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Advanced In Situ Biogeochemical Treatment of Lead and Other Heavy-Metal Contaminated Soils

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Presentation Overview

- Presence of heavy metals in soil and groundwater
- Geochemistry and metals speciation/fate and transport of metals in soil and groundwater
- Successful case study of lead treatment
- Further applications

Heavy Metals in Soil and Groundwater

- Historical issue at a range of sites including metals plating, chrome plating, wood treating, automotive, metals manufacturing, mining, and a host of other manufacturing facilities
- Historical heavy metals contamination at federal facilities across North America
- Co-contamination of metals with organics and organo-metals constituents
- Predominant heavy metals include lead, chromium, arsenic, zinc, cadmium, copper, mercury, and uranium

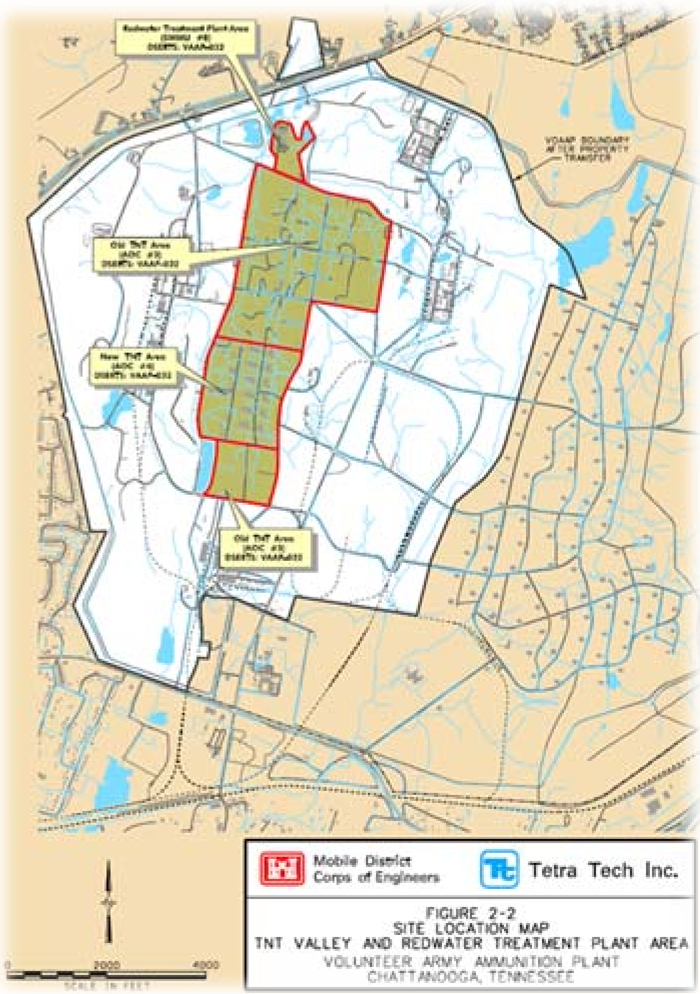
Physical/Chemical/Geochemical Impacts on Heavy Metals in Soil and Groundwater

