EXTENDED ABSTRACT

Construction and Performance Assessment of the Integrated Treatment System for Effective Remediation of Complex Dyes from Wastewater

Department of Chemical Engineering & Technology,

Indian Institute of Technology (BHU) Varanasi

Supervisor

Prof. R. S. Singh

Submitted By

Himanshu Tiwari

18041002

Introduction

Textile industries generate large volumes of wastewater containing synthetic dyes, posing environmental and health risks. To address this, sustainable and efficient treatment methods are crucial. Microbial degradation-based biological treatment methods have emerged as promising alternatives. Packed bed bioreactors with bacterial consortia offer advantages such as enhanced degradation efficiency and continuous operation. This study focuses on the biodegradation of brilliant green dye using a bacterial consortium in a packed bed bioreactor, investigating varying organic loading rates and their impact on dye removal efficiency. Acid Blue 113, a recalcitrant dye of concern, requires advanced treatment strategies. Sequential photocatalytic oxidation and biodegradation, combining TiO_2 photocatalysis with *Klebsiella michiganensis*, provide a synergistic approach for complete dye removal. To enhance biodegradation efficiency, microbial cell entrapment techniques have gained attention. Graphene oxide-calcium alginate hydrogel beads were used to immobilize *Klebsiella grimontii* for Acid Blue 113 biodegradation. The immobilization ensures prolonged contact between the cells and the dye, and a fluidized bed bioreactor was employed for efficient mass transfer and improved contact. This study aims to explore the efficacy of biological treatment processes, hybrid techniques, and graphene oxide hydrogel-based approaches for dye removal from textile wastewater. The research aims to achieve efficient, cost-effective, and environmentally friendly solutions.

Materials and Methods

In this study, soil samples were collected from industrial sites of Ambey Processors, Gida, Sahjanwa (28°29'0.384" N, 77°30'29.2248" E) U.P, India, and acclimatized to various dye loadings to assess their potential for dye degradation. Bacterial species capable of degrading dyes were isolated and identified using 16S rRNA gene sequencing. To investigate the degradation of brilliant green dye, a packed bed bioreactor was employed, with the use of Mineral Salt Medium (MSM) as the growth medium. The extent of mineralization was quantified using several analytical techniques. Absorbance measurements were used to determine the dye concentration, while COD (Chemical Oxygen Demand), TOC (Total Organic Carbon), and TSS (Total Suspended Solids) analyses were performed to assess the degradation of the dye and the overall organic content in the system. Furthermore, the toxicity of the treated dye solution was evaluated using phytotoxicity assays and bacterial toxicity tests using *Pseudomonas fluorescens*, with bioluminescence intensity measurements as an indicator of toxicity. To understand the kinetics of the degradation process, Langmuir-Hinshelwood, Monod, and Andrew Haldane models were applied, providing insights into the reaction rates and substrate utilization efficiency.

Results and Discussion

The biodegradation of Brilliant green (BG) dye was performed in an indigenously designed recirculating packed bed bioreactor (RPBBR). Modified Polypropylene-Polyurethane foam (PP-PUF), a support packing material, was immobilized with a newly isolated bacterial consortium of *Enterobacter asburiae* strain SG43 (BGT1) and *Alcaligenes* sp. SY1 (BGT2). The bioreactor was operated under various organic loading rates (OLRs) of 2.7, 1.27, 0.93, 0.71, and 0.53 kg $COD/m^3 .d^{-1}$ with a hydraulic retention time (HRT) of 4 days. The bioreactor exhibited the maximum BG dye removal efficiency of 91%.

The performance of the integrated system (i.e., a Photocatalytic reactor followed by a Fixed bed bioreactor (PC-FBR)) for the degradation of complex Acid Blue 113 from wastewater. Initially, a Photocatalytic reactor was employed to improve the biodegradability index (i.e., BOD/COD) of wastewater from 0.21 ± 0.0062 to 0.395 ± 0.0058. The preliminary photocatalytic oxidation study revealed a maximum of 86.42 ± 0.33% dye removal at TiO_2 loading of 1.5 g/L and an initial concentration of 50 mg/L of AB 113. An integrated reactor system significantly achieved a maximum of 92 ± 2.6% of dye removal efficiency under a retention time of 120 hr. The stand-alone FBR dye shock loading study suggested that the reactor system was reasonably able to further restore its degradation efficiency.

The degradation of Acid Blue 113 (AB 113) dye was carried out using *Klebsiella grimontii* entrapped Graphene Oxide-Calcium Alginate Hydrogel beads (KG-GO-CA) in a Fluidized Bed Bioreactor (FBBR) under varying inlet loading rates. The minimum fluidization velocity of the KG-GO-CA hydrogel beads in FBBR was found to be 0.15 mm/s. The KG-GO-CA beads showed a maximum removal efficiency of 94.6% at an inlet flow rate of 20 mL/h over 15 days. Reusability studies indicated a removal efficiency of 70.6 ± 2.5% for AB 113 after the 12^{th} cycle. Langmuir adsorption isotherm showed the best fit (R^2 = 0.98724) with model parameters of Q_m (203.83 mg/g) and K_i (0.0101 L/g).

Conclusions

This study highlights the efficacy of biological treatment methods, hybrid techniques, and graphene oxide hydrogel-based approaches for efficient synthetic dye removal from textile wastewater. The use of bacterial consortia in packed bed bioreactors enhances degradation efficiency and adapts to varying organic loading rates. Sequential photocatalytic oxidation and biodegradation utilizing TiO_2 photocatalysis and specific bacterial species synergistically remove recalcitrant dyes like Acid Blue 113. Immobilizing bacteria within graphene oxide-calcium alginate hydrogel beads prolongs contact, improving degradation efficiency, while the fluidized bed bioreactor optimizes mass transfer and contact for enhanced dye removal. These findings contribute to sustainable and cost-effective textile wastewater treatment solutions, mitigating environmental and health risks associated with synthetic dyes. Future research should explore scalability and practical implementation on an industrial scale and investigate combined treatment methods for diverse dye types, paving the way for sustainable practices in the textile industry.

Publications

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