Chapter 6

Summary and Conclusion

6.1 SUMMARY

Reduction of Cr(VI) by indigenous bacteria

- The indigenous bacteria (*B. subtilis* VITSUKMW1, *A. junii* VITSUKMW2, and *E.coli* VITSUKMW3) isolated from Sukinda chromite mine water were tolerant to a maximum of 1000 mg/l of Cr(VI).

- On sequential adaptation of the indigenous bacterial isolates to 100 mg/l of Cr(VI), a higher specific growth rate, reduction rate, and reduction capacity were achieved compared to the unadapted ones.

- The formation of binary consortium followed by the tertiary consortium using adapted *B. subtilis* VITSUKMW1, *A. junii* VITSUKMW2, and *E.coli* VITSUKMW3 demonstrated enhanced specific growth rate, reduction rate, and reduction capacity compared to the individual adapted isolates.

- SEM-EDX and FT-IR explained the interaction of Cr(VI) with the bacterial cells and possible changes in the surface functional groups of bacteria which facilitated the reduction of Cr(VI) to Cr(III) in the solution.

Adsorptive removal of Cr(VI) by indigenous bacterial isolates

- The adapted bacterial consortium (*B subtilis* VITSUKMW1, *A junii* VITSUKMW2, *E coli* VITSUKMW3) were immobilized in alginate beads.

- Upon immobilization, the adsorption capacity of the adapted bacterial consortium increased from 46.3 to 65.86 mg/g in batch reactor under optimized condition.

- The batch sorption data of immobilized bacterial consortium followed the Langmuir isotherm model, which suggested that a monolayer of sorption was highly probable.

- Pseudo second order kinetics was the best fit for immobilized adapted bacterial consortium.
• The thermodynamics data for the immobilized bacterial consortium in batch reactor suggested that the sorption process was spontaneous, and endothermic in nature.

• The adsorption of Cr(VI) onto immobilized bacterial consortium was non-competitive in the presence of Cr(III) in the concentration range of 5-100 mg/l.

• In the continuous flow reactor, the immobilized bacterial consortium removed Cr(VI) at a maximum sorption capacity of 657 mg/g, when an adsorbent dosage of 1 g/L, a flow rate of 5 ml/min, a bed height of 20 cm, an initial Cr(VI) concentration of 300 mg/L was employed.

• The breakthrough curves for the adsorption of Cr(VI) in the continuous flow reactor can be predicted by Thomas and Yoon-Nelson model.

• The adsorptive removal of Cr(VI) by immobilized bacterial consortium from Cr(VI) spiked environmental water matrices suggested efficient application of the same.

• Five subsequent cycles of alternating sorption/desorption studies yielded a decrease in the sorption capacity (100, 99.63, 95.31, 80.7 and 74.22%) with increase in sorption cycles.

• BET analysis of the immobilized bacterial consortium showed a decrease in the pore size and surface area after adsorption of Cr(VI).

• Scanning electron micrographs displayed the changes on the surface of the sorbent after the adsorption of Cr(VI) on immobilized bacterial consortium.

• Cr(VI) sorption on immobilized bacterial consortium was confirmed with Energy dispersive X-ray spectroscopy.

**Adsorptive removal of Cr(VI) by freshwater algal isolates**

• The process (isolate → adaptation → consortium → immobilization) developed for enhanced adsorption of Cr(VI) in the above study was evaluated using fresh water algal isolates (*Oocystis* sp., *Nostoc* sp., *Synechococcus* sp. and *Desimococcus* sp.).

• Upon immobilization, the adsorption capacity of the adapted algal consortium increased from 49.23 to 83.53 mg/g in batch reactor under optimized condition.
The batch sorption data of immobilized algal consortium followed the Langmuir isotherm model, which suggested that a monolayer of sorption was highly probable.

The Cr(VI) sorption kinetics of the immobilized algal consortium followed Pseudo first order rate equation, which indicated that, in the presence of excess Cr(VI) ions, the rate of sorption was highly dependent on the biosorbent capacity which is related to the number of available sites for binding.

The thermodynamics data for the immobilized algal consortium in batch reactor suggested that the sorption process was spontaneous.

In the continuous flow reactor, the immobilized algal consortium removed Cr(VI) at a maximum sorption capacity of 579.2 mg/g, when an adsorbent dosage of 1 g/L, a flow rate of 3 ml/min, a bed height of 20 cm, an initial Cr(VI) concentration of 300 mg/L was employed.

The breakthrough curves for the adsorption of Cr(VI) in the continuous flow reactor can be predicted by Thomas and Yoon-Nelson model.

The adsorptive removal of Cr(VI) by immobilized algal consortium from Cr(VI) spiked environmental water matrices suggested wide spectrum of application.

Four subsequent cycles of alternating sorption/desorption studies yielded a decrease in the sorption capacity (100, 99.51, 85.42 and 83.7 %) with increase in sorption cycles.