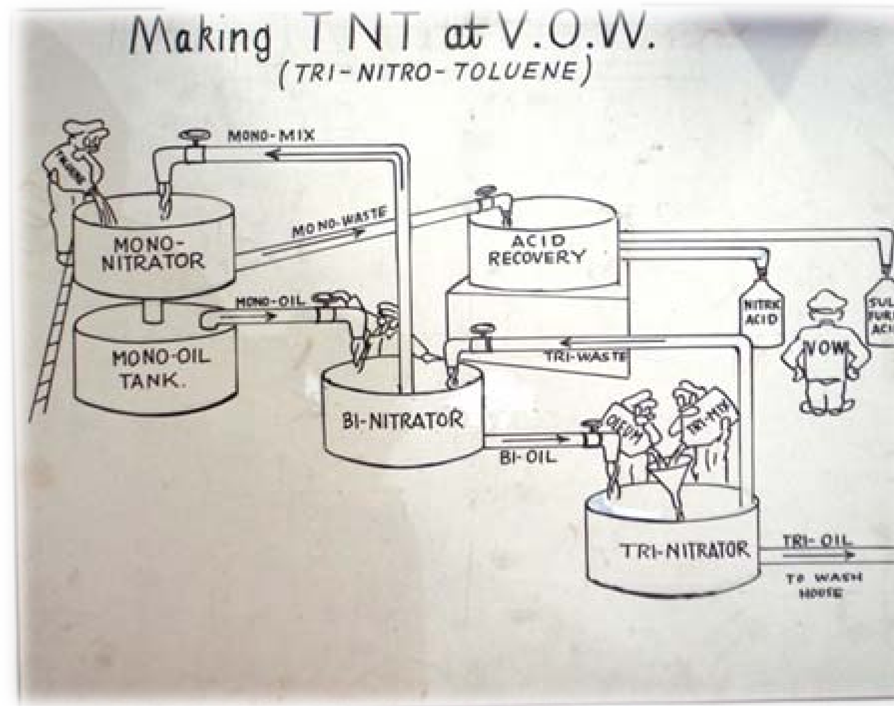
- Soil type and lithology
- Heavy metal type
- Solubility
- Adsorption/desorption
- Chelation/complexes
- Iron in soil/groundwater
- Co-precipitation
- pH, DO, ORP

Case Study

- Treatment of lead in soil at the government-owned/contractor-operated Volunteer Army Ammunitions Plant (VOAPP) in Chattanooga, Tennessee
- Primarily used for the production and storage of trinitrotoluene (TNT)
- Built 1941 to 1943 in support of World War II effort, then Korean and Vietnam conflicts; production ceased in 1977
- In addition to extensive nitroaromatics contamination, metals contamination was also present resulting from acid production in support of TNT manufacturing
- Primary metal-related COC detected in soil was lead

Technology Implementation at VOAAP: A Pioneering Effort





Site Background

- Soil lead concentrations were as high as 2,400 mg/L
- Original mechanisms for remediation focused on either:
  - onsite treatment using conventional chemical and physical stabilization
  - offsite disposal to an appropriate landfill
- Lead concentrations at these levels would make the soil classification hazardous, thus making off-site disposal very expensive
- Initial pilot testing indicated that conventional stabilization methods were not very effective at achieving regulatory TCLP levels of 5 mg/L for lead

Site Background

- As a result, a combination biogeochemical (biotic/abiotic) treatment process was implemented that included:
  - Bench-scale studies for biotic/abiotic treatment of soil lead contamination
  - Pilot-scale test based on bench-scale findings
  - Full-scale application of lead treatment and subsequent off-site disposal as non-hazardous waste

Technology Background

- Lead solubility varies in water
- Several factors including pH, DO, and ORP determine the state of lead
- Presence of anions and cations influence the characteristics of lead in soil and water
- Organic carbon (dissolved and total) could also affect the ionic state of lead, its complexation, and the possibility of lead precipitation
- Soil type, moisture content, alkalinity, lead, and concentrations of other metals are all factors

Technology Background

- Various chemical additives can be used for lead treatment to below TCLP levels in soil
- Precipitated forms include lead hydroxide, lead sulfate, lead carbonate, lead phosphate, and lead sulfide
- Additives can be natural, synthetic, or proprietary
- Lead sulfide is stable over a wide range of pHs
- Sulfur states may exist naturally in the soil or can be added in a variety of forms
- A natural form of carbon can be added to the soil to biologically convert natural or added sulfate to sulfide

