Sensitivity analysis of post-combustion CO_2 capture at pilot scale level

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Synopsis

- Objectives
- PACT facility
- Solvent based carbon capture plant
- SCCP model in Aspen HYSYS
- Model validation for 4.5 mol% CO_2
- Sensitivity analysis study
- Sensitivity variation cases
- Conclusions

Objectives

- To understand the process operation of the post-combustion capture system in a closed-loop.
- Estimation of the operability range of the post-combustion capture plant (MEA system) at pilot-scale through process sensitivity analysis.
- Operational parameters are varied, such as:
  - L/G ratio
  - CO_2 composition in flue gas
  - Lean loading
  - Amine strength
  - Flue gas temperature
  - Liquid temperature
  - CO_2 capture rate
  - Stripper pressure
- Performance parameters include:
  - Specific reboiler duty
  - Rich loading
  - Absorber temperature profile
  - Stripper temperature profile

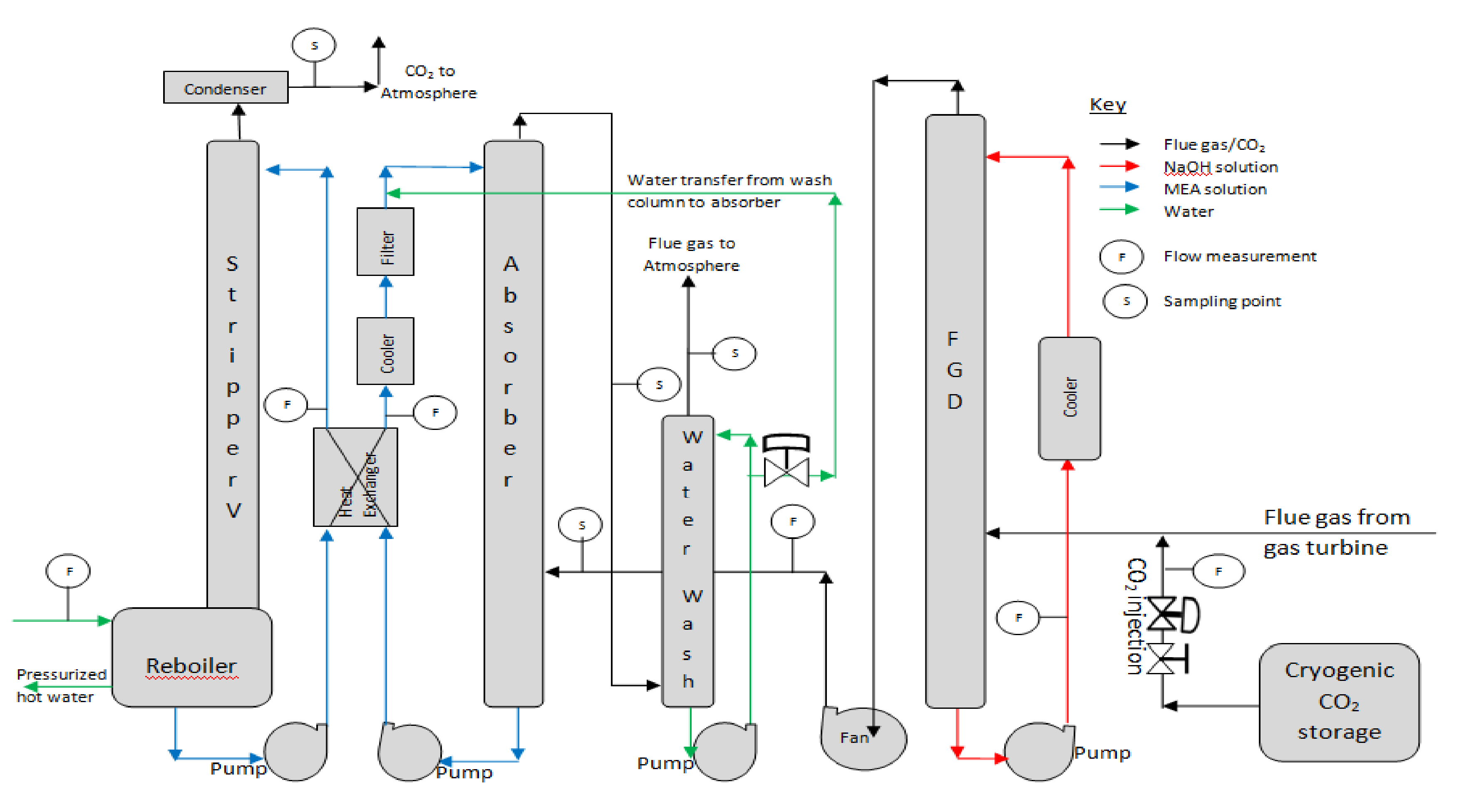
UK CCS Pilot-Scale Advanced Capture Technology (PACT*) Facility

- Deals with a variety of solvents.
- Capacity : 1 ton/day of CO_2 (based on MEA).
- Units: absorber, stripper, water wash column, cross heat exchanger, reboiler and condenser.
- Flue gas desulphurization through carbonate wash.
- Dedicated control system.
- Integration with:
  - 250 kW air/oxy fired combustion plant.
  - 300 kW gas turbine.

