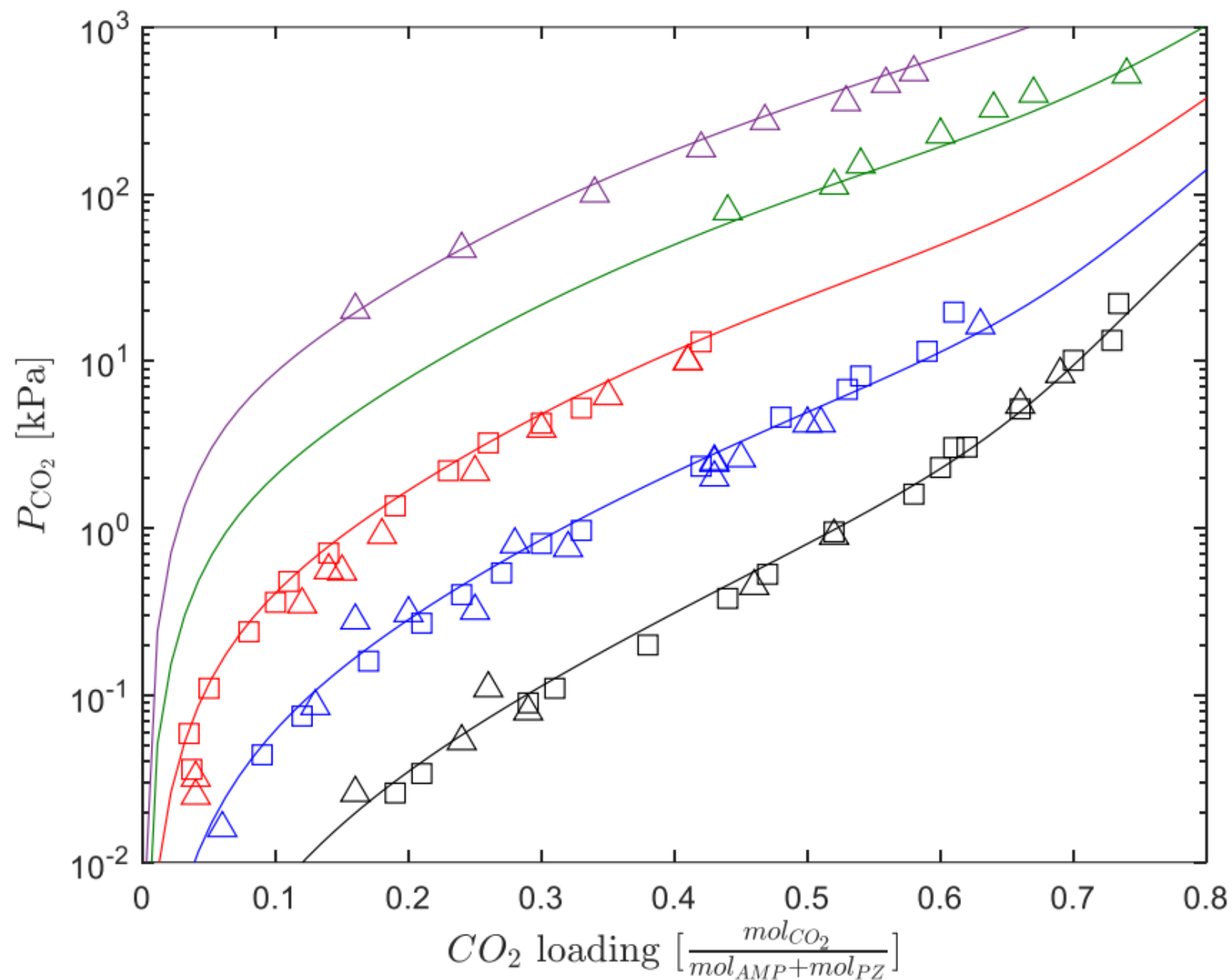
