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AI-driven parametric optimization of gas-liquid absorption for the intensification of CO_2 capture under a Gas-phase pulsation condition

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ABSTRACT

Traditional CO_2 capture using amine-based solvents is effective but not an energy-intensive and requires frequent replenishment. This study explores enhancing CO_2 absorption in packed bed columns by switching to sodium hydroxide and incorporating gas phase pulsation to improve mass transfer efficiency. Optimising a CO_2—NaOH absorption process through its intensified volumetric mass transfer coefficient under a gas phase pulsation using artificial intelligence model is the main objective of this study. The mutual effects of pulsation amplitude, frequency, bed height, and solvent content on volumetric mass transfer coefficient was observed by Central Composite Design model of Response Surface Methodology where under an ideal frequency of 7.5 Hz, an amplitude of 18 mm, a bed height of 12 cm, and a solvent concentration of 2 N, the model attained a maximum volumetric mass transfer coefficient of 53.166 ± 0.55 s^{-1}. This result was further validated through the Genetic Algorithm and Particle Swarm Optimisation models of Artificial Neural Networks. It revealed maximum coefficients of 54.52 ± 40 s^{-1} and 56.12 ± 60 s^{-1}, respectively, with marginally differing ideal parameters. This study shows that artificial intelligence can substantially optimize CO_2 capture processes by maximizing the volumetric mass transfer coefficient, leading to more efficient and cost-effective greenhouse gas reduction methods.

1. Introduction

Global warming is a major environmental concern that humanity is currently facing. The escalating carbon dioxide (CO_2) concentrations in the Earth's atmosphere are the primary catalyst for climate change-related issues [1]. This issue is receiving increased focus because of its significant consequences. Climate Watch's 2023 data reveals that industrial activity released 1.63 billion tonnes of CO_2 into the atmosphere last year [2,3]. Projections suggest that this amount will climb by 1.2 times in both 2024 and 2025 [4]. Although CO_2 has a lower global warming potential than other greenhouse gases, its second-highest concentration, after water vapor, is the primary factor in causing temperature changes [5]. Several types of CO_2 emission reduction technology have been adopted worldwide, but most of the technology either provided less capturing efficiency or less scalable possibility [6–8]. The post-combustion CO_2 capture method, specifically removing CO_2 using absorption systems with chemical solvents in packed-bed columns, is widely used due to its advanced development and great effectiveness [9]. Nevertheless, these procedures can consume a significant amount of energy, particularly when utilizing amine-based mixtures, the aqueous solution of monoethanolamine (MEA) and N-Methyl-2-Pyrrolidone (NMP) absorption methods for treating Natural gas or flue gas mixtures [10,11].

Frequent replenishment of such solvents is essential due to its rapid

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