This document is the eighth quarterly status report on a project that is conducted at the High Temperature Gasdynamics Laboratory at Stanford University, Stanford, California and is
concerned with enhancing the transformation of iron pyrite to non-slagging species during staged, low-NO$_x$ pulverized coal (P.C.) combustion. In general, the project has the following objectives: (1) the characterization of the various mechanisms of intraparticle mass transfer and chemical reaction that control overall pyrite combustion rates and (2) the synthesis of the reaction rate resistances of the various mechanisms into a general rate expression for pyrite combustion. The knowledge gained from this project will be incorporated into numerical codes and utilized to formulate slagging abatement strategies involving the minor adjustment of firing conditions. Ultimately, the benefit of this research program is intended to be an increase in the range of coals compatible with staged, low-NO$_x$ combustor retrofits.


An excellent knowledge base in soil and water chemistry - the ideal basic text for students of the environmental sciences In Environmental Soil and Water Chemistry, leading soil and water authority V. P. Evangelou presents a complete overview of the principles and applications of soil science, addressing the subject by viewing the interactions between soil and water as a basis for understanding the nature, extent, and treatment of polluted soil and water. The text opens with a discussion of principles-the fundamental tenets of chemistry needed to understand soil and water quality and treatment of polluted resources-and continues with a look at applications for the control and treatment of soil and water. Suitable for advanced undergraduates and beginning graduate students, this extensive, timely volume covers: * Water chemistry and mineral solubility; soil minerals and surface chemical properties and their behavior; and electrochemistry and kinetics * The control of agricultural chemical pollution and land disturbance pollution; colloids and transport processes in soils; and technologies for measuring quality and executing treatment * Specific chemical contaminants and the procedures for their neutralization In a world where chemical pollutants pose a grave threat to the earth's natural resources, Environmental Soil and Water Chemistry offers students both an excellent textbook and a handy reference on the wide spectrum of environmental problems they will confront outside the classroom.

Surface Water Pollution and its Control

The accumulation of large amounts of ash from fossil fuel combustion for electric power plant generation is becoming a major environmental concern in the United States. Furthermore, stringent environmental regulations mandated by the Environmental Protection Agency through the Clean Air Act, Clean Water Act, Resource Conservation and Recovery Act, as well as state and local environmental regulations may result in even more ash production with subsequent contact with the environment. The concentrations of trace elements in coal residues are extremely variable and depend on the composition of the original coal, conditions during combustion, the efficiency of emission control devices, storage and handling of byproducts, and climate. The research papers in this book were presented as a part of the
Sixth International Conference on the Biogeochemistry of Trace Elements held at the University of Guelph, Ontario, Canada, from July 29-August 2, 2001. The purpose of this conference was to present current knowledge on the source, pathways, behavior and effects of trace elements in soils, waters, plants and animals. In addition, the book also includes invited research papers from scientists who have done significant research in the area of coal and coal combustion byproducts. All the research papers presented herein have been subjected to peer review.

Environmental Soil and Water Chemistry

Pyrite Oxidation and its Control is the single available text on the market that presents the latest findings on pyrite oxidation and acid mine drainage (AMD). This new information is an indispensable reference for generating new concepts and technologies for controlling pyrite oxidation. This book focuses on pyrite oxidation theory, experimental findings on oxidation mechanisms, as well as applications and limitations of amelioration technologies. The text also includes discussions on the theory and potential application of novel pyrite microencapsulation technologies for controlling pyrite oxidation currently under investigation in the author's laboratory.

Bernissart Dinosaurs and Early Cretaceous Terrestrial Ecosystems

Cryosols

In 1878, the first complete dinosaur skeleton was discovered in a coal mine in Bernissart, Belgium. Iguanodon, first described by Gideon Mantell on the basis of fragments discovered in England in 1824, was initially reconstructed as an iguana-like reptile or a heavily built, horned quadruped. However, the Bernissart skeleton changed all that. The animal was displayed in an upright posture similar to a kangaroo, and later with its tail off the ground like the dinosaur we know of today. Focusing on the Bernissant discoveries, this book presents the latest research on Iguanodon and other denizens of the Cretaceous ecosystems of Europe, Asia, and Africa. Pascal Godefroit and contributors consider the Bernissart locality itself and the new research programs that are underway there. The book also presents a systematic revision of Iguanodon; new material from Spain, Romania, China, and Kazakhstan; studies of other Early Cretaceous terrestrial ecosystems; and examinations of Cretaceous vertebrate faunas.

