Interactions between microbes and metals have a huge economic importance. Metallic structures and apparatus can be corroded leading to reduced efficiency of operation and even danger to users. However, microorganisms have enormous potential for the removal of economically important metals from their ores. There has been intense research in this field of biotechnology in recent years, and this is reviewed here. Specialists cover the different aspects of the subject in separate chapters, which include marine corrosion and the prospects and management of biomining bacteria. The chemical and electrochemical aspects and the prospects for controlling the positive and negative effects of these microorganisms are covered in detail.

Mining and oil industries engineers and researchers will find the contents of this book extremely pertinent. Researchers in biotechnology, metallurgy and microbiology will also find much of interest here.

Cambridge University Press
0521417570 - Bioextraction and Biodeterioration of Metals
Edited by Christine C. Gaylarde and Hector A. Videla
Frontmatter
More information

Bioextraction and biodeterioration of metals

The Biology of World Resources Series

The impact of organisms on the world's materials, foodstuffs, structures and environments

Series Editors

DR DENNIS ALLSOPP
Head of Genetic Resources and External Services, International Mycological Institute

DR BRIAN FLANNIGAN
Reader, Department of Biological Sciences, Heriot-Watt University

DR RITA COLWELL
President, University of Maryland Biotechnology Institute and Professor of Microbiology

The Biology of World Resources is an international research series that examines the influence of living organisms (both micro and macro) on the world's manufactured, built and natural resources. The important role played by organisms in the world-wide economy requires a greater understanding if resources of all kinds are to be used responsibly and to the best effect.

Initial volumes will be concerned with biodeterioration of materials such as the microbial deterioration of metals, hydrocarbons and plastics materials. More traditional materials of organic origin such as lignocellulosic materials and foodstuffs will also be covered.

The negative aspect of biodeterioration of materials will be balanced by chapters and volumes concerned with the biodegradation of wastes and their bioconversion into less harmful or useful products. Biological extraction and concentration of materials will also be covered.

These materials-centred works will be complemented by volumes covering the broader problems presented by composite structures and systems such as buildings (domestic and commercial), transport systems, utilities and natural environments utilized for production or environmental purposes.

The Biology of World Resources Series 1

Series Editors
Dennis Allsopp
Brian Flannigan
Rita Colwell

Bioextraction and biodeterioration of metals

Edited by

CHRISTINE C. GAYLARDE
Departamento de Solos, Universidade Federal do Rio Grande do Sul, Brazil

HÉCTOR A. VIDELA
Sección de Electroquímica, INIFTA, Universidad Nacional de la Plata, Argentina

CAMBRIDGE
UNIVERSITY PRESS

Published by the Press Syndicate of the University of Cambridge
The Pitt Building, Trumpington Street, Cambridge CB2 1RP
40 West 20th Street, New York, NY 10011-4211, USA
10 Stamford Road, Oakleigh, Melbourne 3166, Australia

First published 1995

A catalogue record for this book is available from the British Library

Library of Congress cataloguing in publication data

Bioextraction and biodeteriodarion of metals / edited by Christine C.
Gaylarde and Héctor A. Videla.
p. cm. – (The Biology of world resources : series 1)
ISBN 0 521 41757 0
1. Metals – Biodegradation. 2. Bacterial leaching. I. Gaylarde,
Christine C. II. Videla, Héctor A. III. Series.
QR135.5.M37B54 1995
620.1.'623 – dc20 94–26747 CIP

ISBN 0 521 41757 0 hardback

Transferred to digital printing 2004

RO

Contents

Contributors

PROFESSOR S. C. DEXTER

College of Marine Studies, University of Delaware, Lewes, DE 19958-1298, USA

DR R. G. J. EDYVEAN

Department of Chemical Engineering, University of Leeds, Leeds IS2 9JT, UK

PROFESSOR T. FORD

Harvard School of Public Health, Department of Environmental Health, 665 Huntington Avenue, Boston, MA 02115, USA

PROFESSOR C. C. GAYLARDE

Departamento de Solos, Universidade Federal do Rio Grande do Sul, Avenida Bento Gonçalves 7712, 91540-000 Porto Alegre, RS, Brazil

DR R. A. KING

Corrosion Services, 34 Cecil Road, Manchester M9 2RQ, UK

DR J. S. MAKI

Department of Biology, Marquette University, Wehr Life Sciences Building, Milwaukee, WI 53233, USA

PROFESSOR R. MITCHELL

Laboratory of Microbial Ecology, Division of Applied Sciences, Harvard University, 40 Oxford Street, Cambridge, MA 02138, USA

DR D. MORIN

Direction de Recherches, Département Géomatériaux et Géoprocédés, Avenue de Concyr, Orléans-La Source, BP 6009, 45060 Orléans cedex 2, France

