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Investigation of amino acids promotional influence on electrochemical carbon capture

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Abstract

Introduction

To achieve carbon neutrality by 2050, energy intensive industries with process-bound CO_2 emissions will need to implement cost-effective and reliable carbon removal technologies. However, current CO_2 capture processes still face several technical and economic barriers to reach large-scale deployment. This work investigated the effect of an innovative CO_2 capture absorbent coupled with electricity-driven regeneration. We evaluated the effect of amino acid promotors addition to an alkaline absorbent (1 m KOH) for carbon capture and the effect on electrochemical regeneration energy consumption using bipolar membrane electrodialysis (BMED). BMED as a promising alternative to traditional thermal carbon capture technologies, especially as it aligns with renewable electricity sources. The research evaluated how these promoters influence the performance of an integrated system that combines an absorption column with an electrochemical cell as a function of current density while keeping the load ratio constant (the ratio of electrical current to moles of K^+ entering the electrochemical stack) constant.

Methodology

Figure 1 shows a schematic representation of the developed process. The KOH aqueous solution enters the absorption tower and reacts with CO_2 to form potassium carbonate/bicarbonate solution (K_2CO_3/$KHCO_3$). After absorption, an electrochemically-driven pH swing is used to simultaneously desorb CO_2 as high-purity (>96%) gas stream and regenerate the solvent for further absorption cycles. First, the effect of aminoacid concentration (0.1 m to 1 m) was

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tested by adding glycine to a KOH solvent and investigating specific energy consumption. Thereafter, the promotional effects of glycine, proline, and sarcosine were compared with the optimized concentration found in the first step. The CO_2 capture efficiency ($\eta_{CO_2\,capture}$) of the absorber was calculated as $\eta_{CO_2\,capture}(\%) = \frac{y_{CO_2,in} - y_{CO_2,out}}{y_{CO_2,in}}$ where $y_{CO_2,in}$ and $y_{CO_2,out}$ are the CO_2 concentrations in the gas at the inlet and outlet of absorber, respectively. For electrochemical regeneration, the specific energy consumption (SEC, GJ/ton CO_2), was calculated as $SEC = \frac{VjA_m}{\dot{m}_{CO_2}}$, where V is the stack voltage (V), j is the current density (A/m^2), A_m is the active membrane area (m^2), and $\dot{m}_{CO_2}$ is the measured CO_2 gas flow rate (kg/s) produced in the regeneration cell.

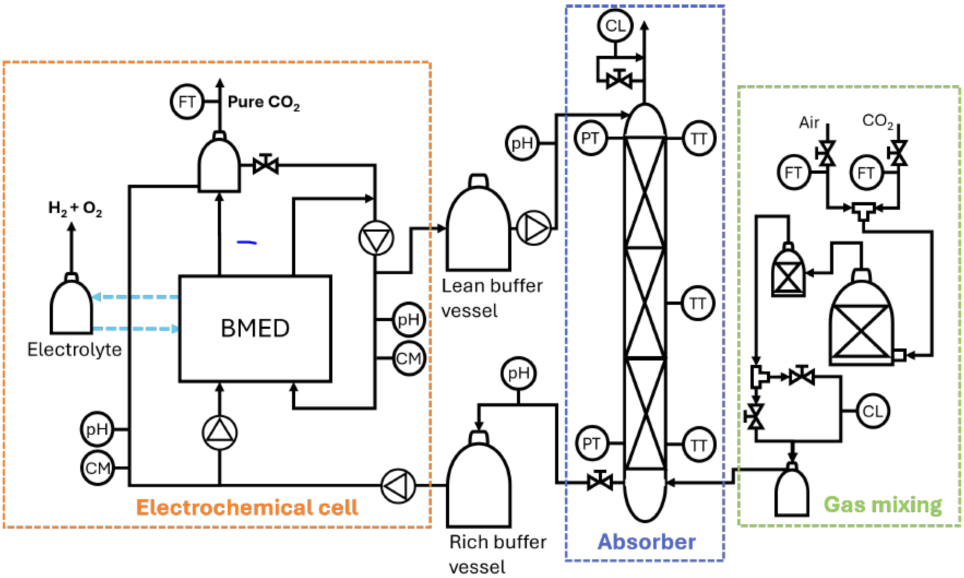
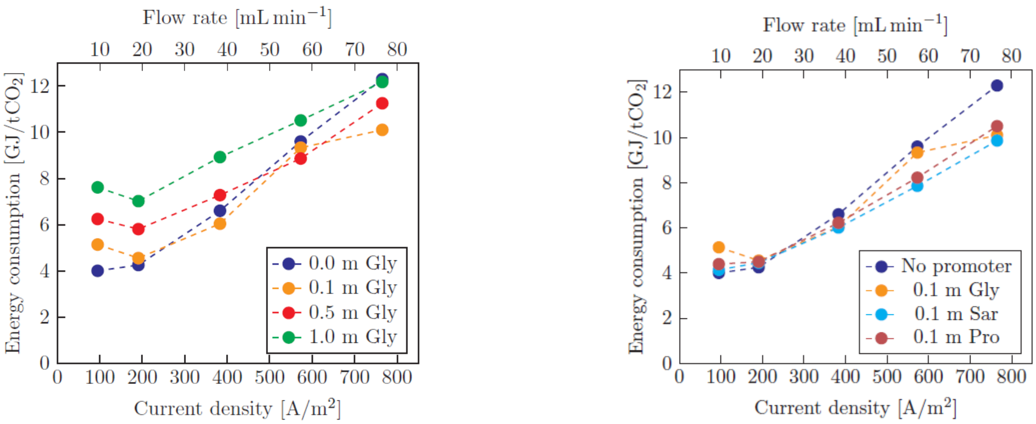


Figure 1. Schematic representation of the laboratory scale CO_2 capture setup based on alkaline absorption and electrochemical regeneration used in this work.