Basics of Metal Mining Influenced Water

Basics of Metal Mining Influenced Water is a must-read for planners, regulators, consultants, land managers, students, researchers, or others concerned about the environmentally sound management of metal mine wastes and drainage quality. The first of a series of six handbooks on technologies for managing metal mine and metallurgical process draining, this book offers a unique, comprehensive perspective on the subject. Unlike other texts that focus primarily on acid drainage from coal mines, the authors examine both acidic and neutral pH waters that can be hazardous to the environment. Planning a new mine in today's increasingly contentious regulatory and political environment demands a different philosophy. Basics of Metal Mining Influenced Water takes an innovative, holistic approach by considering all aspects of the mine life cycle, including closure. Written by a team of experts from state and federal governments, academia, and the mining industry, Basics of Metal Mining Influenced Water also discusses the major physical and chemical relationships between mining, climate, environment, and mine waste drainage quality. The authors have included an extensive glossary defining hundreds of technical terms for easier reading and understanding.

EPA-600/7

Control of Pyrite Surface Chemistry in Physical Coal Cleaning. Tenth Quarterly Progress Report, December 1, 1991--February 29, 1992

Acid mine drainage (AMD), an acidic and dissolved metal effluent from oxidative dissolution of sulphide minerals, particularly pyrite, in waste rock dumps and tailings dams, has serious impacts on the receiving environment. Legislation on mine waste management and AMD emission and heavy financial burdens for AMD treatment have forced mining operators to look for improved, cost-effective alternatives for reducing acid generation from the source during mining operations and after closure of the mine. Currently, there are many options to diminish sulphide or pyrite oxidation including passivating barrier methods that aim to isolate pyrite surfaces from oxygen or water, chemical additives and inhibition of iron-oxidising and sulphide oxidising bacteria. Moderation of pyrite oxidation can significantly lower acid generation rates and reduce AMD emission. This dissertation is composed of fundamental and applied studies that aim to understand formation conditions of surface coatings on pyrite surface and the effectiveness of these coatings in preventing the oxidation process which is the primary source of acid mine drainage.

Water Pollution Control Research Series 14010 DKN 11/70

Control of Pyrite Surface Chemistry in Physical Coal Cleaning. Final Report
This document is the seventh quarterly status report on a project that is conducted at the High Temperature Gasdynamics Laboratory at Stanford University, Stanford, California and is concerned with enhancing the transformation of iron pyrite to non-slagging species during staged, low-NO\(_X\) pulverized coal (P.C.) combustion. The project aims to identify the mechanisms of pyrite combustion and to quantify their effects, in order to formulate a general rate expression for the combustion of pyrite that accounts for coal properties as well as furnace conditions. In general, the project has the following objectives: 1) the characterization of the various mechanisms of intraparticle mass transfer and chemical reaction that control overall pyrite combustion rates and 2) the synthesis of the reaction rate resistances of the various mechanisms into a general rate expression for pyrite combustion. The knowledge gained from this project will be incorporated into numerical codes and utilized to formulate slagging abatement strategies involving the minor adjustment of firing conditions. Ultimately, the benefit of this research program is intended to be an increase in the range of coals compatible with staged, low-NO\(_X\) combuster retrofits. 9 refs., 12 figs.

