**Soil, Sediment, Bedrock and Sludge**

**Enhanced Bioremediation**

**Introduction:**

Distributing water-based solutions through contaminated soils to improve *in situ* biological degradation of organic contaminants or immobilisation of inorganic contaminants encourages the activity of microbes.

**Description:**

Enhanced bioremediation is a process where indigenous or inoculated microorganisms degrade (metabolise) organic contaminants found in soil and/or ground water, changing them to less toxic end products. Nutrients, oxygen, or other amendments may be utilised to increase bioremediation and contaminant desorption from subsurface materials.

*Aerobic*

In the presence of adequate oxygen and other nutrient elements, microorganisms will in due course convert many organic contaminants to carbon dioxide, water, and microbial cell mass.

Enhanced bioremediation of soil characteristically includes the percolation or injection of ground water or uncontaminated water mixed with nutrients and saturated with dissolved oxygen. Occasionally acclimated microorganisms and another oxygen source such as hydrogen peroxide are also added. Spray irrigation is normally used for shallow contaminated soils, and injection wells are employed for deeper contaminated soils.

Even though successful *in situ* bioremediation has been established in cold weather climate, low temperature slows down the remediation process. For sites with low soil temperatures, heat blankets can be utilised to cover the soil surface to raise the soil temperature and consequently the degradation rate.

Enhanced bioremediation can be a long-term process, taking a number of years to cleanup a plume.

*Anaerobic*

In the lack of oxygen, organic contaminants will be metabolised to methane, small quantities of carbon dioxide, and trace amounts of hydrogen. Under sulphate-reduction conditions, sulphate is transformed to sulphide or elemental sulphur, and under nitrate-reduction conditions, dinitrogen gas is produced.

On occasion contaminants may be degraded to intermediate or final products that can be less, equally, or more hazardous than the initial contaminant. For example, TCE anaerobically biodegrades to the persistent and more toxic vinyl chloride. To circumvent such problems, most bioremediation projects are conducted *in situ*. Vinyl chloride can effortlessly be broken down further if aerobic conditions are present.

*White Rot Fungus*

White rot fungus is thought to degrade a variety of organo-pollutants due to its lignin-degrading or wood-rotting enzymes. Two separate treatment configurations have been assessed for white rot fungus - *in situ* and bioreactor. An aerobic system utilising moisturised air on wood chips is employed in a reactor for biodegradation. A reactor was used in the bench-scale trial of the process, while in the pilot-scale project, a modifiable shredder was used to make chips for the open system. The open system is comparable to composting, with wood chips on a liner or hard restricted surface that is sheltered. Temperature is not controlled in this system. The most favourable temperature for biodegradation with lignin-degrading fungus ranges from 30 to 38° C. The heat of the reaction helps to preserve the temperature of the process near the optimum. Though white rot fungus degradation of TNT has been detailed in laboratory-scale settings using pure cultures, a number of factors intensify the complexity of using this option for full-scale remediation, and it has not yet been proven successful at this level. Such factors comprise of competition from indigenous microbial populations, toxicity inhibition, chemical sorption, and the incapability to meet risk-based cleanup levels. White rot works greatest in nitrogen-limited environments. In bench-scale studies of mixed fungal and bacterial systems, the majority of the reported degradation of TNT is credited to indigenous microbial populations. Excessive TNT or PCP concentrations in soil also can hold back growth of the white rot fungus. A study recommended that one particular species of white rot fungus was unable to grow in soils contaminated with 20 mg/l or more of TNT. Additionally, some reports point out that TNT losses reported in white rot fungus studies can be accredited to adsorption onto the fungus and soil amendments, such as straw, rather than definite destruction of TNT.

**Applicability:**

Bioremediation techniques have been effectively used to remediate soils, sludge's, and ground water contaminated with petroleum hydrocarbons, pesticides, wood preservatives, and other organic chemicals. Bench and pilot scale studies have verified the efficiency of anaerobic microbial degradation of nitrotoluenes in soils contaminated with munitions wastes. Bioremediation is particularly valuable for remediating low-level residual contamination in conjunction with source removal.

