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Techno-economic benchmarking of membrane contactors for CO_2 capture from diluted gases

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Abstract

Reaching mitigation targets without drastically relying on negative emissions requires tackling emissions from hard-to-abate sectors. An issue with some of these industry sectors is that the CO_2 in their flue gas is diluted to levels inducing significant energy penalties and ultimately resulting in high costs. Examples of these industrial applications are the ferroalloy industry (3-4% CO_2), the aluminium production (around 1% CO_2), petrochemical refinery (3-11% CO_2), and any process relying on the operation of a gas turbine (3-4% CO_2). Some of these cases entail additional challenges, such as space limitation, small scale and presence of multiple emissions point sources. Therefore, an ideal capture technology should be able to separate CO_2 from diluted gases in an efficient manner, while being compact and flexible enough to be integrated within the industrial site. Membrane contactors showed the potential to deliver on those requirements [1] and becoming an attractive solution for several industrial applications [2].

Membrane contactors are a hybrid technology of chemical solvent absorption within a membrane modular design. The technology involves the transfer of CO_2 from the flue gas through a membrane where the CO_2 is chemically absorbed into a solvent on the permeate side. The concept takes advantage of the highly selective nature of the solvent while incorporating the benefits of membrane technology by controlling the flow regimes of the gas and solvent phases [3]. The hybrid nature of the technology leads to additional advantages compared to standard solvent-based solutions using packed columns, such as a high gas-liquid contacting surface area per unit contactor volume, the avoidance of entrainment and foaming issues and the diminished energy for solvent regeneration (as there is no need to vaporise the solvent). Some challenges remain when developing a membrane contactors system. The membrane material must be thermally/chemically compatible with the solvent used and ensure long-term stability. High pressure drops have been reported, where on the liquid side they could limit the maximum liquid flow length [4]. A major concern is to avoid pore wetting that would significantly increase the mass transfer resistance. Pore wetting has been reported in pilot plants studies [5]. The utilization of non-porous membranes can prevent such phenomenon, as it was demonstrated in more recent pilot trials [6]. Techno-economic studies have demonstrated promising numbers, with

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competitive CO_2 capture costs and compact designs [2]. However, to confirm their potential, rigorous techno-economic benchmarking is needed to allow consistent comparison to state-of-the-art technologies such as standard absorption units. This work aims at filling this gap by performing a techno-economic comparative analysis of CO_2 capture systems based on membrane contactors as well as a solvent-based plant with packed columns. Detail designs of these two solutions are developed based on a selected case study, i.e., the flue gas from a natural gas combined cycle (NGCC). The NGCC cycle is assumed to consist of 3 X LMS100 gas turbines and a common bottoming cycle. Exhaust gas recirculation (EGR) is considered (40% of the flue gas is recirculated) to increase the CO_2 concentration (from 2.8% to 4.6%) and decrease the flow rate into the capture unit. This NGCC reflects the design of a large power hub serving offshore installations, thus imposing strict requirements on space and weight limitations.

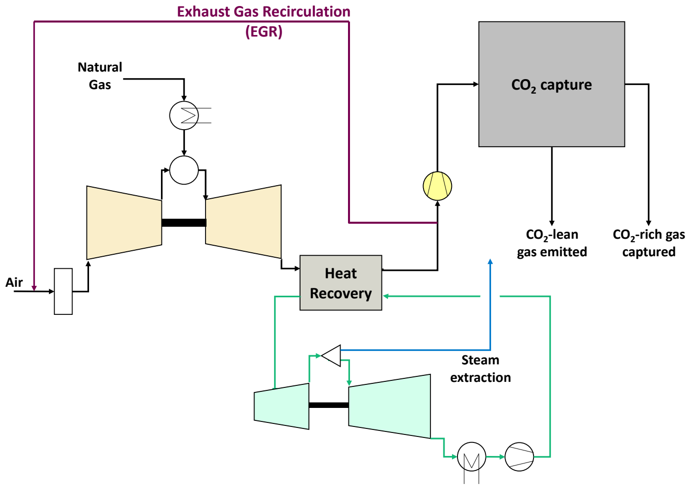

Figure 1. Flowsheet of the case study considered – NGCC cycle with CO_2 capture.

