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PHOTOCATALYTIC APPROACHES TO TREATING MIXTURES OF EMERGING ORGANIC POLLUTANTS IN AQUATIC ENVIRONMENTS

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Abstract

The presence of emerging pollutants (EPs) in aquatic environments has become an increasing global concern due to their persistence, bioactivity, and widespread occurrence in wastewater and natural water bodies. Unlike traditional pollutants, EPs such as pharmaceuticals, personal care products, pesticides, and endocrine-disrupting compounds often occur as complex mixtures, exhibiting variable degradation behaviors and potential synergistic or antagonistic effects. These mixtures pose unique challenges for conventional wastewater treatment plants (WWTPs), which are largely ineffective in eliminating trace-level organic contaminants. Photocatalysis, a prominent advanced oxidation process (AOP), offers significant promise for the effective degradation of EP mixtures through the generation of reactive oxygen species (ROS) under light irradiation.

This review provides a comprehensive analysis of the current state of knowledge on the photocatalytic degradation of EP mixtures, covering fundamental principles, photocatalyst development, reactor configurations, and kinetic modeling approaches. Special attention is given to the mechanisms of heterogeneous photocatalysis, recent advances in semiconductor-based materials (e.g., doped TiO₂, ZnO, heterojunctions, and carbon-based composites), and operational parameters influencing degradation performance. The review further examines critical challenges such as competitive adsorption, radical scavenging by matrix components, the formation of transformation products (TPs), and toxicity variation during treatment. Integration strategies that combine photocatalysis with other AOPs (e.g., ozonation, photo-Fenton, photoelectrocatalysis) or biological processes are discussed as effective means to improve efficiency, reduce energy consumption, and ensure complete mineralization. Real-world applications, including pilot-scale studies treating WWTP effluents, demonstrate the potential for practical deployment of photocatalytic systems, particularly in hybrid or modular configurations. Comparative trends and case studies are used to highlight performance benchmarks, material innovations, and implementation barriers.

Overall, the review underscores the relevance of photocatalysis in addressing the multifaceted challenge of EP mixtures in water. It concludes that continued advancements in photocatalyst engineering, reactor design, and integrated treatment strategies will be essential for transitioning from laboratory validation to full-scale, environmentally sustainable water treatment solutions.

Key words: biodegradability, emerging pollutants, photocatalysis, transformation products, wastewater treatment

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