A Sustainable Nanomaterial Synthesis Approach for Application in Dye Degradation and Bacterial Growth Inhibition

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DOCTOR OF PHILOSOPHY

by

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Chapter 6

Summary, Conclusions, and Scope for Future Work

This chapter aimed to summarize the results of the previously presented studies on the sustainable production of TiO_2 NPs, G-rGO nano-adsorbent, and hydrochar using plant extracts and waste. Applied them for the removal or reduction of concentrations of dyes from textile effluent and also tested bacterial growth inhibition against several bacteria. A summary of the thesis and an overview of the scope of future work comprise the two sections of this chapter.

6.1 Summary of the Thesis

The research work presented in this thesis has concentrated on the sustainable production of photocatalyst nanoparticles and nano adsorbents for the degradation and removal of dyes from textile effluents by using photocatalysis and adsorption methods and also use them to study the bacterial growth inhibition activity of these plant-mediated nanomaterials. In this thesis, green synthesis of TiO_2 NPs, green reduction of graphene oxide (GO), and sustainable production of hydrochar have been done successfully. These synthesized nanomaterials were applied for the removal of Acid Blue 113 (anionic) and Methylene Blue (catatonic) dye from textile effluent and also tested for bacterial growth inhibition against *S. aureus* and *E. coli*. The results obtained through various experiments were analyzed and discussed and are presented in Chapters 3, 4, and 5 of this thesis.

6.2 Conclusions

In conclusion, this thesis successfully demonstrates the innovative potential of green synthesis methods for the production of TiO_2 nanoparticles (NPs), reduced graphene oxide (G-rGO), and hydrochar for wastewater treatment applications.

- The enhanced photocatalytic and antibacterial properties of green-synthesized TiO_2 NPs using *Tinospora cordifolia* extract, achieving a 94.43% removal efficiency of Acid Blue 113 dye and demonstrating an average crystalline size of 15.02 nm with an irregular shape and band gap of 3.13 eV, lower than commercially available TiO_2. A maximum of 26.5 ± 0.79 mm diameter zone of inhibition region was exhibited by the TiO_2 NPs at a concentration of 500 µg/mL against *E. coli* bacteria.
- The successful green synthesis of G-rGO using the *Tinospora cordifolia* plant stem extract as a reducing and capping agent, which exhibited a 94.85% methylene blue (MB) dye removal efficiency, with an adsorption capacity of 58.81 mg/g, and

significant antibacterial activity against *S. aureus* and *E. coli*, making it a sustainable approach for nanomaterial synthesis.

- Hydrochar produced from the first-ever HTC of sunflower stalk exhibited superior performance compared to biomass (BM) in treating synthetic wastewater containing methylene blue (MB) dye. HC demonstrated a higher pore volume, surface area, and surface complexation, making it more efficient in dye adsorption. At optimal conditions, HC achieved a maximum MB dye removal efficiency of 98.96%, higher than BM's 96.95%, and adsorption capacity of 49.37 mg/g, higher than BM's 24.24 mg/g. The adsorption process was spontaneous and exothermic demonstrating favorable adsorption kinetics and thermodynamics.

Collectively, these findings underscore the efficacy of green and sustainable synthesis methods for developing multifunctional nanomaterials and adsorbents for environmental remediation, promoting eco-friendly alternatives for industrial wastewater treatment.

6.3 Scope for Future Work

- Anatase TiO_2 suffers activity reduction after successive uses, so rigorous attention should be needed to maintain its catalytic activity and incorporate it into large-scale dye wastewater treatment.
- Designing and implementing a continuous photocatalytic reactor would enable the efficient treatment of large volumes of textile effluent.
- Critical attention should be carried out towards the complete use of biomass of plant extract as per the circular economy principles.
- Seek other vital plant extracts as a reducing agent that merely enhances the reduction of Graphene Oxide to Graphene at a reasonably low cost and can be implemented at an industrial scale.