Adsorption/photocatalytic Degradation of Congo Red Using UiO-66 MOF and Activated Carbon Under Natural Solar Irradiation

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Abstract

The presence of synthetic dyes in industrial effluents poses a significant environmental concern due to their high stability and toxicity. This study investigates the removal of Congo Red (CR) dye from aqueous solution using UiO-66 metal–organic framework (MOF), activated carbon (AC), and their composite under natural solar irradiation. The composite was synthesised by simple mechanical mixing of equal (50 wt.%) proportions of MOF and AC powders in a porcelain mortar, a cost-effective and mild synthesis approach that preserves the MOF structure while enabling large-scale preparation. The adsorption/photocatalytic mechanism was evaluated through UV–Vis spectroscopy to assess dye degradation efficiency, while FTIR, Raman, and XRD analyses provided insight into the interaction mechanisms. After four hours of natural sun irradiation, the MOF/AC composite exhibited superior CR removal efficiency (95%) compared to both individual components (≈75%), confirming the synergistic role of MOF and AC in photocatalytic degradation, where AC acts as an electron sink. XRD, FTIR, and Raman spectroscopy revealed that CR interacts with the Zr–O nodes of MOF through its S=O groups, indicating chemisorptive bonding. Additionally, all samples achieved a removal efficiency more than 50% higher than in dark conditions. The reusability study indicated that pure MOF maintained the highest stability over multiple cycles, while composites gradually lost activity due to AC surface saturation. These findings demonstrate that combining MOF with AC provides a sustainable and energy-efficient strategy for dye removal under natural solar conditions.

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