Insight into the transient operation of a post-combustion CO_2 capture system

Mathew Dennis Wilkes [a]; Solomon Brown [a]

[a] Department of Chemical and Biological Engineering, University of Sheffield, Sheffield, S1 3JD, United Kingdom

Introduction

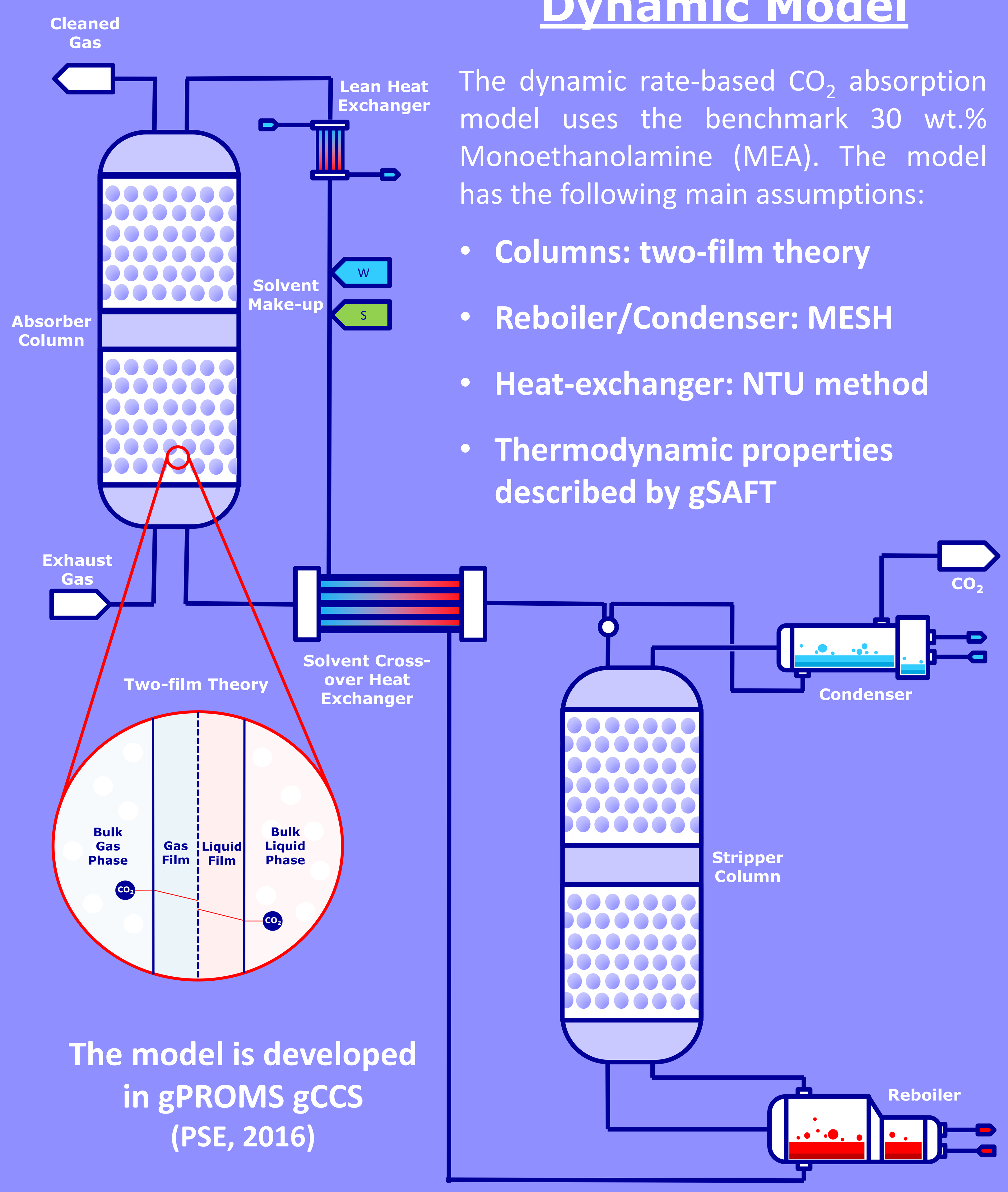
The transition to a low-carbon future will require balancing capacity to counteract the intermittency of renewable power. One such technology is open-cycle gas turbines (OCGT), which have quick start-up times and operation flexibility (Parsons Brinckerhoff, 2014). Partnered with post-combustion capture (PCC) of CO_2, they can aid in decarbonising the power industry. This study presents:

