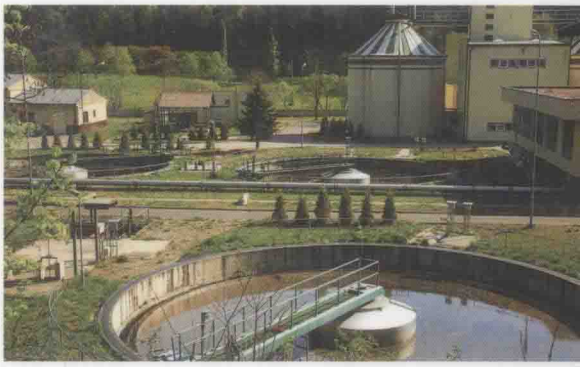
ROMEELA MOHEE and ACKMEZ MUDHOO, Editors

BIOREMEDIATION AND SUSTAINABILITY

RESEARCH AND APPLICATIONS



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Bioremediation and Sustainability

Research and Applications

Edited by

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Dedicated to my family especially my daughter Mansha without whose support this book would not have been possible

— Romeela Mohee

For Yaana, Teena, Assad, mum and dad

— Ackmez Mudhoo

Preface

Soils in the same way as aquatic environments are the target of thousands of contaminants that vary in composition and in concentration. These contaminants enter the system as a result of a wide range of actions such as intentional applications, inadequate residue disposal, accidental wastes and inappropriate use. The pollution by inorganic compounds such as nitrates, phosphates and perchlorates is due to inadequate disposal of manufacture residues of fireworks and matches; explosives such as hexahydro–1,3,5–trinitro–1,3,5–triazine (RDX) and octahydro–1,3,5,7–tetranitro–1,3,5,7–tetrazocine (HMX) from their manufacture and tests; monoaromatic hydrocarbons like benzene, toluene, ethylbenzene and xylene (known as BTEX) fromoil spills and of storage tanks leaking; polycyclic aromatic hydrocarbons from accidental spills; a range of herbicides such as diuron, linuron and chlorotoluron used in weed control and by heavy metals. Heavy metal contamination can be a consequence of industrial activities that eliminate residues in the soil that, over the long term, promote their accumulation. The majority of the sources are originated by human actions like metal manufacture and mining industries with storage, disposal and transportation problems. Among the metals found more frequently there are cadmium, lead, cobalt, copper, mercury, nickel, selenium and zinc. For cadmium, lead, copper and zinc, their toxicity increases as follows: lead<zinc<copper<cadmium, depending on countless abiotic and biotic factors.

Sustainable development requires the development and promotion of environmental management and a constant search for green technologies to treat a wide range of aquatic and terrestrial habitats contaminated by increasing anthropogenic activities with the main sources of contaminants being from the chemical industries. Bioremediation is a technique that uses living organisms to degrade or transform contaminants into their less toxic forms. It is

based on the existence of microorganisms with capacity to enzymatically attack the compounds. The strategies can be applied *in situ* or *ex situ*, depending on the site in which they will be applied. *In situ* is the treatment done in the site of the contamination and *ex situ*, refers to the removal of soil or water to subsequent treatment. There is a wide variety of techniques that has been developed in the past, and some of these techniques are natural attenuation, bioaugmentation, biostimulation, biosorption, composting, phytoremediation, rhizoremediation and bioleaching. Since bioremediation and these techniques not only represent an emerging (green) technology but also present a great advantage of being cost effective when compared to the traditional remediation methods due to the use of indigenous microorganisms with a versatile metabolism, this book presents an up–to–date and comprehensive collection of chapters prepared in bioremediation technology research and application. The chapters cover bioleaching, biosorption, bioaugmentation, biostimulation, bioventing, biofiltration, biostimulation, natural attenuation, phytoremediation, biosurfactants, anaerobic digestion and composting.

