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ORIGINAL PAPER

TiO_2/ZnS/GO Composites and Beads: A Dynamic Triad with Enhanced Adsorption and Photocatalytic Performance

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Abstract
Ternary composites, featuring TiO_2 as a key component, have gained recognition for their exceptional photocatalytic performance in water treatment. In this study, we investigated the effectiveness of TiO_2/ZnS/GO composites, both in powdered and immobilized forms, for the removal of single and mixed dye pollutants, including methylene blue (MB), methyl orange (MO), and Rhodamine B (RhoB). Comprehensive characterizations utilizing various spectroscopic and microscopic techniques confirmed the successful fabrication of TiO_2/ZnS/GO composites. The findings revealed that the composite achieved impressive individual removal rates of 98.4%, 83.6%, and 95.7% for MB, MO and RhoB, respectively, through adsorption and photocatalytic effects. In the case of co-existing dyes, the composite eliminated 99.1%, 44.3%, and 62.1% of MB, MO and RhoB, respectively. Furthermore, when incorporated into alginate, TiO_2/ZnS/GO–CaAlg beads displayed exceptional dye adsorption capacity and facilitated easy recovery from the reaction medium. This engineered TiO_2/ZnS/GO composite exhibits significant potential in both its powdered and bead forms, particularly due to its superior adsorption capabilities compared to its photocatalytic effects. These findings offer valuable insights into its prospective application in wastewater treatment, with a key emphasis on its efficiency in simultaneously tackling multiple pollutants.

Keywords Photocatalysis · Alginate beads · Wastewater treatment · Titanium dioxide · Surface area

Introduction

In recent years, the contamination of water has emerged as a serious threat to human life, primarily driven by technological advancements, rapid industrialization, and substantial population growth. Moreover, water pollution has intensified due to the continuous introduction of both organic and inorganic pollutants into aquatic ecosystems, resulting in adverse consequences for aquatic habitats. The textile industry, in particular, is a global source of concern due to the unintentional discharge of contaminated wastewater into water bodies, significantly affecting the quality of water resources [1]. Research by the World Bank has indicated that textile dyeing and treatment processes contribute to approximately 17–20% of industrial water pollution. The textile industry is widely recognized as one of the most environmentally detrimental sectors due to its release of contaminated effluents into pristine water bodies. An estimated daily treatment of 12–20 tonnes of textiles results in the discharge of approximately 1000–3000 m^3 of water [2]. To effectively address the issue of organic pollutants, particularly dyes generated by human activities like dyeing processes and industrial discharges, there is a pressing need for stringent regulations and efficient treatment solutions. In light of this, the utilization of semiconductor-based photocatalysts for photodegradation emerges as one of the most promising approaches for remediating dye-laden wastewater. It is well-established that the performance of photocatalysts in water treatment hinges on various factors, including their (1) narrow band gap, (2) adsorption capacity of organic molecules on the surface area, (3) oxygen vacancies, (4) impurity energy level, and (5) ability for electron trapping [3, 4].

While possessing exceptional photocatalytic properties,

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