



Chapter 7: Summary and Future Work



7.1. Summary of thesis

The present work isolated various potential microbial species from activated sludge procured from IOCL Mathura Refinery, Mathura (UP), for biodegradation of *p*-cresol. The isolated microbial species were identified as *Serratia marcescens* HL 1, *Ochrobactrum intermedium* and *Ochrobactrum intermedium* VrB9 using the 16S rRNA DNA sequencing method. The batch experiment was performed for biodegradation of *p*-cresol from synthetic wastewater using an isolated gram-negative bacterial strain (i.e., *Serratia marcescens* strain HL 1 (EU371058)). Biodegradation rates affecting parameters such as pH, *p*-cresol concentration, and retention time were optimized using response surface methodology (RSM). The maximum degradation (86.32 %) of *p*-cresol was obtained at an initial concentration of 60 mg L⁻¹, pH of 7.5, and retention time of 48 h. Based on the Haldane model, the maximum specific growth μ_{max} of the cell was 0.2 h⁻¹, and the inhibition constant K_I of the substrate was 76 mg L⁻¹. FTIR was used to identify the available functional group in biodegraded *p*-cresol solution. FTIR spectrum of biodegraded *p*-cresol confirms the various functional groups are present in the solution, such as the O-H group of the *p*-cresol, hydroxyls or carboxyl, carbonyl group (C=O) carboxylic and ester group and C-O-C functional group. C-H group availability confirms symmetric and asymmetric deformations in methyl and phenolic alcohol. Phytotoxicity and Chlorophyll assessment of *Vigna radiata* seeds and leaves ensure that degraded products can be used for irrigation purposes.

In the next study, an effort was made to treat the *p*-cresol from synthetic wastewater using immobilized bacterial consortium (*Serratia marcescens* HL 1 and *Ochrobactrum intermedium*) on packing material (PUF) in Recirculating Packed Bed Biofilm Reactor (RPBBR). The effect of process parameters, namely inoculum dose, pH, and NaCl (w/v) concentration, on specific growth was analyzed and obtained to be 14 mL, 7.0, and 1% NaCl (w/100 mL), respectively, for maximum specific growth (experimental) (0.20±0.0032 h⁻¹). After optimizing the various parameters, a comparative study has been done for batch and continuous mode operation of RPBBR. The maximum *p*-cresol removal efficiency was 99.36±0.2% in continuous mode operation at 100 mg L⁻¹ concentration. The first-order rate constants were found to be 0.70 day⁻¹ and 0.96 day⁻¹ for batch and continuous mode, respectively. The intermediates were analysed using FT-IR and GC-MS analysis. The intermediates, maleic acid, glycerol, and 4-methyl catechol, were found during *p*-cresol biodegradation. *Pseudomonas fluorescens* was used

to assess the bacterial toxicity of the biodegraded product, and it was observed that the toxicity was reduced in continuous mode operation, which is better than batch mode operation.

In further study, an effort has been made to degrade the high concentration of *p*-cresol from wastewater through integrating photocatalysis and biodegradation, which has shown great potential in wastewater treatment technology. Focusing this idea in mind, a photocatalytic and packed bed bioreactor was integrated. In the initial experimental operation, the biodegradability index (BOD_5/COD , BOD_5/TOC) of high concentrations of *p*-cresol (700 mg L^{-1}) was improved from 0.098 ± 0.023 to 0.59 ± 0.089 for BOD_5/COD and from 0.27 ± 0.030 to 1.74 ± 0.03 for BOD_5/TOC in the photocatalytic reactor at optimized conditions (pH, catalytic dose and irradiation time). It was observed that photocatalysis of *p*-cresol followed the pseudo-first-order kinetics with rate constant (k_{ap}) 0.011 min^{-1} . The % removal of the integrated system was found to be $98.43 \pm 1.31\%$ at an initial concentration of 700 mg L^{-1} and residence time of 120 h, which was significantly higher than the PBBR operated alone ($34.82 \pm 2.62\%$) under optimized conditions (pH 7.0 and $T = 32 \pm 2 \text{ }^\circ\text{C}$). Further, another study was done to remove *p*-cresol and methylene blue dye simultaneously using the Upward-Flow Packed Bed Biofilm Reactor (UFPBBR).

Maximum specific growth for *p*-cresol (100 mg L^{-1}) and methylene blue dye (MBD) (50 mg L^{-1}) was found to be $0.21 \pm 0.0083 \text{ h}^{-1}$ and $0.05 \pm 0.0028 \text{ h}^{-1}$, respectively. Three independent parameters, such as contact time, pH, and effect of sodium acetate (g/100 mL), were optimized. The maximum removal of *p*-cresol, MBD, and Total organic carbon (TOC) was found to be $91.69 \pm 2.13\%$, $95 \pm 1.58\%$, and $82.28 \pm 1.24\%$, respectively. The biodegradation rates were analyzed using various kinetic models. After optimizing process parameters, the performance of UFPBBR was evaluated based on % removal efficiency (RE), elimination capacity of pollutant (EC_p), and inlet loading rate of pollutant (ILR_p) by varying the inlet flow rate from 10 to 50 mL min^{-1} . The maximum % RE and EC_p were found to be 97.23 %, $1400.112 \text{ mg L}^{-1} \text{ day}^{-1}$ for *p*-cresol and 98.41%, $687.61 \text{ mg L}^{-1} \text{ day}^{-1}$ for MBD, respectively. First-order kinetic followed for *p*-cresol and MBD degradation with a rate constant of 0.55 day^{-1} and 0.50 day^{-1} , respectively. Phytotoxicity and bacterial toxicity assessments were evaluated to explore the possibility of treated wastewater in green belt development and other applications.

7.2. Scope for future work

Biological methods are preferred due to the relatively lower processing cost and the capability of complete mineralization of various types of pollutants. However, conventional biological process is not suitable when wastewater has a low biodegradability index ($BOD_5/COD < 0.2$). In this case, integrated or combined processes (AOPs with biodegradation) may provide better solution. The integrated processes are costly require more technical information, and regular monitoring of biodegradability parameters. Therefore, the future outlook may focus on determining the intermediates, byproducts, mass transfer aspects, and scaling the integrated treatment system with real industrial wastewater. In addition, further study may be explored to employ the treated wastewater irrigation of energy crops.