Pyrite Oxidation and Its Control

In Part I, Surface Chemistry of Coal Pyrite the mechanisms responsible for the inefficient rejection of coal pyrite were investigated using a number of experimental techniques. The test results demonstrate that the hydrophobicity of coal pyrite is related to the surface products formed during oxidation in aqueous solutions. During oxidation, a sulfur-rich surface layer is produced in near neutral pH solutions. This surface layer is composed mainly of sulfur species in the form of an iron-polysulfide along with a smaller amount of iron oxide/hydroxides. The floatability coal pyrite increases dramatically in the presence of frothers and hydrocarbon collectors. These reagents are believed to absorb on the weakly hydrophobic pyrite surfaces as a result of hydrophobic interaction forces. In Part III, Developing the Best Possible Rejection Schemes, a number of pyrite depressants were evaluated in column and conventional flotation tests. These included manganese (Mn) metal, chelating agents quinone and diethylenetriamine (DETA), and several commercially-available organic depressants. Of these, the additives which serve as reducing agents were found to be most effective. Reducing agents were used to prevent pyrite oxidation and/or remove oxidation products present on previously oxidized surfaces. These data show that Mn is a significantly stronger depressant for pyrite than quinone or DETA. Important factors in determining the pyrite depression effect of Mn include the slurry solid content during conditioning, the addition of acid (HCl), and the amount of Mn. The acid helps remove the oxide layer from the surface of Mn and promotes the depression of pyrite by Mn.

Control of Pyrite Surface Chemistry in Physical Coal Cleaning. Twelfth
One of the most difficult separations in minerals processing involves the differential flotation of pyrite and coal. Under practical flotation conditions, they are both hydrophobic and no cost-effective method has been developed to efficiently reject the pyrite. The problem arises from inherent floatability of coal and pyrite. Coal is naturally hydrophobic and remains so under practical flotation. Although pyrite is believed to be naturally hydrophilic under practical flotation conditions it undergoes a relatively rapid incipient oxidation reaction that causes "self-induced" flotation. The oxidation product responsible for "self-induced" flotation is believed to be a metal polysulfide, excess sulfur in the lattice, or in some cases elemental sulfur. It is believed that if incipient oxidation of pyrite could be prevented, good pyrite rejection could be obtained. In order to gain a better understanding of how pyrite oxidizes, a new method of preparing fresh, unoxidized pyrite surfaces and a new method of studying pyrite oxidation have been developed this reporting period.

Bureau of Mines Research and Technologic Work on Coal, 1962

The separation of pyrite from coal by flotation is based on exploiting the wettability difference between coal and pyrite. There is evidence that the wettability of coal pyrite changes upon superficial oxidation. Therefore, the oxidation of coal pyrite has been studied under carefully controlled electrochemical conditions. In order to identify the species responsible for the changes in wettability, the surface products formed during oxidation have been identified by means of various surface analysis techniques, including X-ray photoelectron spectroscopy (XPS) and ion scattering spectroscopy (ISS). It has been found that pyrite oxidation creates a sulfur-rich surface along with iron oxides/hydroxides. The ratio between these hydrophobic and hydrophilic species correlates well with the results of the wettability measurements.

Tenth Anniversary of the Surface Mining Control and Reclamation Act of 1977

This is the 9th quarterly technical progress report for the project entitled Pyrite surface characterization and control for advanced fine coal desulfurization technologies”, DE-FG22-90PC90295. The work presented in this report was performed from September 1, 1992 to November 31, 1992. The objective of the project is to conduct extensive fundamental studies on the surface chemistry of pyrite oxidation and flotation and to understand how the alteration of the coal-pyrite surface affects the efficiency of pyrite rejection in coal flotation. During this reporting period, the surface oxidation of pyrite in various electrolytes was investigated. It has been demonstrated, for the first time, that borate, a pH buffer and electrolyte used by many previous investigators in studying sulfide mineral oxidation, actively...
participates in the surface oxidation of pyrite. In borate solutions, the surface oxidation of pyrite is strongly enhanced. The anodic oxidation potential of pyrite is lowered by more than 0.4 volts. The initial reaction of the borate enhanced pyrite oxidation can be described by: \( \text{FeS}_2 + \text{B(OH)}_4 \rightarrow [\text{S}_2\text{Fe-B(OH)}_4]_{\text{surf}} + e \). This reaction is irreversible and is controlled by the mass-transfer of borate species from the solution to the surface. It has been shown that the above reaction inhibits the adsorption of xanthate on pyrite. Comparative studies have been made with other sulfide minerals. The solution chemistry of the iron-borate systems have been studied to understand the electrochemical results.

