Bench Testing for the Successful Implementation of Remediation Technologies

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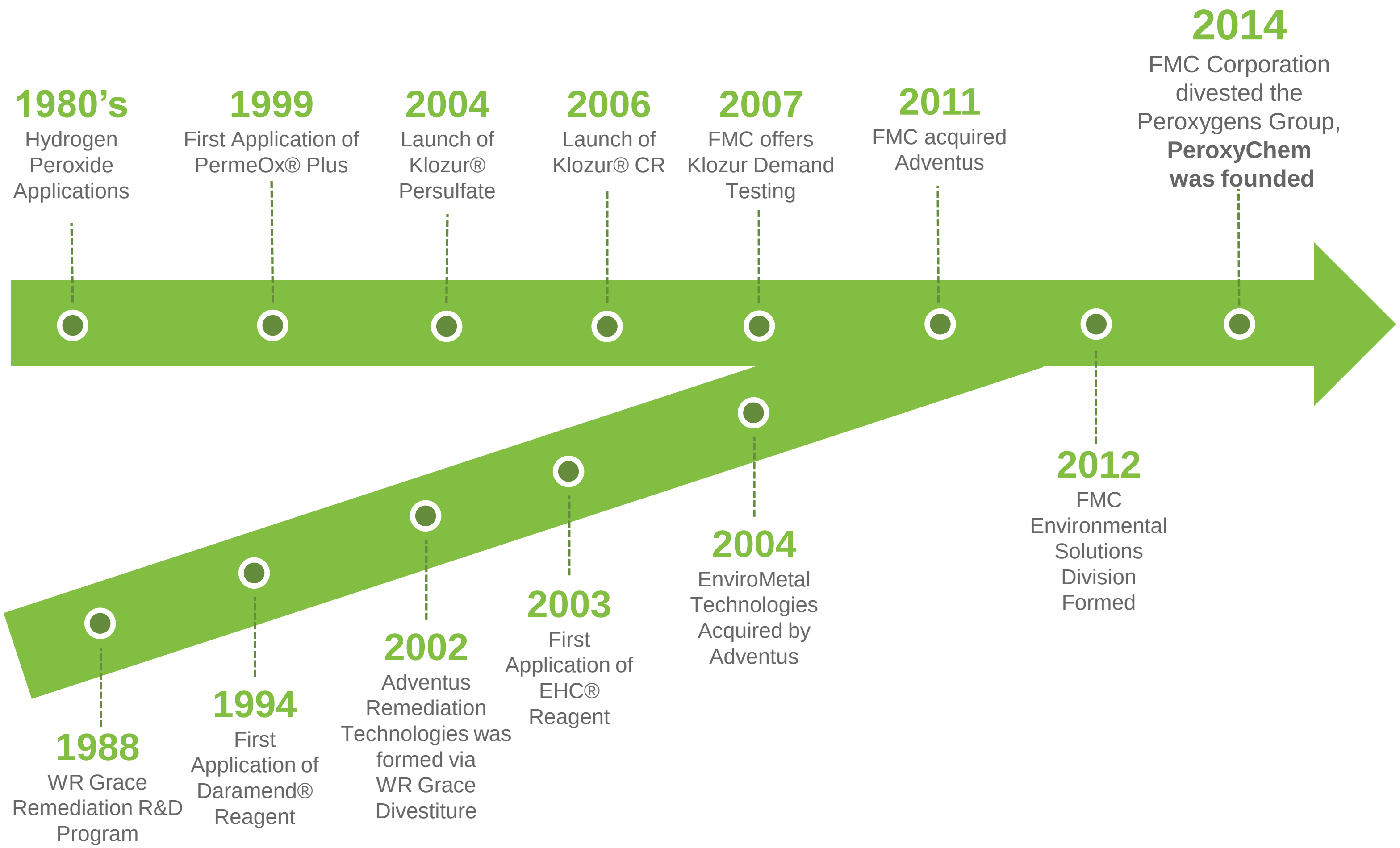
Who We Were…

New Name.
Decades of Experience.



