Chapter 1
Introduction to Waste Bioremediation

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Abstract Incomplete discharge of waste materials into the environment is of concern due to its slow degradability, highly soluble and biomagnification features in animals and plants. Conventional treatment techniques include chemical precipitation, ion-exchange, reverse osmosis and combustion are effective but energy intensive and consumes huge amounts of chemicals which may give rise to secondary problems such as spillage, corrosion and toxicity. The application of biological approach notably from use of microorganisms is an interesting alternative. Microorganisms such as bacteria, yeast and algae are known to survive in waste-containing environments owing to its ability to reduce, accumulate, sequester, absorb and oxidize different types of waste materials into forms, mostly making it less soluble and easily precipitated, that is, less toxic to the environment. This monograph covers biological approaches to remediate waste generated from various industries such as petroleum, electronic, textile, electroplating and landfill site(s). The role of microbes in composting and anaerobic digestion processes is also discussed. Apart from this effectiveness of microbes living in legumes of plant to remediate toxic heavy metals are also reported.

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Composting

Bioremediation is the use of microbes or other living things to clean-up contaminated soil and groundwater. This process proceeds from the ability of microbes and plants to carry-out various energy-dependant processes including oxidation, reduction, accumulation and precipitation, of the compounds of interest present in contaminants. Bioremediation occurs both in aerobic or anaerobic conditions where naturally the process requires long completion period. To expedite this condition, scientists and engineers would create a favourable environment for the process to take place where it would normally involve deciding on the best process arrangements (either in situ or ex situ), availability of nutrients (if not, has to be provided), right temperature as well as whether it is best to apply aerobic or anaerobic approaches (would determine whether an air pumping system needs to be installed). One important consideration that must not be taken lightly by all bioremediation operators is the bioavailability of contaminants. This factor is extremely important as it is more important limiting rate in all biodegradation processes. If bioavailability of a contaminant is perceived too low by microbial cells, the induction of catabolic gene system used in biodegradation will not occur; hence, the bioremediation process will not proceed. Some of the factors limiting bioavailability of contaminants for bioremediation includes irreversible sorption of contaminant to soil or sediment, chemical kinetics of desorption, extent of dissolution of contaminants into aqueous phase, diffusion rate through natural organic matters and rate of diffusion within particles. Some contaminated sites may allow in situ bioremediation while some sites may not notably due to a number of reasons such as soil might be too dense to allow amended nutrients to spread evenly underground. This would warrant such contaminants to be excavated and treated ex situ, i.e. above ground, whether in tanks or in a more controlled bioreactor. Depending on whether final major compound(s) arising from bioremediation processes would require a post-treatment step (due to potential hazard), the treated waste may be used as organic compost for agricultural application, pumped back to the ground or simply discharged to surface water or to a municipal wastewater system.

Nevertheless, all these bioremediation ventures will not be possible without early investigation carried out by thousands of scientists, engineers, researchers and students who have sacrificed hours after hours of experimentation in order to justify or proof some concepts which is highly crucial prior to any scaling-up or on-site demonstration attempts.

One example is the study on microbial fuel cells (MFCs). In MFC systems, chemicals are reduced at the cathode, and in some systems it is possible to achieve chemical oxidation at the anode in situations when high concentration of biodegradable organics is present in wastewater. For this to work, however, sufficient electron acceptors should be present at the cathode. For example, if a site is contaminated with petroleum or gasoline, the water can be channelled through consecutive hydraulic chambers similar to that used for zero valent iron walls for treating chlorinated aliphatics in groundwater.

Bacteria have been investigated in various processes such as biological removal of sulphate from water or wastewater. The treatment of sulphate rich wastewater using sulphur reducing bacteria (SRB) is advantageous due to minimal sludge production, ability to perform simultaneous oxidation of organic matter and the reduction of sulphate. Sulphate reduction in bioreactors is affected by parameters such as type of electron donor, COD: sulphate ratio, pH, HRT and reactor configuration. Most of the sulphate-reducing bioreactors are also able to handle fluctuations in COD or sulphate loading rates. The ability of the SRB to overcome feast and famine periods clearly shows the application of this technology for industrial situations.

Another example of laboratory-scale investigation of bioremediation properties using bacteria is the biodegradation of textile dyes either by using single bacterium or bacterial consortium. These systems utilize inducible consortial oxidoreductases for detoxification and mineralization into least/reduced toxic metabolites. Presently, the design of such consortial systems is gaining pervasive importance as they work under adverse conditions. Further, tailoring of process parameters is required for utilizing bacterial consortia for making the process viable and serving necessity of environmental safety and health.

