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Enzyme accelerated carbon capture in different contacting equipment - a comparative study

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Abstract

CO_2 capture is an essential step for providing a sustainable and ecological solution to cope with increasing energy supply burning fossil fuels. However, industrial application of current CO_2 capture technologies is limited due to the significant energy penalty. In order to reduce this energy penalty two different approaches of process intensification are examined in this study. The first approach aims at the intensification of mass transfer to compensate for low absorption rates of solvents with high capacity that would allow for more energy-efficient CO_2 capture. Here the tertiary amine methyldiethanolamine (MDEA) is combined with a highly efficient biocatalyst, the enzyme Carbonic Anhydrase (CA), for which significant enhancement of absorption performance was demonstrated in literature.

In addition to the intensification of the solvent system, the contacting of gas and liquid streams in ab- and desorption can be improved in intensified contacting devices (ICD). Here especially membrane contactors (MC) and rotating packed beds (RPB) are promising alternatives to classical packed columns. MC provide a well-defined interfacial area that is orders of magnitude higher than for conventional equipment and introduces additional operational flexibility, expressed by the independent flow ratio between liquid and gas phase. In a RPB centrifugal forces are exploited to increase acceleration of the liquid and improve turbulence and mass transfer. The rotational speed of the rotating packing introduces an additional degree of freedom compared to common static equipment. Both ICDs offer a very compact design.

While both, ICD and the improved solvent system with CA, can significantly intensify the CO_2 capture process, research on the combination of both is scarce. In order to evaluate the potential benefit of a joint implementation, a first step of imminent importance is to characterize the operating windows of such an intensified process. Based on prior results concerning the energy requirements for solvent regeneration, an aqueous amine solution with 30wt.-% MDEA is investigated in this study without and with dissolved CA. In order to evaluate the potential improvement of a joint application of the ICD and the application of CA absorption experiments in a packed column and in the two ICDs are performed. While all three devices show similar absorption performance without CA added, the RPB offers the advantage to handle exceptionally high gas loads while the MC can be operated over a much wider range of liquid loads. When CA is added to the solvent system the packed column and the RPB show superior performance compared to the MC. While none of the combinations is generally superior, the different means for process intensification extent the operating window and facilitate improved absorption performances.

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1. Introduction

According to the Intergovernmental Panel on Climate Change (IPCC), global CO_2 emissions have to be cut by at least 50 % until 2050 in order to limit average global temperature rise to less than 2°C [1]. Since the growing global energy demand cannot be fully covered by renewable energies in the short to medium term, fossil fuels will continue to play an important role in power generation, especially for time-independent energy supply [2]. Therefore, near-term realizable concepts to minimize CO_2 emissions associated with power generation are needed. State of the art for the removal of CO_2 is amine scrubbing (mostly applying monoethanolamine (MEA)) in packed columns [3]. Due to the energy intensive solvent regeneration, power plant efficiency is significantly decreased, resulting in almost no CO_2 capture plants, implemented at industrial scale. Only the reduction of the high energy and cost penalty by means of more energy-efficient processes can make CO_2 capture economically more viable. One option for achieving this objective is an optimized solvent choice to facilitate the necessary separation of CO_2 with a minimum of effort for solvent regeneration. However, the solvent selection is usually based on a compromise between high capacity, being able to operate with a low amount of solvent and therefore minimum energy for regeneration, as well as improved mass transfer and reaction kinetics, which govern the size of the required equipment for mass transfer. In order to exploit the benefits of a solvent with higher capacity, combinations of intensified contacting devices (ICD) and the application of an additional biocatalyst, the enzyme Carbonic Anhydrase (CA), are considered to compensate for kinetic limitations of the solvent in the current study. A graphical overview of the contacting devices and materials considered in this work is presented in Fig. 1 and will be explained in detail in the following.

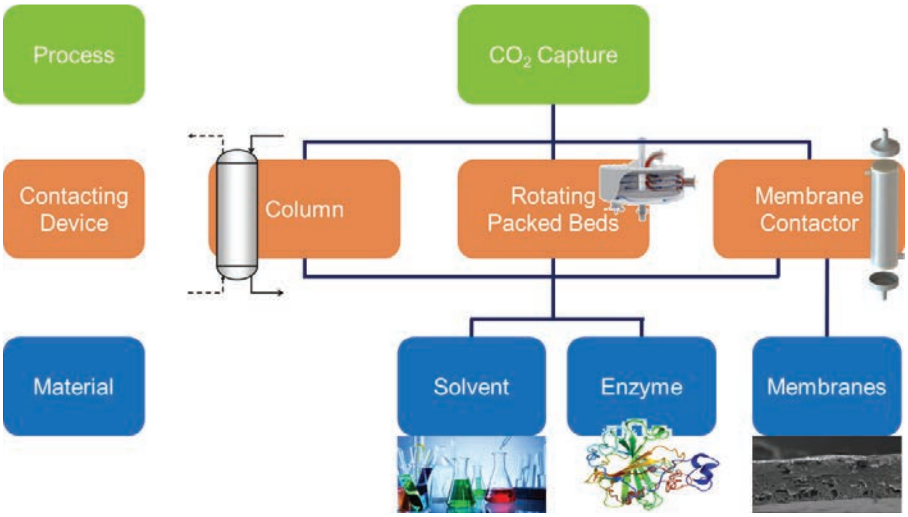

Fig. 1: *Overview of contacting devices and materials investigated in this study*

1.1. Intensified fluid contacting devices

In recent decades the intensification of chemical separation processes by applying new devices for contacting two fluids has been raising a lot of interest [4–7]. Especially rotating packed beds (RPB) and membrane contactors (MC) offer significant improvements to mass transfer in comparison to packed columns. In a MC both the fluids are separated by a porous membrane. Due to opposite wetting tendencies of the fluids the pores of the membrane are