Environmental Footprints and Eco-design of Products and Processes

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Biodegradation and Bioconversion of Hydrocarbons

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Preface

Hydorcarbon oil contamination poses severe environmental risks and polycyclic aromatic hydrocarbons (PAHs) arising from pyrogenic origins can adversely affect human health through consumption of contaminated food. Hydrocarbon inputs into waterways, sediments and seas and oceans arise from both natural seepages and anthropogenic activities. While acute-large inputs arising from shipping and oil and gas exploration/refining accidents attract large media attention, chronic inputs from non-point sources are far less well described. In particular inputs from previously buried sediments through dredging and other sediment disturbance events can only be quantified using costly sophisticated radioisotope analyses and gas-chromatography/mass spectrometry. As oil and gas exploitation increase to service the growing energy demand of the fast rising population, so should our attempts to manage soil, water and air pollution in an economic and environmentally sustainable way. This book tackles bioremediation problems of crude oil and its recalcitrant aromatic fractions in soil, water and air. It also investigates potential of value-adding co-product development such as biosurfactants and the option to use specialist bacteria, fungi and yeast for biological upgrading of our vast heavy and extra-heavy crude oil reserves.

Chapter "The Assessment of Hydrocarbon Contamination in Contrasting Sedimentary Environments" provides a detailed summary of oil-born pollutant origins and historic trend lines, particularly for the sedimentary environment of the North Sea and reports on progress made lowering hydrocarbon-based pollution from point sources due to implementation of government and self-appointed regulations, reporting and surveillance. It highlights the importance of considering historic inputs which can be re-introduced in significant amounts based on sediment characteristics and sediment disturbance events. It concludes that, despite the expense, advanced fingerprinting techniques are required to better account for and understand hydrocarbon sources, persistence, weathering, toxicity and carcinogenicity. Specifically, a better characterisation of sediment contaminant reservoirs is required to predict release concentrations and impacts, especially PAHs, during sediment disturbance events.

Given the carcinogenic, mutagenic and cytotoxic nature of PAHs, Chapter "HC-0A-02: Analysis of Polycyclic Aromatic Hydrocarbons from Food" reviews sources of pollution and analytical techniques for the detection and quantification of pyrogenic origin PAHs in food. This chapter presents a thorough treatise of traditional, novel and automatable and miniaturised analytical approaches taken for the determination of PAHs in foods, including food matrices, parameters measured, and extraction, clean-up and determination techniques. The evaluation ends with a critical review of method validation, which highlights, that despite regulations, precision and ruggedness are often least considered.

Chapter "HC-0B-06: Biodegradation of Hydrocarbons" reviews the degradation of oil hydrocarbons in contaminated soils and groundwater. Following an introduction on the parameters that influence the speciation and bioavailability of hydrocarbon contaminants, the chapter focuses on microbial and phytobioremediation. On-site (in situ) and off-site (ex situ) biological systems are evaluated in the context of addition of enriched cultures of microbes (bioaugmentation) and nutrients. Based on demonstration-scale case studies, the chapter concludes that bioventing, biosparging, soil vapour extraction, enhanced bioremediation/biorestauration, and phytoremediation are cost-efficient in situ strategies for the remediation of hydrocarbon-polluted environments.

Chapter "HC-0B-01: Biodegradation of Hydrocarbons by Extremophiles" has a focus on the biodegradation of hydrocarbon pollutants under extremophilic conditions (i.e., acidophilic (pH 1–5), alkaliphilic (pH >9) halophilic (>3 % salt), thermophilic (>50 °C), psycrophilic (<10 °C), piezophilic or barophilic (>38 MPa) and xerophilic (a_w 0.60–a_w 0.90)). It presents a detailed summary of molecular tools for identification, identified strains capable of biodegradation of PAHs, their source of isolation and conditions of maintenance. It highlights physiological and molecular adaptations required to withstand extremophilic conditions, as well as novel biodegradation pathways that are expressed by certain environmental stressors.

The biodegradation of benzene, a carcinogenic parent compound of aromatic hydrocarbons present in petroleum, under anaerobic conditions is detailed in Chapter "Biodegradation of Benzene Under Anaerobic Condition". It summarises sources of exposure, organ distribution and metabolic fate upon exposure, before summarising the environmental distribution and fate of benzene. A focal point of the chapter is devoted to anaerobic benzene metabolic pathways, as it explores the effect and effectiveness of supplementing the anaerobic degradation of benzene with various electron acceptors. Modern molecular tools and integrated metabolomic approaches are described highlighting advantages of "extremozyme" applications for benzene biodegradation under environmentally unsuitable conditions.