PROFESSOR H. H. PARADIES

Biotechnology and Physical Chemistry, Markische Fachhochschule, Frauenstuhlweg 31, D-58644 Iserlohn, Germany

PROFESSOR D. E. RAWLINGS

Microbiology Department, University of Cape Town, 22 University Avenue, Private Bag, Rondebosch 7700, South Africa

PROFESSOR C. A. C. SEQUEIRA

Laboratorio de Electroquímica, Instituto Superior Técnico, Avenida Rovisco Pais, 1096 Lisboa, Portugal

PROFESSOR H. A. VIDELA

Sección de Electroquímica, INIFTA, Universidad Nacional de La Plata, Sucursal 4, Casilla de Correo 16, (1900) La Plata, Argentina

DR D. R. WOODS

Microbiology Department, University of Cape Town, 22 University Avenue, Private Bag, Rondebosch 7700, South Africa

Series Editors' Foreword

The natural, manufactured or environmental resources of the world constitute a vast range of substrates and habitats, which to a lesser or greater degree may be influenced or modified by the activities of living organisms. In the case of materials such as metals, plastics, cellulosics and stored food the response to organisms is only passive, but where a resource is a complex environmental one such as a lake or agricultural land there is an extra dynamic element, provided by its living components, that will respond to changes in an active manner.

The material and environmental resources of the world are under increasing pressure, both from the increasing demands of growing populations and also from increasing standards and aspirations of consumers. The demand for 'more and better' in all things places us in a doubly difficult situation. Imbalance in economic activities also can create difficulties; higher crop yields in one area may be at the expense of harmful eutrophication in another. Sustainability is a term now well recognized in agriculture and in certain areas of manufacturing that have planned recycling programmes, but the universal acceptance and implementation of such concepts is still some way off. Current and future innovations in materials manufacture, use and disposal may bring their own particular problems. These problems will be difficult to forecast, with no long experience to draw on.

This series of books aims to address the involvement of biological factors in material and environmental resources. The concept grew from a proposed series on the biodeterioration of materials and the biodegradation of wastes, to one which also encompassed complex environmental resources, as all these topics are interlinked.

It is the biological factors, which are so central and infringe on all human activity and yet are often overlooked, that will be examined. A building constructed with only engineering or aesthetic considerations in mind may be rendered uninhabitable if a large microbial load builds up in its atmosphere. For example, the creation of energy-economical 'tight buildings' has led to problems of condensation and attendant mould growth that have implications for both the fabric of the buildings and the health of the occupants. Again, an electrical component designed with regard only for its physical, chemical and electrical properties may be rendered useless by attack by organisms. Conformal coatings, designed to protect delicate electrical components against water, corrosion and vibration may be broken down by fungi, which can also cause direct electrical malfunctions by bridging circuits on small components.

A better understanding of how materials and organisms interact is therefore vital to the sensible and most economic choice and use of such resources both long and short term, and is the starting point for studies on the use of complex natural and artificial environments as resources. It is the intention of both the Series Editors and the Volume Editors to reflect the need for this understanding, and to present the complexities of important areas and issues in which living organisms have a profound influence.

Dennis Allsopp
Brian Flannigan
Rita Colwell

Preface

This volume links together two important aspects of the biology of metals: the extraction of metals from their ores using bacteria and the corrosion of artificial metallic objects by biological activity. The bioextraction of metals is a centuries old process, but the role of living organisms in metal leaching was only recognized some years after the discovery that microorganisms were involved in metal corrosion. Both topics are currently commanding much interest from both research and industrial sectors of society because of their great economic importance. The contributors to this volume have produced up-to-date reviews of progress in their areas of expertise. This introduction provides some basic and historical background information.

Bioextraction of metals

Leaching methods for the extraction of copper from ores were used in combination with the cementation process as early as the fifteenth century in northern Hungary. Dump leaching has been employed in many countries since this time, although the pioneer is generally regarded to be the Rio Tinto mine in Spain in 1725. The Russians and North Americans were active in the field from an early stage and by the mid-1970s the world production of copper using the dump leaching technique was estimated to be 280 000 tons, of which the USA produced 230 000 tons.

Bacteria of the genus *Thiobacillus* were first isolated by Beijerinck in 1902 and *Thiobacillus thiooxidans* was identified by Waksman in 1922. Until the 1960s, the leaching process was generally considered to be purely chemical, even though it had been shown that sulfur-oxidizing microorganisms could oxidize pyrite and sulfide ores of zinc. Even after the isolation of a pure culture of *T. ferrooxidans* from acid mine waters in 1947, it was some years before real attention was paid to the importance of these organisms in metal leaching. The first patent utilizing *Thiobacillus* was granted in the USA in 1958 and the method was used commercially in dump leaching of copper in Bingham Canyon, Utah.