Field-Proven Portfolio of Remediation Technologies Based on Sound Science

In Situ Chemical Oxidation

1. Klozur® persulfate
2. Klozur® CR

In Situ Chemical Reduction

3. EHC® Reagent
4. EHC® Liquid
5. Daramend® Reagent

Aerobic Bioremediation

6. Terramend® Reagent
7. PermeOx® Ultra

Immobilization/Stabilization

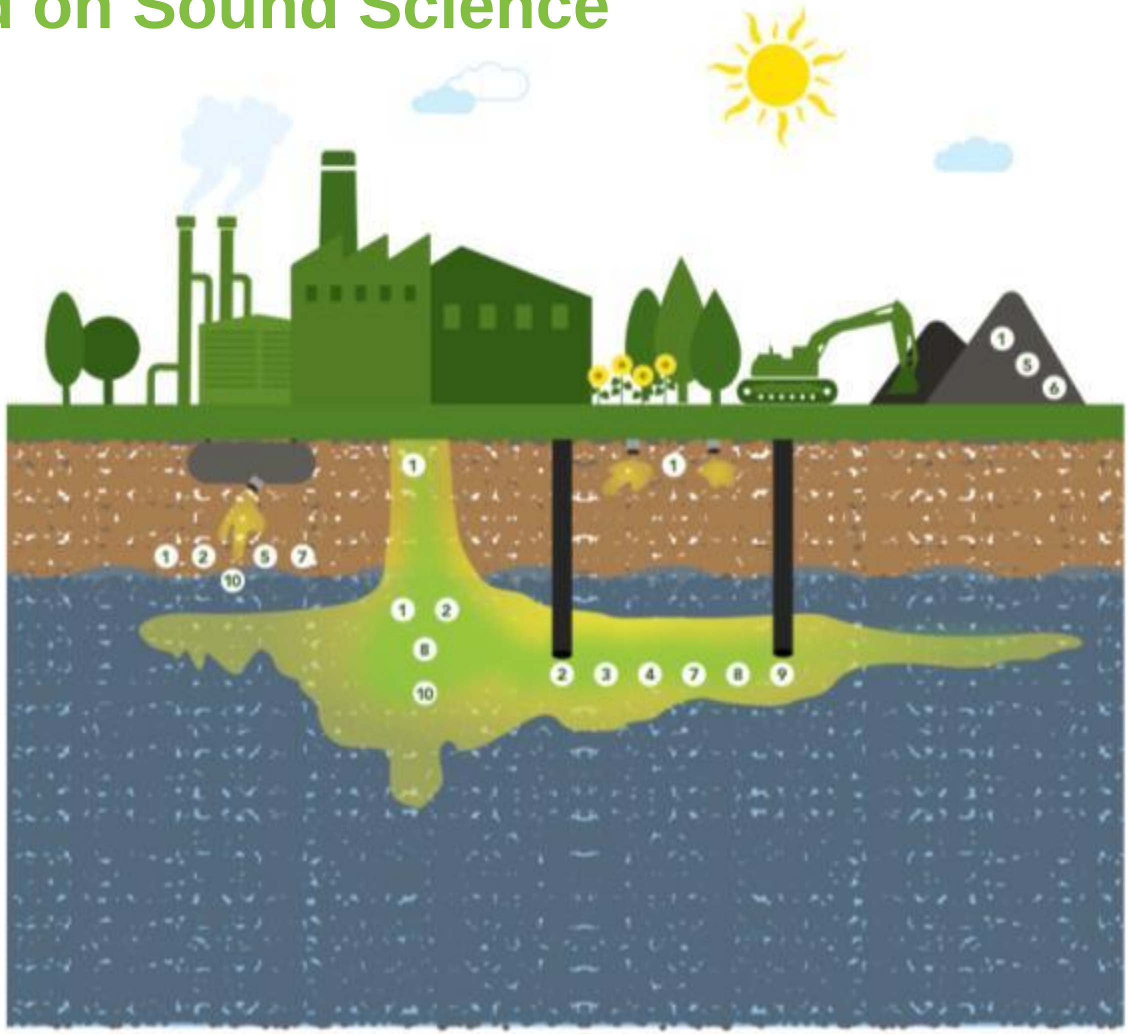
8. EHC® Metals and MetaFix® Reagent

Enhanced Reductive Dechlorination

9. ELS™ Microemulsion

NAPL Stabilization/Mass Flux Reduction

10. ISGS™ Technology



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Support We Provide

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Presentation Outline

- Bench Tests: What, When, Where, and Why?
- Bench Test Set Up Basics
- Typical Bench Tests
  - Oxidative Technologies
  - Stabilization Technologies
  - Reductive Technologies
- Limitations, Issues and Scale Up
- Summary and Conclusions

BENCH TESTS: WHAT, WHEN, WHERE AND WHY?

