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Insights Into Mechanistic and Degradation Pathways of Methylene Blue Using CuO/Graphene Nanocomposites for Visible-Light-Driven Photocatalysis

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Abstract : This study explores the fabrication and detailed characterization of cost-effective copper oxide (CuO)/graphene (G) nano-heterostructure photocatalyst designed for environmental remediation. Utilizing a hydrothermal synthesis method, the CuO/G nanocomposite was successfully developed. It demonstrated exceptional photocatalytic activity for degrading methylene blue (MB), a commonly used dye and model pollutant in wastewater treatment research. The optimized CuO/G nanocomposite achieved a remarkable photodegradation efficiency of 98.4% under visible light irradiation, significantly surpassing the performance of bare CuO. To understand the kinetics of the degradation process, reaction rate constants ("k") were analyzed. The CuO/G nanocomposite exhibited a rate constant 10.8 times higher than that of bare CuO, emphasizing the role of graphene in enhancing charge carrier separation and reducing recombination. The synergy between CuO and graphene improved catalytic efficiency and increased the photocatalyst's stability and reusability. Advanced analytical techniques, including high-performance liquid chromatography-mass spectrometry (HPLC/MS), were employed to identify the intermediates formed during the MB degradation. These analyses facilitated the proposal of a comprehensive reaction pathway, shedding light on the degradation mechanism. The degradation steps involved oxidative cleavage, demethylation, and aromatic ring breakdown, ultimately leading to the mineralization of MB into simpler, less harmful by-products. The remarkable photocatalytic efficiency of the CuO/G nanocomposite can be attributed to the integration of graphene, which provides a high surface area, excellent electronic conductivity, and enhanced interaction with CuO nanoparticles. The nano-heterostructure facilitates efficient light absorption and charge transfer, thereby boosting photocatalytic activity under visible light. Additionally, the material's low cost and straightforward synthesis method make it highly scalable and suitable for large-scale environmental applications. This study underscores the potential of CuO/G heterostructures as a robust and economical solution for wastewater treatment and other environmental remediation challenges. By addressing the growing need for clean water and sustainable pollution management technologies, the CuO/G nanocomposite represents a significant step forward in the development of advanced photocatalytic materials. Its ease of synthesis, outstanding photocatalytic performance, and environmental compatibility highlight its practical relevance and adaptability for addressing global water pollution issues.

Keywords : copper oxide, graphene, nanocomposite, methylene blue, photocatalytic, clean energy

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