GUIDELINES FOR BIOREMEDIATION

Martinez Vila, Alvaro Martin
Universidad Nacional de Ingenieria, Lima, Peru

Bioremediation is the use of microorganisms for the degradation of hazardous chemicals in soil, sediments, water, or other contaminated materials. Often the microorganisms metabolize the chemicals to produce carbon dioxide or methane, water and biomass. Alternatively, the contaminants may be enzymatically transformed to metabolites that are less toxic or innocuous. It should be noted that in some instances, the metabolites formed are more toxic than the parent compound.

There are at least five critical factors that should be considered when evaluating the use of bioremediation for site clean up. These factors are:

1. Magnitude, toxicity, and mobility of contaminants.

It is imperative that the site be properly investigated and characterized to determine the (a)horizontal and vertical extent of contamination; (b) the kinds and concentrations of contaminants at the site; (c) the likely mobility of contaminants in the future, which depends in part on the geological characteristics of the site.

2. Proximity of human and environmental receptors.

Whether bioremediation is the appropriate cleanup remedy for a site is dependent on whether the rate and extent of contaminant degradation is sufficient to maintain low risks to human or environmental receptors.

3. Degradability of contaminants.

The biodegradability of a compound is generally high if the compound occurs naturally in the environment (e.g., petroleum hydrocarbons). Often, compounds with a high molecular weight, particularly those with complex ring structures and halogen substituents, degrade more slowly than simpler straight chain hydrocarbons or low molecular weight compounds. Whether synthetic compounds are metabolized by microorganisms is largely determined by whether the compound has structural features similar to naturally occurring compounds. The rate and extent to which the compound is metabolized in the environment is often determined by the availability of electron acceptors and other nutrients.

4. Planned site use.

A critical factor in deciding whether bioremediation is the appropriate cleanup remedy for a site is whether the rate and extent of contaminant degradation is sufficient to reduce risks to acceptable levels.

5. Ability to properly monitor.

There are inherent uncertainties in the use of bioremediation for contaminated soils and aquifers due to physical, chemical and biological heterogeneities of the contaminated matrix. It is important to recognize that biological processes are dynamic and, given current knowledge, often lack the predictability of more conventional remediation technologies.

Bioremediation can be used as a cleanup method for contaminated soil and water. Bioremediation applications fall into two broad categories: *in situ* or *ex situ*. In situ bioremediation treats the contaminated soil or groundwater in the location in which it was found. Ex situ bioremediation processes require excavation of contaminated soil or pumping of groundwater before they can be treated.

<u>In Situ Bioremediation of Soil:</u> In situ techniques do not require excavation of the contaminated soils so may be less expensive, create less dust, and cause less release of contaminants than ex situ techniques. Also, it is possible to treat a large volume of soil at once. In situ techniques, however, may be slower than ex situ techniques, may be difficult to manage, and are most effective at sites with *permeable* (sandy or uncompacted) soil.

The goal of aerobic in situ bioremediation is to supply oxygen and nutrients to the microorganisms in the soil. Aerobic in situ techniques can vary in the way they supply oxygen to the organisms that degrade the contaminants. Two such methods are **bioventing** and **injection of hydrogen peroxide.** Oxygen can be provided by pumping air into the soil above the water table (bioventing) or by delivering the oxygen in liquid form as hydrogen peroxide. In situ bioremediation may not work well in clays or in highly layered subsurface environments because oxygen cannot be evenly distributed throughout the treatment area. In situ remediation often requires years to reach cleanup goals, depending mainly on how biodegradable specific contaminants are. Less time may be required with easily degraded contaminants.

Bioventing. Bioventing systems deliver air from the atmosphere into the soil above the water table through injection wells placed in the ground where the contamination exists. The number, location, and depth of the wells depend on many geological factors and engineering considerations.

An air blower may be used to push or pull air into the soil through the injection wells. Air flows through the soil and the oxygen in it is used by the microorganisms. Nutrients may be pumped into the soil through the injection wells. Nitrogen and phosphorous may be added to increase the growth rate of the microorganisms.

Injection of Hydrogen Peroxide. This process delivers oxygen to stimulate the activity of naturally occurring microorganisms by circulating hydrogen peroxide through contaminated soils to speed the bioremediation of organic contaminants. Since it involves putting a chemical (hydrogen peroxide) into the ground (which may eventually seep into the groundwater), this process is used only at sites where the groundwater is already contaminated. A system of pipes or a sprinkler system is typically used to deliver hydrogen peroxide to shallow contaminated soils. Injection wells are used for deeper contaminated soils.

