CHAPTER 9

SUMMARY AND CONCLUSION

9.1 SUMMARY

Biological phenol degradation was performed experimentally in a gas-liquid-solid inverse fluidized bed biofilm bioreactor (IFBBR) using \textit{P. fluorescens}. IFBBR was developed with draft tube arrangement to achieve simple and efficient control of biofilm growth. The feasibility and performance of three-phase IFBBR for biodegradation of synthetic wastewater containing phenol (substrate) was investigated. The studies revealed the biofilm and biomass characteristics of \textit{P. fluorescens} for different initial concentration of phenol. Biodegradation kinetic studies for the suspended biomass and biofilm culture were analyzed with respect to its specific growth rate and specific phenol consumption rate.

The work was extended to study the hydrodynamic characteristic performance of IFBBR for biodegrading higher concentration of phenol. The study revealed the hydrodynamic aspects of IFBBR such as flow regimes, aspect ratio, bed height, phase holdup for different superficial air velocity by varying the ratios of settled bed height volume to reactor volume. The optimum superficial air velocity and settled bed volume to reactor volume was determined for efficient biodegradation of phenol from the reduction in COD. The influence of hydrodynamics on biofilm characteristics for phenol degradation was determined using optimized hydrodynamic operating parameters with support particles of various sizes. The effect of
hydrodynamic detachment force on the structure and behavior of biofilm in degrading phenol was studied, and discussed how biofilm respond to detachment force under hydrodynamic conditions in three phase IFBBR. Finally, the support particle size was optimized for better hydrodynamic effects.

The gas-liquid and liquid-solid mass transfer characteristics in three phase IFBBR was studied for various particle sizes at different superficial air velocity. The gas-liquid mass transfer studies revealed the effect of hydrodynamic parameters such as superficial velocity of the air and gas holdup on volumetric mass transfer coefficient, $k_{l,a}$. The liquid – solid mass transfer studies explained the mass transfer diffusion effects in biofilm system by determining the effectiveness factor and, the effect of particle properties, biofilm characteristics on liquid-solid mass transfer coefficient.

Finally, the performance of IFBBR in treating industrial effluent from leather and tannery under the optimized hydrodynamic and mass transfer conditions of synthetic phenolic effluent was studied. The industrial effluent was characterized for its physio – chemical properties before and after treatment process. The performance of IFBBR in treating organic and inorganic contaminants along with other heavy metals was investigated. The biodegradation mechanism of phenol was studied by identifying the formation of intermediates during the degradation process. The degradation effects of phenol and other heavy metals on *P. fluorescens* were studied by the cell cytological and morphological changes such as cell wall disruption, cell size elongation, swelling of the cell, extracellular secretion in the microbial cells before and after degradation.

The conclusions obtained from the foregoing studies are given elaborately in the subsequent section.
9.2 CONCLUSION

The bioremediation potential of an indigenous *P. fluorescens* was investigated in IFBBR using synthetic phenol of various concentration (400, 600, 800, 1000, 1200 mg/L) as a model limiting substrate. Biofilm performance and characteristics including biofilm dry density and thickness, bioparticle density, suspended and attached biomass concentration and COD and phenol removal rate were evaluated. Kinetic analysis of phenol degradation with respect to specific growth rate and specific phenol consumption rate showed that suspended biomass undergone substrate inhibition effect, whereas the biofilm coated onto support particles tolerated the higher concentration levels. The substrate inhibition Haldane model and non-inhibition Monod model fitted well with experimental data for suspended biomass and biofilm systems respectively.

