Simulation of cold membrane processes for post-combustion carbon capture

Universidade do Porto
Faculdade de Engenharia
FEUP

Catarina Marques*, José Miguel Loureiro*, Maarten Nauta**, Adekola Lawal**

*Faculty of Engineering, University of Porto, Porto, Portugal **Process Systems Enterprise, Head Office, London, United Kingdom

Introduction

Conventional fuel-fired power plants are largely responsible for energy production related emissions and thus in dire need of post-combustion implementation of carbon capture. However, the large volumes of dilute flue gas at atmospheric pressure and high temperature impair most capture processes. Monoethanolamine (MEA) absorption, the current benchmark technology, inflicts an efficiency penalty of 8-14%[1] and literature predicts the annual carbon capture cost with 90% recovery to be \$40-100/tonCO_2[2]. Seeing that MEA absorption is a mature technology, significant improvements are unlikely to happen in the future and the spotlight falls on alternative processes such as membrane separation.

Process flow sheet

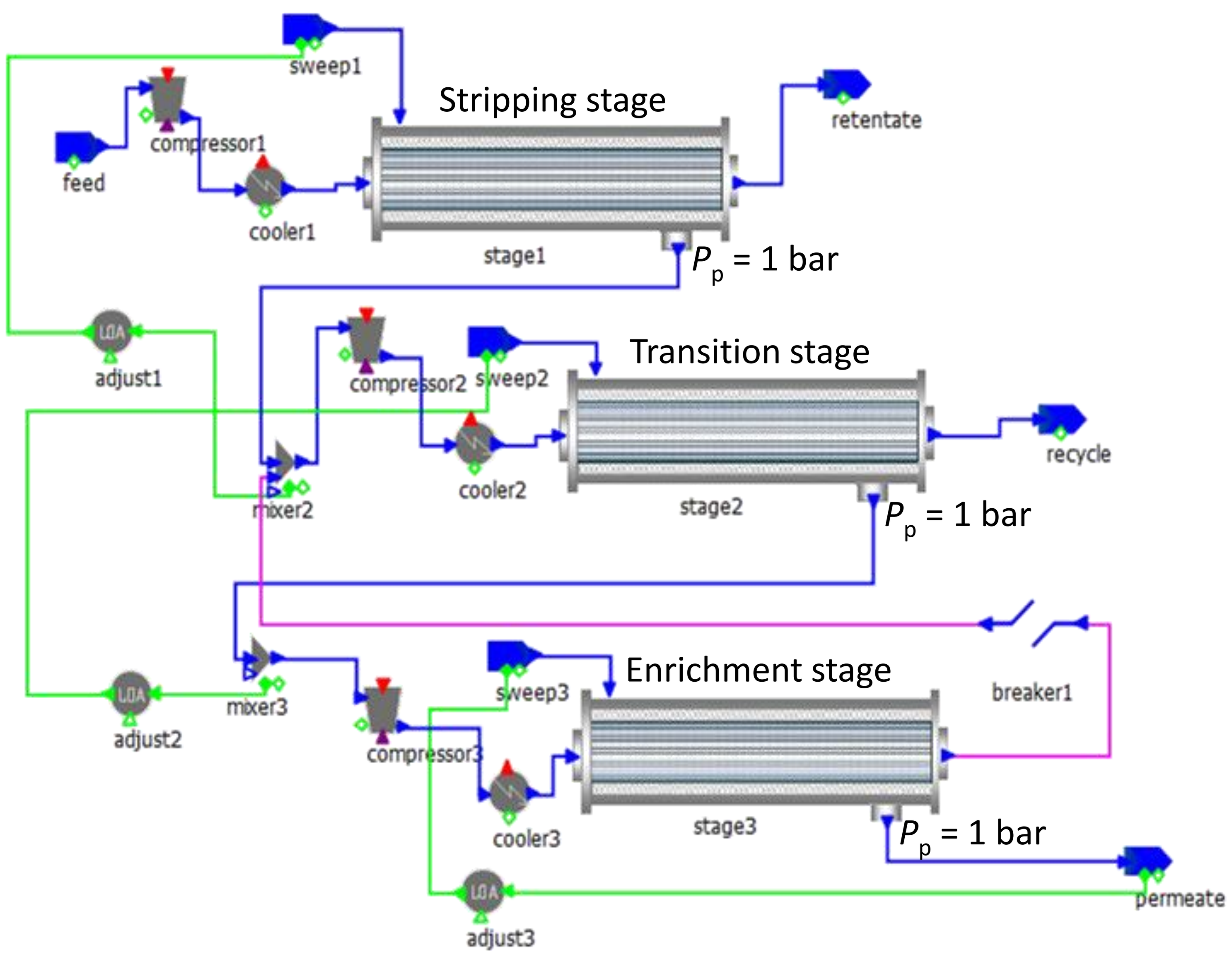

Figure 1 – gPROMS® topology of the membrane cascade

The reference flow sheet is that of a pilot-scale 4-stage membrane cascade reported by Choi et al. (2013)[3], designed to treat flue gas and attain a recovery of 90% while producing 99 vol.% CO_2. As illustrated in **Figure 1**, the process was redesigned to consist of only 3 stages and include the following:

