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PROCESS MODELLING ASSESSMENT OF MODIFICATIONS TO A DETAILED COMMERCIAL PCC DESIGN USING 35% MEA TO ACHIEVE 95%+ CAPTURE LEVELS, PLUS ESTIMATED COST AND REVENUE IMPLICATIONS

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Presentation at PCCC6 Conference - 19th-21st October 2021 - https://ieaghg.org/conferences/2-uncategorised/1042-pccc-6

UPCC: ULTRA-HIGH POST-COMBUSTION CO_2 CAPTURE
CO-CAP: COLLABORATION ON COMMERCIAL CAPTURE

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Sherman retrofit design features

- Used as basis for higher capture level studies
- See separate presentation for additional details
- Solvent: 35 wt% MEA - previous study suggests competitive costs and open-access
- Design capture level: 85% of the CO_2 in the flue gas going to the absorber
- Packing height: 15 metres of structured packing (vendor TBC)
- Design flue gas flow: 704 kg/s, around minimum stable generation flow, into two absorbers
- CO_2 captured: 129 t/h of CO_2
- Heat recovery: 0.14 GJ/tCO_2 from CO_2 compressors intercooling, used for semi-lean flash
- CO_2 delivery pressure: 151 bara, centrifugal compressor, send out pump and dehydration

Modelling approach

- Modelling using Aspen V10 CCSI toolkit[1]. US DOE software, which has been calibrated against NCCC (US).
- The developed library include models for various physical properties. The Billet and Schultes correlation is regressed with data from Tsai (2010)[2] for MellapakPlus™ 250Y packing.
- NCCC web site - https://www.nationalcarboncapturecenter.com
- CCSI[2] web site - https://www.acceleratecarboncapture.org/

[1] Morgan, J. C. et al. (2018) 'Development of a Rigorous Modeling Framework for Solvent-Based CO2 Capture. Part 2: Steady-State Validation and Uncertainty Quantification with Pilot Plant Data', Industrial & Engineering Chemistry Research, 57(31), pp. 10464–10481. doi: 10.1021/acs.iecr.8b01472

[2] Tsai, R. E. (2010) Mass Transfer Area of Structured Packing. The University of Texas at Austin.

UPCC/Co-Cap study Aspen PFD

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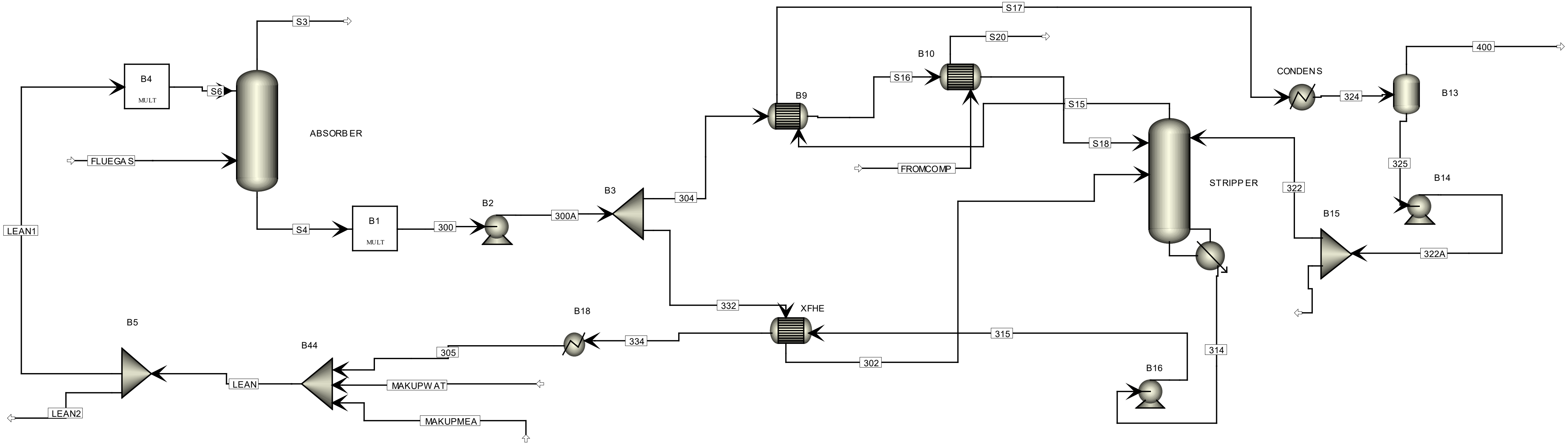
- Two identical absorbers
- Absorber height, 15-24 m (each)
- 11.8 m diameter unless shown otherwise
- Stripper height, 20m
- MellapakPlus™ 250Y
- Rich split, 5%
- Heat from compressors and stripper top is utilised to heat split and reduce reboiler heat input

- 35% w/w MEA
- Stripper pressure, 2.4 bar
- Stripper temperature, 127°C-131°C
- Capture rates, 90% - 99%
- Lean, ~ 0.1 - 0.2 mol/mol
- L/G, ~ 0.6 - 1.1