**Control of Pyrite Surface Chemistry in Physical Coal Cleaning**

**Environmental Mineralogy**

Volume is indexed by Thomson Reuters CPCI-S (WoS). The main focus of this collection of peer-reviewed articles is biohydrometallurgy. This is the field of microbial ecology which is the key to answering central questions concerning not only the diversity and behavior of microorganisms in commercial operations, but also possible applications in biohydrometallurgy of extremophiles coming from very different environments. The 134 papers are grouped as follows: Chapter 1: Microbial Ecology, Geomicrobiology and Bioprospecting in Natural and Mining Environments; Chapter 2: Omics, Molecular Genetics and Biochemistry of Microorganisms in Mining Processes; Chapter 3: Industrial Biohydrometallurgy: Studies, Practices and Operation; Chapter 4: Biohydrometallurgy as a Remediation Strategy.

**Mine Drainage Abstracts**

**Chemistry of Trace Elements in Fly Ash**

Cryosols – permafrost – occupy a unique part of the earth and have properties greatly different from other soils. They also occur where the greatest impact of global warming is predicted. This is the first book bring together the leading researchers in the area of permafrost soils to produce a review of the geography, cryogenic soil forming processes, ecological processes, classification and use of soils that are affected by permafrost.

**Practical Considerations of Pyrite Oxidation Control in Uranium Tailings**

Pyrite (FeS2) is one of the most common naturally occurring minerals that is present in many subsurface environments. It plays an important role in the genesis of enriched ore deposits through weathering reactions, is the most abundant sulfide mineral in many mine tailings, and is the primary source of acid drainage from mines and waste rock piles. The pyrite oxidation reaction serves as a prototype for oxidative weathering processes with broad significance for geoscientific, engineering, and environmental applications. Mathematical modeling of these
 processes is extremely challenging because aqueous concentrations of key species vary over an enormous range, oxygen inventory and supply are typically small in comparison to pyrite inventory, and chemical reactions are complex, involving kinetic control and microbial catalysis. We present the mathematical formulation of a general multi-phase advective-diffusive reactive transport model for redox processes. Two alternative implementations were made in the TOUGHREACT and TOUGH2-CHEM simulation codes which use sequential iteration and simultaneous solution, respectively. The simulators are applied to reactive consumption of pyrite in (1) saturated flow of oxidizing water, and (2) saturated-unsaturated flow in which oxygen transport occurs in both aqueous and gas phases. Geochemical evolutions predicted from different process models are compared, and issues of numerical accuracy and efficiency are discussed.

Evaluation of Coal Refuse Reclamation Projects for Long-term Control of Pyrite Oxidation and Water Quality

Pyrite Oxidation in Saturated and Unsaturated Porous Media Flow

This is the 9th quarterly technical progress report for the project entitled "Pyrite surface characterization and control for advanced fine coal desulfurization technologies", DE-FG22-90PC90295. The work presented in this report was performed from September 1, 1992 to November 31, 1992. The objective of the project is to conduct extensive fundamental studies on the surface chemistry of pyrite oxidation and flotation and to understand how the alteration of the coal-pyrite surface affects the efficiency of pyrite rejection in coal flotation. During this reporting period, the surface oxidation of pyrite in various electrolytes was investigated. It has been demonstrated, for the first time, that borate, a pH buffer and electrolyte used by many previous investigators in studying sulfide mineral oxidation, actively participates in the surface oxidation of pyrite. In borate solutions, the surface oxidation of pyrite is tronly enhanced. The anodic oxidation potential of pyrite is lowered by more than 0.4 volts. The initial reaction of the borate enhanced pyrite oxidation can be described by: FeS2 + B(OH)4{sup =} --> [S2Fe-B(OH)4]{sub surf} + e. This reaction is irreversible and is controlled by the mass-transfer of borate species from the solution to the surface. It has been shown that the above reaction inhibits the adsorption of xanthate on pyrite. Comparative studies have been made with other sulfide minerals. The solution chemistry of the iron-borate systems have been studied to understand the electrochemical results.

