CHAPTER 6

Summary of the thesis and scope for future work

CHAPTER 6

Summary of the thesis and scope for future work

6.1 Summary of the work

In the present work, potential bacterial species were isolated from the textile effluent contaminated sites for the biodegradation of Brilliant Green and Acid Blue 113 dye. In first study, BGT1, BGT2, BGT3, BGT4, and BGT5 were isolated and among them BGT1 and BGT2 were found to be the potential bacterial species for the biodegradation of BG dye. The biodegradation of 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%. Proton Nuclear Magnetic Resonance (^{1}H NMR), UV-Vis spectroscopy, and Fourier Transform Infrared Spectroscopy (FTIR) depicted the biodegradation of BG dye. *Phaseolus mungo* seeds germinated in BG dye biodegraded wastewater was significantly high (83.56%) than the untreated wastewater (32.4%), which was reasonably subjected to the detoxification of treated wastewater.

In the next study, 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 was investigated. 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 87.56 ± 2.38 % removal at pH 3 for 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. Langmuir–Hinshelwood kinetic model, Monod model, and Andrew-Haldane model were fitted. Langmuir– Hinshelwood kinetic model was best fitted by the photocatalytic oxidation reaction system and the Langmuir reaction rate constant (k_c) and the combined adsorption equilibrium constant for the dye and its intermediates (K_c) were 3.6014 min^{-1} and 0.91452 L/mg, respectively. Monod model parameters μ_{max} and K_s were 0.123 day^{-1} and 44.5 mg/L, respectively, whereas under the substrate inhibition the Andrew-Haldane model parameters μ_{max}, K_s, and K_i were 0.176 day^{-1}, 48.5 mg/L, and 130 mg/L, respectively. The bacterial toxicity assessment was carried out using the *Pseudomonas fluorescens*.

Furthermore, the degradation of AB 113 dye was unveiled using novel developed *Klebsiella grimontii* entrapped Graphene Oxide-Calcium Alginate Hydrogel beads (KG-GO-CA). The hydrogel beads were prepared by adding GO and *Klebsiella grimontii* to microporous sodium alginate and cross-linked with $CaCl_2$. The structure, surface, and thermal characteristics of the GO-CA hydrogel beads were examined using FTIR, SEM, S_{BET}, and TGA. The performance of a Fluidized Bed Bioreactor (FBBR) filled with KG-GO-CA was investigated under varying inlet loading rates. The minimum fluidization velocity of the KG-GO-CA hydrogel beads within the FBBR was found to be 0.15 mm/s. FBBR exhibited a maximum removal efficiency of 94.6% with an inlet flow rate of 20 mL/h under 15 days. The reusability study indicated that the KG-GO-CA beads exhibited a removal efficiency of 70.6 ± 2.5% for AB 113 after the 12^{th} cycle. The experimental data were fitted to Langmuir and Freundlich adsorption isotherms. Langmuir 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). Furthermore, the residual toxicity of treated wastewater was carried out. The results confirmed that treated wastewater was more environmentally safe for domestic and commercial uses than untreated wastewater. The study provides insight into the potential use of KG-GO-CA hydrogel beads for the removal of dyes from wastewater.

6.2 Overall Conclusion of the Thesis

This study underscores the effectiveness of various biological treatment methods, hybrid techniques, and graphene oxide hydrogel-based approaches in the removal of synthetic dyes from textile wastewater. Bacterial consortia in packed bed bioreactors demonstrated enhanced degradation efficiency and adaptability to fluctuating organic loading rates. Furthermore, the investigation into sequential photocatalytic oxidation and biodegradation, leveraging TiO_2 photocatalysis and specific bacterial species, has proven successful in synergistically removing complex dyes like Acid Blue 113. The immobilization of bacteria within graphene oxide-calcium alginate hydrogel beads extended contact time, thereby improving degradation efficiency. Additionally, the utilization of a fluidized bed bioreactor optimized mass transfer and contact for heightened dye removal.

These findings represent a significant step towards sustainable and cost-effective solutions for treating textile wastewater, consequently mitigating environmental and health hazards associated with synthetic dyes. Looking ahead, future research endeavors should focus on exploring scalability and practical implementation on an industrial scale. Moreover, investigating combined treatment methods for diverse dye types will be crucial in paving the way for sustainable practices within the textile industry.

This study provides valuable insights and methodologies that contribute to the ongoing efforts towards sustainable textile wastewater treatment. By continuing to innovate and collaborate, effective solutions can be developed to address the challenges posed by synthetic dyes, ultimately promoting environmental stewardship and safeguarding public health.

6.3 Scope for further work

While this study has made significant strides in revolutionizing textile wastewater treatment, several avenues for future research remain unexplored. The scalability of the developed techniques is an essential consideration. The transition from lab-scale to pilot-scale or industrial-scale applications is essential to validate the feasibility and practicality of the developed techniques. This involves designing and testing larger reactors while ensuring consistent performance and cost-effectiveness. Collaboration with industries will be crucial to ensure real-world applicability and integration. Exploring the potential synergy between AOPs and biological treatment methods can achieve new dimensions in organic pollutant degradation. Integrating AOPs with microbial cell entrapment techniques or other biological processes could lead to synergistic effects, enhancing overall treatment efficiency. Further exploration of novel hybrid materials, such as Graphene-based nanocomposites, could yield advanced sorbents and catalysts with enhanced dye removal and degradation capabilities. Incorporating Internet of Things (IoT) technologies and automation could enhance process control, monitoring, and efficiency. Real-time data collection and analysis, coupled with automated adjustments, can optimize resource utilization, reduce energy consumption, and minimize human intervention.