**Development of an Efficient Continuous Photocatalytic System for Sustainable Wastewater Treatment**

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Heterogeneous photocatalysis is a promising technology for wastewater treatment, due to its ability to degrade organic pollutants using renewable energy sources. Titanium dioxide (TiO₂) is among the most studied photocatalysts due to its chemical stability, non-toxicity, and low cost. However, its large-scale application remains limited by several drawbacks: its activation occurs mainly under UV light, which constitutes only a small portion of the solar spectrum; TiO₂ nanoparticles are difficult to recover from aqueous media; and the reaction kinetics are often slow.

To overcome these limitations, this research focused on developing a simple and effective doping strategy to extend the catalyst’s activity into the visible light range. Furthermore, the photocatalyst was immobilized on polystyrene spheres, enabling easy recovery and reuse, and allowing integration into a continuous-flow reactor system. The catalyst was extensively characterized using various analytical techniques (SEM, XRD, UV-Vis-DRS, BET, AAS, etc.) to investigate the morphological and structural modifications induced by doping. Additionally, the photocatalytic performance was evaluated under different pH conditions and in the presence of common inorganic ions typically found in real wastewater, to assess the robustness and applicability of the system in complex matrices.

To further enhance the efficiency of the process, photocatalysis was coupled with ultrasound irradiation and hydrogen peroxide (H₂O₂), accelerating the reactive oxidative species production and significantly increasing degradation rate. Finally, to directly harness solar energy, a continuous-flow pilot plant was developed to operate under real sunlight. The system enabled the study of degradation kinetics as a function of solar irradiance, with the aim of predicting process performance under fluctuating conditions and mitigating the effects of intermittency and instability typical of renewable energy sources.

The results demonstrate that the combination of doping, catalyst immobilization, and process intensification strategies effectively addresses the traditional limitations of TiO₂, paving the way for the practical application of photocatalysis in wastewater treatment

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