Reboiler duties – 15 m absorber

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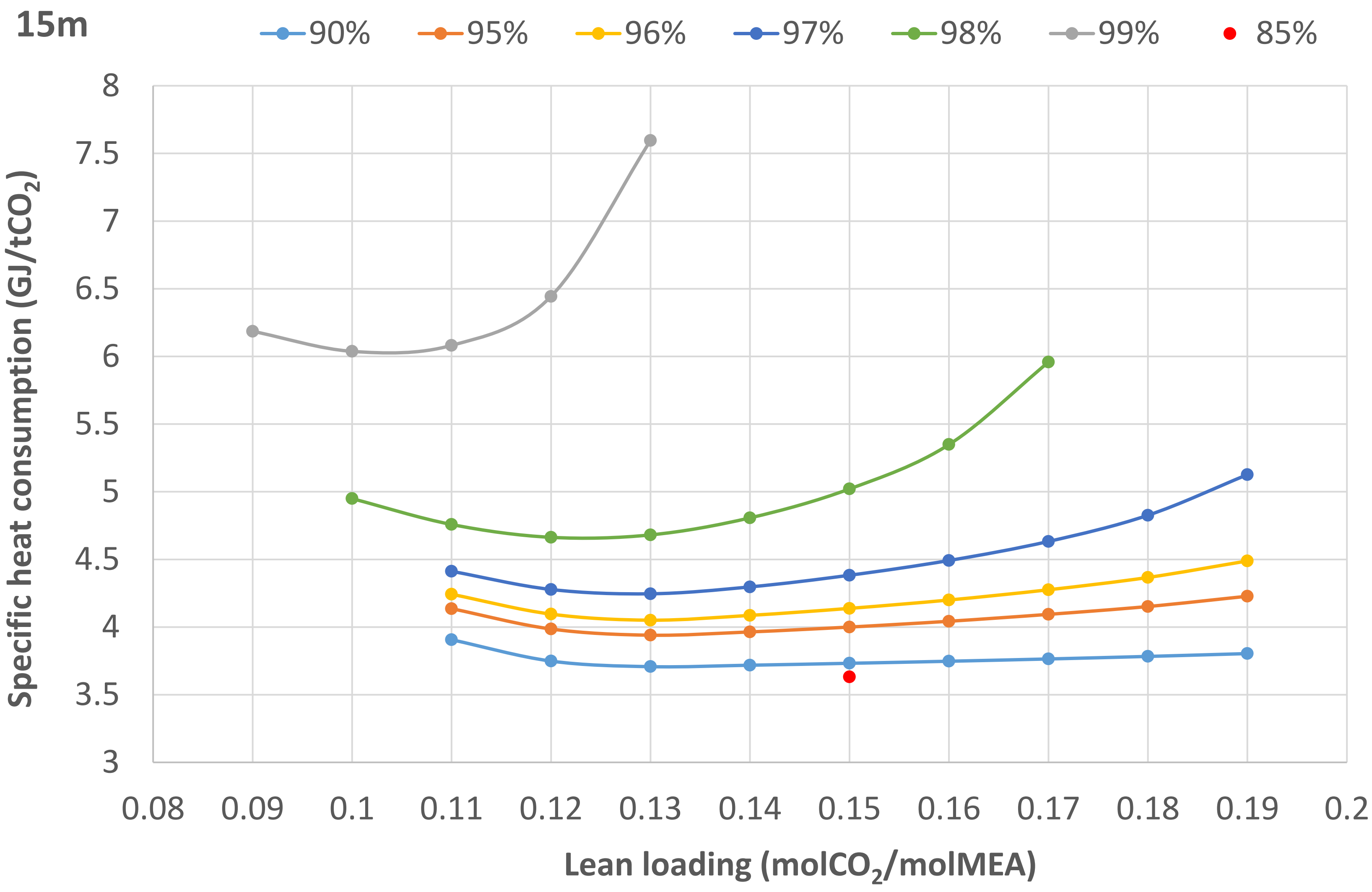
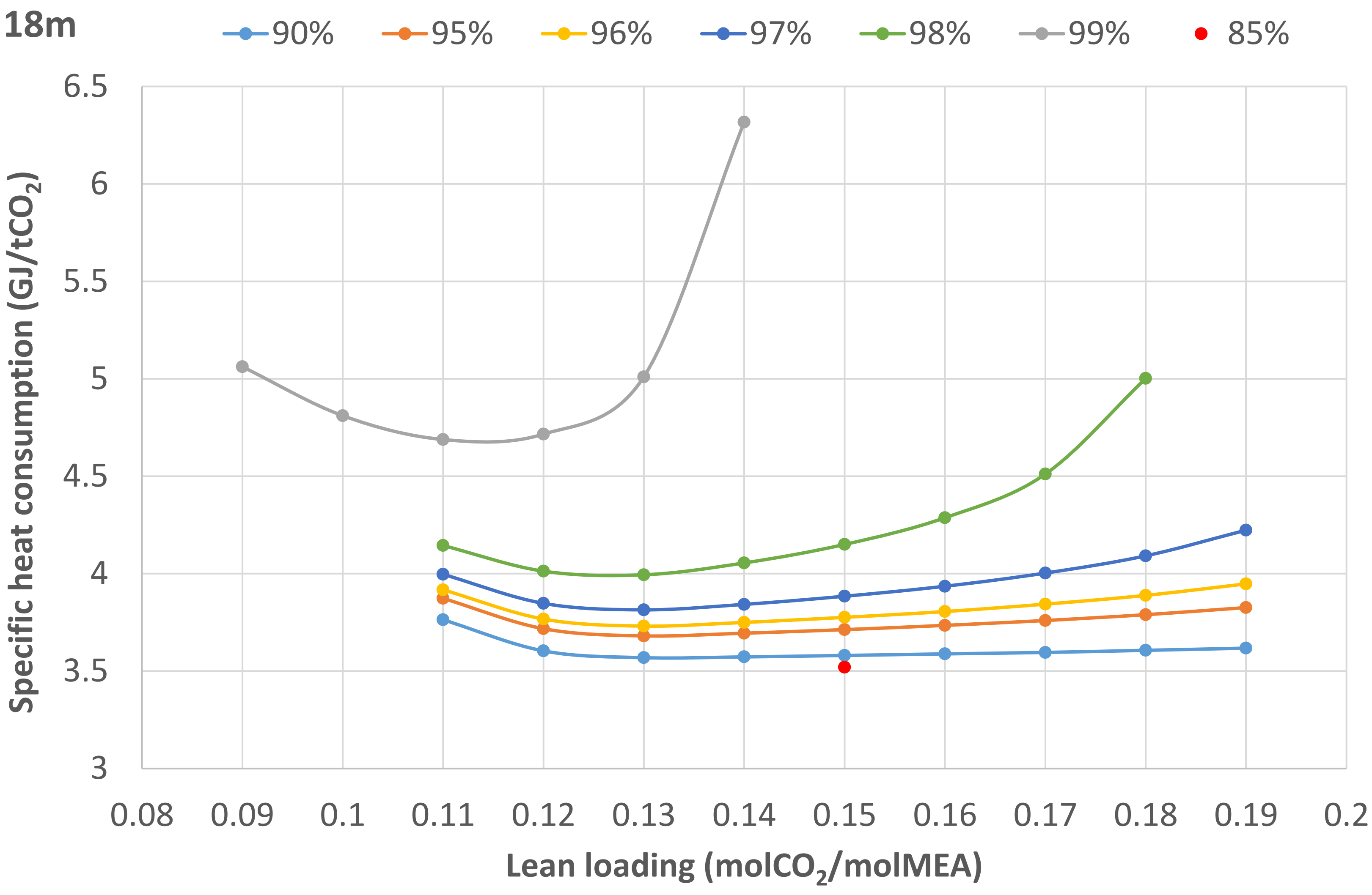
L/G and lean loading varied together to give 90, 95-99% capture, with varying consequences for stripping heat requirement