What is a Bench Test?

- Tests conducted on a bench?
  - ***Yes….exactly***

- Allows for the opportunity to evaluate various test conditions
  - Limited basis
  - Controlled setting

- Lower cost and risk compared to evaluation in the field

What is a Bench Test?

R&D-Concept Evaluation

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Site Specific Evaluation

- Evaluate:
  - Site soils and groundwater with **proven technology**
- Intent/Objectives:
  - Develop site specific **design parameters**
  - Optimize treatment conditions
  - Confirm treatment efficacy
  - Compare treatment efficacy between competing technologies
  - Satisfy regulatory concerns

When do You Bench Test?

- Remedial Investigation
- Feasibility Study
  - Bench tests
- Technology Selection
- Design
  - Bench tests
- Field Application
  - Pilot scale application
  - Full scale application

Where do You Bench Test?

- Sufficient demand that several bench test options exist
  - Industry (e.g. PeroxyChem)
  - Design and implementation companies
  - Dedicated bench test facilities
  - Academia
- Very few, if any, method standards for bench tests
  - Understanding laboratory method and how it applies
- Consult design and implementation team for preferred vendors
  - May favor a specific treatability laboratory
  - Have familiarity on how to best implement one labs methods and results

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Why Bench Test?

- Typical Objectives
  - Develop site specific **design parameters**
  - Optimize treatment conditions
  - Confirm treatment efficacy
  - Compare treatment efficacy between competing technologies
  - Satisfy regulatory concerns

- Cost effective for most sites
  - Perhaps not always small sites

- Risk
  - Issues, if identified, did not result in negative consequences in the field

Bench Test Expectations

- Bench Tests provide:
  - Results
  - Not always solutions
- Failure to achieve results is not necessarily a failed bench test
  - Identified an unexpected result
  - Potential design modification
  - Prevent a failed application
- An unexpected result identified on a bench is typically more cost effective than a failure in the field

BENCH TEST SET UP BASICS

Bench Test Design

- Key Design Parameters
  - Batch vs. column reactors
  - Sample volume needed for analysis
    - Batch reactors
    - Column reactors
  - Specific test condition set up

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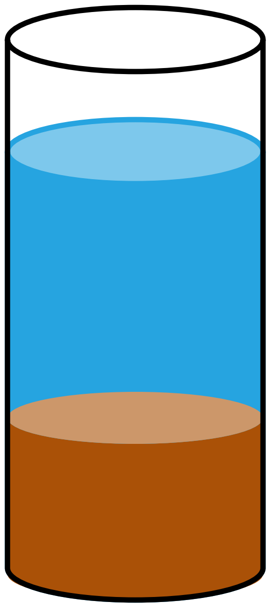
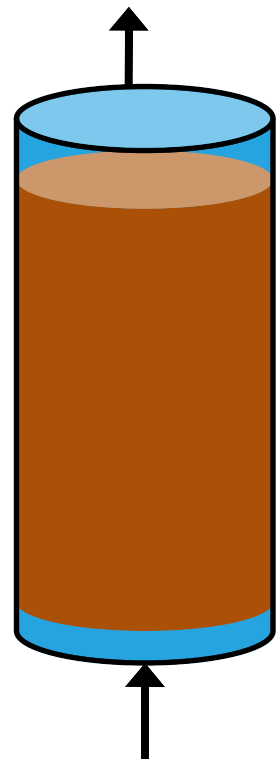
Batch vs Column Reactors

Batch Reactors



vs.

