Novel environmentally benign dual *Z*-scheme $SrTiO_3$/g-C_3N_4/ZnO heterojunction for efficient H_2 evolution and polluted water treatment: Optimization, mechanism interpretations and toxicity assessment

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Abstract

In this study, a novel and robust ternary $SrTiO_3$/g-C_3N_4/ZnO (STCZ) photocatalyst was synthesized and characterized for its efficiency in photocatalytic hydrogen production and tetracycline (TC) degradation under visible light illumination. The ternary composite was prepared by incorporating an optimized 40 %-$SrTiO_3$/g-C_3N_4 (STC) binary mixture onto ZnO nanoparticles, and its performance was systematically evaluated. The optimal 35 %-STCZ nanocomposite demonstrated a remarkable hydrogen evolution rate of 603.94 $\mu mol \cdot g^{-1} \cdot h^{-1}$, representing a twofold increase compared to the STC binary photocatalyst. Furthermore, it achieved a 96 % TC degradation efficiency under the following optimized conditions: catalyst dosage of 0.65 g/L, TC concentration of 28.24 mg/L, reaction time of 71.98 min, and pH 5.11. Comprehensive material characterization, including XRD, XPS, SEM, TEM, BET, and UV–vis DRS analyses, confirmed the successful synthesis and enhanced photocatalytic properties of the 35 %-STCZ composite. Moreover, EIS, PL spectroscopy, and photocurrent measurements indicated efficient charge separation and improved carrier mobility, attributed to the dual *Z*-scheme heterojunction mechanism. Trapping experiments and ESR analysis revealed that hydroxyl (•OH) and superoxide ($\bullet O_2^-$) radicals played pivotal roles in the photocatalytic degradation of TC, with intermediate degradation pathways elucidated via LC-MS analysis. Toxicity assessments demonstrated that the photocatalytic treatment significantly reduced the ecological impact of TC and its byproducts. The 35 %-STCZ composite exhibited excellent stability, maintaining 85 % of its photocatalytic activity over five consecutive cycles for TC degradation. Additionally, the catalyst performed effectively across diverse water sources, underscoring its practical applicability. These findings highlight the potential of the $SrTiO_3$/g-C_3N_4/ZnO photocatalyst for dual applications in environmental remediation and sustainable hydrogen production, offering a promising pathway toward carbon-neutral energy solutions and water pollution control.