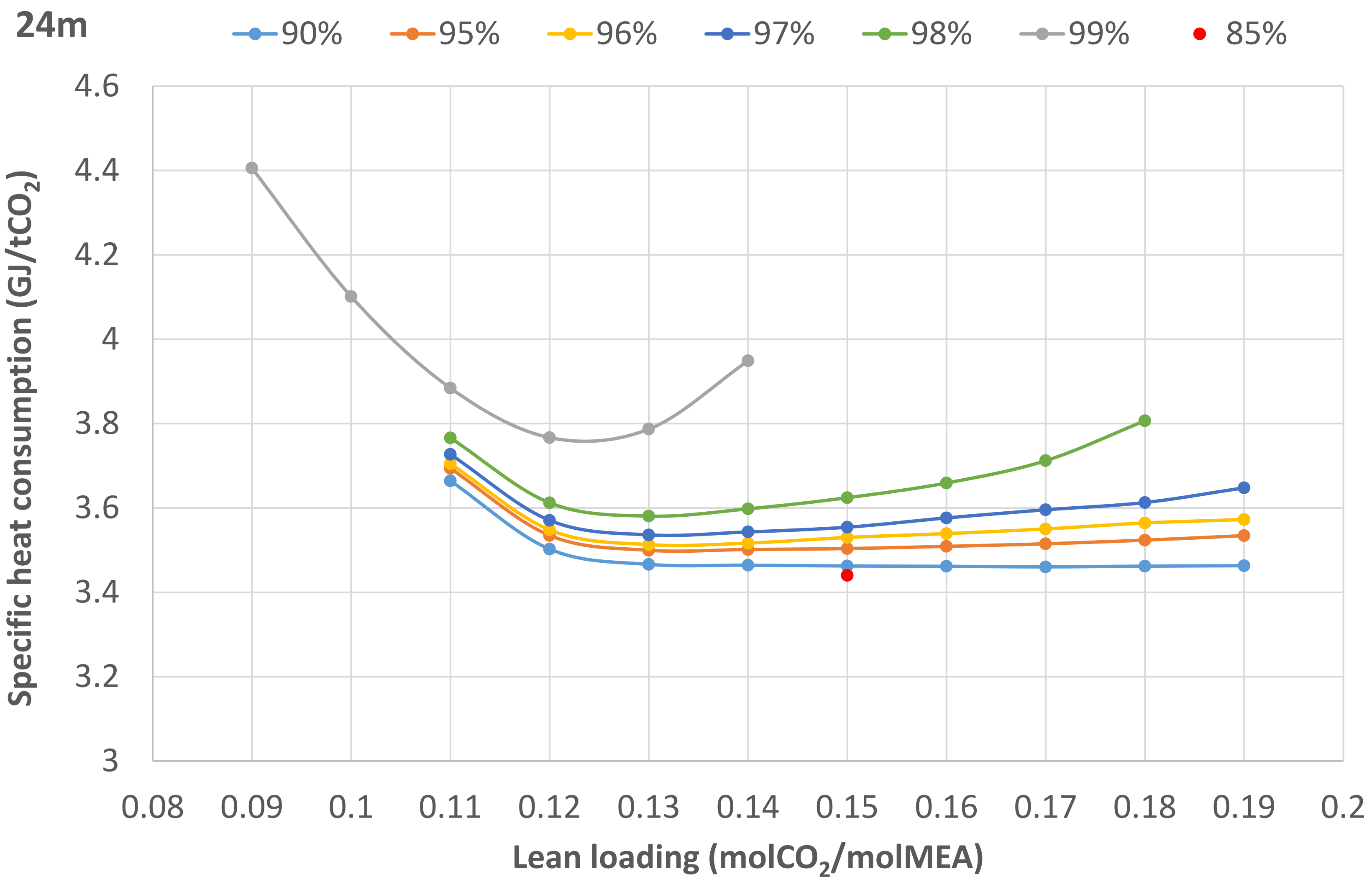
Reboiler duties – 18 m absorber

L/G and lean loading varied together to give 90, 95-99% capture, with varying consequences for stripping heat requirement



