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INTERFACIAL PHENOMENA IN BIOTECHNOLOGY AND MATERIALS PROCESSING

Yosry A. Attia
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Editors

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Interfacial Phenomena in Biotechnology and Materials Processing

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PREFACE

The importance of interfacial phenomena in the processing of biological organic and inorganic materials has been increasingly recognized in recent years. Many processes such as separations, stabilization, aggregation, preparation, formation, transport, lubrication, adhesion, etc. depend primarily on interfacial behavior of the materials involved. The utilization of interfacial and colloidal properties of materials are numerous and include such applications as protein separation, biomembranes, contact lenses, bioengineering of surface-active materials, bacterial transport, bioleaching, superconducting materials, high-performance ceramics, advanced minerals separations, metals processing and composite materials. In materials processing, for example, the development of high-performance ceramics and superconductors requires component reliability with low cost. To meet these goals, refinement of existing forming processes or the development of new processes is required. An understanding of the interactions between particles constituting high-performance materials is recognized as a critical factor in the development of the required technology. In advanced materials processing via the chemical route, synthesis of inorganic, organic, polymer and surface chemistry is involved. It is recognized that controlling the interfacial chemistry during the early stages would lead to the production of materials with the desired properties. Interfacial phenomena are of major significance also in mineral processing. The efficiency of techniques such as selective flocculation for the beneficiation of finely disseminated low grade ores depends critically on the surface chemistry of the particles and solution chemistry of the polymers employed. Understanding the dispersion and aggregation behavior of fine particle suspensions with and without chemical additives is therefore a prerequisite to developing suitable solid-solid separation technology.

This book presents the edited proceedings of an international symposium at which researchers reported the latest discoveries and theoretical and experimental developments leading to the recent advances in the scientific principles and applications of interfacial phenomena in many fields of biotechnology and materials processing. All the papers included in this book, which were selected from the symposium proceedings of over 60 papers, have been peer-reviewed and revised accordingly. Major technical areas covered in this book are: Interfacial Phenomena in Biotechnology; Interfacial Phenomena in Advanced Materials Processing; Interfacial Phenomena in Minerals Processing; and Colloid Formation and Characterization. This book will be of particular interest to researchers, graduate students, and all persons involved in biotechnology, ceramics, superconducting materials, biomedical applications, minerals and energy conservation, as well as investors in industry and new technology.

The success of the symposium and the realization of this book was due to the great cooperation received from the authors, reviewers and the organizing committee, all of whom we would like to thank very much. The financial support of the Ohio State University, which made possible the editing of this book, is gratefully acknowledged. The book cover design was made possible by the University of Florida and we are indebted to them. We would like to thank Patty Permar, Toni DiGeranimo and Chris Schulz as well as Dr. Attia's graduate students, Catherine Dentan, Shanning Yu and Farshad Bavarian, for their help and assistance in editing the manuscripts in a timely manner.

February 5, 1988
Columbus, Ohio

Yosry A. Attia
Brij M. Moudgil
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BACTERIAL CELL ATTACHMENT AND SULFUR LEACHING IN MICROBIAL COAL DESULFURIZATION BY *Sulfolobus Acidocaldarius*

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SUMMARY

Pre-leaching cell attachment and bacterial leaching were studied on finely divided Kentucky #9 coal and an Ohio coal mixture. Rates and extents of *Sulfolobus acidocaldarius* cell attachment on the coals were determined. Batch leaching of the coals by the microorganism were investigated by monitoring sulfate and iron ions released to the leaching solution. The Kentucky #9 coal adsorbed more cells and yielded higher sulfur and iron leaching rates. The results were interpreted in terms of mechanisms of microbial sulfur oxidation, surface areas of the coals and sulfur-containing grain sizes in the coals.