The membrane contactors system is based on two membrane gas-solvent contactor modules, with an internal water-steam circuit and a condenser producing the purified CO_2 product. Thin-film composite polymeric membranes are used, as they ensure high mass transfer through the membrane layer, while preventing pore wetting. Concerning the solvent, 28 wt% monoethanolamine (MEA) is assumed. The membrane contactors are simulated through an in-house model [7], while the remaining processes are simulated in Aspen Plus. As benchmark CO_2 capture technology, a standard chemical absorption-based unit is considered, using 30%wt. MEA. This system is simulated in ASPEN Hysys. The NGCC is also simulated in Aspen Hysys. For the techno-economic analysis (TEA), a systematic cost methodology – based on the guidelines proposed in [8] – is applied, which includes CAPEX based on a bottom-up approach and OPEX based on utilities consumption and standard factors for maintenance and labour. The main economic metric considered is the CO_2 avoidance cost (CAC). The simulations are required to achieve a minimum CO_2 recovery and purity of 90% and 95%, respectively.

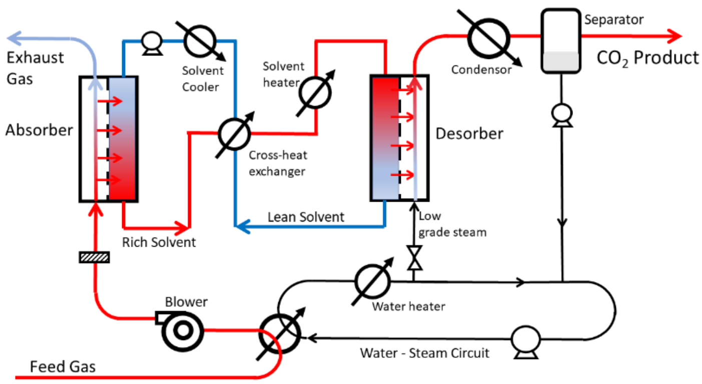

Figure 2. Membrane gas-solvent contactor process for the capturing of carbon dioxide from industrial gas streams (source: [1]).

The results show that membrane contactors significantly decrease the thermal energy required for solvent regeneration in comparison with the standard absorption solution (2.2 GJ/t_{CO2} compared to 3.7 GJ/t_{CO2}), while the power consumption increases (0.7 GJ/t_{CO2} compared to 0.1 GJ/t_{CO2}). The membrane contactor also allows for a more compact process - the volume of the capture unit is reduced by 40%. The developed designs provide inputs to the TEA framework. The related outputs will allow to systematically compare the techno-economic performance of membrane contactors against what is normally considered the benchmark technology for post-combustion CO_2 capture. Additionally, a comprehensive breakdown of the CAC will disclose the key cost drivers, whose impact will be assessed by means of sensitivity analyses, consolidating the outcomes of the study.

Keywords: membrane contactorts, techno-economic analysis, benchmarking, diluted sources, hard-to-abate sectors.

References

[1] Scholes CA, 2024, Membrane gas-solvent contactor process for efficient carbon capture from multiple emission sources within an industrial complex, GHGT-17, 20th -24th October 2024 Calgary, Canada

[2] Scholes CA, 2023, Membrane gas-solvent contactor process for carbon capture from small-to-medium industrial sources, Chemical Engineering Science, 278, 118915

[3] Falk-Pedersen O, Grønvold MS, Nøkleby P, Bjerve F, Svendsen HF, 2005, CO_2 Capture with Membrane Contactors, International Journal of Green Energy, 2, 2

[4] Hoff KA, Svendsen HF, 2014, Membrane contactors for CO2 absorption – Application, modeling and mass transfer effects, Chemical Engineering Science, 116, 331-341

[5] Scholes CA, Qader A, Stevens GW, Kentish SE, 2014, Membrane Gas-Solvent Contactor Pilot Plant Trials of CO_2 Absorption from Flue Gas, Separation Science and Technology, 49, 2449–2458

[6] Scholes CA, Kentish SE, Qader A, 2020, Membrane gas-solvent contactor pilot plant trials for post-combustion CO_2 capture, Separation and Purification Technology, 237, 116470

[7] Miandoab ES and Scholes CA, 2022, A rigorous membrane gas-solvent contactor model for process simulation of industrial-scale carbon capture with monoethanolamine solvents, Industrial & Engineering Chemistry Research, 61,26

[8] Roussanaly S, Berghout N, Fout T, Garcia M, Gardarsdottir S, Nazir SM, et al. Towards improved cost evaluation of carbon capture and storage from industry. Int J Greenh Gas Control 2021;106:103263.