MASS TRANSFER STUDIES ON CATALYST AIDED DESORPTION USING A BLENDED SOLVENT IN A POST COMBUSTION CAPTURE PLANT


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Introduction

Optimizing efficiency, as well as cost and energy penalties of the reactive absorption process has continued to be the focus of many post-combustion capture studies. Technology developments, process modification, solvent chemistry and blending are generally the areas of investigation for improvements. Compared to the extensive developments on CO₂ absorption, there are relatively scarce literature information on the enhancement of the desorption cycle despite the fact that the desorber is the major cost and energy intensive component in the capture process. A novel and promising technology that seeks to bridge the divide and enhance the desorption process is the use of stable solid acid catalyst. The goal is to augment desorption of CO₂ from loaded solvents physically by utilizing the surface area of porous catalyst to tremendously increase the interfacial area for mass transfer and chemically by relying on the catalyst acid sites to catalyze desorption of CO₂.

Two commonly used industrial acid catalysts were selected for this study. These were: Protonated zeolite socony mobile-5 (HZSM-5), a Brønsted acid catalyst with a relatively high surface area, and gamma alumina (γ-Al₂O₃), a Lewis acid catalyst. A 5M monoethanolamine and 2M methyl diethanolamine blend (7M MEA/MDEA) was selected as the solvent for the catalytic study. From solvent chemistry analysis, CO₂ is desorbed from the carbamate ion (MEACOO⁻) or bicarbonate ion (HCO₃⁻). Thus, HZSM-5’s chemical property as a proton acceptor facilitates MEACOO⁻ breakdown whilst γ-Al₂O₃, an amphoteric oxide substitutes the role of HCO₃⁻ to release CO₂ gas with lower energy penalties. The interaction between loaded solvent, CO₂ gas and solid acid catalyst is studied to identify the process parameters that improve the mass transfer characteristics while minimizing the heat duty for regeneration
Experimental Section

The experiment was conducted in a bench-scale full cycle CO₂ capture plant. The dimensions of the cylindrical stainless steel absorber and desorber columns were 1.07m x 0.00174m². The column internals consisted of different layers of packing: a 0.18m height of a 0.051m diameter Sulzer structured packing found at the topmost and bottom of the column that aids solvent distribution; a 0.051m height 10mm inert marble that sits on the top and bottom of the catalyst bed serving as support for the bed and a 0.51m height 6mm diameter inert marble randomly mixed with a specified mass of solid acid catalyst for each experimental condition to reduce the pressure drop in the column.

The columns were designed for a counter-current mode of operation in which MEA/MDEA solvent circulation was set by variable-speed gear pumps. A mass flow meter and an infrared CO₂ gas analyzer were used to ensure a 15% CO₂ in N₂ gas mixture circulation in the absorber. Heat circulation is set to attain an average catalyst bed temperature of 85°C in the desorber. The error of the experiment was computed to be ±2.1%. The solution molar density (ρₘ), lean loading, rich loading and rich amine flow rate were evaluated when the system reached steady state. A mass balance error less or equal to 10% was considered a valid data set for analysis. An estimate of the interfacial area at experimental conditions was evaluated using a 5M MEA base solvent. A kinetic study was investigated for the system and the interfacial area estimated by the equation:

\[ a = \frac{N_{\text{CO}_2}^2}{C_{\text{CO}_2}^* S z / D_{\text{CO}_2} k_1} \]

Where
- \( a \) = interfacial area;
- \( N_{\text{CO}_2} \) = rate of reaction;
- \( k_1 \) = rate constant;
- \( S \) = column area;
- \( C_{\text{CO}_2}^* \) = equilibrium concentration of CO₂;
- \( z \) = column height;
- \( D_{\text{CO}_2} \) = Diffusivity of CO₂

The overall volumetric liquid side mass transfer coefficient (\( K_L a_v \)) was estimated by the equation:

\[ K_L a_v = \frac{1}{z} \int \frac{L_m d x_A}{\rho_m (1 - x_A) (x_A^* - x_A)} \]

Where \( L_m \) is the molar liquid flow rate
- \( x_A \) is the mole fraction of CO₂ in the liquid
- \( x_A^* \) is the mole fraction of CO₂ in equilibrium with the bulk vapour
- \( z \) is the differential packed column height

Results

The addition of catalyst exponentially increases the interfacial area for mass transfer with γ-Al₂O₃ showing a slightly higher increment than HZSM-5. The mass transfer coefficient increases with catalyst
weight with HZSM-5 catalyst exhibiting superior performance to γ-Al₂O₃ at the 85°C temperature. Also, the use of a primary and a tertiary solvent blend gave better performance than a single solvent MEA with both HZSM-5 and γ-Al₂O₃ catalyst.

Figure 1: Increments in interfacial area with varying catalyst weight

Figure 2: $K_La_v$ enhancements with varying catalyst weight at 85°C
Conclusions
The physical enhancement in terms of interfacial area shows better performance of γ-Al₂O₃ compared to HZSM-5 however the mass transfer coefficient increases by an average of 2% and 12.8% using γ-Al₂O₃ and HZSM-5 catalyst respectively at 85°C. Thus the combined effect of the physical and chemical property has an intricate but beneficial effect to increasing the mass transfer in the desorber. The percentage rise implies a reduction in the size of desorber columns and further translates to manufacturing cost. Another benefit is a reduction in the energy penalty for desorption due to higher reaction and transfer rates.

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References

