Summary of the thesis and scope for future work

7.1 Summary

In the present work, soil samples were collected from the dye-contaminated site close to textile industries, Bhadohi, India (25.3805° N, 82.5677° E) to isolate the potential dye-degrading bacterial species. The most suitable bacteria were isolated by serial dilution and plating methods. The strain was identified as *Bacillus licheniformis* and sequencing was then submitted to the Gen Bank database of NCBI and from there we got an accession number (MZ220456). Process parameters such as; pH, dye concentration, inoculum dose, and temperature were optimized using RSM and ANN approaches. From the experimental and predicted data, it was observed that the response predicted by the ANN model was highly significant and a high correlation coefficient (0.999) indicates the effectiveness of the ANN model. For the biodegradation study, PBBR was utilized which is made of borosilicate glass (height = 100 cm; diameter = 5 cm) having a total capacity of 1.9 L. Polyurethane foam (PUF)/LDPE was used as packing material to immobilize the microorganisms.

The biodegradation study shows 91% removal efficiency of BG dye in immobilized PBBR. Kinetic analysis shows Andrew – Haldane model could be best fit in case of substrate inhibition. The toxicity assessment shows the content of chlorophyll (a, b) was notably reduced in the untreated sample. SOD activity was noticeably elevated for untreated samples, demonstrating the significance of these enzymes in plant tolerance to dye contamination. The biologically treated sample showed less toxicity toward *P. luminescence* bacteria in comparison to the untreated sample.

Next study was focused on the mass transfer assessment for the biodegradation of BG dye in PBBR. A new correlation $J_D = 5.71\, {N_{Re}}^{-0.3}$ was proposed which successfully predicts the experimental data for the biodegradation of BG dye. This correlation can be beneficial for the scale-up and designing of PBBR for dye degradation. A degradation pathway was proposed based on GC – MS analysis of the degraded sample.

The final study was focused on integration of ozonation with biodegradation for the complete mineralization of CR dye. Several studies have shown the existence of non–biodegradable or low-biodegradable compounds in textile effluent. The existence of these non–biodegradable compounds cause a lower biodegradability index ($BOD_5 : \mathrm{COD} < 0.2$) and makes biological treatment ineffective for the majority of industrial wastewater, including textile industry. The biological methods are typically effective for wastewater having $BOD_5 : \mathrm{COD}$ ratios greater than 0.4. In this context, new technologies for the treatment of textile wastewater have been developed. Among all these existing advanced treatment processes, ozonation is preferred as a viable alternative for textile wastewater treatment owing to its high selectivity towards the chromophoric group of an azo dye, less sludge formation, and adaptability across a wide pH range.

The results show that 25 min of ozonation resulted in 94% of color removal and 40% of COD removal. However, the toxicity of the sample was increased after the ozonation, which was further reduced by biodegradation. Therefore, a combination AOPs with biological processes has better potential for the decolorization and complete mineralization of textile wastewater.

7.2 Scope for future work and engineering significance

Future work may focus on scaling-up these bioreactors from lab-scale to industry-scale. Process parameters can be optimized using a combination of ANN and genetic algorithms. A genetically modified enzyme could be used for a better biodegradation rate. Bioreactors are the heart of any biological processes; we can use chemically modified bio-carrier to improve its efficiency. The hybrid treatment is a proven approach for complete mineralization of textile dyes, we can use metallic catalyst that can improve the overall efficiency of the process. A complete life-cycle assessment should be performed for these hybrid treatments.

The hybrid treatment system, which combines ozonation with biodegradation for wastewater treatment, is of great engineering importance. Ozonation contributes by efficiently oxidizing and breaking down organic and persistent contaminants, hence increasing wastewater biodegradability. This pre-treatment procedure allows future biodegradation by microorganisms, which leads to additional pollutant breakdown. The synergistic combination of ozonation and biodegradation not only enhances overall treatment effectiveness, but also enables the removal of a broader range of pollutants. Integrating ozonation and biodegradation allows for the optimization of energy usage. Furthermore, this hybrid technique addresses issues such as recalcitrant chemicals and resistant microbes, making it a promising alternative for sustainable and thorough wastewater treatment with potential applications in many industrial and municipal contexts.