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

Mathias Leimbrink, Laura Mans, Kolja Neumann, Anna-Katharina Kunze, Mirko Skiborowski, Andrzej Górak

TU Dortmund University, Laboratory of Fluid Separations, Emil-Figge-Straße 70, 44227 Dortmund, Germany

In order to achieve the ambitions targets specified by the United Nations Framework Convention on Climate Change in 2011 and reduce GHG emission in the EU by 2020 20% below those in 1990 carbon dioxide (CO₂) emissions have to be reduced significantly. Especially the efficient capture of CO₂ from fossil-fired power plants that are responsible for 40 % of total global CO₂ emissions (Mondal et al., 2012) is one of the crucial challenges facing today’s society. As a result, a wide range of different processes, including absorption, adsorption, cryogenic processes and membrane technologies, is available and studied intensively in recent years (Mathias et al., 2013). Nevertheless, current state-of-the-art for CO₂ capture is the reactive absorption in columns using amines. Especially primary amines, like Monoethanolamine (MEA), are often used because of the covalent bonding of the CO₂, resulting in fast absorption rates. However, the recovery of the solvent, which is necessary for a continuous operation, becomes the economic bottleneck the stronger the CO₂ is bound.

Therefore, a trade-off arises between fast absorption rates and energy efficient solvent recovery. The latter one causes 80 % of the total capture costs for the MEA process and results in a loss in overall power plant efficiency of up to 15 % (Neveux et al., 2013). Consequently, solvent recovery represents the bottleneck of the reactive absorption/desorption process, which is practically not considered for large scale industrial application (Mondal et al., 2012). A lot of research effort is carried out in order to overcome this restriction with a focus on more energy efficient solvents. While tertiary amines or potassium carbonate require less energy in the regeneration step, application of these solvents is restricted by their relatively low absorption rate (Le Moullec et al., 2014).

Process intensification can help to overcome this restriction in different ways, which are investigated in this study. In order to compensate for the low absorption rates of tertiary amines enzymes are integrated as efficient biocatalysts to the solvent system. Here, especially the enzyme Carbonic Anhydrase (CA) is considered as promising catalyst for the hydration of CO₂ (Gundersen et al., 2014). A significant enhancement of the absorption performance was demonstrated in literature, proving the direct influence on the reaction rate (Vinoba et al., 2013). In parallel, carbonic anhydrase as a biocatalyst introduces also additional restrictions to the process due to sensitivity towards temperature and pH.

Secondary to an intensification of the solvent system, the way of contacting can be intensified as well by application of intensified contacting devices (ICD). The use of a membrane contactor provides a well-defined interfacial area that is orders of magnitude higher than for conventional equipment (Li et al., 2013). Due to the modular nature and operational flexibility, expressed by the independent flow ratio between liquid and gas phase, membrane contactors offer a promising alternative to conventional equipment. However, it has to be considered as well that mass transfer
resistance is increased by introducing a membrane in the mass transfer pathway and additionally transmembrane pressure difference has to be controlled. Another ICD that can present an added value to ab- and desorption is the rotating packed bed (RPB) technology. In RPB processes centrifugal forces are exploited to increase acceleration of the liquid. In a counter-currently operated RPB gas flows through the torus-shaped rotating packing from the outside to the middle of the rotor. Liquid is sprayed into the eye of the rotor and flows counter-currently to the gas outwards, driven by the centrifugal movement. RPBs offer the benefit of improved mass transfer due to high turbulences, as well as the enlargement of the operating window with the rotational speed as an additional degree of freedom. All these advantages result in high capacity combined with compactness (Sudhoff et al., 2015). Application of RPBs is still limited due to lack of reliable data on the performance efficiency.

While both, ICD and CA, have the potential to significantly intensify the CO₂ capture process, literature studies and research on the combination of both is limited. Therefore, a first step of imminent importance is to characterize the operating windows of such intensified processes in order to evaluate the potential benefit for an actual implementation. In preliminary work (Kunze et al., 2015), the tertiary amine N-Methyldiethanolamine (MDEA) has shown promising result to be more energy-efficient compared to MEA and is therefore chosen as solvent (30 wt.-%) for this work. Absorption experiments in a column and the different ICD are performed to determine the operating windows and compare separation efficiency. Subsequently, CA is added to the solvent system in order to evaluate the potential to intensify the absorption carried out in a packed column as well as ICDs. The results enable the discrimination between the different means for process intensification depending on the determined operating windows and separation performances. Finally, the obtained results are evaluated and benchmarked against the current state-of-the-art process. Future work will also investigate the application of the different means for process intensification to the desorption step in order to provide a complete picture for a potential industrial application.

REFERENCES

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