Apart from application of bacterial cells as single or consortium, bacteria can also be immobilized in a suitable carrier such as calcium alginate. Immobilized cells offer robust and continuous application which is an important feature in real life bioremediation application. This approach is definitely advantageous for processes such as reduction of hexavalent chromium to trivalent chromium where the effect of chromium toxicity towards bacterial cells can be significantly reduced. However, further investigation on factors affecting both microbial growth and chromate reduction processes in free and immobilized forms is necessary. Understanding reduction pathways, possible formation of toxic intermediates, and if more stable products are implicated on the process, is also necessary. Another useful application of chromate reduction is from the use of plant growth-promoting bacteria (PGPR) in phytoremediation of chromium polluted soils. Since, the efficiency of specific PGPR strains varies according to the soil type and environmental conditions; an extensive research is required to enhance root colonization and chromium phytoextraction ability of PGP bacteria under soil stressed conditions. In addition, use of consortium instead of monoculture can be undertaken for research in order to enhance the PGPR and chromium phytoextraction process.

Other than that, numerous investigations are currently ongoing on the application of biological processes for the management of electronic and electrical waste (E&E or simply E-waste). Every management strategies concentrated upon organic and inorganic portions of E-waste. Organic part consists of variety of thermosetting plastic(s) with the presence of halogenated material. Microbes are involved in process of dehalogenation in many ways. Microbes can manage leaching of inorganic portion of E-waste which consists of both metallic and non-metallic components.

Plant also offers interesting solution in bioremediation processes. One example is the use of vetiver plant, which is a highly resilient and versatile plant that is used in various application including soil erosion control, water conservation, bioremediation, fragrance oil production, household and energy applications. However, several policy measures are required for successful implementation of this bioremediation system in large scale that needs to overcome several limitations through rigorous research, collaboration from developed and developing countries and large-scale test trials. In addition, growing vetiver for bioremediation and harvesting shoots for energy purpose could generate economic returns and employment.

This monograph highlighted recent studies on the applications of bioremediation for various types of waste including, viz. textile dyes, polyaromatic hydrocarbons, polymer and electric and electronic as well as microbial fuel cells, sulphate removal, hexavalent chromium reduction. Specific topics covered in the manuscript include:

- Energy recovery with microbial fuel cells: bioremediation and bioelectricity
- Bioprocesses for sulphate removal from wastewater
- Microbial depolymerisation
- Bioremediation techniques for E-waste management
- A review on bioremediation potential of vetiver grass
- Organic waste and pollutants reduction through composting
- Role of bacterial consortia in bioremediation of textile recalcitrant compounds
- Polycyclic aromatic hydrocarbons from petroleum oil industry activities: effect on human health and their biodegradation
- Bioreduction of hexavalent chromium using moderate thermophilic and thermophilic microorganisms
- Mechanism and action of *Aureobasidium pullulans* on biosorption of metals
- Bioremediation of leachates
- Microbial transformation of heavy metals
- Bioremediation of lithium ion battery (LIB) waste
- Characterization of leachate and groundwater in and around saduperi municipal solid waste open dump site, Vellore district, Tamil Nadu, India
- Effectiveness of plant-growth promoting rhizobacteria in phytoremediation of chromium stressed soils
- Biomining of natural resources
- Anaerobic digestion: factors affecting anaerobic digestion process
- Biodigester technology for effective and eco-friendly decomposition of night soil.

Author Biographies

Dr. Sunita Varjani is Scientific Officer at Gujarat Pollution Control Board, Gandhinagar, Gujarat, India. Her major areas of research are Industrial and Environmental Microbiology/Biotechnology and Molecular biology. She has delivered talks as invited speaker in many international conferences including the countries India and China. She is recipient of visiting scientist fellowship from EPFL, Lausanne, Switzerland (2017).

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Dr. Deepak Pant is currently the Dean and Head of Environmental Science, Central University of Himachal Pradesh, Dharamshala. He received the Silver Jubilee Research Fellowship Award in 2003 from Kumaun University, Nainital, India; the UCOST Young Scientist Award 2009, INSA Fellow (2010), DST-SERC, Visiting Fellow (2010) and DST-SERC Young Scientist Award (2011), Visitor's Award (2017) from the President of India.

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