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The use of catalysis for faster CO_2 absorption and energy-efficient solvent regeneration: An industry-focused critical review

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ABSTRACT

Absorption in an aqueous amine solution is currently the most mature industrial process to capture anthropogenic and native CO_2. The high cost of the technology prevents its massive deployment. There is a growing number of experimental reports on the benefits of using a catalyst to speed up the absorption of CO_2 or to lower the energetic cost of the solvent regeneration. In this review the basics of industrial absorption and regeneration are first reviewed, as well as the mechanisms to catalyze the absorption and the desorption of CO_2. Subsequently, the results in the literature on heterogeneous and homogeneous catalytic CO_2 capture are critically assessed with a focus on the industrial reality of the process. It is shown that a catalyst for the regeneration has only little room for maneuver because the desorption is fundamentally controlled by thermodynamics. The overall benefice of catalyzing the absorption still needs to be proven. The review aims to realign the research with the industrial reality and indicates several key points of attention to perform more industry-focused experiments and to analyze the overall benefit of using a catalyst.

1. Introduction

Global warming due to the greenhouse effect has become a major issue for our society. One of the main greenhouse gases is CO_2 and its concentration in the atmosphere is constantly increasing. To fight against global warming and to reduce the CO_2 emissions scientists are developing technologies to capture the CO_2. The most mature and widespread technology today is absorption by aqueous amine solutions [1,2]. This technology can capture the CO_2, whether it is present at low pressure in industrial flue gases or at high pressure in natural gas. The major obstacle to the implementation of this technology on industrial sites remains its high cost [3], which is today significantly higher than the carbon taxes. The CAPEX (Capital Expenditure) are elevated due to the significant size of the installations, which is primarily determined by the volume of (flue) gas that needs to be treated. The OPEX (Operational Expenditure) are high due to the large amount of energy required for the regeneration of the CO_2-loaded amine solution. The minimum energy depends strongly on the CO_2 concentration in the gas and on the CO_2 recovery. For an aqueous MEA (MethylEthanolAmine) solution, the average value of 4.2 GJ/tCO_2 is often cited [4], to illustrate the high energy of regeneration. Capturing and compressing CO_2 currently requires ~30% of the energy of a coal power station and would require even more if biomass rather than coal was burned [5–7].

An increasing number of researchers have studied the possibility to catalyze the absorption or the desorption of CO_2 [8–48]. The reasoning is the following: the absorption of CO_2 is limited by the reaction with the amine. Moreover, amines which absorb CO_2 relatively slow typically show a lower regeneration energy. The use of a catalyst would accelerate the CO_2 absorption and thus reduce the solvent flow rate and the size of the column, while maintaining the regeneration energy-efficient. The industrial desorption of CO_2 takes place at elevated temperatures, typically 120–140 °C. Adding a catalyst during the solvent regeneration step would reduce this temperature and result in considerable energy gains.

Abbreviations: AGRU, Acid Gas Removal Unit; BAS, number of Brönsted Acid Sites; B/L, number of Brönsted Acid Sites/number of Lewis Acid Sites; BEA, ButylEthanolAmine; CAPEX, Capital Expenditure; CCUS, Carbon Capture Utilization and Storage; DEA, DiEthanolAmine; DEAPA, 3-(DiethylAmino)PropylAmine; LAS, number of Lewis Acid Sites; LVC, Lean Vapor Compression; LVE, Liquid-Vapor Equilibrium; MAS, Mesoporous Acid Surface; MEA, MethylEthanolAmine; MDEA, MethylDiEthanolAmine; OPEX, Operational Expenditure; PZ, Piperazine; RPB, Rotating Packed Bed; 1DMA2P, 1-DiMethylAmine-2-Propanol.

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