<u>In Situ Bioremediation of Groundwater:</u> In situ bioremediation of groundwater speeds the natural biodegradation processes that take place in the water-soaked underground region that lies below the water table. For sites at which both the soil and groundwater are contaminated, this single technology is effective at treating both.

Generally, an in situ groundwater bioremediation system consists of an extraction well to remove groundwater from the ground, an above-ground water treatment system where nutrients and an oxygen source may be added to the contaminated groundwater, and injection wells to return the "conditioned" groundwater to the subsurface where the microorganisms degrade the contaminants.

One limitation of this technology is that differences in underground soil layering and density may cause reinjected conditioned groundwater to follow certain preferred flow paths. Consequently, the conditioned water may not reach some areas of contamination.

Another frequently used method of in situ groundwater treatment is *air sparging*, which means pumping air into the groundwater to help flush out contaminants. Air sparging is used in conjunction with a technology called soil vapor extraction.

Ex Situ Bioremediation of Soil ***:*** Ex situ techniques can be faster, easier to control, and used to treat a wider range of contaminants and soil types than in situ techniques. However, they require excavation and treatment of the contaminated soil before and, sometimes, after the actual bioremediation step. Ex situ techniques include slurry-phase bioremediation and solid-phase bioremediation.

Slurry-phase bioremediation. Contaminated soil is combined with water and other additives in a large tank called a "bioreactor" and mixed to keep the microorganisms -- which are already present in the soil -- in contact with the contaminants in the soil. Nutrients and oxygen are added, and conditions in the bioreactor are controlled to create the optimum environment for the microorganisms to degrade the contaminants. Upon completion of the treatment, the water is removed from the solids, which are disposed of or treated further if they still contain pollutants.

Slurry-phase biological treatment can be a relatively rapid process compared to other biological treatment processes, particularly for contaminated clays. The success of the process is highly dependent on the specific soil and chemical properties of the contaminated material. This technology is particularly useful where rapid remediation is a high priority

Solid-phase bioremediation. Solid-phase bioremediation is a process that treats soils in above-ground treatment areas equipped with collection systems to prevent any contaminant from escaping the treatment. Moisture, heat, nutrients, or oxygen are controlled to enhance biodegradation for the application of this treatment. Solid-phase systems are relatively simple to operate and maintain, require a large amount of space, and cleanups require more time to complete than with slurry-phase processes. Solid-phase soil treatment processes include *landfarming*, *soil biopiles,* and *composting*.

Landfarming. In this relatively simple treatment method, contaminated soils are excavated and spread on a pad with a built-in system to collect any "leachate" or contaminated liquids that seep out of contaminant soaked soil. The soils are periodically turned over to mix air into the waste. Moisture and nutrients are controlled to enhance bioremediation. The length of time for bioremediation to occur will be longer if nutrients, oxygen or temperature are not properly controlled. In some cases, reduction of contaminant concentrations actually may be attributed more to volatilization than biodegradation. When the process is conducted in enclosures controlling escaping volatile contaminants, volatilization losses are minimized.

Soil biopiles. Contaminated soil is piled in heaps several meters high over an air distribution system. Aeration is provided by pulling air through the heap with a vacuum pump. Moisture and nutrient levels are maintained at levels that maximize bioremediation. The soil heaps can be placed in enclosures. Volatile contaminants are easily controlled since they are usually part of the air stream being pulled through the pile.

Composting. Biodegradable waste is mixed with a bulking agent such as straw, hay, or corn cobs to make it easier to deliver the optimum levels of air and water to the microorganisms. Three common designs are *static pile composting* (compost is formed into piles and aerated with blowers or vacuum pumps), *mechanically agitated in-vessel composting* (compost is placed in a treatment vessel where it is mixed and aerated), and *windrow composting* (compost is placed in long piles known as windrows and periodically mixed by tractors or similar equipment).

Table 1 – Potential Advantages and Disadvantages of Bioremediation Technologies

Advantages	**Disadvantages**
Lower cost than conventional technologies.	May be difficult to control.
Contaminants usually converted to innocuous products.	Amendments introduced into the environment to enhance bioremediation may cause other contamination problems.
Contaminants are destroyed, not simply transferred to different environmental media.	May not reduce concentration of contaminants to required levels.
Nonintrusive, potentially allowing for continued site use.	Requires more time.
Relative ease of implementation.	May require more extensive monitoring.
	Lack of (hydraulic) control.
	Dynamic process, difficult to predict future effectiveness.