Bioremediation of Oil-Contaminated Sites

Case Studies Involving Light and Heavy Petroleum Hydrocarbons

Talaat Balba, M.S.C., Ph.D. Conestoga-Rovers & Associates



Presentation Content

- Introduction to Petroleum Hydrocarbons
- Characteristics of Petroleum Hydrocarbons
- Problems with Oil Spills
- Treatment Techniques
- Discussion on Bioremediation
- Case Studies



Petroleum Hydrocarbons

- Manufactured from crude oil
- * Made mainly from hydrogen and carbon
- * Found in crude oil, gasoline, kerosene, heating fuel oil, and asphalt
- Stored and transported in large volumes by ship, rail, truck, and pipelines
- One of most prevalent contaminants in subsurface





Petroleum Hydrocarbons



Oil Chemical Composition

- * Four main groups of constituents:
 - saturates (or alkanes);
 - aromatics, including such compounds as BTEX and PAHs;
 - resins, consisting of compounds containing nitrogen, sulphur, and oxygen, that are dissolved in oil; and
 - asphaltenes, which are large and complex molecules that are colloidally dispersed in oil



Petroleum Hydrocarbon Characteristics



Potential Problems Associated with Oil Spills

- Oil migrates down through soils, adsorbing to soil particles until it reaches groundwater, where oil constituents will dissolve in water, float on water surface (light-end fraction) or sink to bottom of water aquifer (heavy heating fuel oil)
- Any constituent that dissolves in water will travel with flowing groundwater



Treatment Techniques

- Conventional Methods:
 - Free product removal by pump and treat of groundwater
 - Excavation and off-site disposal of impacted soil
 - Vapor extraction
- Innovative cost-effective alternative:
 - Bioremediation



What is Bioremediation?

Treatment process whereby contaminants are metabolized into less toxic or nontoxic compounds by naturally occurring microorganisms. The microorganisms can utilize many of the oil constituents as a source of carbon and energy. The byproducts are mainly carbon dioxide and water.



Oil-Eating Bacteria





Bioremediation cont'd...

- The microbial population becomes dormant or dies out once all of the contaminants have been consumed
- Can take place under aerobic or anaerobic conditions in presence of other suitable electron acceptors such as nitrate, sulfate, or carbonate
- Can be applied in situ or ex situ to treat both soil and groundwater



Key Biochemical Electron Acceptors

Electron Acceptor	Condition	Microorganisms Aerobes			
Oxygen	Aerobic				
Nitrate	Anaerobic	Facultative Anaerobes/Denitrifiers			
Sulfate	Anaerobic	Sulfate Reducers			
CO ₂	Anaerobic	Methanogens			
		1H			
& ASSOCIATES					

Bioremediation cont'd...

- * Effective in treating wide range of chemicals including petroleum hydrocarbons
- Two basic ways to treat petroleum hydrocarbon-impacted sites by bioremediation: in situ treatment and treatment of impacted soil after excavation



Key Environmental Factors Influencing Oil Bioremediation

- Nutritional factors
- Electron acceptors
- * Microbes (degraders) in high numbers
- Soil-water content
- Soil structure and organic content
- * Temperature
- Toxic compounds
- Solubility of pollutants



Ex Situ Methods

- * Landfarming
- Composting piles
- * Bioventing
- Phytoremediation



Landfarming





Composting Piles





Bioventing



Phytoremediation



Ways to Enhance Bioremediation

- Supplement with suitable sources of nitrogen and phosphorus to enhance biodegradation of Site contaminants by indigenous microbial population
- * Injection or infusion of air or oxygen
- Injection of oxygen release compounds (ORC) to optimize aerobic conditions (oil biodegrades much faster under aerobic conditions)



More Ways to Enhance Bioremediation

- * Microbubbles
- Oxygen infusion through microporous membranes
- Application of surfactants to enhance
 bioavailability of heavy oil hydrocarbons and
 PAHs
- * Bioaugmentation







In situ Biological Treatment Scheme



Case Study #1 - Bioremediation of Heavy Oils in Soil

- * Locomotive maintenance yard in CA
- * Soils contaminated with long chain alkanes in C_{22} + range
- In some areas, levels of contamination were near soil saturation level