SCCP Plant

* www.pact.ac.uk

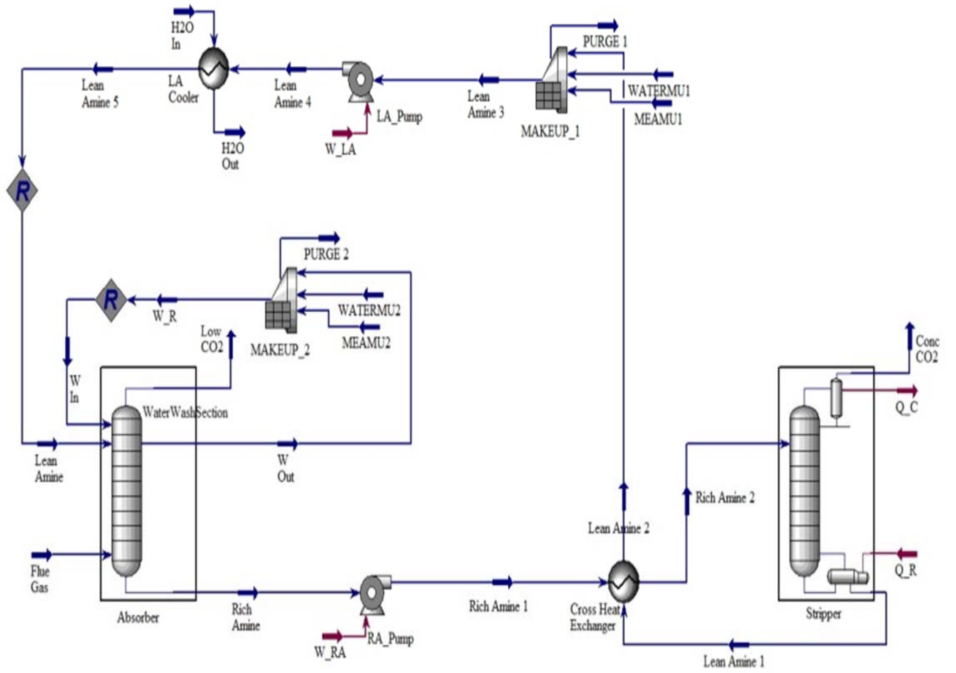
Solvent based Carbon Capture Plant



Schematic of Solvent based Carbon Capture Plant (SCCP).

SCCP Model In Aspen HYSYS

- Property Package: Acid Gas (Rate base method).
- Mass Transfer method: Bravo-Fair
- Interfacial Area method: Bravo-Fair
- Packing Pressure Drop Correlation: Vendor Specified
- Packing Type: IMTP(25mm)
- **Absorber:**
  - Height = 3 + 3 m
  - Diameter = 0.303 m
- **Water Wash Section:**
  - Height = 1.2 m
  - Diameter = 0.303 m
- **Stripper:**
  - Height = 3 + 3 m
  - Diameter = 0.303 m



Post-combustion capture plant model developed in Aspen HYSYS® V8.6.

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Model Validation at 4.5 mol% CO_2 in flue gas

Parameter	Experimental Value	Simulated Value
Lean amine flow rate, (kg/hr)	515.6	515.6
Lean CO_2 loading, (mol/mol)	0.25	0.25
Rich amine flow rate, (kg/hr)	531	531.4
Rich CO_2 loading, (mol/mol)	0.41	0.411
CO_2 in flue gas, (kg/hr)	18.2	18.2
CO_2 captured, (kg/hr)	16.5	16.51
Reboiler duty, (kW)	27	25.3
Specific Reboiler duty, (MJ/kgCO_2)	5.92	5.51

Sensitivity Analysis Study

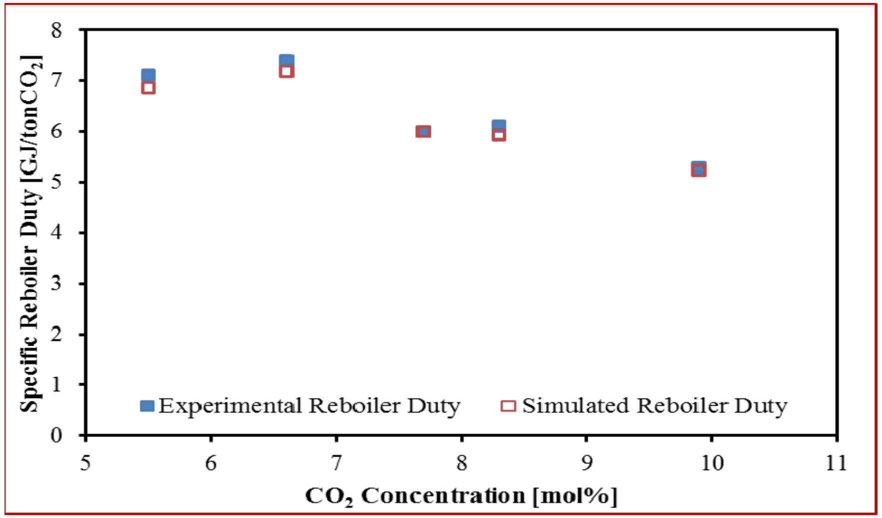
Set No.	Sensitivity Analysis	Type
Set A	Variation of **CO_2 composition** in flue gas (5.5 mol% ≥ y_{CO2} ≤ 9.9 mol%)	Experimental and Modelling
Set B	Variation of **CO_2 capture rate** (60% ≥ ψ ≤ 95%)	Experimental* and Modelling
Set C	Variation of **liquid flow rate** (0.6 ≥ L/G ≤ 2.6)	Modelling
Set D	Variation of **amine strength** (20wt% ≥ ω ≤ 36wt%)	Modelling
Set E	Variation of **lean amine loading** (0.10 ≥ α ≤ 0.35)	Modelling
Set F	Variation of **flue gas temperature** (30°C ≥ T_G ≤ 50°C)	Modelling
Set G	Variation of **liquid temperature** (30°C ≥ T_L ≤ 50°C)	Modelling
Set H	Variation of **stripper pressure** (1.2bar ≥ P_s ≤ 2.2bar)	Modelling

