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Tailoring the Physicochemical Properties of Zn/Al-LDH for Superior CO_2 Capture Performance

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Structured Abstract

Background: Layered Double Hydroxides (LDHs) have attracted significant interest due to their strong anion exchange capacity and tunable layered structures, which make them promising materials for applications such as carbon dioxide capture. ZnAl-NO_3 LDH is of particular interest because its structural stability and anion intercalation behavior are strongly influenced by the Zn/Al molar ratio and thermal treatment. This study focuses on the synthesis of ZnAl-NO_3 LDH with different Zn/Al ratios and multiple calcination treatments to evaluate their effects on structural and thermal properties relevant to CO_2 capture applications.

Methods: ZnAl-NO_3 LDH samples were synthesized via a co-precipitation method using zinc nitrate ($Zn(NO_3)_2$) and aluminum nitrate ($Al(NO_3)_3$) as metal precursors. Two distinct Zn/Al molar ratios (2:1 and 3:1) were prepared by maintaining a constant pH of 10 with NaOH, followed by aging and calcination at 450 °C. To investigate structural reconstruction behavior, repeated intercalation treatments using Na_2CO_3 and subsequent recalcination steps were performed. The synthesized materials were characterized by Powder X-ray Diffraction (PXRD), Fourier Transform Infrared Spectroscopy (FTIR), Thermogravimetric Analysis (TGA), and CHNS elemental analysis. These techniques were employed to evaluate structural evolution, interlayer composition, and thermal stability, with the aim of correlating these properties to the material's efficiency for carbon capture.

Results: PXRD analysis confirmed the formation of a well-defined hydrotalcite-like structure for both Zn/Al ratios, as evidenced by the characteristic (003) basal reflection. The LDH with a 3:1 ratio demonstrated notably sharper diffraction peaks, indicating superior crystallinity relative to its 2:1 counterpart. Upon calcination, a significant reduction in basal spacing was observed, conclusively demonstrating the collapse of the layered framework and its transformation into mixed metal oxide phases. FTIR spectra confirmed successful nitrate intercalation through characteristic stretching bands, the intensity of which diminished post-calcination, confirming the effective removal of interlayer species. TGA profiles revealed two distinct mass loss stages, attributed to the evolution of interlayer water and the decomposition of nitrate anions, underscoring the material's inherent thermal stability. Finally, CHNS elemental analysis consistently showed low residual carbon content, verifying the absence of significant carbonate contamination during synthesis.

Conclusion: This study demonstrates that the Zn/Al molar ratio and the intercalation / calcination treatment cycle critically govern the structural and thermal properties of ZnAl-NO_3 LDH relevant for carbon capture. The ZnAl-LDH with a 3:1 molar ratio exhibited superior crystallinity and thermal stability, confirming its strong potential for advanced CO_2 capture technologies.

Keywords: ZnAl-NO_3 LDH, Layered Double Hydroxides, Co-precipitation, Calcination, Carbon Dioxide Capture.

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