FOCUS ON BIOTECHNOLOGY

Biotechnology for the Environment: Soil Remediation

Edited by

Spiros N. Agathos and Walter Reineke

Series Editors: Marcel Hofman and Jozef Anné

Kluwer Academic Publishers

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Volume 3B

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KLUWER ACADEMIC PUBLISHERS
DORDRECHT / BOSTON / LONDON

A C.I.P. Catalogue record for this book is available from the Library of Congress.

ISBN 1-4020-1051-6

Published by Kluwer Academic Publishers,
P.O. Box 17, 3300 AA Dordrecht, The Netherlands.

Sold and distributed in North, Central and South America
by Kluwer Academic Publishers,
101 Philip Drive, Norwell, MA 02061, U.S.A.

In all other countries, sold and distributed
by Kluwer Academic Publishers,
P.O. Box 322, 3300 AH Dordrecht, The Netherlands.

Printed on acid-free paper

Printed in the Netherlands.

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Focus on Biotechnology is an open-ended series of reference volumes produced by Kluwer Academic Publishers BV in co-operation with the Branche Belge de la Société de Chimie Industrielle a.s.b.l.

The initiative has been taken in conjunction with the Ninth European Congress on Biotechnology. ECB9 has been supported by the Commission of the European Communities, the General Directorate for Technology, Research and Energy of the Wallonia Region, Belgium and J. Chabert, Minister for Economy of the Brussels Capital Region.

EDITORS PREFACE

At the dawn of the 21st century we are witnessing an expanding human population in quest of survival and continued well-being in harmony with the environment. Many segments of society are increasingly preoccupied with the battle against both diffuse and concentrated pollution, the remediation of contaminated sites, the restoration of damaged areas due to anthropogenic activities and the re-establishment of functioning biogeochemical cycles in vulnerable ecosystems. There is an enhanced awareness of the value of pollution prevention and waste minimization in industrial, urban and agricultural activities, as well as an increased emphasis on recycling. Faced with these major contemporary challenges, biotechnology is emerging as a key enabling technology, and, frequently, as the best available technology for sustainable environmental protection and stewardship.

Although the activities of microorganisms and their subcellular agents have been recognized, studied and harnessed already for many years in the environmental arena, there is a new dynamism in the in-depth understanding of the molecular mechanisms underlying the functioning of microorganisms and their communal interactions in natural and polluted ecosystems, as well as an undeniable expansion of practical applications in the form of the new industry of bioremediation. A number of distinct but increasingly overlapping disciplines, including molecular genetics, microbial physiology, microbial ecology, biochemistry, enzymology, physical and analytical chemistry, toxicology, civil, chemical and bioprocess engineering, are contributing to major insights into fundamental problems and are being translated into practical environmental solutions and novel economic opportunities.

The book set «Biotechnology for the Environment», based on a compilation of some of the outstanding presentations made at the 9th European Congress on Biotechnology (Brussels, Belgium, July 11-15, 1999) and enriched with newly updated thematic chapters, captures the vitality and promise of current advances in the field of environmental biotechnology and is charting emerging developments in the beginning of the new millennium. This second volume, subtitled 'Soil Remediation' offers a view on methodology in the area of bioremediation, illustrating both the diversity and the importance of the multidisciplinary approaches for years to come. After a general opening exemplifying the different approaches in bioremediation of contaminated soil in which the current practice and trends are described, life cycle assessment based software tools for soil remediation planning are compared to calculate the potential environmental burdens of bioremediation and to help soil remediation planners to estimate the overall environmental performance of different remediation concepts.

Two contributions offer state-of-the-art descriptions of *ex situ* clean up technologies, wherein slurry decontamination reactor processes are the central point of discussion. The contaminated site itself is used as integral reactor for the microbial degradation of contaminants when using *in situ* clean up techniques. The principles of the approach and the successful application of aerobic and anaerobic *in situ* processes in the field are clearly described, including "natural attenuation" processes, in the third part of this volume. Two approaches complete the picture on bioremediation, immobilisation of pesticides and humification of nitroaromatic compounds leading to drastically reduced bioavailability and detoxification of contaminants at the affected site. Finally, phytoremediation is presented as a viable bioremediation technique using living green plants to degrade, to contain or to render harmless contaminants of the environment, including recalcitrant organic compounds or heavy metals.