*experimentally CO_2 capture rate is varied from 90 to 94.4%

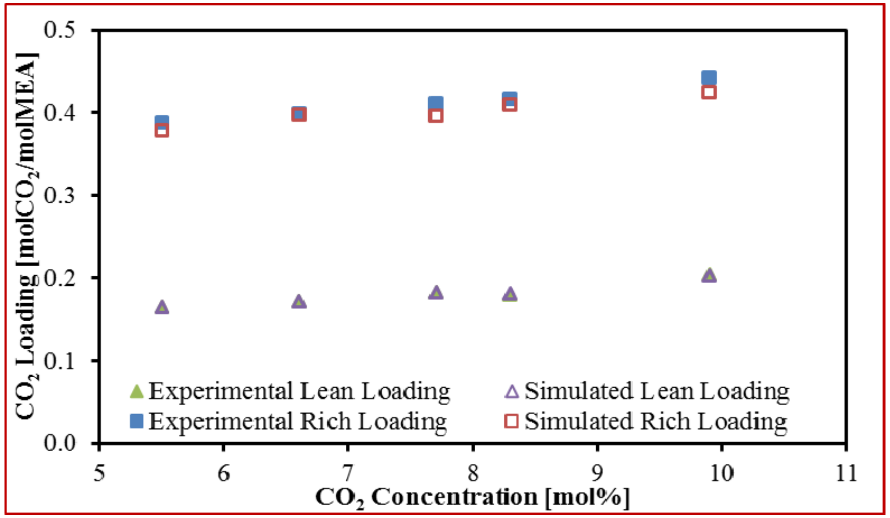
Set A: Variation of CO_2 composition in flue gas (1/2) — Validation

Variation:

- 5.5mol% ≥ y_{CO2} ≤ 9.9mol%
- ω = ~30wt%
- ψ = ~90%
- T_G = 40°C and T_L = 40°C
- P_s = 1.2bar



Measured and simulated lean and rich CO_2 loading versus CO_2 concentration.

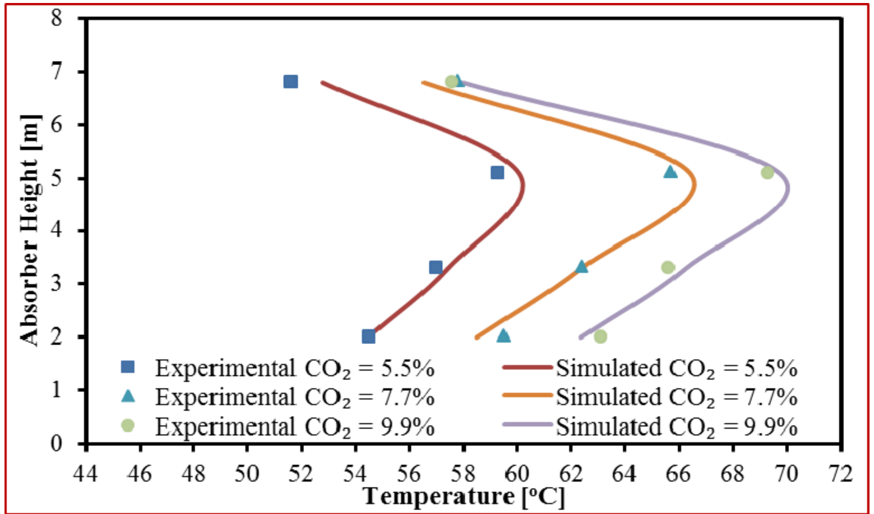


Measured and simulated data specific reboiler duty versus CO_2 concentration.