Results

Figure 2 shows (a) the Effect of current density and glycine concentration on the SEC of electrochemical regeneration, and (b) the effect of current density and different aminoacid promotors (glycine, proline, and sarcosine) composition on the specific energy consumption of electrochemical regeneration. Figure 2 (a) shows that he best concentration was 0.1 m glycine which demonstrated the lowest energy consumption at high current density compared to the base case scenario (solvent without glycine). Larger glycine concentrations also improved energy consumption at high current density compared to the solvent without any promoter but were not better than the 0.1 m Gly case. At low current densities, where the solution without glycine achieved near-complete CO_2 saturation, the promoters had little to no effect. Across all experiments performed on the integrated system, the lowest energy consumption (4.1 GJ/tCO_2) was achieved with a solution containing 1 m KOH + 0.05 m K_2SO_4 at low current density, without the addition of any promoter. This can be explained because experiments with low current density required lower flow rates of rich solvent entering the electrochemical system. Since the gas flow rate in the absorption tower stayed constant during these experiments, the L/G ratio in the was also lower at low current density, favoring large liquid residence times and full saturation of the absorbent. Thus, the results indicate that the promotional effect of glycine becomes apparent only when CO_2 capture is limited by CO_2 absorption kinetics. Furthermore, the results indicated that the concentration of promoters played a crucial role in system performance. Higher promoter concentrations led to lower efficiency, suggesting that an optimal balance between promoter concentration and performance must be identified for effective implementation.



(a) (b)

Figure 2. (a) Effect of current density and glycine concentration on the specific energy consumption of electrochemical regeneration. (b) Effect of current density and different aminoacid promotors (glycine, proline, and sarcosine) composition on the specific energy consumption of electrochemical regeneration.

Figure 2 (b) shows that sarcosine displayed the best results, specially at low current density. Sarcosine enabled a 20% reduction in energy consumption (9.86 GJ/t CO_2) at high current density compared to experiments without any promoter. However, as current density increased, the energy consumption obtained in the experiments was similar among the 3 aminioacid promoters tested. With higher current densities, energy consumption increased due to internal resistance within the BMED unit and differences in solution loadings caused by the different flow rates of liquid solvent entering the absorption tower. Figure 3 shows Capture efficiency as a function of current density for experiments with different promoters. For experiments with different promotors, the capture efficiency increased with current density for all the experiments as more CO_2 was absorbed/desorbed. For lower current density, the capture efficiency was around the same value for all the experiments, as in this case, low liquid to gas ratios favors systems with slow CO_2 absorption kinetics. As current density increased, the experiments with sarcosine showed the highest capture efficiency with a value of 65%, closely followed by proline and glycine. As expected, experiments without any promoter showed the worst results with a maximum capture efficiency of 43%.

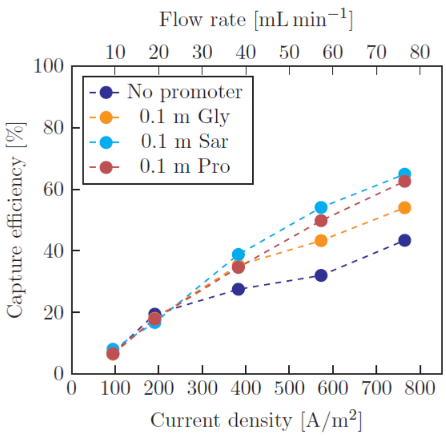


Figure 3. Capture efficiency as a function of current density for experiments with different promoters

Conclusion

These results show for the first time the use of environmentally friendly aminoacid promotors in combination with an alkaline solvent regenerated using BMED. Promoters such as glycine, proline, and sarcosine enhance the system's efficiency when CO_2 absorption was limited by capture kinetics. The effectiveness of amino acid promotors was influenced by concentration, current density in the electrochemical cell, and liquid to gas ratio in the absorption tower. Different concentrations of amino acids were tested, showing optimal results with lower concentrations of amino acids. Under conditions with high current densities, solutions with amino acid promoters outperformed the base case, achieving a 20% reduction in energy consumption with the best-performing amino acid being sarcosine. Although the promotors showed potential improvements in energy consumption, further research is required to optimize the use of promoters, improve energy efficiency, evaluate degradation, and address challenges associated with upscaling. Overall, the findings demonstrate the feasibility of using aminoacid-promoted alkaline absorbents for post-combustion carbon capture and their regeneration using BMED.