Hydrodynamic characteristic performance of three phase inverse fluidized bed biofilm reactor revealed that COD removal was found to be increasing with increase in $U_g$ and $(V_b/V_r)$ attaining higher removal efficiency at $U_{gm}$ and $(V_b/V_r)_m$, and decreases with further increase in $U_g$ and $(V_b/V_r)$. The largest COD removal from 2830 mg/L to 42 mg/L (98.5% COD reduction) was achieved when the reactor was operated at the ratio $(V_b/V_r)_m$ of 0.20 with superficial air velocity, $U_{gm}$ of 0.220 m/s for the particle size of 3.5 mm in 48 hours. Thus, the ratio $(V_b/V_r)_m$ and $U_{gm}$ were found to be the optimal operating parameters of IFBBR. The hydrodynamic shear effects on biofilm performance for various particle sizes (2.9, 3.5 and 3.8 mm) of different superficial air velocity under optimized fixed bed height condition $(V_b/V_r = 0.20)$ were analyzed. By varying the diameter of the support particles and the corresponding superficial air velocity, the optimum $U_g$ for 2.9, 3.5 and 3.8 mm of particle size were found to be 0.240, 0.220 and 0.230 m/s respectively for effective degradation of phenol. Complete degradation of
phenol was achieved in 32, 48 and 52 hours for 2.9, 3.5 and 3.8 mm diameter support particles respectively. Thus the optimum particle size was found to be 3.5 mm operated with low superficial air velocity resulting in better biofilm performance for effective degradation of phenolic effluent.

The gas – liquid mass transfer studies revealed that $k_L a$ increased with particle size and then decreased. $k_L a$ was found to be high ($k_L a = 1.8823$) for the particle size of 3.5 mm for the superficial air velocity $U_g$ of 0.220 m/s. Higher volumetric mass transfer coefficient and oxygen transfer rate resulted in higher percentage of COD removal and phenol degradation in IFBBR. Thus the largest COD removal of 98.5% and phenol degradation of 100% was attained for the particle size of 3.5 mm.

From the liquid – solid mass transfer studies in IFBBR, it was found that smaller size particle had less biofilm thickness but had dense biofilm, which decreased the diffusivity ($D_e$) of phenol into the biofilm. Thus the smaller bead size had less effectiveness factor $\eta$, implying that there was more diffusion limitation. The values of $\eta$ were found to be 0.052, 0.507 and 0.882 for the particle size of 2.9, 3.5 and 3.8 mm respectively. For the particle size of 3.5 and 3.8 mm, the $\eta$ values were not much smaller than one, hence the degradation was combined diffusion and reaction limited rather than diffusion limited alone. The results revealed that the liquid-solid mass transfer coefficient $k_S$ decreased with particle size and it depended mainly on the surface area of the bioparticle in IFBBR. Smaller the size of the particle, the total surface area of the bioparticle was found to be high which increased the average liquid – solid mass transfer coefficient.

Under the optimized hydrodynamic and mass transfer conditions of the synthetic phenolic effluent, the industrial leather and tannery effluent were treated in IFBBR. The results revealed that 89% and 91% of phenol was
degraded in 54 hours of operation respectively. AAS analysis of the effluent showed the ability of *P. fluorescens* to degrade inorganics such as chromium, iron, zinc and manganese in IFBBR.

Thus, in the present study, the biodegradation of synthetic phenolic effluent was carried out in inverse fluidized bed biofilm reactor (IFBBR) using *P. fluorescens* and investigated the performance of IFBBR. The biodegradation kinetics studies were performed for the suspended biomass and biofilm system separately with respect to specific growth and substrate consumption rate which were not discussed combined in any other literature studies. The results proved that the biofilm system had overcome the substrate inhibition effect of phenol at higher substrate concentration. The hydrodynamic and mass transfer (gas-liquid and liquid-solid) characteristics of IFBBR for the biodegradation of phenol were optimized for the synthetic effluent. The optimized parameters were used to treat industrial leather and tannery effluent in IFBBR, which showed better performance in treating organic and inorganic contaminants along with heavy metals.

9.3 **SCOPE FOR FUTURE WORK**

Future scope of the present work is emphasized on the following aspects

- To develop and study a mathematical model of inverse fluidized bed biofilm reactor (IFBBR) with suspended biomass growth in wastewater treatment
- To investigate a biofilm model describing the contribution of biofilm to the IFBBR performance
- To develop a model which can predict the hydrodynamic behavior of gas-liquid-solid IFBBR with particles of different sizes
- To study the substrate utilization and mass transfer diffusion effects in biofilm system by numerical simulation