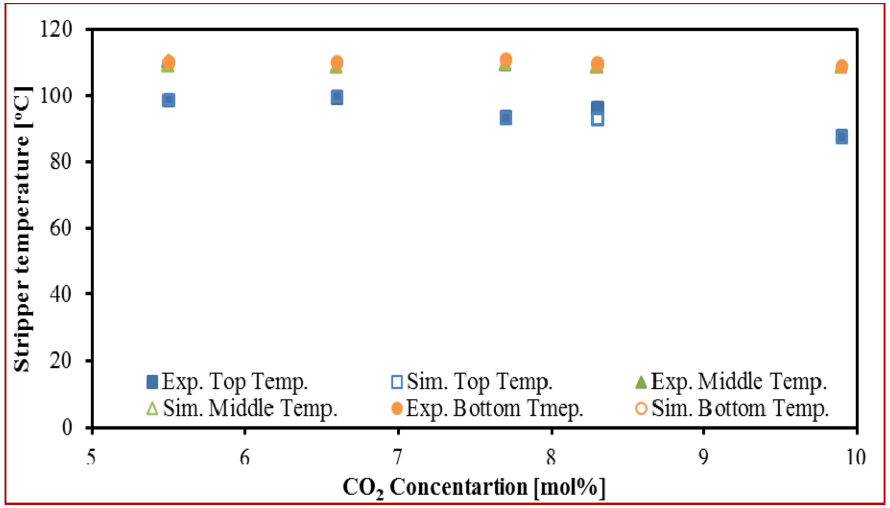
Set A: Variation of CO_2 composition in flue gas (2/2) — Validation

Variation:

- 5.5mol% ≥ y_{CO2} ≤ 9.9mol%
- ω = ~30wt%
- ψ = ~90%
- T_G = 40°C and T_L = 40°C
- P_s = 1.2bar



Measured and simulated absorber temperature profile for different CO_2 concentrations.



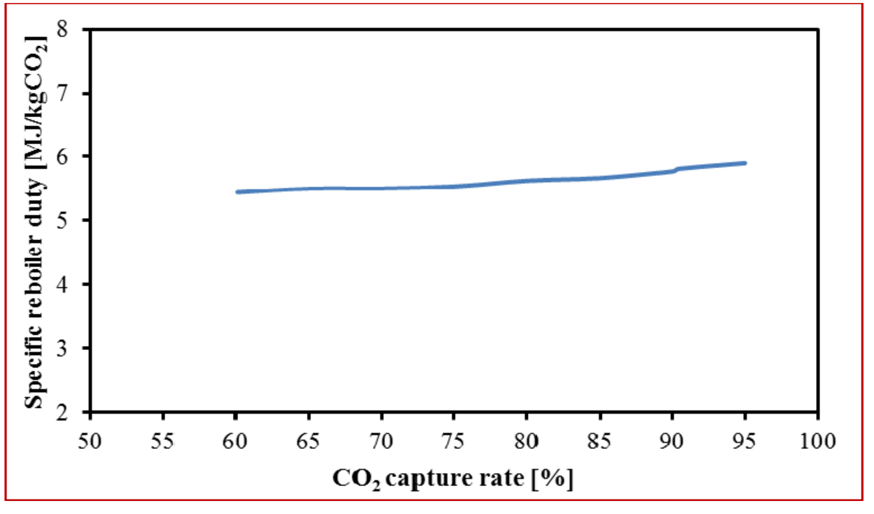
Measured and simulated stripper temperature profile for different CO_2 concentrations.

The University Of Sheffield.

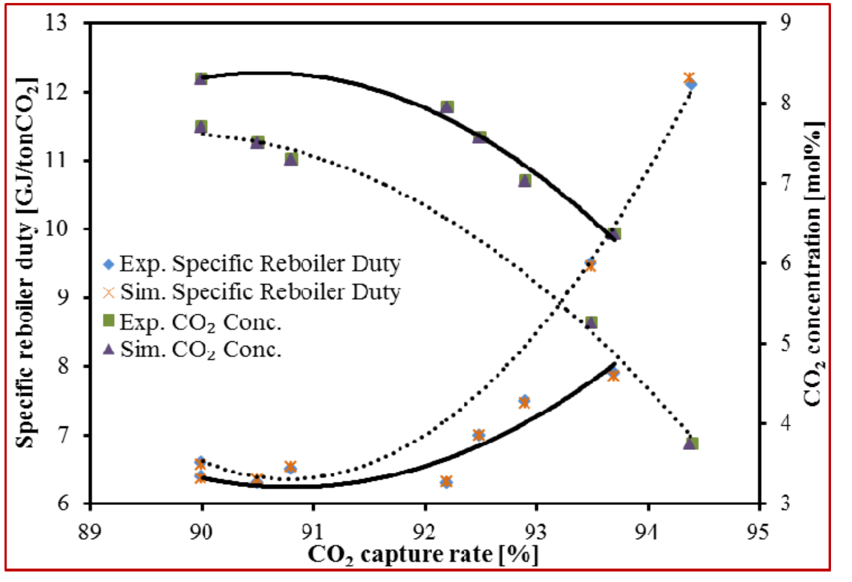
Set B: Variation of CO_2 capture rate — Validation

Variation*:

- y_{CO2} = 4.5mol%
- L/G = 1.9
- α = 0.25 and ω = 28.5wt%
- 60% ≥ ψ ≤ 95%
- T_G = 40°C and T_L = 40°C
- P_s = 1.2bar



CO_2 capture rate versus specific reboiler duty.



Measured and simulated specific reboiler duty and CO_2 concentration versus CO_2 capture rate for different flow rates.

*for modelling results only.