- **Development and validation of a dynamic PCC model**
- **flexible OCGT operation**
- **Transient PCC operation for a small-scale OCGT plant**

Dynamic Model

The dynamic rate-based CO_2 absorption model uses the benchmark 30 wt.% Monoethanolamine (MEA). The model has the following main assumptions:

- **Columns: two-film theory**
- **Reboiler/Condenser: MESH**
- **Heat-exchanger: NTU method**
- **Thermodynamic properties described by gSAFT**



The model is developed in gPROMS gCCS (PSE, 2016)

Model Validation

The model has been validated against pilot scale data from Tait et al. (2016). Steady-state (presented in Table 1) and dynamic (not presented) validation highlights the models high degree of fidelity.

Table 1: Model validation against pilot scale data from Tait et al. (2016).

Parameter	Value	Pilot	% Difference
Flue Gas Flowrate (m^3/h)	120.50	120.50	0.00
Solvent Flowrate (L./h)	344.40	344.40	0.00
Capture Rate (%)	92.21	92.25	0.04
Lean-loading (mol CO_2/mol MEA)	0.218	0.212	2.83
Rich-loading (mol CO_2/mol MEA)	0.333	0.336	0.89

Gas Turbine Operation

OCGT operation is analysed using data from the Balancing Mechanism Reporting Service (BMRS). Analysing data from the previous four years, shows OCGT generation comes on the system in the winter months, and Figure 1 shows the load in January over the previous four years. The following highlights are made:

- **Used for peak demand in the evenings**
- **Highly transient behaviour, i.e. ramping to different loads during one operating cycle**
- **Average operating cycle is 5 hours**
- **Total annual power output varies**

