A Study on Bioremediation of Arsenic and Chromium Under Different Conditions

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DOCTOR OF PHILOSOPHY

by

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Chapter VIII:

CONCLUSIONS AND SUGGESTIONS

8.1 Concluding remarks

From the observations made in this study, the following important conclusions can be drawn:

i. The bacteria isolated from the Ratanpur Village of Varanasi District, Uttar Pradesh, showed good potential for removal of arsenic.

ii. Several parameters, such as pH, temperature, incubation period, etc., were found to affect bacterial growth significantly and also influence the arsenic removal capacity of bacteria.

iii. The bacteria, *Proteus alimentorum* strain TY6 was able to oxidize arsenite to arsenate [i.e., As(III) to As(V)], whereas *Pseudomonas aeruginosa* strain K7Pb could reduce arsenate to arsenite [i.e., As(V) to As(III)].

iv. Apart from arsenic, both isolates were found to be resistant to heavy metal(loid)s (Cd, Cr, Co, Hg, Ni and Pb).

v. In recirculating packed bed bioreactor, bacteria immobilized on PUF were found to be effective in removal of arsenic even at very high concentrations of 50 mg/L. The toxicity test revealed that the samples treated with bacteria were less toxic and showed lower bioluminescence inhibition as compared to untreated samples.

vi. Study on removal of arsenic and chromium from soil revealed that bacteria could remediate both metal(loid)s simultaneously. The presence of chromium was found to affect the removal of arsenic. Also, removal efficiency of metal(loid)s was observed to be dependent on the extraction agent used.

vii. Chlorophyll and plant growth assessment revealed that bacteria may have the potential to promote plant growth and uptake of arsenic and chromium by plants.

viii. PS was found to be an environment-friendly and cost-effective feedstock for the preparation of biochar, and adsorbent was effective in the removal of arsenic. The adsorption capacity of the biochar was further enhanced through modification with $KMnO_4$ and KOH. The sorption efficiency of modified biochar was relatively higher than unmodified biochar for As(III) (86%) and for As(V) (91.26%).

ix. Encapsulation of bacteria immobilized on biochar in PVA – SA beads were effective in removal of arsenic. Optimum concentrations of PVA, SA and $CaCl_2$ were 5%, 2% and 1%, respectively. Beads with consortium of bacteria were effective in arsenic removal even at very high concentrations (100 mg/L).

x. Water absorption and mechanical tests revealed that beads had low water absorption capacity (5% - 7%), good stability and mechanical strength. The reusability test revealed that beads of individual strains could be reused for 8 cycles and of bacterial consortium for 12 cycles before removal efficiency was reduced below 50%.

xi. Beads in recirculating packed bed bioreactor were found to be highly effective. The beads had an efficiency of over 70% even after five cycles of treatment and also showed improved biotransformation of arsenic.

8.2 Limitations of the present work

This work contributes significantly to understanding and advancing the bioremediation of arsenic and chromium using bacteria. However, this study is not devoid of limitations and these have been acknowledged to provide a balanced perspective on the research findings:

i. The present study used only bacteria for removal of arsenic. However, in natural environment, bacteria co-exist with other microorganisms such as fungi, algae, yeast and various microflora and fauna. Also, arsenic may be present with other elements in the natural environment. Microenvironment, along with other elements, can influence the bioremediation ability of arsenic by bacteria.

ii. Bacterial metabolism of methylation and demethylation can result in the formation of organic species of arsenic. However, in this study, the formation of organic species of arsenic and their effect on the bacterial community was not explored.

iii. The use of bacteria for a long duration by improving their shelf life can result in bringing down the cost of the treatment process. The present study did not explore the long-term storage of encapsulated bacteria.

iv. The present study was conducted only at a laboratory scale. A detailed cost-benefit analysis and field-based experiments are required to assess the economic viability of the process.

8.3 Scope for further work

Based on research findings obtained and limitations of the present work, the following issues can be explored for future research:

i. The synergistic effects of microorganisms on each other and also, the effect of various other elements, such as iron, manganese, sulfate, etc., on the removal efficiency of arsenic and bacterial metabolism can be explored for a better understanding of the complex mechanisms involved in the process.

ii. Bacteria can be stored for a longer duration in a lyophilized state. A lyophilization study may be carried out in order to assess the shelf life of the bacteria.

iii. The lack of a fully functional industrial-scale application of bacterial remediation of arsenic is a challenge. Life cycle assessment and cost-benefit analysis can be carried out to scale up the process.
iv. Metagenomic analysis to detect the community shift in the microflora and fauna in the arsenic-contaminated sampling locations can be investigated.