Technology Background

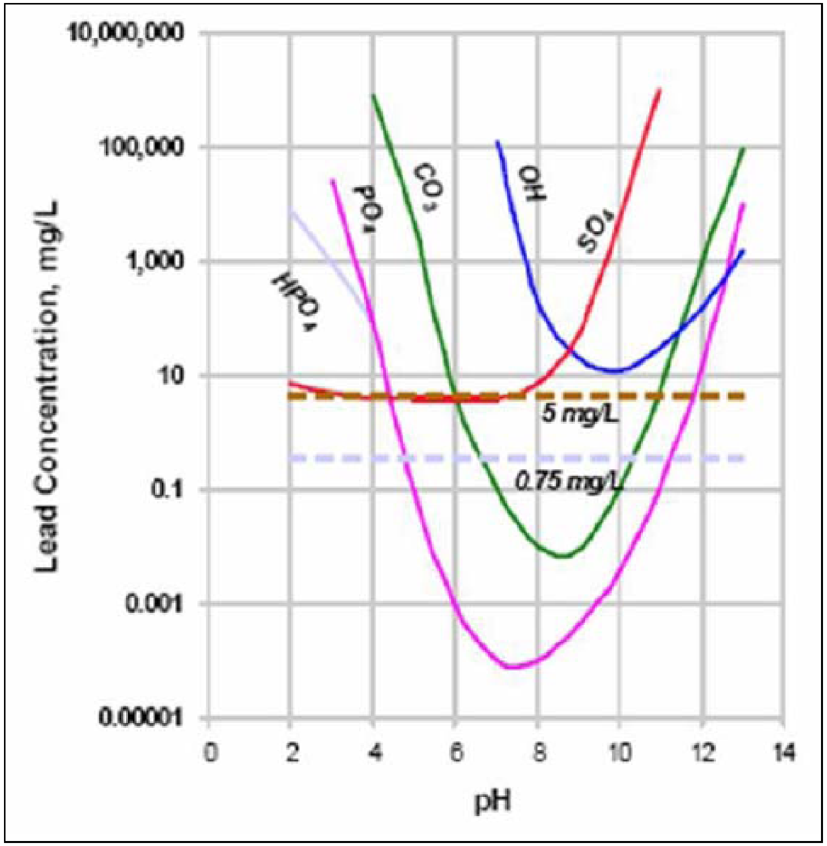
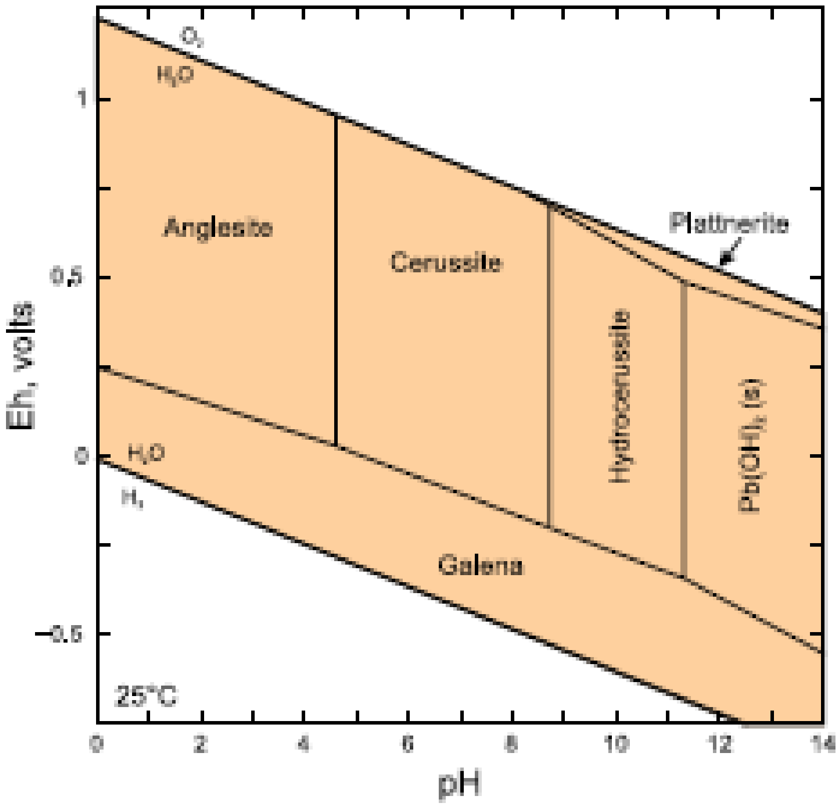


Figure 6. Solubility of common lead compounds by pH with both the TCLP and the UTS for lead indicated.

Reference – ERDC/EL TR-07-19, Evaluation of Lime and Persulfate Treatment for Mixed Contaminant Soil from Plum Brook Ordnance Works – US Army Corps of Engineers

Technology Background



Reference – EPA, October 2007. MNA of Inorganic Contaminants in Groundwater.