The contaminant groups most commonly treated by enhanced bioremediation are PAHs, non-halogenated SVOCs (excluding PAHs), and BTEX.

Bioremediation treatment often does not necessitate heating, requires moderately inexpensive inputs such as nutrients, and generally does not generate residuals requiring additional treatment or disposal. Furthermore, when conducted *in situ*, it does not need excavation of contaminated media. Compared with other technologies, such as thermal desorption and incineration (which require excavation and heating), thermally enhanced recovery (which requires heating), chemical treatment (which may require relatively expensive chemical reagents), and *in situ* soil flushing (which may require further management of the flushing water), bioremediation may have the benefit of a cost advantage in the treatment of non-halogenated SVOCs.

While bioremediation cannot degrade inorganic contaminants, it can be utilised to alter the valence state of inorganics and cause adsorption, immobilisation onto soil particulates, precipitation and the uptake, accumulation, and concentration of inorganics in micro or macroorganisms. These techniques, though still mostly experimental, demonstrate significant promise of stabilising or removing inorganics from soil.

**Limitations:**

- Cleanup goals may not be accomplished if the soil matrix prohibits contaminant-microorganism contact.
- The flow of water-based solutions through the soil could increase contaminant mobility and require treatment of underlying ground water.
- Preferential colonisation by microbes could occur triggering clogging of nutrient and water injection wells.
- Preferential flow paths might decrease contact between injected fluids and contaminants all through the contaminated zones. The system ought not to be used for clay, layered or heterogeneous subsurface environments due to oxygen (or other electron acceptor) transfer limitations.
- Elevated concentrations of heavy metals, highly chlorinated organics, long chain hydrocarbons, or inorganic salts are likely to be noxious to microorganisms.

- Bioremediation decelerates at low temperatures.
- Concentrations of hydrogen peroxide greater than 100 to 200 mg/l in groundwater impede the activity of microorganisms.
- A surface treatment system, for example air stripping or carbon adsorption, may be compulsory to treat extracted groundwater before re-injection or disposal.

A lot of the above factors can be controlled with correct attention to engineering practice. The duration of time involved in treatment can range from 6 months to 5 years and is reliant on site-specific factors.

**Data Needs:**

Essential contaminant characteristics that should be known in an enhanced bioremediation viability investigations are their potential to leach; their chemical reactivity (e.g., tendency toward nonbiological reactions, such as hydrolysis, oxidation, and polymerisation); and, most significantly, their biodegradability. Soil characteristics include the depth and area extent of contamination; the concentration of the contaminants; soil type and properties (e.g., organic content, texture, pH, permeability, water-holding capacity, moisture content, and nutrient level); the competition for oxygen (namely the redox potential); whether there is the presence or absence of substances that may be toxic to microorganisms; nutrients; and the ability of microorganisms in the soil to degrade the contaminants. Treatability or feasibility tests are carried out to determine if enhanced bioremediation is viable in a given situation, and to identify the remediation time frame and parameters.

**Performance Data:**

The benefit of the *in situ* process is that it permits soil to be treated without being excavated and transported, resulting in a smaller amount of disturbance in site activities. If enhanced bioremediation can achieve the cleanup goal in an acceptable time frame, it can save considerable costs over methods that involve excavation and transportation. In addition, both contaminated ground water and soil can be treated concurrently, offering additional cost advantages. *In situ* processes require longer time periods, however, and there is less assurance about the consistency of treatment due to the intrinsic variability in soil and aquifer characteristics and complexity in the monitoring progress. Remediation times are often years, depending on the degradation rates of contaminants, site characteristics, and climate. There is a risk of enhancing contaminant mobility and leaching of contaminants into ground water. Regulators can sometimes not agree to the addition of nitrates or non-native microorganisms to contaminated soils. Enhanced bioremediation has been selected for remedial and emergency response actions at an increasing number of sites. Normally, petroleum hydrocarbons can be readily bioremediated, at moderately low cost, by encouraging indigenous microorganisms through the addition of nutrients.

**Cost:**

Average costs for enhanced bioremediation range from £ 25 to £ 75 per cubic meter. Factors that have an effect on cost consist of the soil type and chemistry, type and quantity of amendments used, and type and degree of contamination.