INTRODUCTION

Bacterial cell attachment is closely related to sulfur leaching in microbial coal desulfurization. The mechanism for pyritic sulfur oxidation was first proposed by Silverman (ref. 1) for *Thiobacillus* species as comprised of direct and indirect oxidative components. The direct mechanism requires direct contact between bacteria and pyrite since no extracellular enzymes are involved. In the indirect mechanism, the ferric iron ion chemically reacts with pyrite to give ferrous ions and elemental sulfur. The bacteria then oxidize ferrous ions to ferric ions and oxidize elemental sulfur to sulfate ions. The chemical and biological reactions are summarized as follows (ref. 1):

$$2\ FeS_2 + 7\ O_2 + 2\ H_2O \xrightarrow{\text{Bacteria}} 2\ FeSO_4 + 2\ H_2SO_4 \quad (1)$$

$$2\ FeSO_4 + 1/2\ O_2 + H_2SO_4 \xrightarrow{\text{Bacteria}} Fe_2(SO_4)_3 + H_2O \quad (2)$$

Overall reaction:

$$2\ FeS_2 + H_2O + 15/2\ O_2 \xrightarrow{\text{Bacteria}} Fe_2(SO_4)_3 + H_2SO_4 \quad (3)$$

Indirect mechanism:

$$FeS_2 + Fe_2(SO_4)_3 \longrightarrow 3\ FeSO_4 + 2\ S \quad (4)$$

$$2S + 3\ O_2 + 2\ H_2O \xrightarrow{\text{Bacteria}} 2\ H_2SO_4 \quad (5)$$

$$2\ FeSO_4 + 1/2\ O_2 + H_2SO_4 \xrightarrow{Bacteria} Fe_2(SO_4)_3 + H_2O \quad (2)$$

In the absence of bacteria, the regeneration of ferric iron ions is the rate limiting step for pyrite oxidation. The bacteria increase the pyrite oxidation rate by oxidizing ferrous iron to ferric iron ions.

The application of the bacterial mechanisms derived for Thiobacillus ferrooxidans to Sulfolobus acidocaldarius is not well documented. One of the reasons is that the cell wall structure of Sulfolobus is different from that of Thiobacillus by the absence of a peptidoglycan layer. However, direct or indirect mechanisms, which are the result of bacterial activities, can be assumed to be valid for Sulfolobus species because:

1) Sulfolobus oxidizes Fe^{2+}, S^0 and pyrite at acidophilic conditions with production of Fe^{3+} and SO_4^{2-} (refs. 2-4),
2) Selective cell attachment of S. brierleyi and of S. acidocaldarius to pyrite have been observed (refs. 5-6)
3) Evidence of Fe and S at the cell attaching sites of S. acidocaldarius on coal was reported (ref. 7)

Irreversible adhesion of Thiobacillus ferrooxidans on substrate surfaces has been studied by many investigators (refs. 8-9). It is generally agreed that a wetting agent is responsible for cell adhesion. Murr and Berry studied cell attachment on mineral ores by scanning electron microscopy and concluded that adhesion is selective on sulfide surfaces (ref. 5). Adsorption of T. ferrooxidans on coal and other particles was studied by some investigators (refs. 10-11). Some researchers even found that surfactants enhanced contact between cells and the sulfide surface and therefore increased sulfur removal rates (ref. 12). The pyrite-selective adsorption characteristics were applied to improve physical separation of coal and pyrite as described in the literature (refs. 13-14). In those studies, the properties of pyrite particle surfaces were modified by cell adsorption. Then the coal was separated by oil agglomeration, selective flocculation or froth flotation.

The attachment of Sulfolobus to solid particles has been reported by some investigators (ref. 3, ref. 5, ref. 15). In their study of sulfur oxidation by S. acidocaldarius, Shivvers and Brock observed that the cells were attached to sulfur crystals until the late exponential stage and stationary stage were achieved (ref. 16). Weiss also studied the phenomenon of cell attachment for S. acidocaldarius and found that the cells attached to sulfur crystals by means of pili (ref. 15). He indicated that cell