Oil Chromatograph





Site Summary

- * Major Railroad Yard in CA
- 30,000 Tons of Oil-Contaminated Soil (Up to 10%)
- * Six other similar sites in CA
- Program Included:
 - Lab Treatability Study
 - Site Demonstration



Site Layout





Project Summary

- Cost-effective biological treatment was developed and field-demonstrated at the site
- Multi-step laboratory treatability study followed by a field demonstration
- Laboratory results showed up to 94 percent removal of TPH in less than 16 weeks



Field Demonstration Results

- Soils contained over 100,000 mg/Kg dry soil of TPH
- Soils were bioaugmented with mixture of microbial inocula and organic and inorganic fertilizers
- More than 85 percent degradation was achieved in less than 28 weeks



Bioremediation of Heavy Petroleum Oil in Soil







Case Study #2 - Bioremediation of Light Oils in Soil

- * Oil refinery in Germany
- Subsurface soils (up to 20 feet below ground surface) and groundwater were impacted by naphthene





Field Demonstration

- Dual treatment process was designed and field demonstrated at the site
- * In situ and ex situ aerobic bioremediation
- Treatments involved application of surfaceactive agent along with nutrients and microbes



Description of Dual Treatments

- Highly contaminated shallow soils (with concentrations as high as 12,800 mg/Kg) were excavated and treated by landfarming
- Less contaminated soils (highest concentrations of 180 mg/Kg) were treated in situ



Ex situ Treatment



In situ Treatment



Results

- Oil hydrocarbon concentrations in ex situ treatment were reduced to less than
 2,000 mg/Kg within 24 weeks (an 84 percent reduction)
- In situ treatment results were similar
 (86 percent reduction to 26 mg/Kg within 15 weeks)





In situ Treatment Results





Case Study #3 - Bioremediation of Oil-Contaminated Desert Soil

 Over 49 Km² of Kuwait's desert soil were contaminated as result of exploding oil wells during Iraqi invasion and occupation of 1990



Scope of Problem

- Over 700 ignited oil wells extinguished and capped
- Additional areas covered with oil and soot aerosols/heavy contamination
- Remediation required to:
 - restore ecosystems
 - avoid underground water contamination
 - protect human health











Treatment

- Bioremediation selected as alternative remedial option
- Three methods were field-demonstrated at large scale: landfarming, composting piles, and bioventing soil piles (with irrigation and bioventing)



Correlation of C₁₈:phytane ratio with TPH degradation

Treatment	C ₁₈ :phytane ratio			TPH concentration (mg/Kg)			TPH reduction
	Γ	T ₆	T ₁₂	T _o	Т ₆	T ₁₂	%
Landfarming	2.4	0.3	ND (0.3)	39400	14000	7200	81.7
Control test	2.4	2.3	2.2	<mark>394</mark> 00	35500	31700	19.5
Windrow piles	2.4	0.4	ND (0.3)	34700	19400	9500	72.6
Control test	2.4	2.4	2.2	35900	39800	30600	14.8
Static piles	1.7	0.5	ND (0.3)	14400	8500	4600	68.1
Control test	1.7	1.6	1.4	14100	13600	12200	13.5



Results

- Landfarming treatment reduced lightly contaminated soils by 80 percent within 6 months and heavily contaminated soils by 80 percent within 12 months
- Results confirm that reduction in TPH concentration was caused primarily by microbial biodegradation and not volatilization







Phytoremediation for Polishing

- Phytoremediation was used as polishing method to further reduce residual level of TPH and to assess phytotoxicity of residual TPH on growth and performance of wide range of domestic and ornamental plant species
- Alfalfa vegetation resulted in much cleaner soil as evident from analysis of TPH, total extractable matter (TEM), and PAHs



Phytoremediation





Phytoremediation Results





Conclusions

- Bioremediation is promising technology for treatment of wide range of contaminants in soil and groundwater, particularly oil contamination
- Bioremediation is site-specific; therefore, treatability studies are highly recommended before full-scale remediation is considered



Conclusions (cont'd)

- Degradation rate of hydrocarbons is dependent on type of contaminants, metabolic capabilities of indigenous microbial population, and also on predominant environmental factors
- Effectiveness depends to great extent on success in identifying rate-limiting factors and optimizing them during feasibility studies



Conclusions (cont'd)

 Important to define limitations to the process; both with respect to range of contaminants that can be treated and residual concentrations that can be achieved within an appropriate time frame

