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Advanced Carbon-Metal Oxide Composites for Water Purification: A Case Study on Benzotriazole Degradation

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Organic xenobiotic compounds from industrial and household products persist in the environment, often passing through wastewater treatment plants and contaminating drinking water sources. This study explores an advanced nanocomposite material for efficient removal of these pollutants. Our approach integrates a carbon-based sorbent (biochar and Hydraffin) with a semiconductor layer (TiO_2 or ZnO) to enable both sorption and photocatalytic degradation under UV/VIS exposure. Benzotriazole (BTR) was selected as a model compound.

Kinetic experiments assessed the pseudo-first-order removal of BTR, analyzing the kinetic coefficient (k) and half-life ($t_{1/2}$). TiO_2 incorporation significantly enhanced removal, reducing the half-life from 572 minutes (control) to 81 minutes. Without a photocatalyst, irradiation had no impact, confirming that photodegradation alone is insufficient. The TiO_2-biochar nanocomposite achieved superior performance ($t_{1/2}$ = 4.96 min, k = 0.140 min^{-1}), demonstrating a strong synergistic effect between sorption and photocatalysis. ZnO-modified composites further improved efficiency, likely due to BTR's higher affinity for Zn. Comparisons of TiO_2- and ZnO-based composites showed ZnO's superior photocatalytic activity, particularly with Hydraffin, which provided a larger active sorption area due to its finer particle size. Under UV/VIS exposure, ZnO-Hydraffin achieved near-complete BTR removal, confirming its high efficiency.

Mechanistic analysis indicates that TiO_2 photocatalysis leads to hydroxylation and nitrogen elimination, forming hydroxylated and methylated BTR derivatives. ZnO follows a similar radical-driven mechanism, though its degradation pathways require further exploration. Future research should focus on identifying transformation products and assessing their toxicity in water treatment applications.

This study highlights the potential of composite materials combining carbon sorbents with metal oxide photocatalysts for effective organic xenobiotic removal. The findings contribute to the advancement of water purification technologies, offering improved performance over conventional biochar-TiO_2 composites.