Pyrite Oxidation and Its Control

Information Circular

The Treatise on Geochemistry is the first work providing a comprehensive, integrated summary of the present state of geochemistry. It deals with all the major subjects in the field, ranging from the chemistry of the solar system to environmental geochemistry. The Treatise

Environmental Geochemistry

The overall objective is to develop methodologies by which metasilicate or fly ash may produce an effective coating on pyrite surfaces for inhibiting pyrite oxidation. During the past six months, the investigators produced wet chemistry evidence demonstrating that pyrite-HCO$_3^-$ complexes promote pyrite oxidation. This is an important finding for their overall strategy in controlling pyrite oxidation because it suggests that pyrite microencapsulation is important in order to control oxidation in near circumneutral pH environments produced by addition of alkaline material, e.g., fly ash. In their previous studies, the investigators reported that pyrite microencapsulation could be carried out by reacting pyrite with a pH buffered solution and in the presence of metasilicate. The coating formed on the surface of pyrite appeared to be an amorphous iron-oxide-silicate material which inhibited pyrite oxidation. During this past six months, the investigators evaluated: the molecular mechanisms of silicate adsorption by iron oxide; the effects of silicate on the bulk and surface properties of iron oxides; and the effect of silicate on metal-cation adsorption properties by iron oxides.

Control of Pyrite Surface Chemistry in Physical Coal Cleaning. Technical Progress Report for the Ninth Quarter, September 1--November 30, 1991

Over the past 10 years, much research has provided convincing evidence that one major difficulty in using froth flotation to separate pyrite from coal is the "self-induced" flotation of pyrite. Numerous studies have attempted to identify reactions that occur under moderate oxidizing conditions, which lead to self-induced flotation, and to identify the oxidation products. During the past two report periods, it was established that: (1) freshly fractured pyrite surfaces immediately assume, at fracture, an electrode potential several hundred millivolts more negative than the usual steady state mixed potentials. Within minutes after fracture, the electrodes oxidize and reach higher steady state potentials. It was also shown, by photocurrent measurements, that a negative surface charge (upward band bending) already exists on freshly fractured pyrite, and (2) particle bed electrodes can be used to control the oxidation of pyrite and to precisely determine the electrochemical conditions where flotation occurs, or is depressed. By circulating the solution phase to an ultraviolet spectrometer, soluble
products produced on pyrite by oxidation and reduction can be determined, e.g., HS\(^{-}\) was identified as a soluble cathodic reduction product. These and other studies have provided considerable information concerning the anodic oxidation of pyrite. Much less is known about the mechanism and kinetics of oxygen reduction, the other half of the mixed potential reaction. To better understand pyrite oxidation kinetics and determine if oxygen reduction is rate determining, studies have been conducted during this report period on the oxygen reduction reaction with pyrite. In addition, to provide further support that the potential of particle bed electrodes can be controlled, the electro-adsorption and desorption of an organic surfactant was studied.

Control of Eh and PH to Evaluate the Rate of Pyrite Oxidation

Making use of information drawn from a variety of sources this book addresses the problems created by all the principal forms of surface water pollution. The chemical, physical and biochemical parameters of water quality, without an appreciation of which no true understanding of river pollution control is possible, are discussed in some detail as are the roles of the variety of micro and other organisms present in natural waters. Self-purification of surface waters is considered in some detail. An up-to-date review of the legislation relating to surface water pollution control both in the UK and the USA is included as is an informative introduction to the potentially confusing subject of water quality modelling. The book provides the student, researcher and scientist interested in river pollution and pollution control with the most up-to-date and comprehensive coverage of the subject available anywhere.