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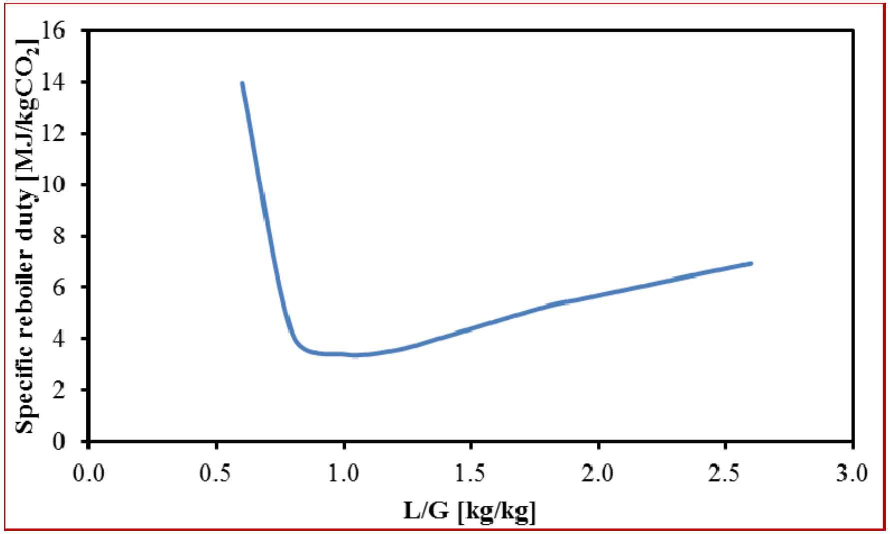
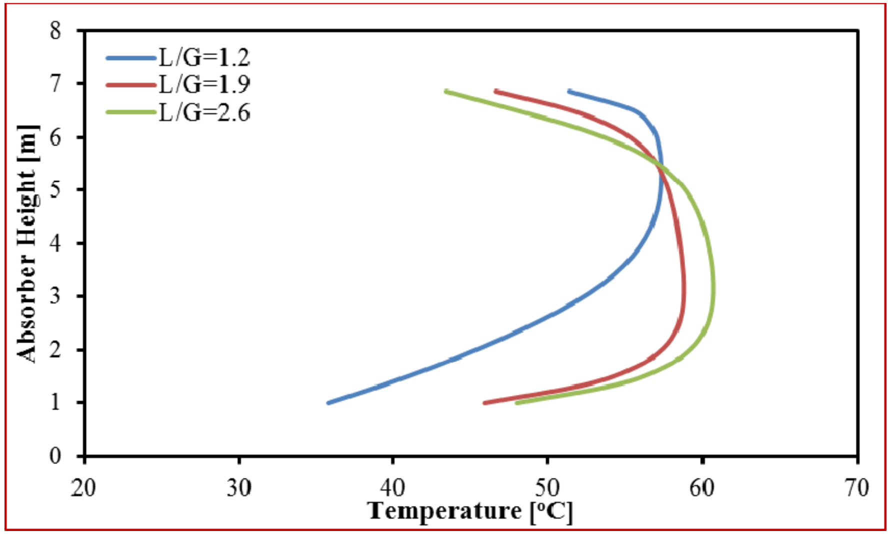
Set C: Variation of liquid flow rate

Variation:

- y_{CO2} = 4.5mol%
- 0.6 ≥ L/G ≤ 2.6
- α = 0.25 and ω = 28.5wt%
- ψ = 90%
- T_G = 40°C and T_L = 40°C
- P_s = 1.2bar



L/G ratio versus specific reboiler duty.

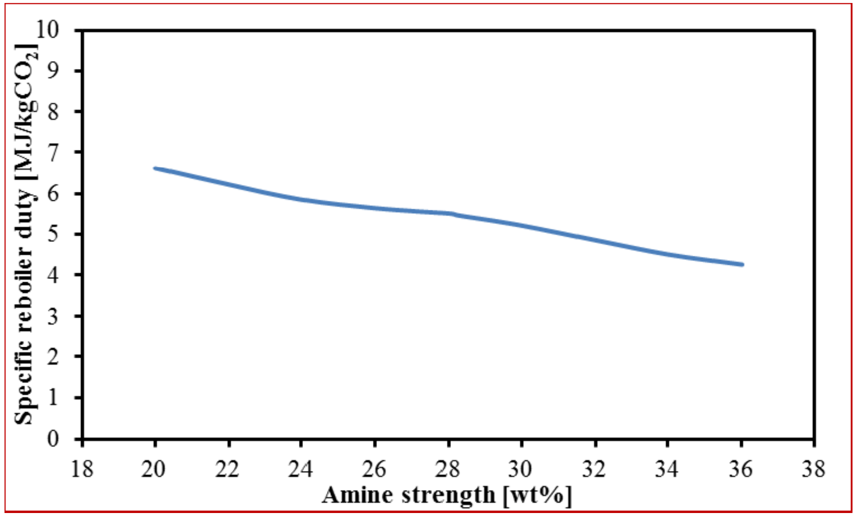


Absorber temperature profiles.