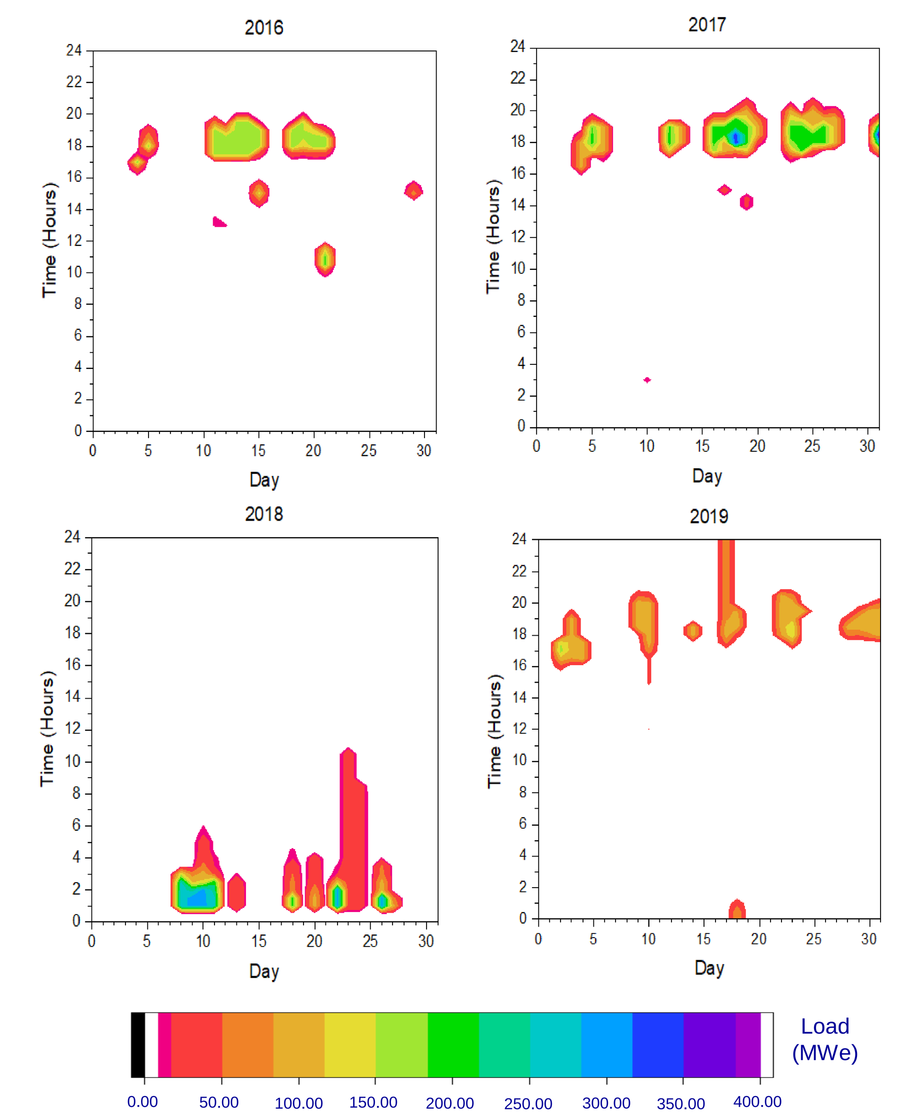


Figure 1: Heat map for OCGT generation in January in 2016, 2017, 2018, and 2019

Transient CO_2 Capture

The model is scaled to handle 33.4 kg/s flue gas flowrate from a Siemens SGT-400 10.4 MWe gas turbine. Four operating scenarios were chosen to assess the transient response of the PCC system:

- **Baseload** – Constant five hour operation
- **Scenario A** – Flue gas changes based off OCGT output
- **Scenario B** – Flue gas and solvent flowrate is ramped to maintain L/G
- **Scenario C** – Flue gas, solvent and reboiler steam flowrate is ramped

The main model outputs are:

- Time-averaged CO_2 capture rates (%):
  - Baseload = 89.36
  - Scenario A = 89.70
  - Scenario B = 90.01 ← Higher capture rates
  - Scenario C = 89.75
- Reboiler duty (GJ/tCO_2):
  - Baseload = 3.96
  - Scenario A = 4.82
  - Scenario B = 4.83
  - Scenario C = 3.95 ← Energy savings