The introduction of leaching technology for other metals may be considered to be the extraction of uranium from its sulfide ores in the 1960s. The commercial recovery of uranium from acid mine drainage at Eliot Lake, Canada, was begun in 1960, although it was not until 1964 that *T. ferrooxidans* was shown to be present in the drainage waters. The Agnew Lake Mines, in Northern Ontario, Canada, began full-scale leaching of uranium in 1977. The direct bioleaching of other metals has still not been shown to be economically competitive with existing methods.

In addition to direct extraction of metal, bioleaching may also be used to remove unwanted components from ores such as gold or lead prior to refining. Tank leaching of ores, leading to the modern methods used for gold extraction, did not begin even on a laboratory scale until the 1960s. Initial results were unpromising, with low oxidation rates produced by bacteria on sulfide ores (some mg/l per h). Later improvements in technology had allowed this to be increased to over 1 g/l per h by 1971, but maximum rates reported since this time seem to imply that a plateau has been reached and future increases will have to come from improvements in the microorganisms. Genetic engineering techniques applied to the leaching bacteria may offer the answer and the genetic systems of *Thiobacillus* are currently the subject of intensive research. The economics of optimum use of the world's mineral resources means that this will be an interesting and highly active research and development area in future years.

Adhesion of microorganisms to surfaces and biofilm formation

The bacteria utilized in bioleaching have been found to adsorb to the surface of the ore particles and this physical contact is believed to be important in the industrial process. Similarly, contact between microbial cells and metal has been shown to be necessary for some biocorrosion phenomena. Hence research into the adsorption of microbial cells to metal-containing surfaces is essential for an understanding of both processes.

The importance of surfaces on microbial activity was first noted in the literature by Sohngen in 1913 and, in 1918, the adsorption of bacteria on to solid particles was studied by Eisenberg. He noted that Gram-positive bacteria of high lipid content adsorbed more strongly than did Gram-negative bacteria. In the 1920s, Mudd & Mudd showed in an elegant series of experiments that bacterial adsorption to an oil/water interface depended on the degree of hydrophobicity of the cell surface. Put simply, the greater the cell surface hydrophobicity, the greater the tendency to collect at the aqueous/non-aqueous interface and also the greater the tendency to pass into the non-aqueous phase.

Following the initial adhesion of cells to an interface, further build-up of the biofilm will depend on factors such as ability of cells to form aggregates and the possible synthesis of extracellular polymeric materials, which may act as gums. Biofilms cause fouling of industrial equipment such as heat exchangers, pipelines and ship hulls, resulting in reduced heat transfer, increased corrosion and increased frictional resistance. Fouling is also of commercial concern in the microelectronics industry and in the production of paper and rolled steel. In the medical field, biofilms are of importance for their ability to harbour and protect pathogenic microorganisms. Research into biofilm formation and activity is currently changing many of the traditional views on microbially influenced metal corrosion.

Biodeterioration of metals

The first suggestion that bacteria might be involved in metal corrosion was made in relation to lead pipes by Garrett in 1891, whilst the role of bacteria in the corrosion of ferrous metals was first recognized by Gaines in 1910. A landmark in the history of microbially induced corrosion was the proposal, by the Dutch workers von Wolzogen Kühr and van der Vlugt in 1934, of an electrochemical explanation for the anaerobic corrosion of pipes in soil induced by sulfate-reducing bacteria (SRB). Their Cathodic Depolarization Theory implicated the activity of the bacterial enzyme hydrogenase in the corrosion process. They concluded that only active sulfate reduction could effect the anaerobic corrosion of cast iron. Although the role of hydrogenase in corrosion has since been questioned, notably by Booth & Tiller in 1968, there is no doubt that the process of sulfate reduction is essential. Following the Dutch publication, a number of alternative theories to explain SRB-mediated corrosion were proposed by workers such as King & Miller in 1971, Costello in 1974, and Iverson & Olson in 1983 and it is now generally accepted that the phenomenon is multifactorial.

The relatively recent recognition of the importance of sessile (attached) microbial cells and biofilms in corrosion has led to the elaboration of a number of new monitoring techniques and has shown that the traditional electrochemical view of corrosion, which has held sway since the early pioneer work of Booth, Tiller and Iverson, among others, is in need of radical rethinking. In addition, the need for improved control methods, both by cathodic protection and coatings and by the use of biocides, has become obvious. Future research in this subject will include the development of more sensitive and more rapid detection techniques, together with the elaboration of control agents and processes designed to combat sessile, as well as planktonic, organisms. Economic losses caused by biologically mediated corrosion have been estimated to be above 1% of the gross national product in the UK and hence investment into the understanding and control of these processes should have a high priority.

It is intended that this volume should indicate the economic importance of the bioextraction and biocorrosion of metals, in addition to reviewing the current research in progress. We hope that we have achieved these aims and should like to thank all the authors for their excellent contributions.

Christine C. Gaylarde
Héctor A. Videla