

Mechanisms of Perchlorate Degradation: An Overview

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5th Annual Joint Services Pollution Prevention and
Hazardous Waste Management Conference and Exhibition
San Antonio, Texas
August 23, 2000



Presentation Overview

- **Perchlorate Chemistry and Biotreatment Mechanisms**
- **In Situ Biotreatment Techniques for Perchlorate-Contaminated Soil and Groundwater**
- **Case Study**
 - Application of Innovative In Situ Biotreatment Technology

Physical/Chemical Properties of Perchlorate

■ Ammonium Perchlorate Dissociation

■ Solubility

- Perchlorate (inorganic salts) is Extremely Soluble in Water
 - Sodium Perchlorate: 8 M
 - Potassium Perchlorate: 0.12 M

Physical/Chemical Properties of Perchlorate

■ Adsorption

- Perchlorate Adsorbs Weakly to Soil
- Factors Include:
 - Soil Mineralogy
 - Organic Matter
 - pH
 - Ionic Strength
 - Competing Ions



Physical/Chemical Properties of Perchlorate

■ Volatility

- Relatively Low Vapor Pressure
- Volatilization is Not a Critical Remediation or Health Consideration

■ Chemical Reactivity

- Reduction is Thermodynamically Favorable
- Kinetically Limited in the Absence of Chemical or Biological Enzymes/Catalysts

Physical/Chemical Properties of Perchlorate

■ Precipitation and Complexation

- Precipitates Poorly in Saturated Systems
- **Presence of K^{+1}** \implies Precipitation of Potassium Perchlorate
- **High Concentrations** \implies Potential Ammonium or Potassium Perchlorate Precipitation in Vadose Zone
- Poor Complexing Agent

Biochemistry of Perchlorate

- Oxidized State
- Reduction is Thermodynamically Favorable
 - Acts as an Electron Acceptor in Microbial-Mediated Enzymatic Reactions
 - Perchlorate Respiration
 - Enzymes Reduce Kinetic Barrier and Thereby Facilitate Degradation

Biochemistry of Perchlorate

- **Biodegradation Generally Occurs Under Anaerobic Conditions**
 - Absence of Oxygen
- **An Electron Donor is Required to Complete the Microbial Degradation Process**
 - Carbon Substrate or Other Energy Source
- **Perchlorate Competes with Other Electron Acceptors**

Commonly Utilized Substrates for Perchlorate Biodegradation

- **Natural Organic Carbon (TOC)**
- **Natural Organic Carbon Additives**
 - Compost
 - Cottonseed
 - Mulch/Wood Chips
 - Vegetable Oil
 - Kenaf
- **Industrial Sources: Food Process Wastes**

Commonly Utilized Substrates for Perchlorate Biodegradation

■ Synthetic Carbon Sources

- Fructose/Sucrose
- Acetate
- Lactate
- Ethanol
- Citrate
- Slow-Release Patented Lactate Compounds

■ Carbon Source Selection

■ Advantages and Limitations

Electron Acceptor Competition

- Dissolved Oxygen
- Nitrates
- Sulfates
- Chlorinated Solvents
 - Related Issues:
 - Overcoming Competition
 - Nitrate Reduction Similarity
 - Co-Contaminants

Perchlorate-Reducing Microorganisms

■ Bacterial Isolates

- HAP-1
- KJ1

■ Mixed Microbial Cultures

- Industrial Sources
- Natural (Indigenous and Ubiquitous) Cultures
- Domestic Wastewater

Bench-Scale Studies

■ Significance

- Perchlorate is a Relatively New Environmental Contaminant of Concern
- Site Specific Wastes and Conditions
- Can Cleanup Levels be Obtained?
- Instills Remediation Confidence

■ Objectives

- Microbial Kinetics and Degradation Rates
- Design Scale-up Factors

Bench-Scale Studies

■ Types

- Soil
- Groundwater

■ Mechanisms

- Aqueous Phase
- Attached Growth

■ Location

- Ex Situ
- In Situ

■ Bioreactors

- Batch
- Continuous

Bench-Scale Studies: Ex Situ

■ Media Selection

- Sand
- Plastic Bio-Rings
- Gravel
- Plastic Beads

■ Substrates

- Ethanol
- Lactate
- Acetate
- Fructose (or Molasses)

■ Microbial Acclimation/Inoculation

■ Flow Rates

Bench-Scale Studies: In Situ

■ Bio-Barrier Simulation

■ Attached Media Selection

– Natural Soil

– Gravel

■ Substrates

– Compost

– Cottonseed

– Sawdust

– Slow-Release Patented

– Vegetable Oil

Lactate Compounds

Bench-Scale Studies: In Situ

- **With/Without Microbial Inoculation**
- **Cleanup Goal Attainment**
- **Biochemical Changes**
- **Length of Effectiveness**

Perchlorate Biodegradation Summary

- Natural Treatment
- Relatively Low Cost
- Reduces Concentrations Below Detection Limits
- Co-Contaminant Reduction
- In Situ and Ex Situ Applications

Perchlorate Biodegradation Summary

■ Design Issues

- Length of Effectiveness
- Microbe Selection and Acclimation
- Concentrations
- Treatment Consistency: Meets Regulatory Requirements
- Operation & Maintenance

Perchlorate Biodegradation

Summary

- Applications
- Limitations
- Conditions
- Challenges
- Public Acceptance