→ **Cold membrane processes**

Enable the tuning of selectivity to exceptional values while maintaining high permeability. The selected membrane was reported by Liu et al. (2014)[4] to have a CO_2 permeance of 112-337 GPU and a CO_2/N_2 selectivity of 30-160 between 35 and -40 °C.

→ **Cascade zone division**

In cold membrane processes, a stripping stage operating under higher pressure (5.884 bar) and temperature (50 °C) ensures high recovery while an enrichment stage under lower pressure and temperature improves product purity[5].

→ **Sweep operation**

Introducing a low flow rate of decompressed retentate from the stripping stage into the permeate considerably reduces membrane area requirements while permeate purity remains roughly the same[2].

Table 1 – Simulation cases

Stage	2		3	
Case	*T* (°C)	P_f (bar)	*T* (°C)	P_f (bar)
A2	50	5.884	25	5.884
A3	50	5.884	0	5.884
A4	50	5.884	-25	5.884
B1	25	5.884	25	5.884
B2	25	5.884	0	5.884
B3	25	5.884	-25	5.884
→ B4	25	5.884	-40	5.884
C4	50	5.884	-25	2.942
C5	50	5.884	-40	2.942
→ D2	25	5.884	0	2.942
D3	25	5.884	-25	2.942
D4	25	5.884	-40	2.942

Simulation and optimisation results

Simulation of the cases in **Table 1** produced the results in **Figure 2** and facilitated the estimation of the values in **Figure 3**, while the scale-up of case D2 to a power plant with a 1,000 MWe output such as that reported by Zhao et al. (2008)[5], achieved the results in **Table 2**.