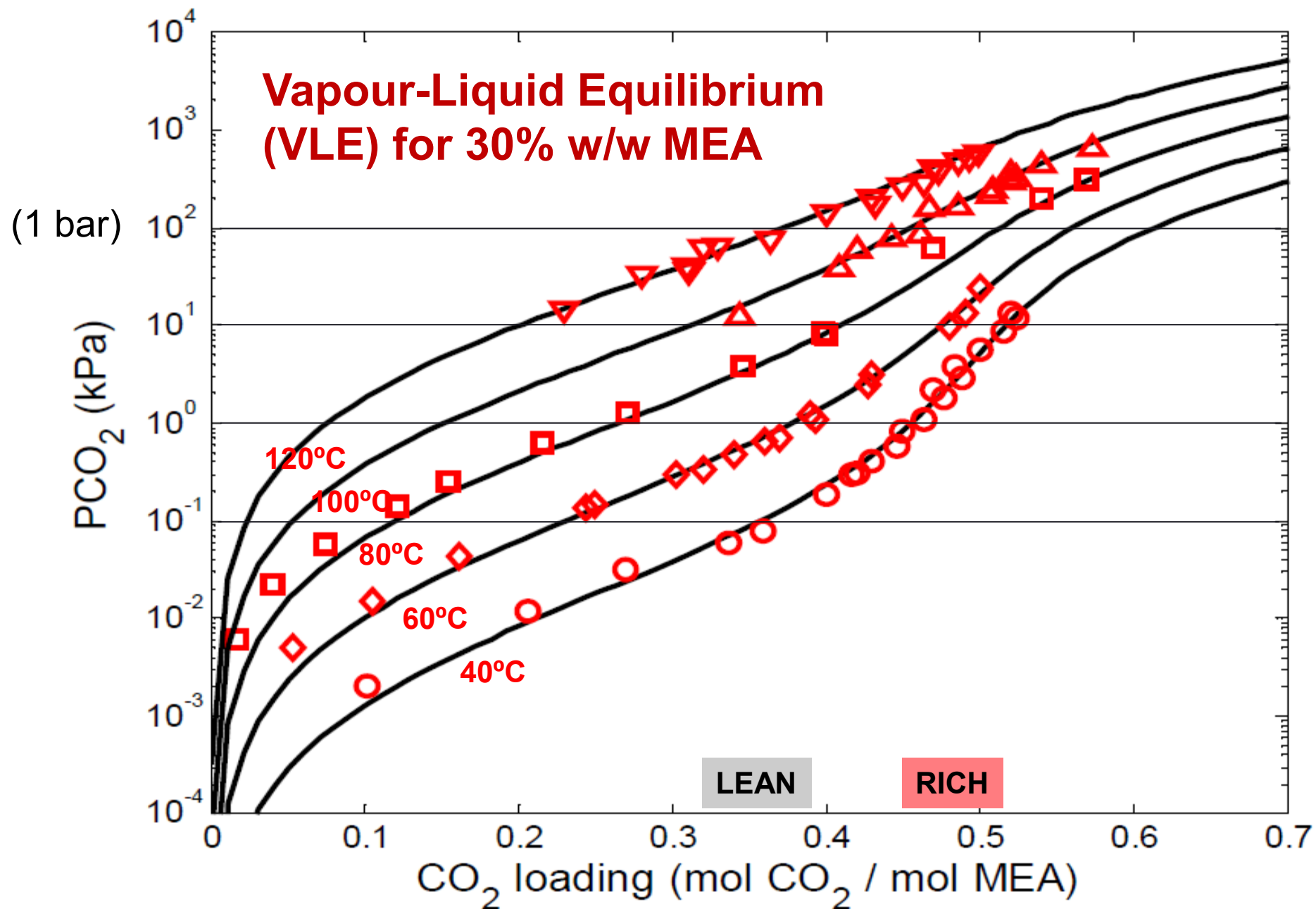
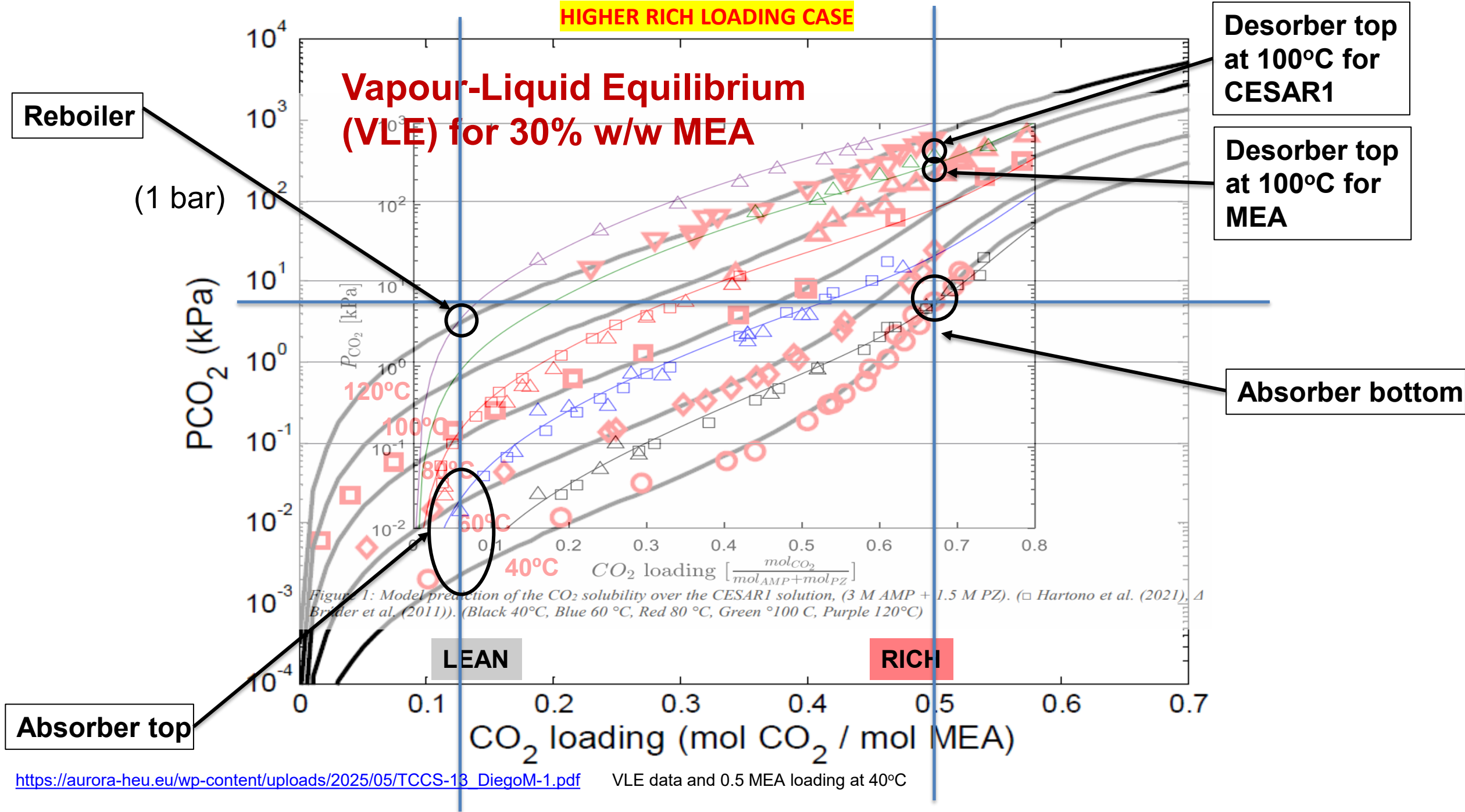