Bench-Scale Studies

- Four bench-scale studies were performed to test a range of potential amendments including:
  - potassium bicarbonate and potassium carbonate
  - sodium metabisulfite and bentonite
  - sodium sulfate and compost, and
  - compost only
- All bench-scales were analyzed for pH and TCLP Lead
- The TCLP lead remediation goal was 5 mg/L

Bench-Scale Study – Set-Up

- The fourth study focused on compost as the amendment
- Four soil test pans each containing 5 lbs of contaminated soil were amended as follows:
  - BS-A – Control, no amendments
  - BS-B – 10% compost
  - BS-C – 20% compost
  - BS-D – 30% compost
- On Day 6, samples were collected from each soil test pan and analyzed for TCLP lead and sulfate
- Results showed that all 3 test trials were successful at treating lead to below the TCLP limit of 5 mg/L

Bench-Scale Study: Set-Up

- Soil contaminated with lead was homogenized and added to pans
- Bench-scale tests were performed and evaluated for several biotic/abiotic amendments.
- Water was added and the contents of the pan were thoroughly mixed
- Soil was periodically collected from each of the test trials and analyzed for TCLP lead, pH, sulfates, and sulfides

Pilot Study

- A 75 m^3 soil pile that had been previously subjected to physical stabilization and failed was selected for pilot-scale treatment using compost
- 15 m^3 of an industrial compost was applied to the soil to obtain a 20% application rate
- Compost was mixed into the soil using traditional construction equipment
- Samples were collected at one-week and two-weeks post-treatment
- Three 10-point composite samples were collected per 75 m^3

Pilot Study

- Resulting composite lead TCLP results were at 0.64 mg/L, which was well below the 5 mg/L cleanup goal
- Based on the results, 4 more treatment cells (each 100 cy) were mixed with 20% compost
- Lead TCLP results ranged from 1.3 to 4.3 mg/L for treatment areas 2, 3, and 4
- Treatment area 5 showed a lead concentration of 22.9 mg/L, therefore 200 lbs of sulfate were added to the treatment cell to complete remediation of lead

FULL-SCALE REMEDIATION

Full Scale – Process

- Soil was treated for metals contamination, if required, based on initial sampling results
- Each 230 m^3 batch was treated with 20 – 25% compost
- Soil was mixed and then allowed to sit covered and undisturbed
- Samples were collected 7 days post-treatment to verify reduction in lead TCLP concentrations to below 5 mg/L
- The average treatment time for remediation of 230 m^3 of soil was approximately 10 days

Full Scale – Process

- Each soil pile took different time periods for treatment
- Based on results from the third bench-scale, the combination of sodium sulfate and compost reduced the TCLP lead concentrations to non-detect levels
- As a result, sulfate was added to these piles to speed up the reactions
- Sulfate, if required, was added at a rate of approximately 45 kg per 230m^3
- Upon completion of treatment, soil was transported to a non-hazardous landfill for disposal

Full Scale Summary

Soil To Be Treated

Full Scale: Process

Mixing Operations

Full Scale Summary

- Successful treatment of total lead concentrations as high as 2,400 mg/kg (TCLP > 35 mg/L) to less than 1 mg/L for TCLP
- Approximately 7,000 m^3 of soil has been successfully treated to date
- Costs Associated With Treatment –
  - Total cost of treatment was approximately $700,000
  - Regular off-site disposal as a hazardous waste would have cost approximately $2,400,000
  - ***Total Savings of $1,700,000***

Technological Advantages

- Unique combination of biotic and abiotic stabilization mechanisms
- Geochemical manipulation (varying the additives) to form the most stable precipitate
- Long term stability provided by mineral formation and slow release carbon sources
- Variation in use of additives – safe handling and green solution
- Flexible design
- Economical

Applications

- Can be applied to other heavy metals, Cd, U, Hg
- Currently being employed at a second army plant in Ohio
- Applicable to higher concentrations of lead
- Substitute organic substrates
- Vadose zone and saturated soil applications
- Liquid and gaseous injectates
- Co-contaminated sites, for example, cVOCs
- Climate Impacts

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Questions