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Comprehensive Review on Microbial Degradation of Dyes

Yash. S. Jadhav and Asst. Prof. Nabisa Tol
D. G. Tatkare Mahavidyalaya, Mangaon, Raigad, Maharashtra

Abstract: *The extensive use of synthetic dyes in industries such as textiles, paper, and leather has led to severe environmental pollution due to the release of toxic and non-biodegradable dye effluents. Conventional physico-chemical treatment methods, such as adsorption, coagulation, and chemical oxidation, are often inefficient, costly, and environmentally unsustainable. Microbial degradation has emerged as an eco-friendly and cost-effective alternative for dye removal, utilization of bacteria, fungi, and algae to break down the complex dye molecules into less toxic or non-toxic metabolites. Various microbial species, including Pseudomonas, Bacillus, Phanerochaete chrysosporium, and Aspergillus, produce enzymes such as laccases, peroxidases, and azoreductases that facilitate the degradation of different dye classes, including azo, anthraquinone, and triphenylmethane dyes. Factors such as pH, temperature, oxygen availability, and microbial adaptability influence the efficiency of dye biodegradation. Recent advancements in genetic engineering and microbial consortia optimization have further enhanced degradation rates and efficiency. Additionally, immobilization techniques and bioreactor-based systems offer promising solutions for large-scale applications. Despite its potential, challenges such as the toxicity of dye intermediates, microbial resistance, and the need for process optimization remain. Future research should focus on metabolic pathway elucidation, strain improvement, and the integration of microbial degradation with other treatment technologies to achieve complete mineralization of dyes. Overall, microbial degradation provides a sustainable and efficient approach to mitigating dye pollution, promoting environmental safety, and supporting circular bioeconomy initiatives.*

Keywords: environmental pollution, physico-chemical treatment, Bacteria & fungi, biodegradable, sustainable approach

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