BET analysis of the immobilized algal consortium showed a decrease in the pore size and surface area after adsorption of Cr(VI).

Scanning electron micrographs displayed the changes on the surface of the sorbent after the adsorption of Cr(VI) on immobilized algal consortium.

Cr(VI) sorption on immobilized algal consortium was confirmed with Energy dispersive X-ray spectroscopy.

**Fate of bio-sorbed Cr(VI)**

After equilibrium sorption, 48.8% of adsorbed Cr(VI) was reduced by immobilized bacterial consortium, whereas, 55.6% of adsorbed Cr(VI) was reduced to Cr(III) by immobilized algal consortium as the interaction time was extended to 192 h.
• Speciation of Cr released into the solution from the Cr(VI) loaded sorbents (immobilized bacterial and algal consortium) confirmed that only the adsorbed Cr(VI) were reduced and not the un-adsorbed Cr(VI) present in the solution.

• The kinetic modeling of Cr(VI) biosorption and bio-reduction suggested that the removal of Cr(VI) was facilitated by adsorption followed by reduction in the case of both bacterial and algal consortium immobilized alginate beads.

• The FT-IR spectrum of immobilized bacterial and algal consortium loaded with Cr(VI) provided an insight into the possible mechanism of Cr(VI) removal (biosorption coupled bio-reduction).
6.2 CONCLUSION

The heavy metal tolerance, and the reduction capacity of indigenous isolates, *B. subtilis* VITSUKMW1, *A. junii* VITSUKMW2 and *E. coli* VITSUKMW3 from the Sukinda mine water were directly proportional to the initial Cr(VI) concentration, suggesting that, they had an inherent capacity to reduce Cr(VI). The native bio-reduction capability of the three indigenous isolates was considerably enhanced by adaptation and by developing consortia from the adapted isolates. The adsorption capacity of the adapted mine water bacterial isolates increased on consortium development and immobilization on alginate beads. The enhancement in Cr(VI) adsorption capacity of adapted consortium on immobilization was evaluated using freshwater algae. The advantages of enhanced bio-sorption capacity, with high regeneration potential, can be effectively exploited for scaling up of large scale reactors for applications in contaminated sites. The possible mechanism of adsorption coupled with reduction was well understood by SEM-EDX, FT-IR and EPR analysis. The reduction potential of bio-sorbed Cr(VI) by adapted bacterial and algal consortium immobilized in alginate beads suggests a adsorption coupled reduction strategy for the removal of Cr(VI).

6.3 RECOMMENDATIONS

The findings clearly project that adaptation and consortium development enhance the reduction capacity in indigenous bacterial consortium. Hence, the indigenous microbes in contaminated areas can be used for the efficient removal of contaminants through adaptation and consortium development. The increased Cr(VI) adsorption capacity and regeneration efficiency on immobilization of adapted microbial consortium compared to the free cells, suggests that immobilization can be used as an effective process to enhance the removal of Cr(VI) and increased usage of the bio-sorbent. Also, further scale up of the process would enhance the Cr(VI) removal potential of the microbes. The removal was efficient in different natural water matrices. However, the complete reduction of adsorbed Cr(VI) could not be facilitated by the biomass in the present study, which can be overcome by using chemical reducing agents like citric acid, oxalic acid, malic acid, ascorbic acid, sodium meta bisulphate and etc. An integrated approach of using biomass immobilized beads and chemical reducing agents may assist in complete removal of toxic Cr(VI) from the environment. The removal of Cr(VI) by the current
process is economically cheap owing to its high capacity using less sorbent dosage and high regeneration efficiency. Also, the bacteria are viable inside the alginate bead even after regeneration and can be re-grown which makes the work simple.

6.4 APPLICABILITY

The indigenous bacteria were isolated from Sukinda chromite mine water. The adsorption of Cr(VI) in continuous flow reactor using adapted bacterial consortium immobilized alginate beads can be scaled up for field applications at Sukinda chromite mine for remediating the contaminated water. In the scale-up process, the following factors are vital to be considered,

- Technical feasibility and
- Economical feasibility

However, this requires exhaustive study and it is beyond the objective of the current study.

6.5 ECONOMICAL FEASIBILITY

“It is trivial to note that the future is uncertain.

It is, however, far from trivial to analyze that uncertainty”.


The use of cost-analysis has become common place in environmental and other health-and-safety regulation. A cost benefit analysis informs the decision-making process by estimating the net present value of a project or policy. By incorporating risk and uncertainty into the analysis, the reliability of the estimated expected net present value can be assessed. The economic feasibility of the current study can be calculated by considering the following factors,

- Establishment cost (permanent)
- Maintenance cost
- Sorbent Cost per cycle
- Chemicals cost per cycle
- Cost of power per cycle
- Labor cost per cycle

However, this requires exhaustive study and cutting edge research for the field application in the future.