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Membrane gas separations and post-combustion carbon dioxide capture: Parametric sensitivity and process integration strategies

Bouchra Belaissaoui [a], David Willson [b], Eric Favre [a,*]

[a] Université de Lorraine, LRGP, UPR CNRS 3349, 1, rue Grandville, 54001 Nancy, France
[b] Stanbridge Capital, 37 East 18th Street, New York, NY 10003, USA

HIGHLIGHTS

- ▶ Master curves of membrane performances for CO_2 capture.
- ▶ For diluted CO_2 flue gases, multistage membrane processes are needed.
- ▶ Membranes can play a key role as a pre-concentration step for low CO_2 content.
- ▶ Membranes can play a key role as a polishing step for concentrated CO_2 flue gases.

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ABSTRACT

Reducing the energy requirement is the primary challenge for post-combustion CO_2 capture technologies. Growing interest is being shown in membrane processes as an alternative to the reference technologies (such as gas–liquid absorption in amine absorption). However, these membrane processes remain energy intensive when the recommended CO_2 purity and capture ratio (both typically at 90%) are imposed. In this study, a systematic parametric analysis of the energy requirement of a single stage membrane gas separation module has been performed. Different inlet CO_2 contents and membrane selectivity performances have been compared. In contrast to previous studies, the capture ratio and CO_2 purity constraints have been relaxed below the 90% target in order to possibly identify the most appropriate role and place of membrane processes in a Carbon Capture and Storage (CCS) framework. It is shown that diluted CO_2 feed streams (such as natural gas turbine flue gases) systematically require excessive energy for CO_2 capture. However, single stage membrane units offer interesting possibilities with a very low energy requirement when used as a pre-concentration step for a moderate inlet CO_2 content (15–30%) or as a final step for concentrated streams (50% inlet CO_2 content or more). Finally, guidelines for improved integration strategies of membrane units in different carbon capture scenarios, with a particular emphasis on hybrid processes, are proposed.

1. Introduction

CO_2 capture from large sources attracts considerable attention as a key strategy to mitigate greenhouse gas emissions. Among the different possibilities, post-combustion Carbon Capture and Storage (CCS) is particularly interesting because it can be in principle applied to any type of emission and offers retrofit possibilities. Nevertheless, whatever the strategy (oxy-combustion, pre-combustion or post-combustion), reducing the energy cost (and hence also the parasitic power loss) is the main challenge for the capture step. A 90% CO_2 capture ratio and 90% CO_2 purity are targets that have been imposed by the Energy Information Administration (EIA) in Europe and the Department of Energy (DOE) in the USA.

In this context, many studies are dedicated to improve existing and already mature technologies (i.e. gas–liquid absorption in amine solvents, cryogenic separation, adsorption) or to develop innovative process design. Their success hinges on their possibility of lowering the cost of CO_2 capture while still attaining the targets for CO_2 purity and for the recovery ratio.

In early selection studies, membrane processes have been discarded for CO_2 capture applications. A too low CO_2/N_2 selectivity (below 50) was often mentioned as a major bottleneck. Nevertheless, a steadily increasing number of publications have been reported recently reported on the material challenges for carbon capture; numerous studies can be found on tailor-made polymeric membranes [1–3], fixed site reactive membranes [4–7] and

* Corresponding author. Tel.: +33 383 17 53 90.
E-mail address: Eric.Favre@univ-lorraine.fr (E. Favre).

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