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Enhancing CO_2 absorption efficiency using carbonic anhydrase in MDEA-based hollow fibre membrane contactors

Mohamed Nadir Khelifi [a], Ouacil Saouli [a], Lokmane Abdelouahed [b], Alain Ledoux [b], Manawwer Alam [c], Byong-Hun Jeon [d,*], Hyun-Jo Ahn [d], Yacine Benguerba [e,**]

[a] *Laboratoire de Génie des Procédés pour le Développement Durable et les Produits de Santé (LGPDDPS), Ecole Nationale Polytechnique de Constantine, Constantine 25000, Algeria*
[b] *INSA Rouen Normandie, Univ Rouen Normandie, Normandie Univ, LSPC UR 4704, Rouen F-76000, France*
[c] *Department of Chemistry, College of Science, King Saud University, PO Box 2455, Riyadh 11451, Saudi Arabia*
[d] *Department of Earth Resources and Environmental Engineering, Hanyang University, 222 Wangsimni-ro, Seongdong-gu, Seoul 04763, Republic of Korea*
[e] *Laboratoire de Biopharmacie Et Pharmacotechnie (LPBT), Ferhat Abbas Sétif 1 University, Sétif 19000, Algeria*

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ABSTRACT

Global warming, driven by greenhouse gases such as carbon dioxide (CO_2), leads to rising global temperatures and climate disruption. CO_2, a major contributor to the greenhouse effect, is a critical focus for mitigating climate change through innovative capture and reduction technologies. This paper presents a comprehensive study on the mass transfer simulation of CO_2 absorption in a hollow-fibre membrane contactor, utilising chemical and Multiphysics modules for mass transfer and reacting flow within COMSOL software. Theoretical simulations were performed to investigate the absorption process and assess the potential of membrane contactors as an effective strategy for intensified CO_2 capture through gas-liquid absorption. The study features an advanced model designed to explore the impact of incorporating human carbonic anhydrase (hCA) with *n-methyldiethanolamine* (MDEA) solvent in a counter-current hollow fibre membrane contactor. It is demonstrated that hCA with MDEA enhances CO_2 absorption by 34 % compared to MDEA due to its high reaction rate. Key operational parameters, such as gas flow rates and thickness, are investigated, and a decrease in CO_2 absorption efficiency is observed with these parameters. However, the membrane porosity, fibre length, liquid flow rate, number of fibres, and solvent concentration all contribute to the increased efficiency of absorption. The solvent concentration is analysed to evaluate its impact on mass transfer during CO_2 absorption. This integration of the enzyme represents an innovative approach in green chemistry, offering a more sustainable and environmentally friendly solution for CO_2 capture.

1. Introduction

Global warming is primarily driven by increased greenhouse gas emissions, especially carbon dioxide (CO_2), mainly due to the combustion of fossil fuels. Over the last 150 years, fossil fuel consumption has increased substantially to meet growing energy demands, leading to significant CO_2 emissions. This rise in greenhouse gases is one of the critical environmental challenges globally, contributing to climate change, a gradual increase in global temperatures, and adverse impacts on populations, ecosystems, and economic development [1]. To mitigate these effects, carbon dioxide capture and storage (CCS) has been proposed as a key strategy against global warming [2,3]. Several CO_2 capture methods are available, including physical and chemical absorption [4], solid adsorption [5], cryogenic techniques [6], and membrane technology [7]. Chemical absorption using aqueous amine solutions is the most widely applied method for industrial CO_2 capture due to its high efficiency and well-established processes; however, it faces drawbacks such as high energy consumption and operational complexity. Membrane technology is emerging as a promising alternative, offering a potential solution to the limitations of conventional separation methods by efficiently isolating CO_2 and other pollutants from gas mixtures [8]. As innovative gas absorption devices, hollow-fibre membrane contactors (HFMCs) have recently gained

* Correspondence to: Dept. of Earth Resources and Environmental Engineering, Hanyang University.IT/BT 1207, Hangdang dong, Sungdong Gu, Seoul 04763, Korea.
** Corresponding author.
E-mail addresses: bhjeon@hanyang.ac.kr (B.-H. Jeon), benguerbayacine@yahoo.fr (Y. Benguerba).

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