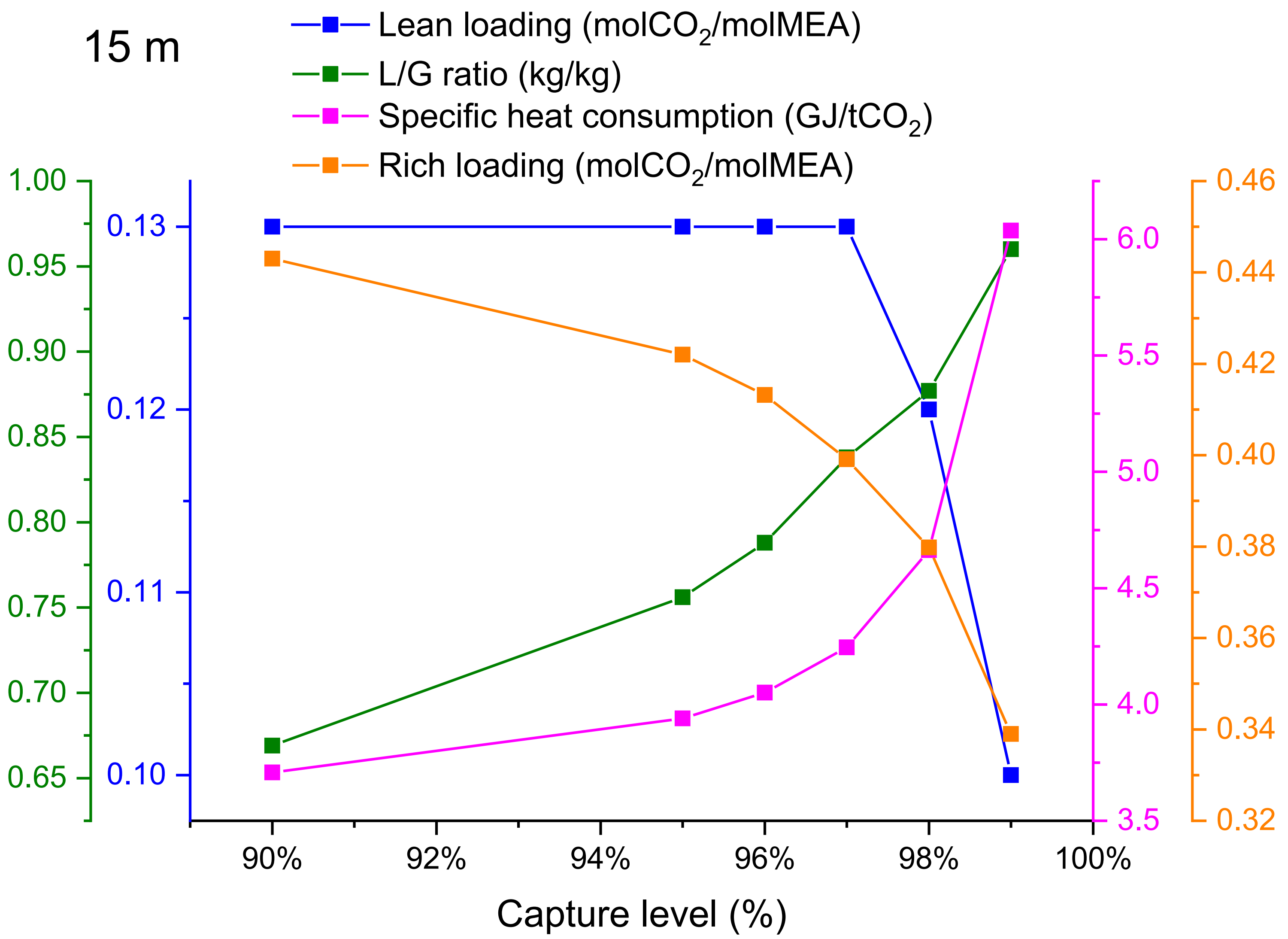
Reboiler duties – 24 m absorber

L/G and lean loading varied together to give 90, 95-99% capture, with varying consequences for stripping heat requirement



Multiple performance parameters – 15 m absorber

Optimum L/G and lean loading used to give 90, 95-99% capture with minimum reboiler heat input



Multiple performance parameters – 18 m absorber

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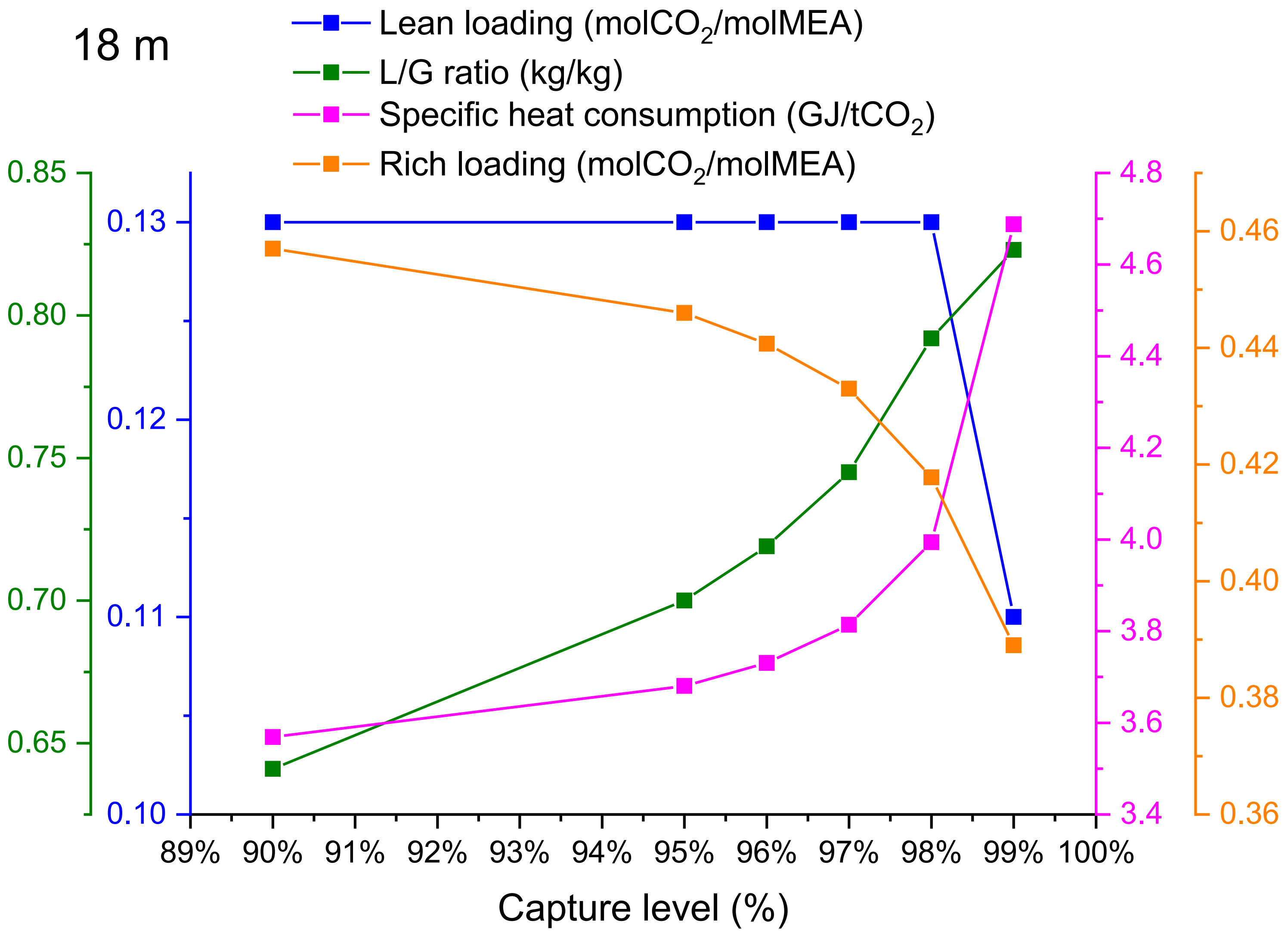