Column Reactors



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Column vs Batch Reactors

Batch Reactors

- *Relatively* less expensive
- Uses less soil and groundwater
- Best for test durations of days to weeks
- Sample volume:
  - Soil to groundwater ratio

Column Reactors

- *Relatively* more expensive
- More soil and groundwater
- Can simulate permeable reactive barrier technologies
  - Can take 3-12 months
- Sample volume:
  - Flow rate

Test Condition Set Up

- Test Duration
- Reagent dose/concentration
- Contaminant concentration
  - Phase
  - Spiking
- Site soils and groundwater
- Dosed in a manner that will allow for estimation of design parameters

TYPICAL BENCH TESTS: OXIDATIVE TECHNOLOGIES

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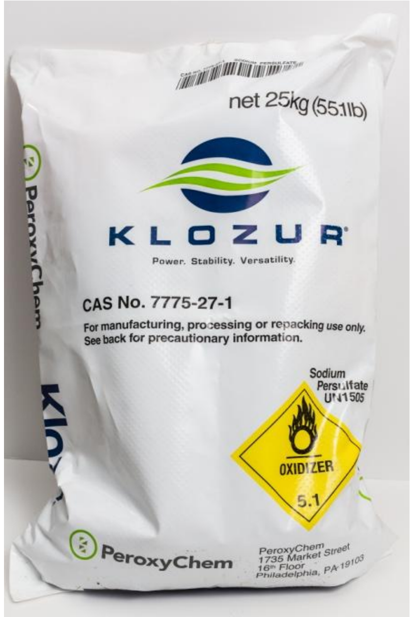
Oxidative Technologies

- In Situ Chemical Oxidation (ISCO)
  - Klozur® Persulfate
  - Hydrogen Peroxide
- In Situ Bioremediation (ISB)
  - PermeOx® Ultra
- Combined ISCO and ISB
  - Klozur®CR



Klozur Persulfate

Fundamental Bench Tests

- Klozur Demand Test (soil oxidant demand-SOD)
- Base Buffering Capacity
  (Alkaline activated persulfate only)
- Treatability Study

Optional Bench Tests

- Total oxidant demand (TOD)
- Persulfate stability
- Technology Screening Test
- Activator Optimization Test
- Metals analysis

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Klozur: Fundamental Bench Tests

Klozur Demand Test

- Objective:
  - Quantify non-target (soil oxidant) demand associated with the native soil and groundwater
  - Prevent underdosing of sites
- Result:
  - Mass of Klozur persulfate needed to satisfy the non-target demand
    - Usually g Klozur per Kg soil
- Importance:
  - Critical design parameter

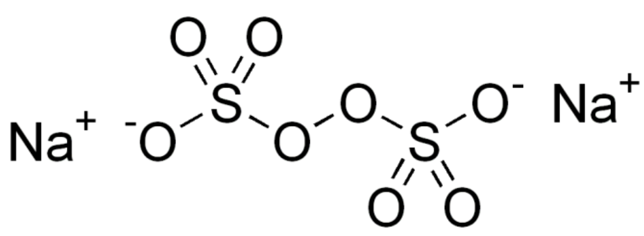
Base Buffering Capacity

- Objective:
  - Quantify the amount of 25% sodium hydroxide needed to raise the aquifer system to pH > 10.5
  - Monitor for precipitation in GW-Only reactor
- Result:
  - Mass of 25% NaOH needed to achieve and sustain pH >10.5
    - Usually g 25% NaOH per Kg soil
- Importance:
  - Critical design parameter for alkaline activated persulfate

Klozur: Fundamental Bench Tests

Treatability Study

- Objective:
  - Confirm site objectives on the bench scale
  - Treatment effectiveness
  - Degradation ratio
- Result:
  - Progress toward site objectives
    - Contaminant destruction
    - Over time (rate of destruction)
    - Degradation ratio (w/w)
- Importance
  - Confirm treatment on a bench scale
  - Degradation ratio (w/w)



Klozur: Optional Bench Tests

- Total Oxidant Demand (TOD)
  - Natural and contaminant demand
- Persulfate Stability
  - Rate Klozur persulfate decomposes
  - Low Soil:GW ratio
- Technology Screening Test
  - ISCO technologies
  - Klozur activators
- Activator Optimization Test
  - Iron-chelate
  - Others
- Metals Analysis
  - Evaluate metals concentrations after treatment
  - After return to baseline geochemical conditions

