

HAZARDOUS WASTE MANAGEMENT: IN SITU BIOREMEDIATION

Unfortunately, the LaGrega textbook is woefully outdated in its discussion of in-situ bioremediation. This treatment technology is gaining in popularity for application at Superfund sites and other types of contaminated sites (particularly leaking underground storage tanks - USTs).

1.35 M cubic yards of soil treated at Superfund sites with in situ bioremediation (a of 1998) making it the 5th highest used treatment technology for contaminated soil based on volume

(2nd highest of the in-situ technologies behind SVE)

In situ bioremediation has been used for soil treatment at 29 Superfund sites.

In situ bioremediation has also been used for groundwater remediation at 19 Superfund sites.

In situ biodegradation of toxic organic compounds occurs naturally in many soils and aquifers. Natural bacteria are attached to the soil and aquifer material, and some possess the ability to degrade contaminants. At most sites, the natural rate of bioactivity is slow. However, if the biodegradation rate is sufficient to prevent the spread of contaminant plumes (where the contaminant is slowly dissolving from NAPL or water and the groundwater migration rate is slow), regulators may determine that no ACTIVE intervention by engineers is needed at the site for remediation to occur. This is so-called NATURAL ATTENUATION (or INTRINSIC BIOREMEDIATION). To prove that natural bacterial activity is sufficient for remediation, site data must be gathered and models incorporating groundwater flow and biodegradation must be run.

Natural attenuation will only work if:

The contaminant is biodegradable by natural bacteria.

The bacteria needed are present at the site.

The bacteria required are ACTIVE at the site.

The rate of bioactivity is sufficient to protect human health and the environment (based on risk assessment and contaminant fate models).

It will cost money to prove these points to EPA, and monitoring is required as long as the contaminant source area (landfill or trapped NAPL or contaminants sorbed to soil) is present. Natural attenuation may take 50 years or more to fully degrade all of the contaminant present. It is most commonly used for hydrocarbon contamination (gasoline, diesel fuel, BTEX compounds). It is considered less certain for chlorinated compounds (generally solvents such as TCE, PCE, CT,....)

Our book emphasizes AEROBIC biodegradation, and the need for oxygen. They state that biodegradation is often oxygen limited. In reality, while aerobic biodegradation is usually FASTER, anaerobic degradation can also be significant. At hydrocarbon sites undergoing natural attenuation, less than 20% of the total hydrocarbon degraded is by aerobic bacteria. Due to the low solubility of oxygen and therefore low availability (and the consumption of about 3 g oxygen per g of BTEX degraded), other "electron acceptors" (things the bacteria "breathe") are

needed. Bacteria can use nitrate, Fe+3, sulfate, and water/CO2 instead of oxygen to degrade organic compounds. Since these other compounds may be present at significant concentrations, significant potential for ANAEROBIC (non-oxygen utilizing) bioactivity exists.

In particular, highly CHLORINATED compounds are easier to degrade anaerobically than aerobically. Some bacteria actually BREATHE the chlorinated compound... They remove Cl from the molecule.

example: PCE -> TCE -> DCE -> vinyl chloride -> ethene
 #cl 4 3 2 1 0

Other bacteria COMETABOLIZE the chlorinated compounds. In COMETABOLISM, the bacteria does not get energy (as it would from BREATHING the compound) or carbon (which is needed to grow and build new cells) while transforming the organic compound. Also, the compound is generally not mineralized (converted to CO2 and water) or fully degraded, but only partially transformed. However, the cometabolism requires that other specific carbon sources or growth substrates be present for the bacteria to survive.

examples: TCE may be cometabolized by AEROBIC bacteria if those bacteria are fed methane, phenol, toluene, propane,....

example: TCE may be cometabolized by anaerobic bacteria if lactate, hydrogen, etc. are present.

If natural biodegradation is too slow or not occurring, engineers can modify the subsurface environment to allow more optimal remediation. Common “engineering” options include:

1. add more oxygen

can pump air into the vadose zone (bioventing) which can also help groundwater treatment since the enriched oxygen in the soil vapor will diffuse and partition into the groundwater

can pump air into the saturated zone (air sparging) below the water table

can pump pure oxygen into the saturated zone

can add hydrogen peroxide into the groundwater

can pump oxygen-enriched water into the saturated zone

can put “oxygen releasing compounds” (ORC) solids into a well or trench

2. add more nutrients

bacteria need nitrogen, phosphorus, and other trace nutrients to survive which may be limited in the natural soil and groundwater. Adding common “fertilizer” can supply these needed elements. Bacteria are trying to grow new cells. Cells are about 80-90% water, and the non-water mass is about 50% carbon, 14% nitrogen, and 3% phosphorus.

3. add a supplemental carbon source

this works especially well for anaerobic bacteria; also unique carbon source addition can allow cometabolism

4. add anaerobic “electron acceptors”

add nitrate, sulfate into the groundwater

5. add specific bacteria into the subsurface
this generally doesn't work very well and is not commonly used
6. modify temperature, pH, moisture (in vadose zone)

“Additions” are most commonly added via injection wells, but may also be added in trenches or infiltration from the surface.

If injection trenches are used they may serve as “biobarriers” which will intercept the contaminant plumes, so that groundwater leaving the trench is “clean”.

Another thing that can limit or slow biodegradation are the concentrations of the contaminants. If concentrations are very HIGH (generally 100s of mg/L) they can be toxic to bacteria. However, very LOW concentrations ($\mu\text{g/L}$) generally result in SLOW biodegradation rates.

example: removal rate of compound, $\text{mg/d} = K_1 * \text{conc of compound in mg/L}$
where K_1 is a first order decay coefficient, L/d

as the concentration increases, the removal rate also increases