Multiple performance parameters – 24 m absorber

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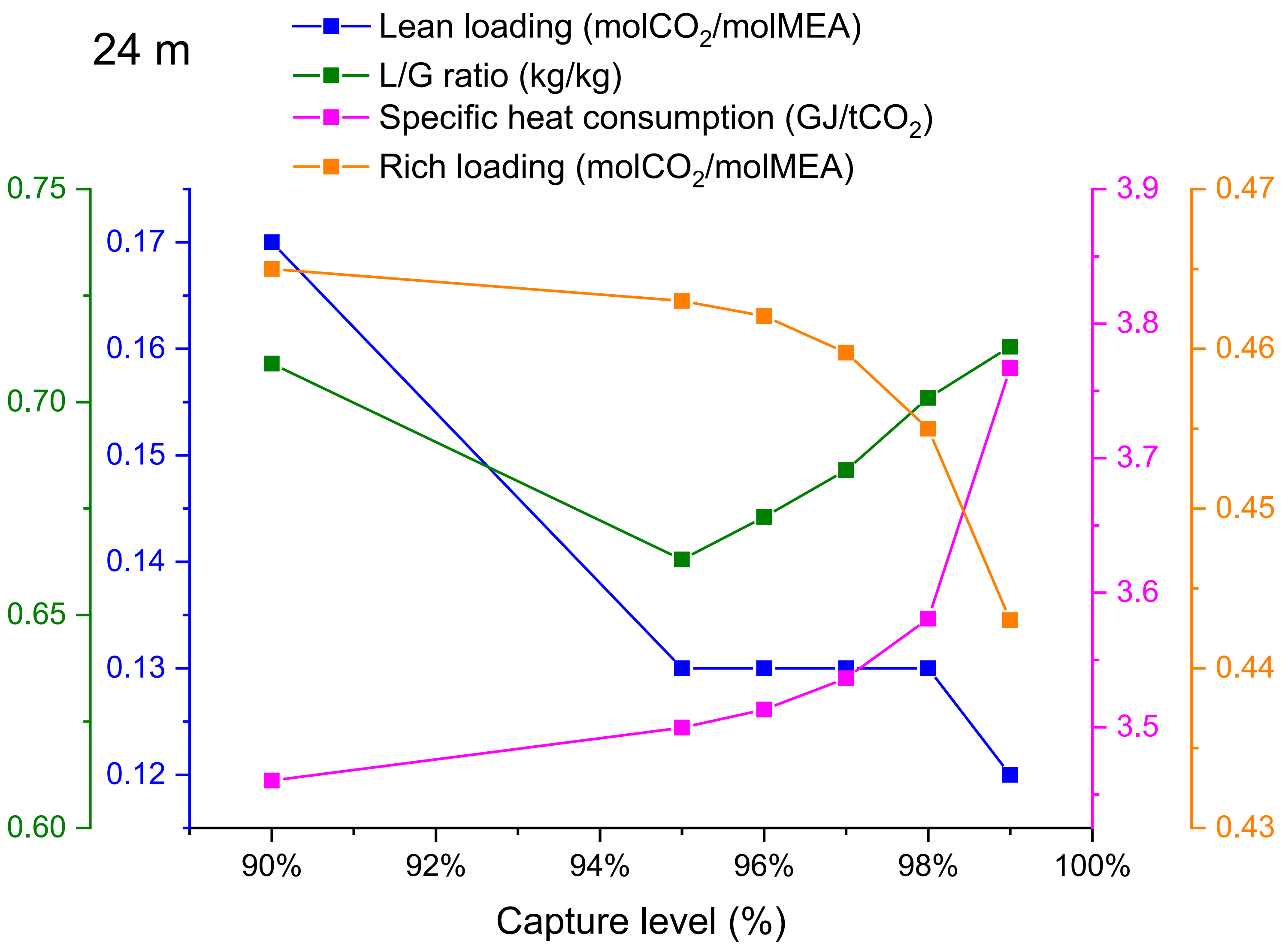

Sensitivity to achieved rich loading

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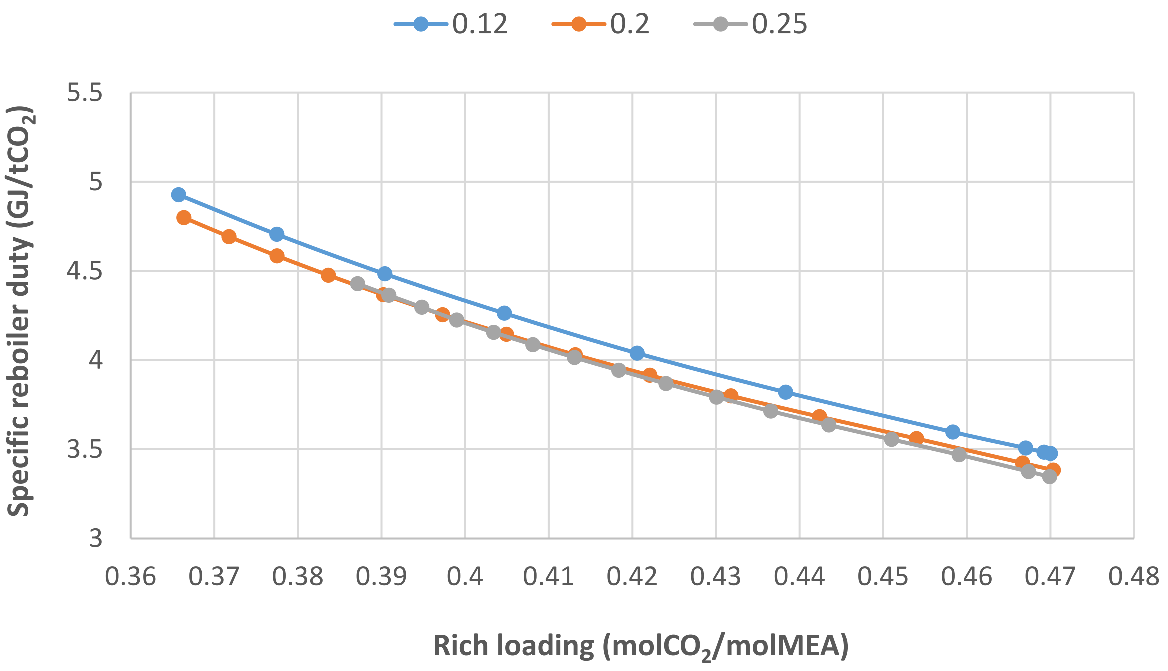
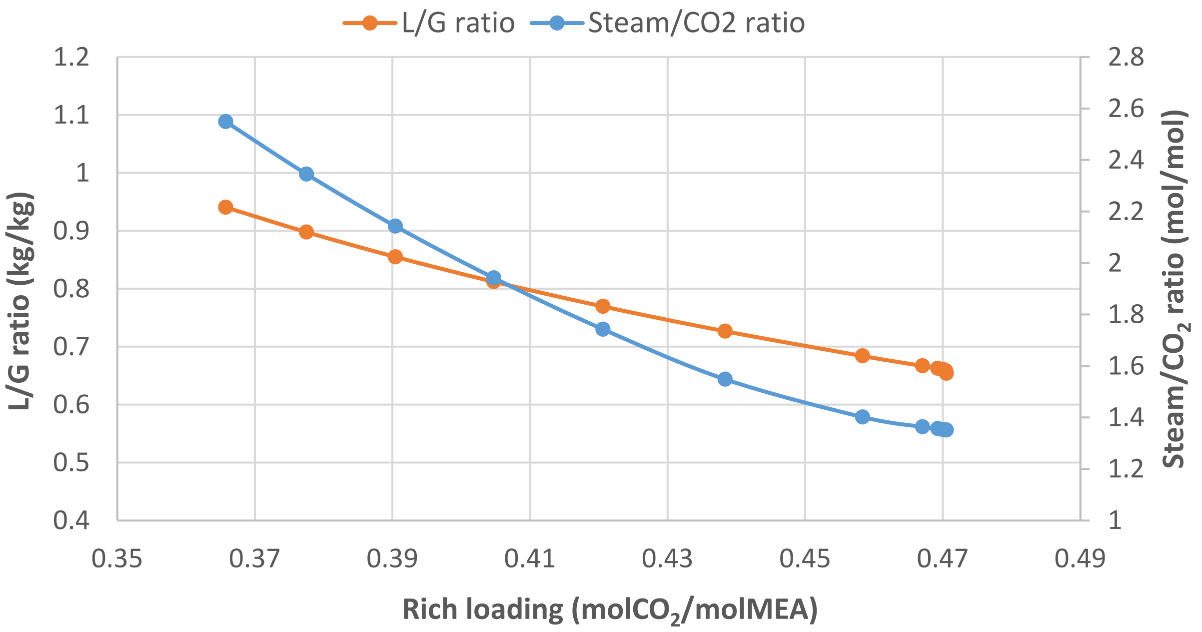
Calculated specific reboiler duty is insensitive to lean loading but very sensitive to rich loading over a range of lean loadings