The Editors hope that the integration of the depth of scientific fundamentals with the breadth of current and future environmental applications of biotechnology so evident in these selected contributions will be of value to microbiologists, chemists, toxicologists, environmental scientists and engineers who are involved in the development, evaluation or implementation of biological treatment systems. Ultimately, a new generation of environmental scientists should take these lessons to heart so that new catalysts inspired from the biosphere can be designed for safe, eco- and energy-efficient manufacturing and environmental protection.

Spiros N. Agathos | Walter Reineke

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CURRENT PRACTICE AND TRENDS

BIOLOGICAL SOIL TREATMENT

Status, development and perspectives

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1. Introduction

Environmental protection over the past few decades has meant primarily the protection of air and water. Only with the increasing use of land in industrialised societies and the highlighting of possible hazards from contaminated soil did the public become aware of soil protection in the early 80s. This has also prompted industry to take up this market segment. Engineers and scientists have thus been spurred on to look for technically optimised, ecologically sound and economically appropriate solutions.

For more than a century natural biochemical processes (nature's self-cleaning forces) have been utilised to treat effluent, and reactors and plant systems had been adapted with increasing effect to cope with the difficult conditions, but only in the 80s was work begun on testing biological methods for cleaning up soil. The experience accumulated in biological soil clean up in the first few years was characterised both by successes and failures, including those of unprofessional suppliers. Initially therefore the acceptance of biological soil clean up was only limited. But now, thanks to intensive and interdisciplinary work, impressive successes are in evidence. Consequently biological soil clean-up methods now enjoy a high technical level and a broad acceptance (Klein 1996).

In 1998 approximately 2.2 million tonnes of soil were remediated in Germany in 108 stationary soil treatment facilities, of which 1.2 million tonnes or 60 % was treated by biological means. For on-site biological treatment there is an available capacity of about 0.4 million t/a (Table 1).

The aim is to maintain and apply this level, even if the prospects for soil clean up in Germany are seen from a more modest point of view. In addition to the preference for securing techniques and to the competition from less expensive suppliers in neighbouring countries, low-price dumping has in recent times represented a challenge to operators of soil decontamination facilities in Germany.

S.N. Agathos and W. Reineke (eds.).
Biotechnology for the Environment: Soil Remediation, 7-21.

Table 1: Soil treatment plants (status December 1997)

Technology used		Biological	Scrubbing	Thermal	Total
Treatment Centres	Number	80	24	4	108
Capacity	in Mio.t/a	1.9	1.38	0.17	3.45
	in %	55	40	5	100
Throughput	in Mio. t/a	1.24	0.85	0.11	2.20
	in %	56.4	38.7	4.9	100
Mobile Plants:	Number	8	7	5	20
Capacity	in Mio.t/a				~1.0
Contaminants handled		TPH	TPH	TPH	
		BTEX	BTEX	BTEX	
		Phenol	Phenol	Phenol	
		PAH	PAH	PAH	
		VOCH	VOCH	VOCH	
			Pesticides	Pesticides	
			PCB	PCB	
			PCDD/F	PCDD/F	
			Cyanide	Cyanide	
			Phosphor		
			Heavy metals	Heavy metals	

TPH: total petroleum hydrocarbons, BTEX: benzene, toluene, ethylbenzene, xylene; PAH: polycyclic aromatic hydrocarbons; VOCH: volatile halogenated hydrocarbons; PCB: polychlorinated biphenyls; PCDD: polychlorinated dibenzodioxin; PCDF: polychlorinated dibenzofurans

2. Fundamentals

The use of biological processes for treatment of liquid wastes from human activities is an established technology dating back at least 4000 years. The knowledge of the biodegradation mechanisms of organic pollutants and especially of synthetic compounds, however, is more recent and has only been developed in the second part of the 20th century.

In biological processes, use is made of the capacity of microorganisms to consume organic substances as a nutrient (substrate) and to convert them to harmless natural materials, such as CO_2, water and biomass. For degradation of noxious substances in contaminated soils, bacteria and fungi are of foremost importance.

The attack of organic substances in soils by microorganisms results either in full degradation (mineralisation) or in a partial degradation process producing metabolites which may be used by other members of the biocenosis or which remain in the soil. Furthermore, the original substance and the metabolites can be cycled to the soil's carbon depot. This is called humification. The decisive point in that case is that the noxious matter or the resulting metabolite is incorporated into the soil matrix, which reduces sharply their availability for biochemical reactions. This phenomenon is used at present in comprehensive development work aimed at a conversion of the pollutants by microbiological attacks so they are converted to natural substances, such as humic compounds, which involve no further environmental risk. Detoxification can also be obtained by co metabolism using non-growth substances as co substrate.