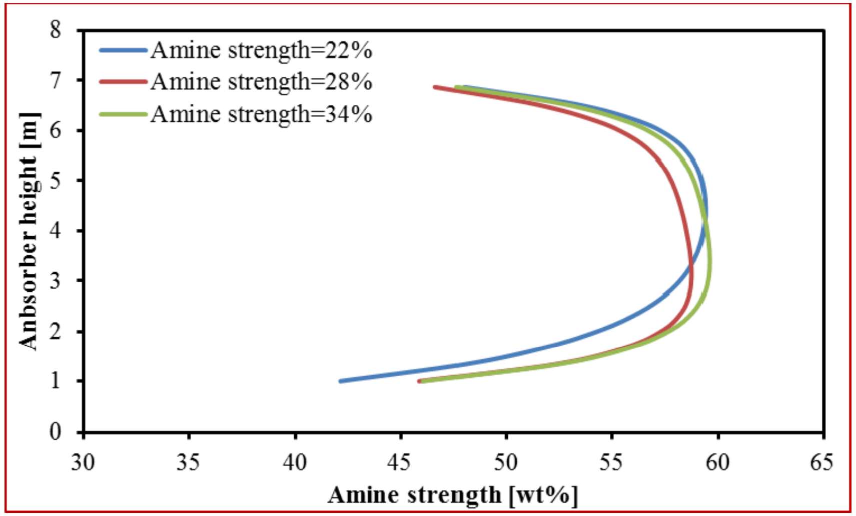
Set D: Variation of amine strength

Variation:

- y_{CO2} = 4.5mol%
- L/G = 1.9 and α = 0.25
- 20wt% ≥ ω ≤ 36wt%
- ψ = 90%
- T_G = 40°C and T_L = 40°C
- P_s = 1.2bar



Amine strength versus specific reboiler duty.

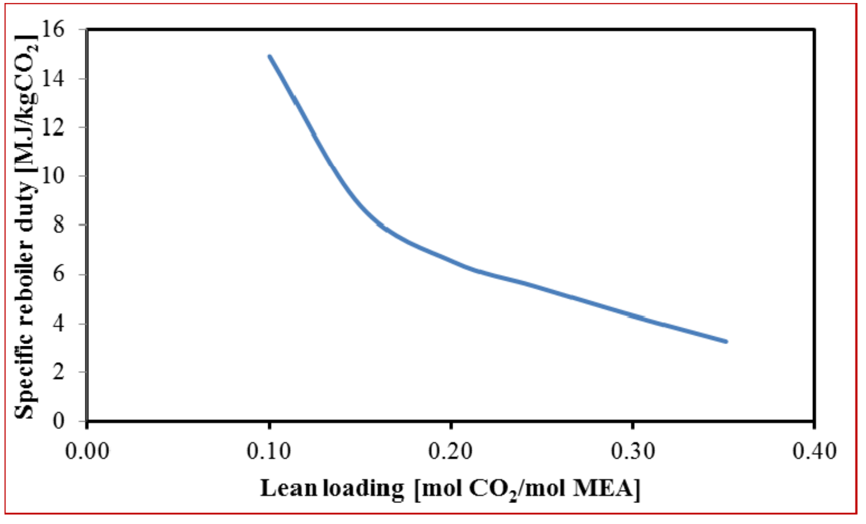


Absorber temperature profiles.

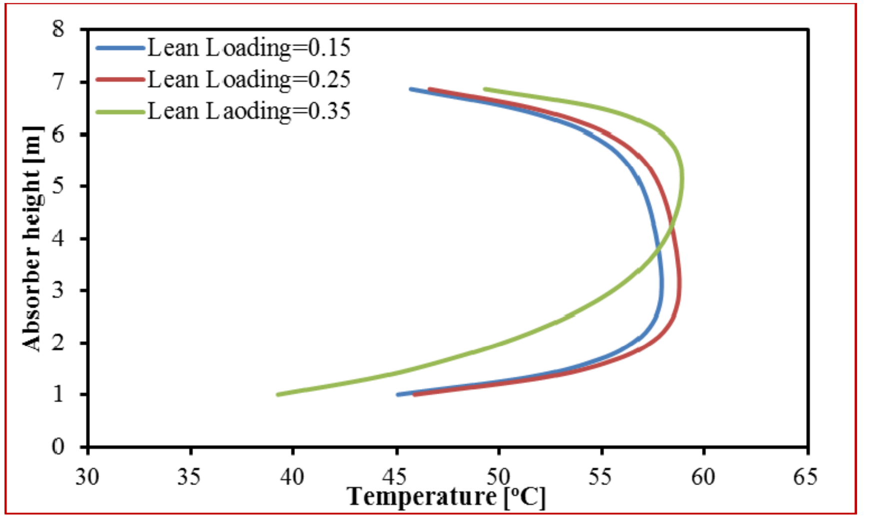
Set E: Variation of lean amine loading

Variation:

- y_{CO2} = 4.5mol%
- L/G = 1.9 and ω = 28.5wt%
- $0.10 \geq \alpha \leq 0.35$
- ψ = 90%
- T_G = 40°C and T_L = 40°C
- P_s = 1.2bar



Lean amine loading versus specific reboiler duty.

