Chapter 5

SUMMARY AND CONCLUSIONS

The present study involves the sequestering of heavy metals viz; Cr (VI), Ni (II), Cd (II) and Pb (II) from simulated as well as industrial effluents with potential leguminocellulosic agricultural waste biomass such as *Arachis hypogea* shells (AHS), *Acacia saligna* pods (ASP) and *Delbergia sisso* pods (DSP). Selected biosorbents were used in three forms viz; natural (ASP, DSP and AHS), immobilized (CAM-ASPCB, CAM-DSPCB and CAM-AHSCB) and carbonized (ASPC, DSPC and AHSC). The characterization of biosorbents was carried out by FT-IR, SEM and XRD studies. An attempt was made to establish the plausible mechanism involved in biosorption process on the basis of participation of the various functional groups in the metal binding process and surface or structural aspects of biosorbents.

Further studies were carried out for removal of metals such as Ni (II), Cd (II), Cr (VI) and Pb (II) in batch and fixed bed column mode. The various process parameters such as pH, adsorbent dose, initial metal ion concentration, stirring speed and contact time were considered for batch studies. Hydraulic dynamics affecting fixed bed column studies were initial metal ion concentration, bed height and flow rate. Removal efficiency, adsorption capacity, regeneration efficiency and breakthrough time were calculated to explore the complete exhaustion time and reusability of the biosorbents to investigate practical utilization at industrial scale. The industrial effluents were characterized for BOD, COD, and turbidity along with concentration of various heavy metals such as Ni (II), Cr (VI), Cd (II), Zn (II) and Pb (II).
The highlights of the present investigations are

- The leguminocellulosic waste biomass viz; *Arachis hypogea* shells (AHS), *Acacia saligna* pods (ASP) and *Delbergia sisso* pods (DSP) were selected on the basis of availability, cost and physico-chemical characterization.

- FT-IR studies indicates the presence of functional groups such as –OH, OCH₃, C=O etc. which can effectively bind the metal ions. Toxic metals Cr (VI), Cd (II), Pb (II) and Ni (II) binding with the functional groups of biosorbents is evident from shifts in the peaks assigned to these groups after adsorption of metal ions.

- Batch experiments with simulated solutions of the selected heavy metals were carried out to find the maximum removal efficiency of the biosorbents taking into account various parameters affecting the adsorption process such as variation in pH, adsorbent dose, initial metal ion concentration, contact time and stirring speed.

- The order of removal efficiency of *Arachis hypogea* shells for selected metal ions was Cr (VI) > Cd (II) > Pb (II) > Ni (II) with percentage removal of 95% > 95% > 84% > 63% respectively. Further increase in removal efficiency has been observed using carbonized and immobilized form of *Arachis hypogea*. The enhanced removal efficiency by a carbonized form of biosorbent is due to lowering of the size of the biosorbent particles to nano-scale (5-7nm) thus leading to availability of large surface area for binding of metal ion. Similarly, increased adsorption efficiency by immobilized biosorbents may be due to uniform distribution of binding sites on surface of beads and reduced rate of desorption of metal ions back to solution.

- The removal efficiency of *Acacia saligna* pods for heavy metal ions was found in order of Ni (II) > Cr (VI) > Cd (II) > Pb (II) with percentage removal efficiency of 93% > 92% > 82% > 70% respectively. Higher removal efficiency was observed by immobilized and carbonized forms.
• *Delbergia sisso* pods in natural form showed removal efficiency in the order of Cr (VI) > Pb (II) > Cd (II) > Ni (II) with percentage removal of 92%, 78%, 76% and 75% respectively. A significant increase was seen by immobilized and carbonized forms.

• The optimized pH value of 6 for Ni (II), Cd (II) and Pb (II) was observed and the pH value of 2 in case of Cr (VI) at an adsorbent dose (1.5 g/100 ml), stirring speed (250 rpm) and contact time (60 min) in natural and immobilized forms. However highest efficiency has been achieved under mild operating conditions; biosorbent dose (0.5 g /100 ml), stirring speed (150 rpm) in case of carbonized form.

• The Good fit of the Freundlich adsorption model was observed with high $K_0$ values and $n$ values supporting the physical adsorption as a part of the biosorption process. Further intra particle diffusion studies supported the probability of pore diffusion.

• Fixed bed column studies with an immobilized form of biosorbents were carried out to demonstrate the potential of biosorbents at industrial scale for practical suitability. Optimized conditions such as bed height (17 cm), flow rate (1.5 ml/min) and initial metal ion concentration (50 mg/l) showed remarkable removal efficiency in terms of high breakthrough time (680 min) and breakthrough adsorption capacity (15.75 mg/g) for the sequestering of selected heavy metal ions.

• Achievement of several (7-10) consecutive sorption desorption cycles for selected metal ions reveals the reusability of the biosorbents at a large scale thus making the process economically viable.

• Further fixed bed column studies with real industrial effluents containing heavy metal ions showed significantly high removal potential, demonstrated the potential of biosorption using leguminocellulosic waste biomass as environmentally sustainable, economically feasible and technically strong technology as a green approach.
The present study will be helpful to further explore scientifically acceptable and technically viable platform to develop and design systems where the leguminocellulosic waste biomass can be utilized and explored for treatment of industrial wastes at a large scale. Further research is to be carried out in the direction of modeling and making the process economically viable. Futuristic approach of study may be directed towards developing hybrid systems involving biosorption with the conventional technique to achieve remediation of environment from the heavy metal load.