3. Necessary preliminary investigations

The decision in favour of a biological decontamination process depends on the following prerequisites:

- Degradability of the contaminants
- Bioavailability of contaminants in the soil matrix
- Adjustability of the biological, physical and chemical conditions required for biological degradation in the soil.

3.1. DEGRADABILITY OF CONTAMINANTS

Laboratory methods for the evaluation of biological soil cleanup processes have been developed by a *Dechema Working Group* (DECHEMA 1992) allowing findingout thoroughly about the microbial degradability of contaminants. However, it has to be considered that the assessment of degradability of soil contaminants requires investigation on the original soil, either in suspension or by means of naturally moist samples.

3.2. BIOAVAILABILITY

In many cases it is not the actual microbial degradability but physico-chemical parameters, such as adsorption/desorption, diffusion, and solution properties of the contaminants found in the soil, frequently in solid phase, which are decisive for degradation and the degradation rate. The availability of contaminants in the soil to the microorganisms, the bioavailability, is decisively influenced by the configuration of the soil matrix, i.e. its material composition and particle size distribution, and also by the history of contamination. For these cases, suitable bioavailability assessment methods are on hand (ITVA 1994).

Figure 1 shows a sequence pattern for close-to-practice preliminary investigations. When following that scheme we arrive - with relatively low expenditure - first at the important decision whether biological decontamination is possible at all. If there is no bioavailability of contaminants in the soil, or if a contamination, which is toxic to microorganisms, cannot be eliminated, this means that the soil concerned is out of question for a microbiological treatment.

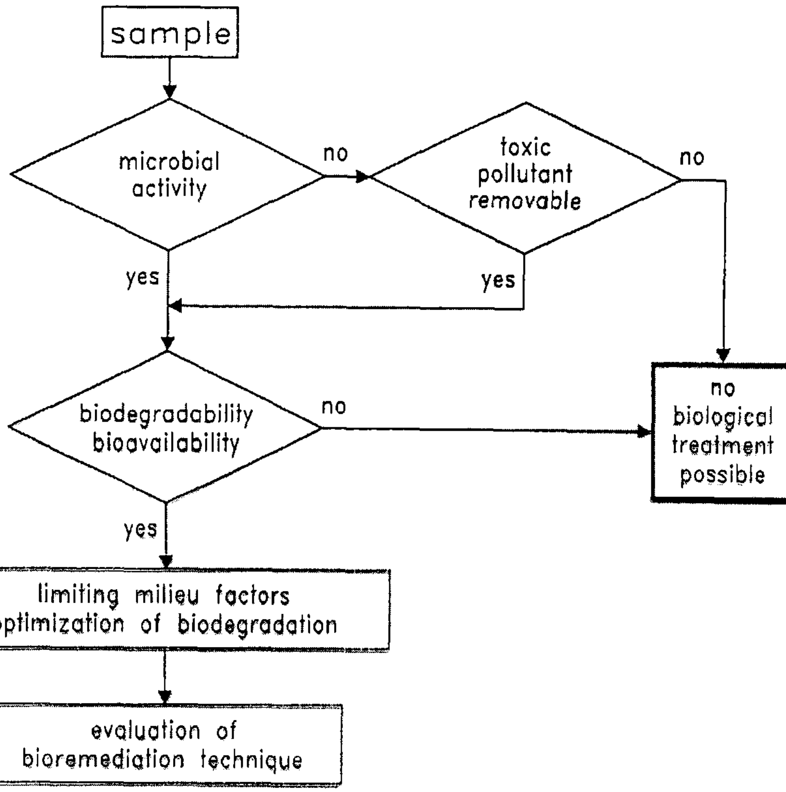

Figure 1: Evaluation of the biodegradability of a pollutant

3.3. ADJUSTABILITY OF THE BIOLOGICAL AND PHYSICO-CHEMICAL CONDITIONS FOR BIOLOGICAL DEGRADATION IN THE SOIL

The physico-chemical and of course, also the geological properties of the soil are decisive for the choice of methods for bioremediation.

Figure 2 shows the sequence of investigations in view of the selection of methods. The decision in favour of an *in situ* or an *ex situ* method generally depends on the hydro-geological configuration of the soil, the permeability coefficient k_f, the soil's homogeneity, and its silt and fines content. The k_f value is regarded as orientation parameter. Experience has shown that with k_f values $< 10^{-5}$ m/s, *in situ* treatment is out of question. Only in relatively few cases, favourable conditions for a microbiological *in situ* decontamination prevail.