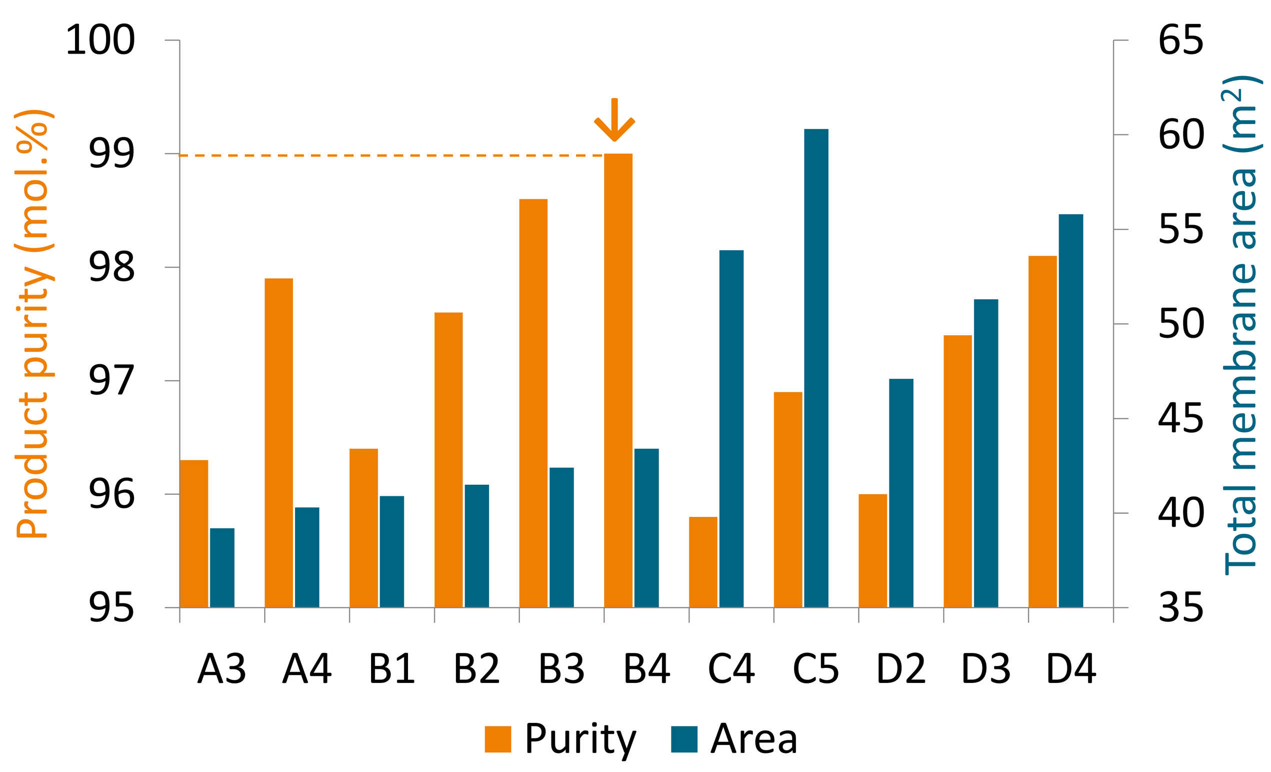

Figure 2 – gPROMS® simulation results for 90% CO_2 recovery

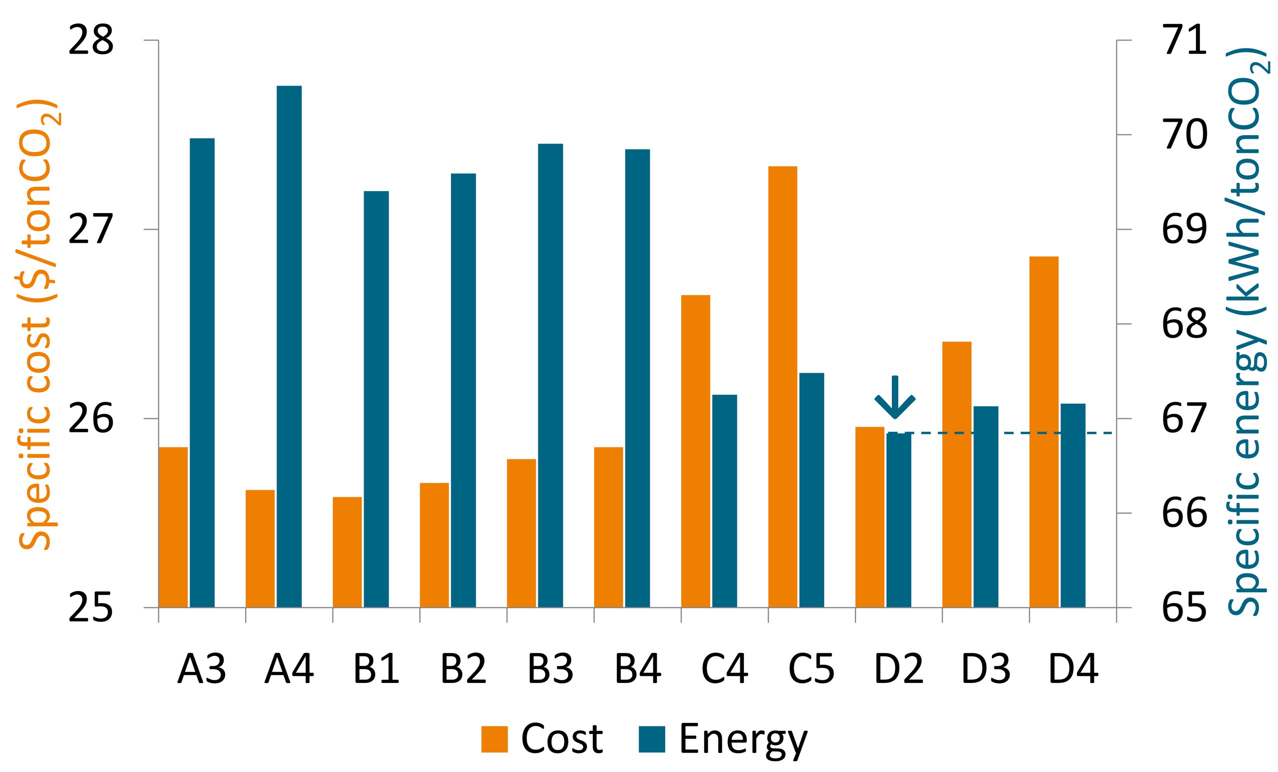

Figure 3 – Estimated process cost and energy requirements

Conclusions

→ Cold membrane process B4 captures 90% of the CO_2 with 99% purity and a specific cost of \$25.8/tonCO_2, much lower than that of MEA absorption.

→ High pressure and moderate temperature in the transition stage result in high purity (≥95%) while cryogenic temperature in the enrichment one is conductive to in ultra-high purity (≥99%).

→ Cold membrane processes outdo conventional ones from an energetic point of view and allow for ≥95% pure CO_2 capture with a specific energy of only 66.8 kWh/tonCO_2.

→ Scale-up of case D2 suggests that the CO_2 emissions of a 1,000 MW power plant could be treated with a specific cost of only 8.0 kWh/tonCO_2 and with an efficiency penalty as minor as 3.6 %, much lower than that currently attained by MEA absorption.

→ Sweep operation in the 2nd stage at industrial scale effectively reduces capture cost but also aggravates the efficiency penalty.

Table 2 – Scale-up results

Retentate recirculation (%)	0	6
Specific energy (kWh/tonCO_2)	68.3	68.5
Specific cost (\$/tonCO_2)	8.0	7.7
