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Application of Alumina-Aerogel in Post-Combustion CO_2 Capture: Optimization by Response Surface Methodology

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Abstract : Dependence of global economics on fossil fuels has led to a large growth in the emission of greenhouse gases (GHGs). Among the various GHGs, carbon dioxide is the main contributor to the greenhouse effect due to its huge emission amount. To mitigate the threatening effect of CO_2, carbon capture and sequestration (CCS) technologies have been studied widely in recent years. For the combustion processes, three main CO_2 capture techniques have been proposed such as post-combustion, pre-combustion and oxyfuel combustion. Post-combustion is the most commonly used CO_2 capture process as it can be readily retrofit into the existing power plants. Multiple advantages have been reported for the post-combustion by solid sorbents such as high CO_2 selectivity, high adsorption capacity, and low required regeneration energy. Chemical adsorption of CO_2 over alkali-metal-based solid sorbents such as K_2CO_3 is a promising method for the selective capture of diluted CO_2 from the huge amount of nitrogen existing in the flue gas. To improve the CO_2 capture performance, K_2CO_3 is supported by a stable and porous material. Al_2O_3 has been employed commonly as the support and enhanced the cyclic CO_2 capture efficiency of K_2CO_3. Different phases of alumina can be obtained by setting the calcination temperature of boehmite at 300, 600 (γ-alumina), 950 (δ-alumina) and 1200 °C (α-alumina). By increasing the calcination temperature, the regeneration capacity of alumina increases, while the surface area reduces. However, sorbents with lower surface areas have lower CO_2 capture capacity as well (except for the sorbents prepared by hydrophilic support materials). To resolve this issue, a highly efficient alumina-aerogel support was synthesized with a BET surface area of over 2000 m^2/g and then calcined at a high temperature. The synthesized alumina-aerogel was impregnated on K_2CO_3 based on 50 wt% support/K_2CO_3, which resulted in the preparation of a sorbent with remarkable CO_2 capture performance. The effect of synthesis conditions such as types of alcohols, solvent-to-co-solvent ratios, and aging times was investigated on the performance of the support. The best support was synthesized using methanol as the solvent, after five days of aging time, and at a solvent-to-co-solvent (methanol-to-toluene) ratio (v/v) of 1/5. Response surface methodology was used to investigate the effect of operating parameters such as carbonation temperature and H_2O-to-CO_2 flowrate ratio on the CO_2 capture capacity. The maximum CO_2 capture capacity, at the optimum amounts of operating parameters, was 7.2 mmol CO_2 per gram K_2CO_3. Cyclic behavior of the sorbent was examined over 20 carbonation and regenerations cycles. The alumina-aerogel-supported K_2CO_3 showed a great performance compared to unsupported K_2CO_3 and γ-alumina-supported K_2CO_3. Fundamental performance analyses and long-term thermal and chemical stability test will be performed on the sorbent in the future. The applicability of the sorbent for a bench-scale process will be evaluated, and a corresponding process model will be established. The fundamental material knowledge and respective process development will be delivered to industrial partners for the design of a pilot-scale testing unit, thereby facilitating the industrial application of alumina-aerogel.

Keywords : alumina-aerogel, CO_2 capture, K_2CO_3, optimization
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