Romeela Mohee
Ackmez Mudhoo

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Mr Ackmez Mudhoo expresses his appreciation for the faith his parents, Mr Azad A. Mudhoo and Mrs Ruxana B. Mudhoo, his brother Assad, sister–in–law Teena, and lovely niece Yanna have placed in him throughout the writing and compilation of this handbook. A. Mudhoo is thankful to Prof Konrad Morgan (Vice–Chancellor & Chairman of Senate of the University of Mauritius, Réduit, Mauritius), Prof Romeela Mohee (Dean, Faculty of Engineering, University of Mauritius, Réduit, Mauritius), and Dr. Vinod K. Garg (Guru Jambheshwar University of Science and Technology, Hisar, Haryana, India) for their presence, encouragement and support.

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Ackmez Mudhoo holds a Bachelors degree (B.Eng. (Hons.)) in Chemical and Environmental Engineering and a Master of Philosophy (M.Phil.) degree by research in Chemical Engineering from the University of Mauritius. His research interests encompass the bioremediation of solid wastes and wastewaters by composting and anaerobic digestion. Ackmez has 56 international journal publications, 4 conference papers and 3 co-edited books to his credit. Ackmez serves as peer reviewer for Waste Management, International Journal of Environment and Waste Management, Journal of Hazardous Materials. He is presently lecturer in the Department of Chemical and Environmental Engineering, University of Mauritius.

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Dr. Safferman is an Associate Professor in the Department of Biosystems and Agricultural Engineering at Michigan State University and is the director of the MSU Anaerobic Digestion Research and Education Center. Previously he served as a faculty member at the University of Dayton for 11 years and an environmental engineer at the U.S. Environmental Protection Agency for 5 years. He also has engineering consulting and industrial experience. Dr. Safferman has a M.S. and Ph.D. in Environmental Engineering and a B.S. in Civil Engineering from the University of Cincinnati. His research and extension programs entail holistic, innovative food processing and animal residual management, sustainability, waste to resource technologies, soil assimilation capacity, and onsite generated wastewater treatment. He also coordinates the Department's student capstone design experience.

Dana Kirk has B.S. degrees in Animal Science and Biosystems Engineering, an M.S. in Biosystems Engineering and a Ph.D. in Biosystems Engineering, all from Michigan State University. He has 10 years of experience as an environmental engineer working on livestock waste related issues. Consulting projects have ranged from CAFO permitting, environmental compliance and reporting, waste storage facility design, livestock facility design, construction oversight, waste treatment technology evaluation, and anaerobic digestion optimization. Dr. Kirk's current research entails bench top, pilot-scale, and commercial anaerobic digestion systems used to evaluate feedstocks, optimize performance, and integrate technologies.

Mr. Faivor has a B.S.in Biosystems and Agricultural Engineering. He manages and conducts research at the Anaerobic Digestion Research and Education Center, Michigan State University, with over 7 years of experience working on lab, pilot, and full-scale anaerobic digestion systems.

Ms. Wu-Haan has Masters of Science degrees from Iowa State University in Animal Nutrition and Environmental Science and Bioresource and Technology. She has conducted research for over

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Dr. Ramkrishna Sen is an Associate Professor (Biochemical and Bioprocess Engineering) in the Department of Biotechnology, Indian Institute of Technology Kharagpur (IIT Kharagpur), India. Before joining IIT Kharagpur, Dr. Sen worked in BITS, Pilani as Assistant Professor and Cadila Pharmaceuticals Ltd., Ahmedabad as the Manager (R&D–Biotech). He has had a teaching and academic research experience of more than ten years after his Ph.D from IIT Madras, Chennai and has industrial R&D experience of three years in the field of large scale production of recombinant therapeutic proteins and bioprocess development and scale up for probiotics and nutraceuticals. Dr. Sen is currently heading a vibrant group of ten Ph.D scholars, three M.Tech and three B.Tech project students, who are involved as a team in developing, modeling, optimizing and scaling up bioprocesses for production, characterization and applications of marine lipopeptides, also called biosurfactants; probiotic based nutraceuticals; plant oil and microalgal lipid feedstock based biorefinery for biodiesel and other commercially valuable products; lignocellulosic bioethanol and microbially treated jute geotextiles. Dr. Sen, being a bioprocess engineer with industrial experience, set his research priorities in the broader areas of health-care and bioenergy. Dr. Sen handled four industrial R&D projects, out of which two products were commercialized by Cadila Pharma Ltd. In IIT Kharagpur, he completed five sponsored projects, has six ongoing sponsored R&D projects and two consultancy projects, out of which one is funded by a Texas (USA) based company. He has about fifty peer reviewed international journal publications with an average impact factor of 3.3 and h-index of approximately 13. He published seven book chapters in internationally published books by reputed publishers. He also edited a book on 'Biosurfactants', which was published in 2010 by Springer. He has seven patent applications filed to his credit. Already, five students have got their Ph.D degree from IIT Kharagpur under his direct guidance. He is the life member of Indian Institute of Chemical Engineers (IIChE) and the founding member of the Global Biorenewables Research Society (www.gbrs.org). Dr. Sen is the member of editorial board of two international journals and reviewer of more than twenty international journals and also of project proposals of various national and international funding agencies.