Energy penalty (%)	3.6	3.8

Acknowledgments

Catarina Marques thanks PSE for having received her to develop her master thesis dissertation in their head office in London, under the European ERASMUS programme.

References

[1] L. Zhao, E. Riensche, R. Menzer, L. Blum, and D. Stolten, "A parametric study of CO_2/N_2 gas separation membrane processes for post-combustion capture," *Journal of Membrane Science,* vol. 325, pp. 284-294, 11/15/ 2008.
[2] T. C. Merkel, H. Lin, X. Wei, and R. Baker, "Power plant post-combustion carbon dioxide capture: An opportunity for membranes," *Journal of Membrane Science,* vol. 359, pp. 126-139, 9/1/ 2010.
[3] S.-H. Choi, J.-H. Kim, and Y. Lee, "Pilot-scale multistage membrane process for the separation of CO_2 from LNG-fired flue gas," *Separation and Purification Technology,* vol. 110, pp. 170-180, 6/7/ 2013.
[4] L. Liu, E. S. Sanders, S. S. Kulkarni, D. J. Hasse, and W. J. Koros, "Sub-ambient temperature flue gas carbon dioxide capture via Matrimid® hollow fibre membranes," *Journal of Membrane Science,* vol. 465, pp. 49-55, 9/1/ 2014.
[5] Y. Huang, T. C. Merkel, and R. W. Baker, "Pressure ratio and its impact on membrane gas separation processes," *Journal of Membrane Science,* vol. 463, pp. 33-40, 8/1/ 2014.