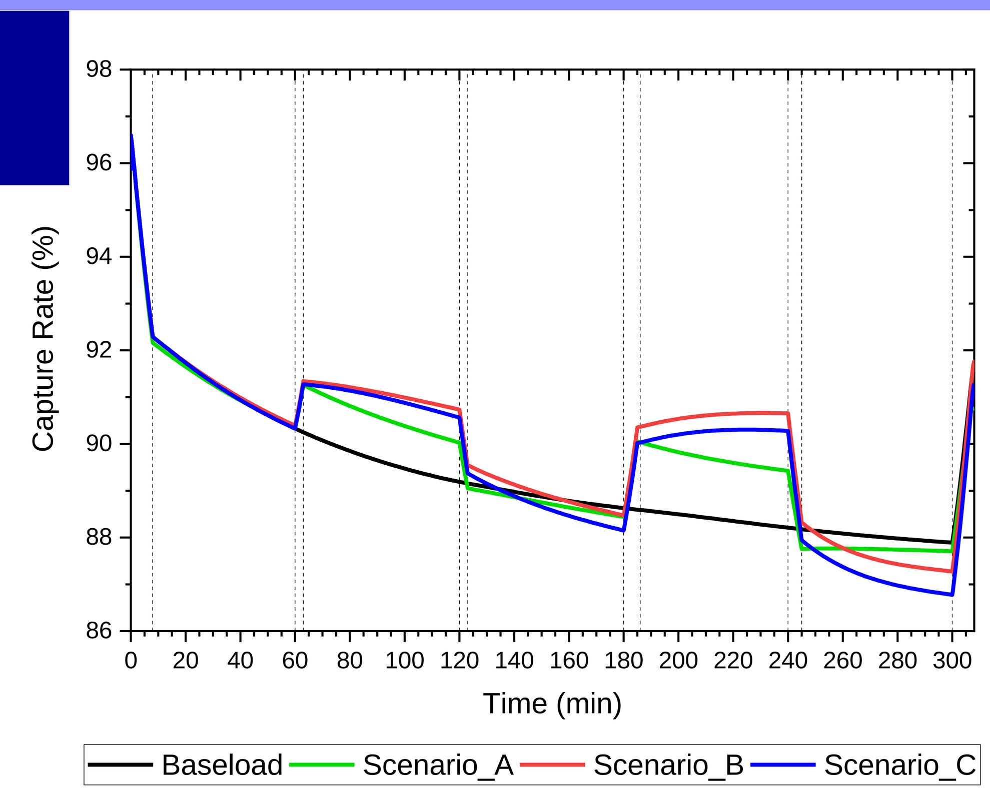


Figure 2: CO_2 capture rate response

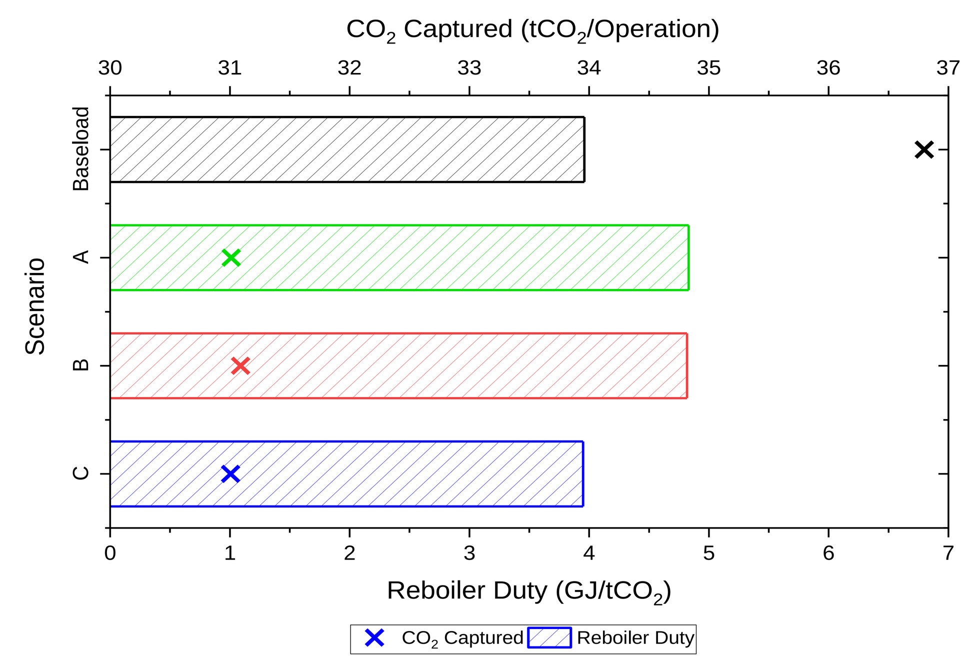


Figure 3: CO_2 Capture and Reboiler Duty

Conclusion

OCGT generation is highly sporadic and is used for peak demand, with an average operating cycle of five hours. Translating this to flue gas flowrates, it is used as an input into the dynamic PCC model. Case studies for different flexible operating scenarios highlighted:

- **Increased time-average CO_2 capture rate when L/G ratio is maintained**
- **Decrease in reboiler duty when ramping steam flowrate**

References

Parsons Brinckerhoff, 2014. Technical Assessment of the Operation of Coal & Gas Fired Plants, London: Department of Energy and Climate Change.

PSE, 2016. gCCS Documentation, London: Process Systems Enterprise Limited

Tait, P., Buschle, B., Ausner, I., Valluri, P., Wehrli, M., & Lucquiaud, M., 2016. A pilot-scale study of dynamic response scenarios for the flexible operation of post-combustion CO2 capture. International Journal of Greenhouse Gas Control, 48(2), 216-233.

Engineering Doctorate Centre in Carbon Capture and Storage and Cleaner Fossil Energy