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Divya Gupta was born in Aligarh district of Uttar Pradesh, India on 3rd January 1990. She took her secondary education from Kishori Raman Girls Inter College, Mathura and senior secondary education from T R R R S V M Inter College, Kashipur, India. She has completed her B.Tech. in Biotech. from, Mangalayatan University, Beswan, Aligarh, India. She got university topper position in B.tech. in 2007–2011 batch. Currently she is doing her M.Tech. in Biotech. from G. B. Pant Engineering college, Pauri, Garhwal, India.

L. K. Singh has done his B. Tech. and M. Tech. in Chemical Technology (with specialization in Biochemical Engineering) from Harcourt Butler Technological Institute Kanpur (UP) in year 2000 and 2002 respectively. After completing his PG degree he has joined Ekta Agro Industries Limited, New Delhi as Manager (Projects). He has joined Harcourt Butler Technological Institute Kanpur (UP) in year 2003 as Lecturer in the Department of Biochemical Engineering and Food Technology. He has organized a National Symposium on "Recent Technological Developments in Bioprocess and Food Processing Industries" and a Refresher course under TEQIP World Bank Project on "Biotechnological Approaches for Chemical Process Industries" at HBTI Kanpur. He is also working on a major research project on "Production of Xylitol (a natural sweetener) by Fermentation sanctioned by University Grant Commission, New Delhi. Presently he is doing his Ph.D. from the Department of Biotechnology, Indian Institute of Technology Roorkee (UK) under the Quality Improvement Program, sponsored by AICTE New Delhi. Simultaneously he is holding the post of Assistant Professor (Biochemical Engineering) in HBTI, Kanpur with about 9 years of teaching and research experience.

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Dr Vikash Babu was born in Bulandshahr district of Uttar Pradesh, India on 1st September 1981. He did his Bachelor's degree from I.P (PG) College Bulandshahr, India. After qualifying all India combined entrance exam for biotechnology conducted by JNU, New Delhi, India, he did his degree in Biotechnology from Kumaun University, Nainital. After completing his M.Sc degree, he qualified many national level competitive exams such as DBT-JRF- 2005, CSIR-UGC NET for lecturership- Dec. 2004 & June 2005 and GATE-2005. In Nov. 2005, he joined as a DBT-JRF in the Department of Biotechnology, Indian Institute of Technology, Roorkee under the superivision of Dr. Bijan Choudhury. On 2nd of Jan 2006, he had registered for the Ph.D in the same department and Institute and completed his Ph.D degree in the year 2011. After finishing his Ph.D research work he joined Mangalayatan University, Beswan, Aligarh as a lecturer. Currently he is working as a lecturer in the same university.

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Hugo Sérgio Pitães Figueiredo was born in Braga, Portugal. He obtained his degree in Applied Chemistry in 2004, at the University of Minho, followed by a Master in Biotechnology in 2007, at the same University. He his currently concluding his Ph.D. studies in Chemical and Biological Engineering at the same University, under the supervision of Prof. Teresa Tavares and Prof. Isabel Neves.

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