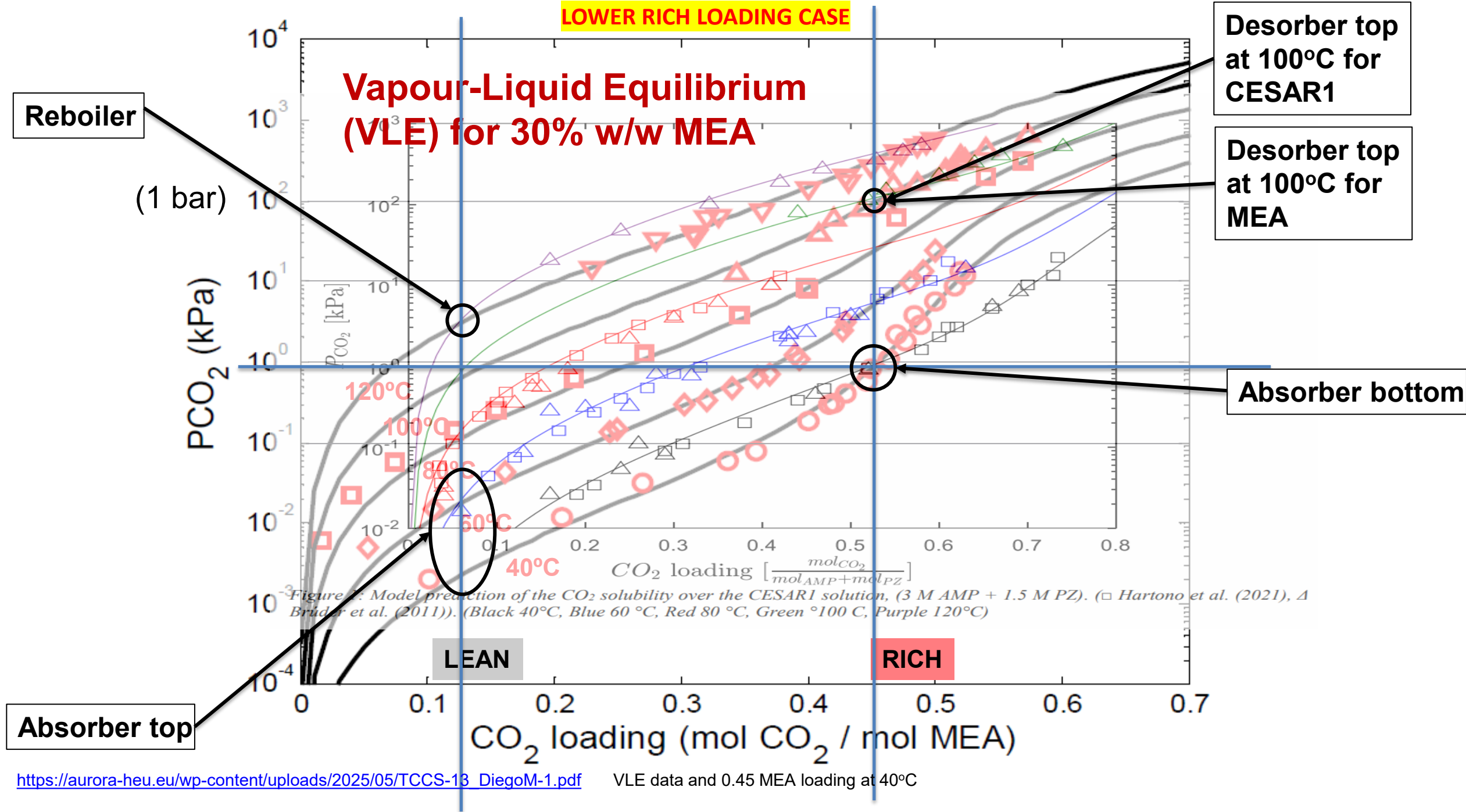