Renewable and sustainable hydrocarbon-based fuel supplies are at the heart of the aviation/ shipping industries and those operating heavy machinery. Following a concise introduction to catalyst-assisted hydrotreatment of plant bio-oils, Chapter "Catalytic Hydro-Cracking of Bio-oil to Bio-fuel" explores oleic acid conversion, a fatty acid present in large quantities in all plant-derived oils, to biofuels using catalytic hydro-cracking with nickel impregnated zeolites (zeolite β,

ZSM-5). Both catalysts are shown to efficiently produce Nonane, Decane, and Dodecane, the main constituents of jet fuel, but zeolite β yields were higher for the former two alkanes due to a higher surface area, while lower yields of the latter may be attributable to a greater abundance of micropores.

Environmental and health impacts of increased air pollution with volatile organic compounds (VOCs), specifically volatile hydrocarbons (VHs), have called for tighter regulations. As these compounds often show microbial toxicity and are often hydrophobic, Chapter "HC-0B-05: Two-phase Partitioning Bioreactors for Treatment of Volatile Hydrocarbons" reviews applications and progress made with using two-phase partitioning bioreactors for the bioremediation of these air pollutants. The chapter reviews design principles, mass transfer balances and selection of non-aqueous phase additives based on target VH characteristics. It identifies remediation capacities of gas mixtures with differing hydrophobicity characteristics of components and reactor design aimed to improve energy requirements as the immediate knowledge requirements for transitioning from laboratory research to implementation.

Microorganisms living in hydrocarbon-contaminated environments often produce biosurfactants for improved access to hydrophobic organic constituents. Owing to the non-toxic and biodegradable nature of biosurfactants, they have wide industrial applications, from enhancing bioremediation outcomes to healthcare and food sectors. Chapter "Biosurfactant Producing Bacteria From Hydrocarbon Contaminted Environment" provides a thorough introduction on biosurfactant types, physiological and molecular details for biosynthesis, and the regulation thereof, including effects of cultivation conditions (age, nutrient status and physico-chemical parameters) on yields. Marriage of biosurfactant environmental services and production optimization is identified as critical for economic sustainability of the biosurfactant industry.

Chapter "Biodegradation of Petroleum Hydrocarbon and its Influence on Corrosion with Special Reference to Petroleum Industry" investigates the role of the enteric bacterium *Serratia marcescens* ACE2 and *Bacillus cereus* ACE4, isolated from a diesel pipeline, on corrosion of carbon steel reservoirs and pipelines and diesel degradation. As a first tropical study, examining enteric bacterial diesel degradation, the presented data prove that both strains degrade aliphatic and aromatic diesel hydrocarbons, while formation of ferric and manganese oxides through Fenton-like reactions led to significant corrosion of API 5LX steel.

Substantial removal of high-quality crude oil resources due to increased fossil fuel-derived energy demands by the growing population requires the progressive exploitation of heavy and extra-heavy lower quality crudes. These crudes are less suitable for today's application. Chapter "HC-0C-03: Biological Treatments to Improve the Quality of Heavy Crude Oils" reviews microbial approaches for the natural upgrading of these heavy oils. Several bacterial strains and consortia, as well as filamentous fungi and yeast are identified for their preference to degrade resins and asphaltenes (present in high amounts in heavy crude oils). For the latter groups, secreted extracellular enzymes, with some belonging to the lignin degradation system, are shown to oxidise resins and asphaltenes without loss of carbon, thereby

maintaining the high calorific value of heavy crude oils, rendering them and/or their enzymes particularly useful for in situ and ex situ upgrading.

The final chapter presents the findings of a study aiming to isolate local endemic bacteria useful for the bioremediation of crude oil-contaminated waste waters of the petrochemical industry in Malaysia. Of the twelve species isolated, three showed promise for n-alkane degradation in crude oil-contaminated sites, two *Acinetobacter* species and one species of the genus *Proteus*. Both *Acinetobacter* isolates preferred non-agitated cultivation conditions, with STL-(-g)-Cr8 showing the highest alkane biodegradation potential and BTL-(+g)-Cr7 a preference for long chain alkanes (C_{36} and C_{38}). In contrast, RSSF-Cr1, a Proteus species preferred agitated cultivation. Further studies using endemic strains and consortia are required for improving bioremediation of crude oil-contaminated sites in developing nations.

As detailed, this book presents a solid background and method review for students and researchers in the areas of hydrocarbon pollution mitigation and the oil and gas industries. Additionally, synthesised details on current limitations to technologies and case study data afford a great data reference for experts in these fields.

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