Design of a Novel Dual-Functional Photocatalyst Based on Metal Oxides and Carbon Dot–Modified MOF-5 for CO2 Capture and Conversion

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The limitations of traditional CO2 capture technologies and the rapid rise in CO2 emissions necessitate efficient methods and materials for CO2 capture and conversion under mild conditions. Despite significant global efforts, many current approaches remain energy-intensive, inefficient, or environmentally unsustainable. To address these challenges, this study designs a novel doubly interpenetrated MOF-5 using terephthalic acid (BDC) and imidazole (Im) linkers via a hydrothermal method. It investigates CO2 adsorption by altering dopant concentrations (1%, 5%, and 10%) in MOF and functionalized TiO2@MOF and WO3@MOF with carbon dots. Structural properties were characterized using XRD, FT-IR, TGA, and SEM-EDX, followed by gravimetric evaluation of CO2 adsorption. Adsorption performance increased across the synthesized materials. CDs@TiO2@MOF and CDs@WO3@MOF showed the lowest and moderate efficiencies (23–27%), while CDs@MOF showed slightly higher efficiency (29.61%). Among metal oxide–doped MOFs, WO3@MOF achieved 29.68% adsorption due to its narrow band gap (2.4–2.8 eV), enabling visible-light absorption, while TiO2@MOF showed improved stability with 31.37% efficiency. The highest CO2 uptake (38.16%) was observed for doubly interpenetrated MOF-5 before functionalization. Beyond adsorption, metal oxide and carbon dot doping enabled effective photocatalytic CO2 conversion into value-added products such as cyclic carbonate. Metal oxide loading enhanced catalytic activity, with CDs@WO3@MOF showing the highest conversion efficiency of 89.87%. These results highlight MOF-5's potential as a scalable, energy-efficient material for combined CO2 capture and photocatalytic conversion under moderate conditions, offering a promising route for sustainable carbon management.

Awards Won:

Aramco: First Place Prize Chemistry (CHEM) / Materials Science (MATS)