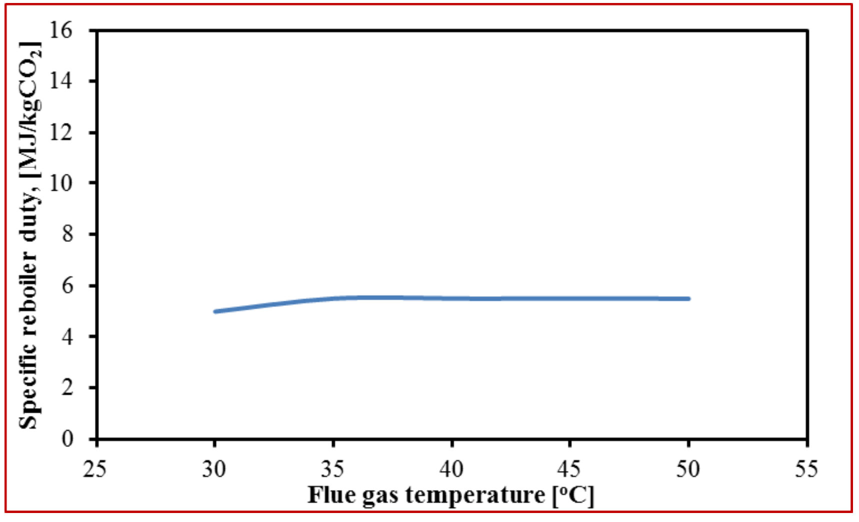


Absorber temperature profiles.

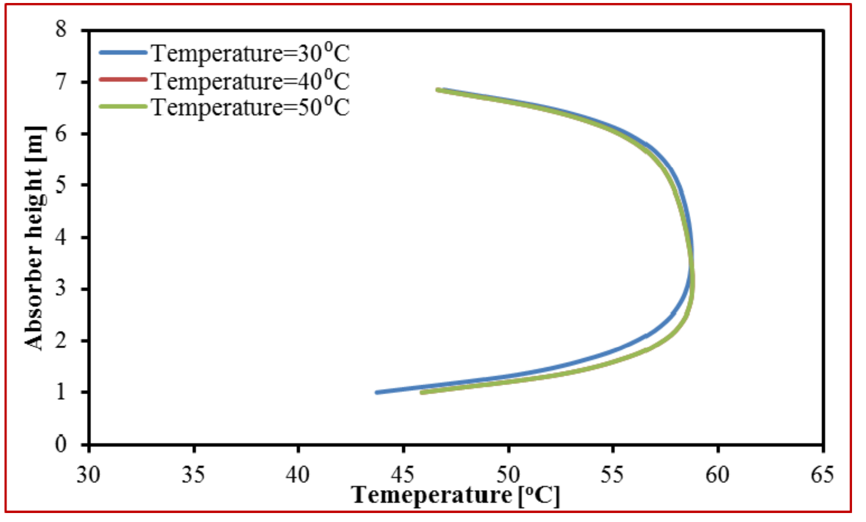
Set F: Variation of flue gas temperature

Variation:

- y_{CO2} = 4.5mol%
- L/G = 1.9 and T_L = 40^{o}C
- α = 0.25 and ω = 28.5wt%
- ψ = 90%
- 30^{o}C ≥ T_G ≤ 50^{o}C
- P_s = 1.2bar



Flue gas temperature versus specific reboiler duty.

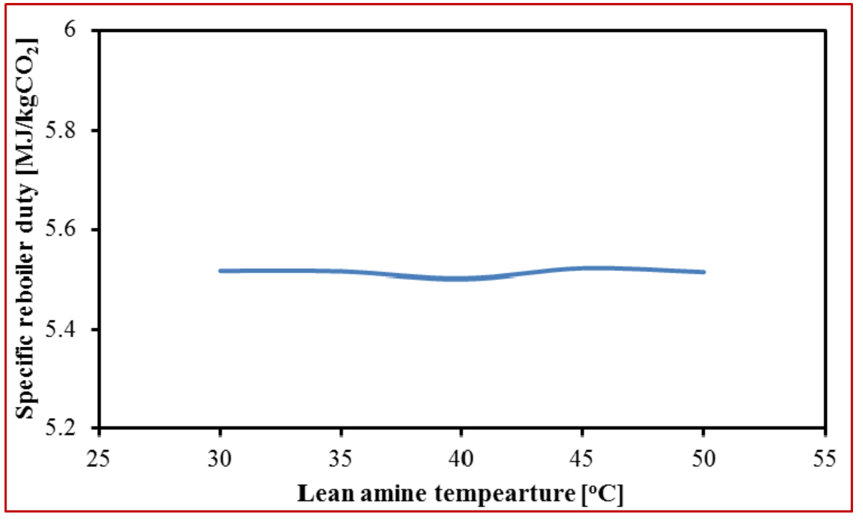


Absorber temperature profiles.