Hydrogen Peroxide: Bench Tests

Hydrogen Peroxide Stability

- Objective:
  - Determine the stability of hydrogen peroxide in the presence of site soils and groundwater
  - Assess stabilization agents
- Result:
  - Rate of decomposition
  - Half life of hydrogen peroxide
- Importance:
  - Critical design parameter

Gas Evolution

- Objective:
  - Determine the overall volume and rate at which gases evolve during the decomposition of hydrogen peroxide
- Result:
  - Rate of gas evolution
  - Ratio of gases evolved (v/v)
- Importance:
  - Critical design parameter

Hydrogen Peroxide: Bench Tests

<u>Treatability Study</u>

- Objective:
  - Confirm site objectives on the bench scale
  - Treatment effectiveness
  - Degradation ratio
- Result:
  - Progress toward site objectives
    - Contaminant destruction
    - Over time (rate of destruction)
    - Degradation ratio (w/w)

- Importance
  - Confirm treatment on a bench scale
  - Degradation ratio

PermeOx® Ultra

PermeOx Ultra

- Calcium peroxide engineered for slow release of dissolved oxygen to promote aerobic bioremediation

$$CaO_2 + 2H_2O \rightarrow Ca(OH)_2 + H_2O_2$$
$$2H_2O_2 \rightarrow O_2 + 2H_2O$$

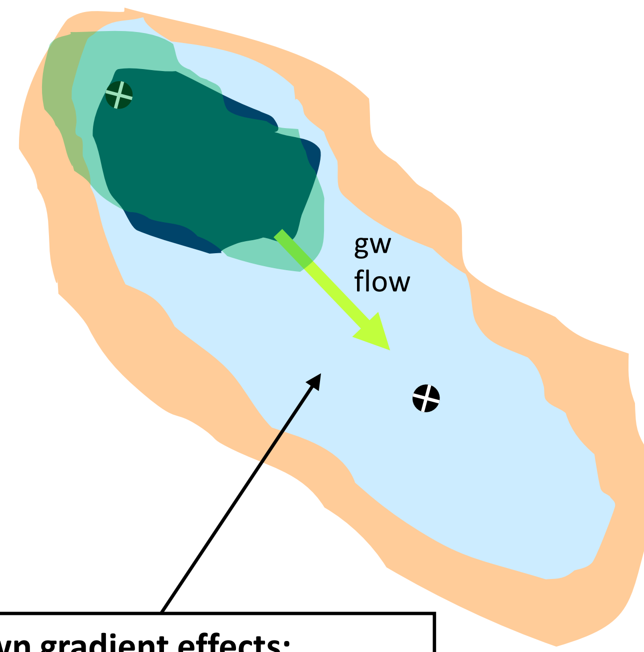
- Applied as a slurry
- 18% active oxygen by weight
- Used to treat petroleum hydrocarbons
- Persists 6-12 months
  - 8-12 mg/L DO

Bench Scale Tests

- Bench scale tests: not typical
- Designs usually based upon subsurface parameters
- Long term column studies possible

Klozur® CR: Bench Tests

- Klozur Demand Test
  - Similar to Klozur persulfate
- Base Buffering Capacity
  - Used to identify potential issues
- Treatability Study
  - Batch reactor: Alkaline activated persulfate
  - Column reactors: Long term ISCO, aerobic and anaerobic bioremediation



Down gradient effects:

- dissolved O_2 → aerobic bio
- sulfate + dissolved organic fragments → anaerobic oxidation

TYPICAL BENCH TESTS: METAFIX® REAGENT

MetaFix® Overview

- MetaFix: category of metals stabilization products
- Multiple proprietary blends of inorganic reagents designed to promote multiple mechanisms of metals removal including reduction, adsorption and precipitation
  - Different mechanisms may work better for different metals and different site conditions
- Does not depend on microbial activity

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MetaFix Testing

- Screening level bench test
- Site geochemistry and formulation optimization
- Objective:
  - Determine optimal MetaFix blend
  - Assess stabilization of metals
- Result:
  - Sequestration of metals
- Importance:
  - Critical design parameter