As rich loading decreases:

a) L/G increases → more solvent to heat, Lean=0.12

b) Steam/CO_2 increases → greater latent heat losses





Sensitivity to lean loading at 95% capture

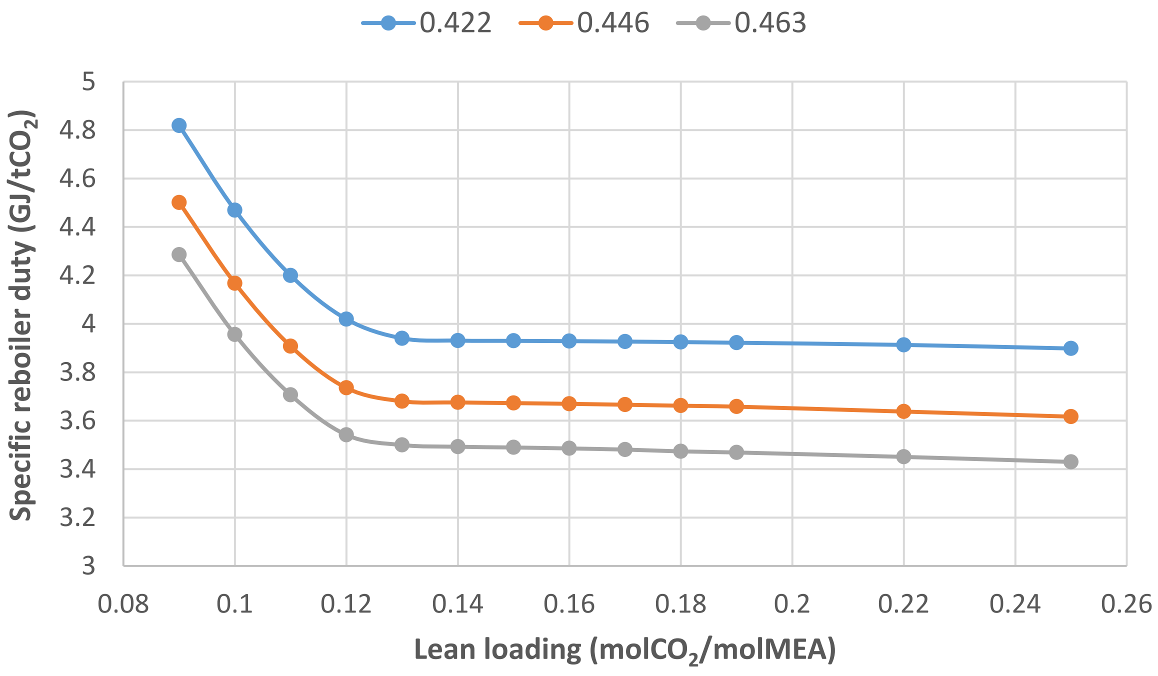
Calculated specific reboiler duty is insensitive to lean loading down to about 0.12, provided that the L/G ratio is reduced and the absorber conditions allow approximately the same rich loading to be achieved.

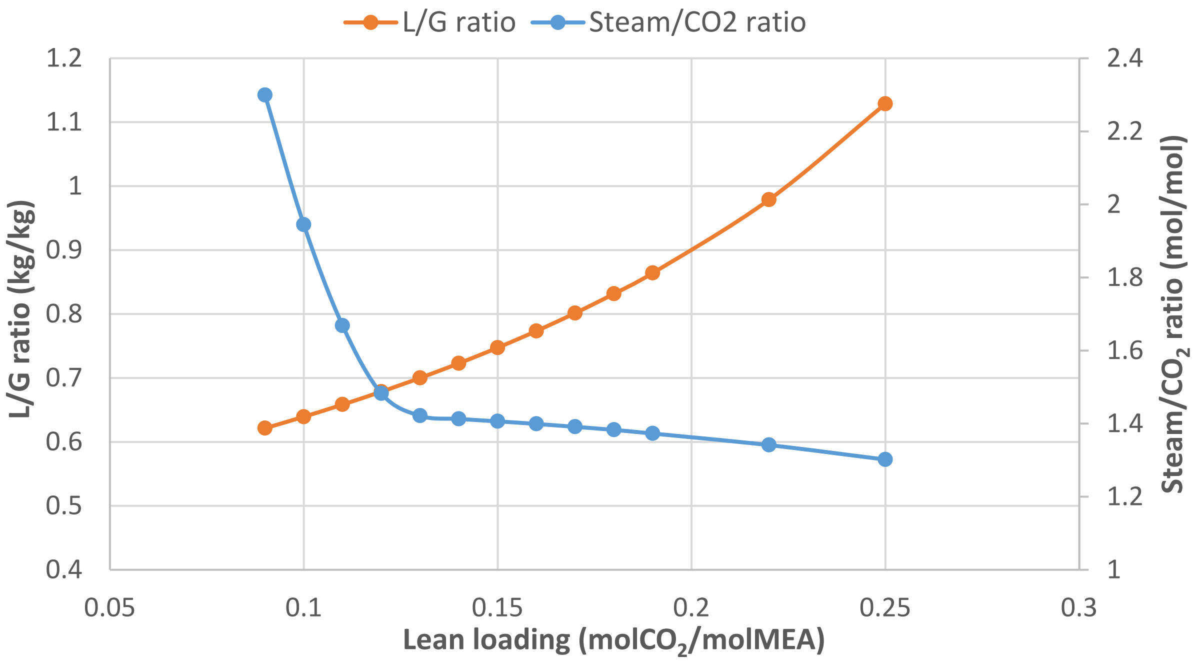
As lean loading decreases for same rich loading (????):

a) L/G decreases → less solvent to heat, Rich=0.446

b) Steam/CO_2 increases → greater latent heat losses

a) compensate for b) down to ~0.12 lean





Effect of reduced gas and liquid inlet temperatures

24 m packing, 99% capture

- Pre-cooling cases slightly better performance than the optimum for the given height and capture