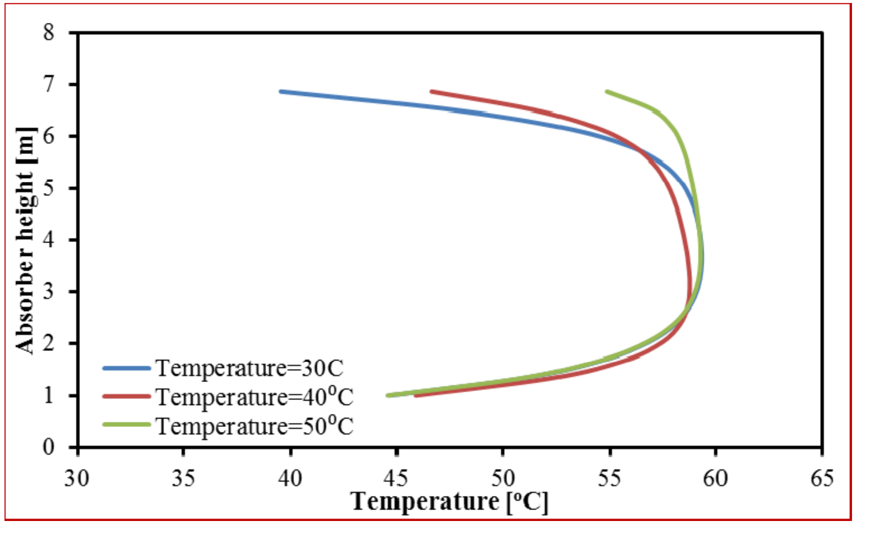
Set G: Variation of liquid temperature

Variation:

- y_{CO2} = 4.5mol%
- L/G = 1.9 and T_G = 40°C
- α = 0.25 and ω = 28.5wt%
- ψ = 90%
- 30°C ≥ T_L ≤ 50°C
- P_s = 1.2bar



Liquid temperature versus specific reboiler duty.

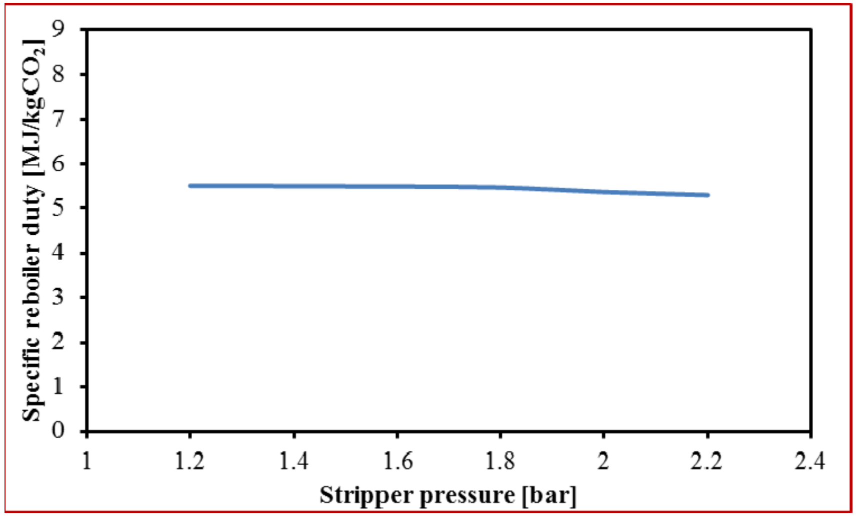


Absorber temperature profiles.

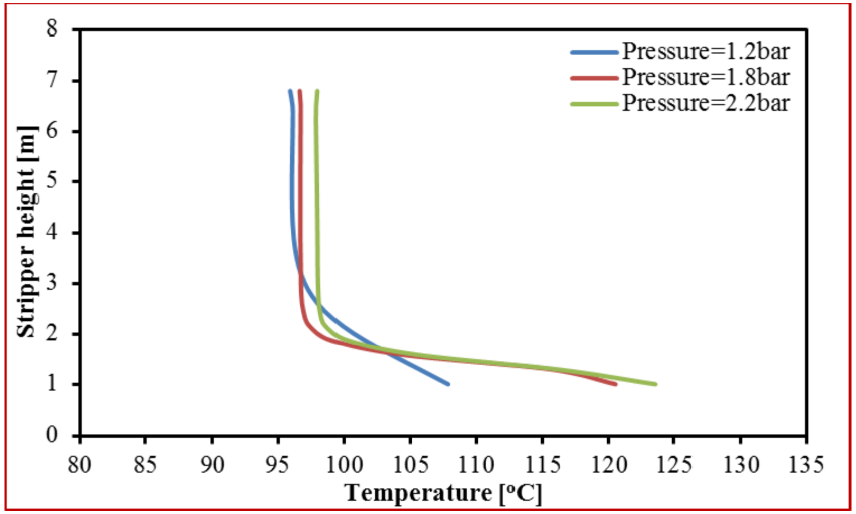
Set H: Variation of stripper pressure

Variation:

- y_{CO2} = 4.5mol%
- L/G = 1.9
- α = 0.25 and ω = 28.5wt%
- ψ = 90%
- T_G = 40°C and T_L = 40°C
- 1.2bar ≥ P_s ≤ 2.2bar



Stripper pressure versus specific reboiler duty.



Stripper temperature profiles.

Conclusions

- Process sensitivity analysis – a useful tool to analyse plant operability range.
- Higher CO_2 composition → decrease in the specific reboiler duty.
  - ~ 7.7% experimentally, 6.6% in the modelling.
- Higher CO_2 capture rate → higher specific reboiler duty.
- Optimum L/G ratio is about 1.0.
- The higher the amine strength, the lower is the specific reboiler duty.
- Lower lean amine loading → decreased cyclic capacity → reduced degree of regeneration.
- No comprehensive conclusion can be drawn for the temperatures.
- Higher stripper pressure → decreased specific reboiler duty → increased reboiler temperature.

Thank you

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