TYPICAL BENCH TESTS:
REDUCTIVE TECHNOLOGIES

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Reductive Technologies

- EHC® Reagent:
  - Stimulates in situ chemical reduction (ISCR)
  - Creates abiotic and biotic reductive pathways
  - Blend of controlled released carbon, zero valent iron (ZVI) particles and nutrients
- ELS™ Microemulsion:
  - Stimulates enhanced reductive dechlorination reactions
  - Creates reducing conditions and serves as an electron donor
  - Lecithin-based substrate of food-grade carbon

EHC Testing

- Both batch and column studies samples are sent for initial geochemical testing
  - Used to look for potential competing electron acceptors
  - Unusual site conditions
- Initial tests are used to evaluate:
  - Initial pH of site soil and groundwater
  - Need for bioaugmentation

EHC Batch vs Column

Batch

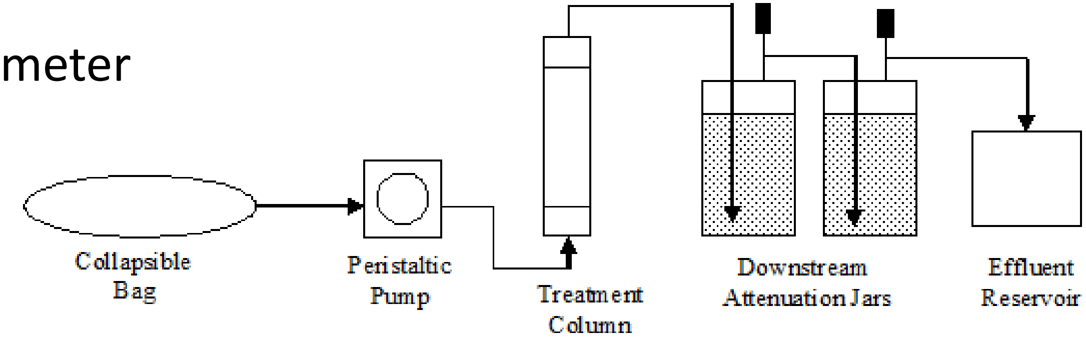
- Pros
  - Greater pH modification
  - Less soil & groundwater
  - Faster test/results
- Cons
  - gas generation & VFA production, accumulate in the system

Column

- Pros
  - more representative of field conditions,
  - no accumulation of gases or VFAs,
  - can adjust flow rate
- Cons
  - takes longer than batch study
  - requires more soil & gw
  - lab cannot do a significant pH adjustment

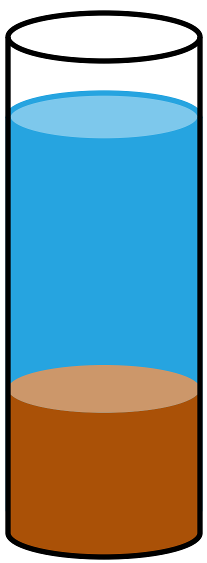
EHC Testing

- Objective:
  - Optimal dosing
  - Assess treatment of contaminants
  - Optimal pH range
- Result:
  - Reduction of contaminants
  - Optimal pH range obtained and sustained
- Importance:
  - Critical design parameter

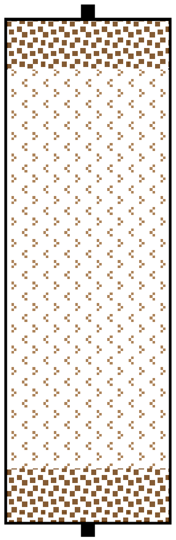


ELS Testing

- Column or batch depending on desired field implementation
- Batch reactors set up same way as EHC batch reactors
- Why run bench study?
  - High sulfate aquifers
  - Inhibition by other parameters
  - Comparison of substrates
  - Unusual aquifer conditions



Batch Reactor



Column Set up

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ELS Testing

- Objective:
  - Optimal dosing
  - Assess treatment of contaminants, if biostimulation alone is sufficient
  - Optimal pH range
- Result:
  - Reduction of contaminants
  - Determine if bioaugmentation is needed
  - Optimal pH range obtained and sustained
- Importance:
  - Critical design parameters