Integration of Scientific and Industrial Knowledge on Biohydrometallurgy


Over the past 10 years, much research has provided convincing evidence that one major difficulty in using froth flotation to separate pyrite from coal is the self-induced" flotation of pyrite. Numerous studies have attempted to identify reactions that occur under moderate oxidizing conditions, which lead to self-induced flotation, and to identify the oxidization products. During the past two report periods, it was established that: (1) freshly fractured pyrite surfaces immediately assume, at fracture, an electrode potential several hundred millivolts more negative than the usual steady state mixed potentials. Within minutes after fracture, the electrodes oxidize and reach higher steady state potentials. It was also shown, by photocurrent measurements, that a negative surface charge (upward band bending) already exists on freshly fractured pyrite, and (2) particle bed electrodes can be used to control the oxidation of pyrite and to precisely determine the electrochemical conditions where flotation occurs, or is depressed. By circulating the solution phase to an ultraviolet spectrometer, soluble products produced on pyrite by oxidation and reduction can be determined, e.g., HS\(^{[\text{sup} [\text{minus}]]}\) was identified as a soluble cathodic reduction product. These and other studies have
provided considerable information concerning the anodic oxidation of pyrite. Much less is known about the mechanism and kinetics of oxygen reduction, the other half of the mixed potential reaction. To better understand pyrite oxidation kinetics and determine if oxygen reduction is rate determining, studies have been conducted during this report period on the oxygen reduction reaction with pyrite. In addition, to provide further support that the potential of particle bed electrodes can be controlled, the electro-adsorption and desorption of an organic surfactant was studied.

**Mechanisms of Pyrite Oxidation to Non-slagging Species. Quarterly Report, April 1, 1996 - June 30, 1996**

Pyrite Oxidation and its Control is the single available text on the market that presents the latest findings on pyrite oxidation and acid mine drainage (AMD). This new information is an indispensable reference for generating new concepts and technologies for controlling pyrite oxidation. This book focuses on pyrite oxidation theory, experimental findings on oxidation mechanisms, as well as applications and limitations of amelioration technologies. The text also includes discussions on the theory and potential application of novel pyrite microencapsulation technologies for controlling pyrite oxidation currently under investigation in the author's laboratory.

**Control of Acid Drainage from Coal Refuse Using Anionic Surfactants**

Pyrite Surface Characterization and Control for Advanced Fine Coal Desulfurization Technologies

**The Mechanism and Conditions of Pyrite Surface Passivation Layer Formation in Preventing Its Oxidation**

The objective of the project is to conduct extensive fundamental studies on the surface chemistry of pyrite oxidation and flotation and to understand how the alteration of the coal-pyrite surface affects the efficiency of pyrite rejection in coal flotation. This report summarizes the studies in the following three aspects: (1) the effects of borate, used as pH buffer or electrolyte, on the pyrite surface oxidation and flotation; (2) the quantification of pyrite surface oxidation kinetics under different oxidation potentials; and (3) finding new coal-pyrite depressants. It has been demonstrated, for the first time, that borate, a pH buffer and electrolyte used by many previous investigators in studying pyrite oxidation, actively participates in the surface oxidation of pyrite. In high borate concentration solutions, the surface oxidation of pyrite is strongly enhanced. The anodic oxidation potential of pyrite is lowered by more than 0.4 volts. At low borate concentration, borate is chemisorbed on pyrite surfaces. In the intermediate concentration range, borate dissolves surface iron compounds. Consequently, the flotation of pyrite in borate solutions (using fuel oil as collector) displays
depression-flotation-depression phenomena as the borate concentration is increased. The oxidation kinetics of pyrite surfaces has been determined by AC impedance spectroscopy. At low oxidation potentials, only capacitive behavior is observed. However, at high oxidation potentials, an inductive loop appears. The charge transfer resistance decreases with increasing potential, indicating that the oxidation rate increases with increasing potential. A chemical reagent has been found to be very effective in depressing the flotation of coal-pyrites from different sources, while it has little effects on the flotation of coal. The surface chemistry involved in the selective pyrite depression by this new reagent has been investigated by electrochemical studies and contact angle measurements.

Pyrite Oxidation in Carbonate - Buffered Systems