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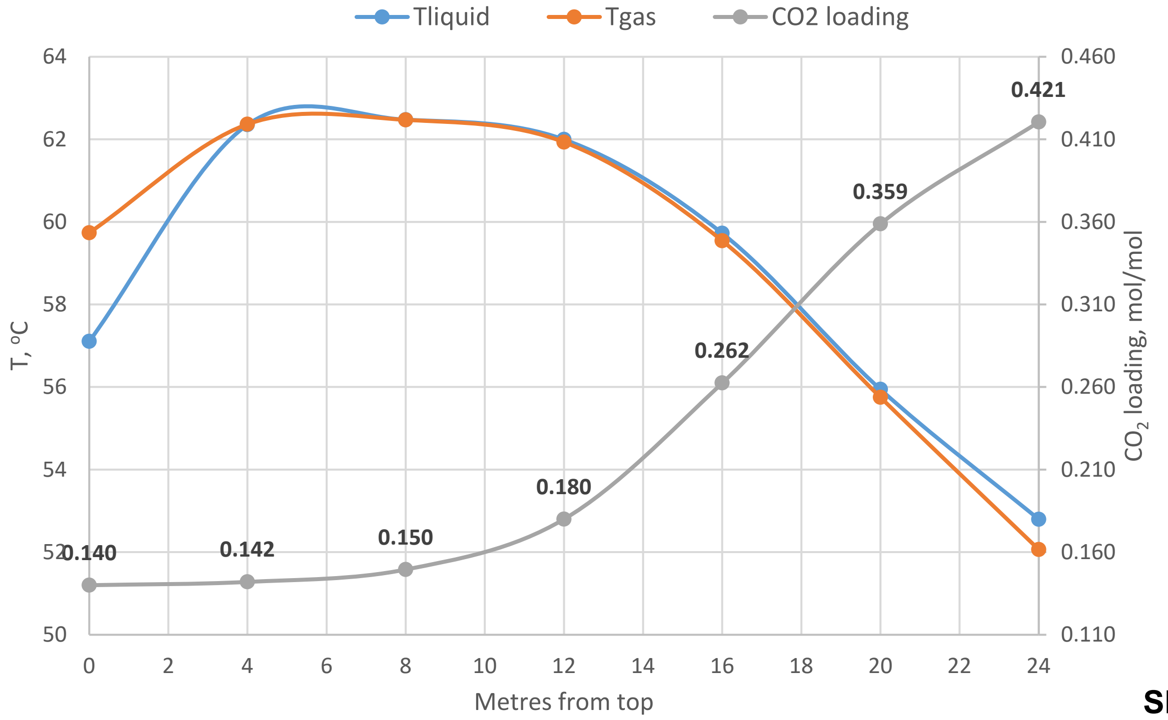
Temperatures	°C	Gas=51, Liquid=49	Gas=40, Liquid=49	Gas=40, Liquid=40	Gas=35, Liquid=49	Gas=35, Liquid=40	Gas=30, Liquid=49	Gas=30, Liquid=40	Gas=51, Liquid=49 (optimum)
Flue gas flow rate	kg/s	721.07	700.28	700.28	692.72	692.72	686.93	686.93	721.07
CO2 in	kg/s	42.09	42.09	42.09	42.09	42.09	42.09	42.09	42.09
Absorber packing height	m	24	24	24	24	24	24	24	24
Absorber diameter	m	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8
CO2 capture level	%	99	99	99	99	99	99	99	99
Lean loading	molCO2/molMEA	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.12
Rich loading	molCO2/molMEA	0.421	0.4393	0.4383	0.4382	0.4371	0.4350	0.4339	0.443
L/G ratio	kg/kg	0.821	0.7907	0.7929	0.8019	0.8044	0.8173	0.8200	0.713
T, bottom stripper	°C	130.737	130.850	130.733	130.903	130.782	130.948	130.829	131.143
Reboiler heat input	MW	164.553	155.266	156.125	155.547	156.371	156.762	157.657	156.966
SRD	GJ/tCO_2	3.949	3.726	3.747	3.733	3.753	3.762	3.783	3.767