Figure 1: Model prediction of the CO_2 solubility over the CESARI solution, (3 M AMP + 1.5 M PZ). ($\square$ Hartono et al. (2021), Δ Brüder et al. (2011)). (Black 40°C, Blue 60 °C, Red 80 °C, Green 100 °C, Purple 120°C)







Impact of high capture rates and solvent and emission management strategies on the costs of full-scale post-combustion CO₂ capture plants using long-term pilot plant data

Henry Weir^a, Eva Sanchez-Fernandez^b, Charithea Charalambous^a, Jasper Ros^d, Juliana Garcia Moretz-Sohn Monteiro^d, Eirini Skylogianni^d, Georg Wiechers^c, Peter Moser^c, Mijndert van der Spek^a, Susana Garcia^{a,*}

^a Research Centre for Carbon Solutions, School of Engineering & Physical Sciences, Heriot Watt University, Edinburgh EH14 4AS, UK

^b Solveto Limited, 6 Westpoint, Dunbar EH42 1TL, UK

^c RWE Power AG, Ernestinenstraße 60, Essen 45141, Germany

^d TNO, Leeghwaterstraat 44, Delft 2628 CA, the Netherlands

“We found that for lignite fired power plants, CESAR1 is not per se a cheaper solvent system than MEA when actual solvent losses (or their mitigation measures) are considered, contrary to what earlier studies have suggested.

It may, therefore, be just as good a benchmark as MEA would be, as long as all degradation and emission (mitigation) costs are included in their cost estimates.”

IEAGHG 8th Post Combustion Capture Conference

16th to 18th September 2025 Marseille, France

The Effect of Solvent Aging on the Performance of CESAR1 at Highest CO₂ Capture Rates from 98.0% to >99.9%

Peter Moser^{a*}, Georg Wiechers^a, Sandra Schmidt^a, Yamid A. Gomez Rueda^b, Didjay F. Bruggeman^b, Peter van Os^b, Juliana Monteiro^b, Diego Pinto^c, Debadrita Ganguly^c

“While an elevated desorber temperature seems to be an effective measure to increase the capture rate at moderate increase of the specific energy demand of the solvent regeneration and to control the nitrosamine concentration in CESAR1, there is always a trade-off between the positive aspects of an increased desorber temperature (higher CO₂ capture rates, higher CO₂ pressure, control of nitrosamine concentration in the solvent) and negative effects (higher pressure and value of the steam needed for the solvent regeneration, increased formation of volatile and non-volatile degradation products, which must be handled or might form hazardous components in consecutive reactions).”

Overall conclusions

Based on the limited testing and publishing of results to date the main differences between MEA and CESAR1 appear to be:

- a) At most, 15% lower specific reboiler duty (SRD) than MEA for CESAR1, possibly zero at very high capture rates (e.g. 100% added CO₂ capture).
- b) Levels of nitrosamines in the circulating CESAR1 that at least several operators do not want to state in public.
- c) Solvent management methods for CESAR1 uncertain and unproven differences in solvent management costs, but those for CESAR1 expected to be somewhat higher, Weir (2023) suggests by a factor of two or more, than those for MEA.
- d) But can CESAR1 be run continuously with a reboiler pressure of 2.4 bara – or can MEA?
- e) And what about emissions to air? What control methods are needed?