BENCH TESTING COMBINED REMEDIES

Combined Remedies

- Combination of different technologies typically applied to the site in sequence
  - ISCO follow by EHC
  - Biogeochemical treatment following EHC or Klozur persulfate
- Bench tests of combined remedies
  - First technology will alter subsurface conditions
  - Second technology is tested on treated soils

LIMITATIONS, ISSUES AND SCALING UP FROM BENCH TO FULL SCALE

Bench Test Limitations

- Typically conducted on homogenized soil
- Assumes tested soil and groundwater are representative of site conditions
- Controlled conditions allow for better contact in laboratory compared to the field
- Groundwater needed for sampling
  - Batch reactors-elevated groundwater to soil ratios
  - Column reactors—elevated flow rates
- Difficult to replicate all aspects of field

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Scale Up from Bench to Field

Potential Issue(s)

- Typically conducted on homogenized soil
- Assumes tested soil and groundwater are representative of site conditions

Scale Up Considerations

- Be cognizant of conditions tests soils represent and how they apply across the site
  - Conduct tests on multiple samples representative of target area, especially of different soil types
  - Have detailed understanding of how soil conditions and contaminant distribution vary across the site
- Safety Factors

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Scale Up from Bench to Field

Potential Issue

- Controlled conditions allow for better contact in laboratory compared to the field

Scale Up Considerations

- Safety Factor applied to design parameters
  - >1x most common (lab more efficient that field)
  - <1x for conditions where contact is expected to be significantly less (i.e. fractured bedrock)

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Scale Up from Bench to Field

Potential Issue

- Groundwater needed for sampling
  - Batch reactors-elevated groundwater to soil ratios
  - Column reactors—elevated flow rates

Scale Up Considerations

- Batch reactors reagent per:
  - Mass of contaminant (Degradation Ratio): lb/lb
  - Mass of soil (Dosage): g/Kg
  - Volume of groundwater (Concentration): g/L
- Column reactors
  - Normalized flow rate to pore volumes
  - Still need to consider if time was a factor
  - Soils still typically are disturbed

Scale Up from Bench to Field

Potential Issue

- Difficult to replicate all aspects of field
  - Migration to down gradient soils
  - In flux on up gradient groundwater
  - Biotic affects
  - Contaminant and native material heterogeneity

Scale Up Considerations

- Complex column reactors
- Safety factors
- Pilot Scale Test

SUMMARY AND CONCLUSIONS

Summary

- Bench Scale Tests are an important part of remedial decision making and design

- Bench scale tests can be used for:
  - Development of site specific design parameters
  - Optimize treatment conditions
  - Confirm contaminant treatability with site specific soil

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Thank You - Questions

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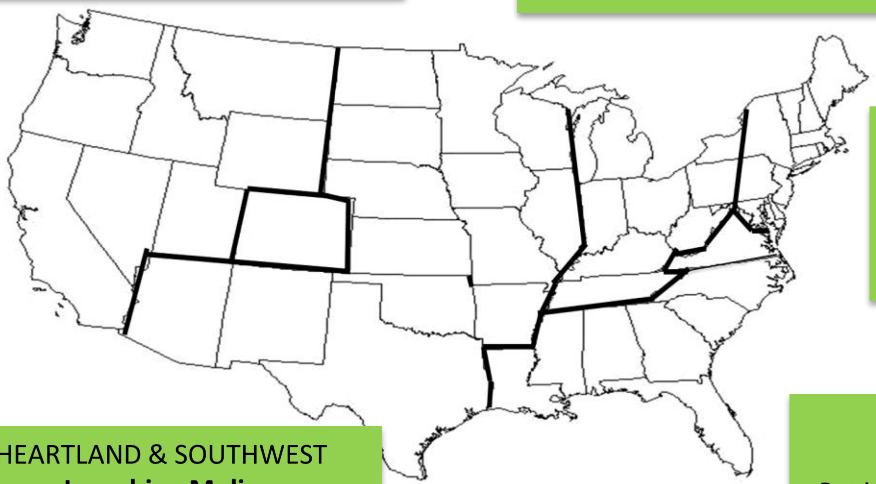

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