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Demonstration of MEA-based direct air capture with validation of process model

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Abstract

Most scenarios for achieving net zero require the deployment of direct air capture (DAC). However, estimates suggest that widespread DAC deployment would cost between $125 and $335 per ton of CO_2 captured on 2022 cost basis [1]. Further, a recent techno-economic analysis on monoethanolamine (MEA)-based DAC calculated that the cost of capture from a standalone DAC absorber was in the range of $273 - $1227/t$CO_2$ [2]. A possible way to reduce these costs, the integration of DAC technologies with amine post-combustion capture plants - termed PCC CoDAC - is explored in this paper. Specifically, we collect experimental data on the performance of MEA-based DAC to validate the accuracy of an Aspen Plus process model which will be used for detailed techno-economic assessment of PCC CoDAC.

Previous conceptual analyses of PCC CoDAC have focused on integrating DAC with MEA-based solvent systems. Notably, Michailos et al. [3] proposed a process in which 35 wt% MEA solvent at a lean loading of 0.12 molCO_2/molMEA is contacted with ambient air in a 'black box' absorber, producing a semi-rich solvent at 0.3 molCO_2/molMEA. This semi-rich solvent is then further contacted with flue gas, increasing its CO_2 loading to 0.45 molCO_2/molMEA before regeneration. The solvent regeneration occurs at a specific reboiler duty (SRD) of approximately 3.6 GJ/tCO_2, comparable to standalone post-combustion capture (PCC) systems in terms of energy consumption.

Despite its potential, the optimal design of PCC CoDAC systems remains uncertain. Previous techno-economic studies which evaluated amine solvent-based DAC [2,4,5] and the conceptual analysis of PCC CoDAC [3] have used process models validated with small-scale post-combustion CO_2 capture equipment. Yet, optimal DAC absorber operating conditions are substantially different than point source CO_2 capture. The mass transfer correlations used in the CO_2 absorber rate-based process models are strongly dependent on liquid flux, but the liquid-to-gas ratio required for DAC is much lower than conventional absorbers because the vapour phase CO_2 concentration is approximately 2 orders of magnitude smaller than post-combustion capture. Kiani et al. [2] and de Joannis et al. [5] assumed large amine recirculation rates around the absorber in their DAC process designs to maintain liquid-to-gas ratio consistent with point source CO_2 capture, thus incurring a substantial energy penalty (c. 1/3 of electricity consumption in ref. [2]). Furthermore, the operating temperature in a DAC absorber will typically be below the normal operating range of post-combustion CO_2 absorbers because the inlet air is typically lower temperature, there will be evaporative cooling due to inlet relative humidity less than 100%, and there is relatively little heat generated from the CO_2 absorption reaction compared to post-combustion capture. A lower absorber operating temperature will affect the CO_2 reaction kinetics and vapour-liquid equilibrium and is outside of the range of most data used to validate CO_2 capture process models.

The rate-based model for CO_2 capture in this presentation uses modern mass transfer correlations developed at the University of Texas[6]. These mass transfer correlations are based on an extensive dataset generated with 39 different random and structured

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packings and account for the effect of viscosity on the liquid mass transfer coefficient, an important attribute given the much lower operating temperature of the DAC absorber compared to post-combustion CO_2 capture. The new process model incorporates a rigorous chemistry model which considers all relevant ionic species and was validated against published vapour-liquid equilibrium data for CO_2-MEA-water.

To evaluate the performance of MEA-based DAC, an experimental rig has been designed consisting of two stainless steel columns for air contacting and water wash. Each column has a height of 1.45 m and an internal diameter of 300 mm. Given the low liquid-to-gas ratio required for DAC operation, the columns are packed with Sulzer BX structured packing, optimized for low liquid flow to enhance CO_2 mass transfer efficiency within the limited column height. The experimental setup can record steady-state temperatures, pressures, flow rates, and gas compositions at all inlet and outlet streams of the air contactor. Additionally, the relative humidity of the inlet air and the temperature profile along the packed bed can be monitored. These data enable mass and energy balance calculations across the air contactor, facilitating direct comparison with process model predictions. The experimental setup is shown in Figure 1.

Figure 1. DAC Absorber and water wash columns used in this study.

Finally, the validation of the accuracy of the MEA-based CO_2 capture process model with the DAC test data is presented with future plans for using the process model to perform detailed techno-economic analysis of the PCC CoDAC concept.

Keywords: DAC; CoDAC; Experimental; Process Model; Monoethanolamine; MEA

References

(1) IEA. Direct Air Capture, A key technology for net zero. International Energy Agency. Available: https://www.iea.org/reports/direct-air-capture-2022 (Accessed 31 Mar 2025). **2022**.
(2) Kiani, A.; Jiang, K.; Feron, P. Techno-Economic Assessment for CO2 Capture From Air Using a Conventional Liquid-Based Absorption Process. *Frontiers in Energy Research* **2020**, *8*. DOI: 10.3389/fenrg.2020.00092.
(3) Michailos, S.; Samson, A.; Lucquiaud, M.; Gibbins, J. A performance modelling study of integrating a MEA direct air capture unit with a CCGT absorber. In *16th International Conference on Greenhouse Gas Control Technologies, GHGT-16*, Lyon, France, 23-27 October, 2022; 2022.
(4) Sabatino, F.; Grimm, A.; Gallucci, F.; van Sint Annaland, M.; Kramer, G. J.; Gazzani, M. A comparative energy and costs assessment and optimization for direct air capture technologies. *Joule* **2021**, *5* (8), 2047-2076. DOI: 10.1016/j.joule.2021.05.023.
(5) de Joannis, P.; Castel, C.; Kanniche, M.; Favre, E.; Authier, O. Direct Air Capture by Monoethanolamine Absorption with Heat Pump Enhancements. *Industrial & Engineering Chemistry Research* **2025**, *64* (4), 2208-2225. DOI: 10.1021/acs.iecr.4c02033.
(6) Song, D.; Seibert, A. F.; Rochelle, G. T. Mass Transfer Parameters for Packings: Effect of Viscosity. *Industrial & Engineering Chemistry*

Research **2018**, *57* (2), 718-729. DOI: 10.1021/acs.iecr.7b04396.