Effect of absorber intercooling

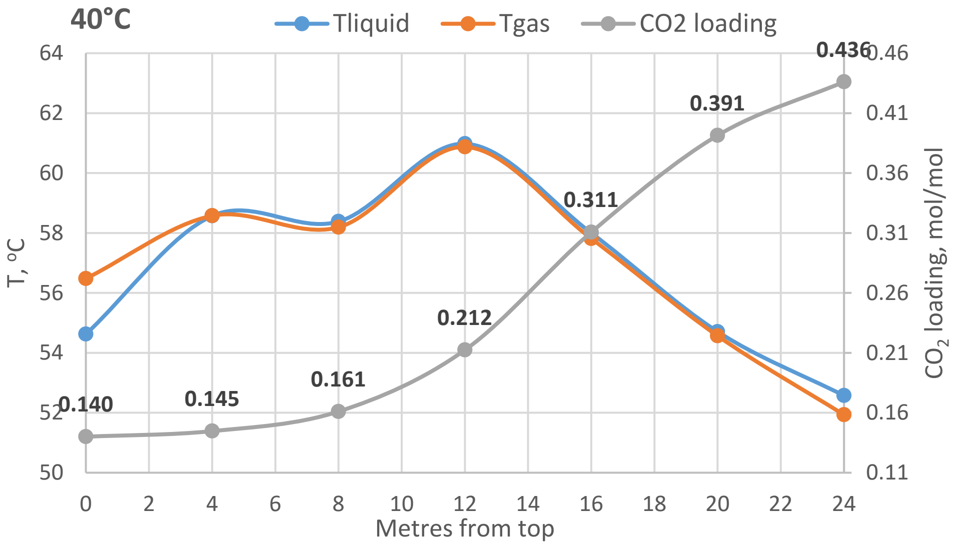
24 m packing, 99% capture, lean=0.14

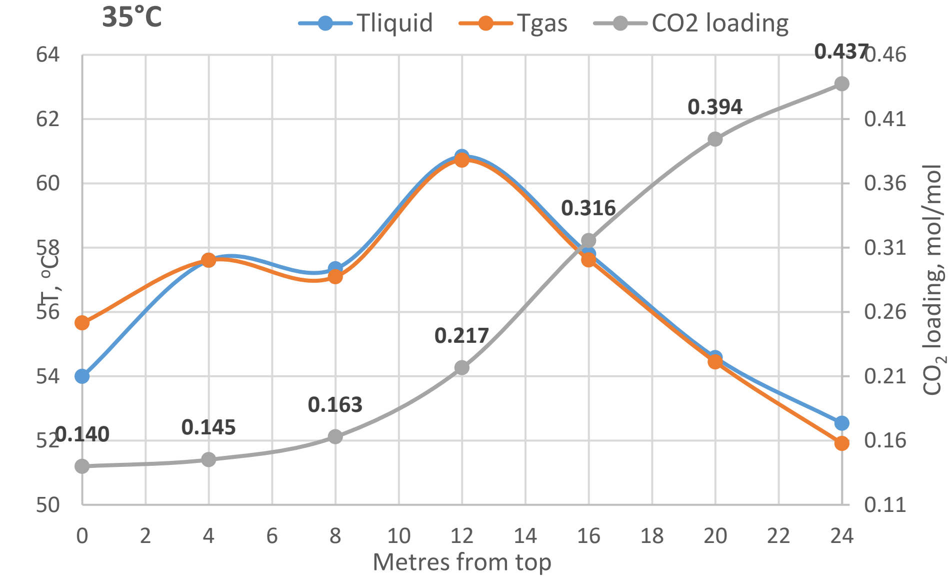
- Slight increase of mass transfer, low sensitivity due to low lean

SRD = 3.949 GJ/tCO_2



SRD = 3.795 GJ/tCO_2





SRD = 3.785 GJ/tCO_2

Effect of increased absorber diameter

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- Significance is that 18 m of packing requires two beds, 24 m three beds
- Increase of diameter from 11.8m to 15.23m (↑66% packing volume via increased cross sectional area) equates to ↑33% volume increase from increased height
- For 99% capture CSA increase required is ↑88% to match ↑33% on height

Absorber packing height	m	18	18	18	24
Absorber diameter	m	11.8	13.62	15.23	11.8
Extra cross sectional area			33%	66%	-
CO_2 capture level	%	95	95	95	95
Lean loading	$molCO_2/molMEA$	0.13	0.13	0.13	0.13
Rich loading	$molCO_2/molMEA$	0.446	0.4591	0.4647	0.4634
L/G ratio	-	0.700	0.672	0.66	0.663
T, bottom stripper	°C	130.952	130.971	130.975	130.98
Reboiler heat input	MW	147.164	141.648	139.679	139.94
SRD	GJ/tCO_2	3.68	3.542	3.493	3.499

Absorber packing height	m	18	18	18	24
Absorber diameter	m	11.8	13.62	16.16	11.8
Extra cross sectional area			33%	88%	-
CO_2 capture level	%	99	99	99%	99
Lean loading	$molCO_2/molMEA$	0.11	0.11	0.11	0.12
Rich loading	$molCO_2/molMEA$	0.3894	0.4345	0.4586	0.443
L/G ratio	-	0.823	0.710	0.661	0.713
T, bottom stripper	°C	131.352	131.359	131.377	131.143
Reboiler heat input	MW	195.352	168.604	156.747	156.966
SRD	GJ/tCO_2	4.688	4.046	3.762	3.767

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Summary

- High capture levels modelled as being achievable in a similar plant configuration to the Sherman FEED study
- Lean loading determines maximum capture level
- Inlet flue gas CO_2 determines maximum potential rich loading
- Stripper specific heat input is a function of liquid flow (lower better) and rich loading (higher better) as well as lean loading (higher slightly better – but relatively insensitive down to ~0.12)
- If L/G is too high for a given lean loading then the rich loading cannot reach the maximum value, however much packing is used – possible turn-down issues on existing pilot plants?
- For Sherman flue gas flow and absorber diameter 15 m is too short for 99% capture, 18 m requires significant energy (but less for 98% and below) and 24 m is probably adequate (for current CCSI model kinetics)
- Absorber diameter can also be increased, with less effective use of packing but may save the costs of adding an extra bed.

Economics of operation at higher capture level

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- At what capture level would a plant be operated, if there were no bottlenecks in operation?
- Preliminary assessment based on carbon emission cost and electricity sale price
- Actual support mechanisms may differ, although exposure to market carbon prices is a basic principle
- Design for 95% capture is also part of UK BAT Guidance for power PCC https://www.gov.uk/guidance/post-combustion-carbon-dioxide-capture-best-available-techniques-bat
- Basic data assumed for a natural gas CCGT plant:

Base power plant efficiency	%LHV	60%
Power output without capture	MW	454.6
Heat to reboiler/lost electricity ratio, COPx*, assumed constant	MWth/MW electrical	4
Specific power for CO_2 compression	kWh/tCO_2	70.00
Specific power for utilities	kWh/tCO_2	30.00

*Lucquiaud, M. and Gibbins, J. (2011), *On the Integration of CO_2 capture with coal-fired power plants: A methodology to assess and optimise solvent-based post-combustion capture systems*, Chemical Engineering Research and Design, Volume 89, Issue 9, September 2011, 1553–1571. https://www.sciencedirect.com/science/article/pii/S0263876211001109

Economics of operation at higher capture level

- At what capture level would a plant be operated, if there were no bottlenecks in operation?
- Indicative carbon price to break even when electricity selling price is £100/MWh
- and capture level changed from:
    - 90% to 95%
    - 95% to 99%

Capture level	90%	95%	99%
Fossil CO_2 out (t/h)	15.15	7.58	1.52
MW out with 18 m of packing	406.2	400.8	388.5
MW out with 24 m of packing	408.2	405.2	400.3

CO_2 price for £100/MWh electricity	90% to 95%	95% to 99%
18 m of packing	71.11	202.36
24 m of packing	39.31	80.71

- It seems likely that high capture levels will be favoured in future markets under some possible combinations of electricity and carbon price – if the plant design allows it

Thank you for your attention