LECTURE 7 & 8

Bioremediation

Bioremediation refers to the productive use of biological catalysis to remove or detoxify pollutants that have found their way into the environment and threaten public health, usually as contaminants of soil, water, gas stream or sediments.

Practical, robust, cost effective.

- Microorganisms destroy organic contaminants in the course of using the chemicals for their own growth and reproduction.
- Organic chemicals provide:carbon, source of cell building material, electrons, source of energy.

Types of Bioremediation

Types of bioremediation based on the source of microorganisms used :

Biostimulation, which involves the addition of nutrients, electron acceptors or electron donors, and sometimes auxiliary substrate to stimulate the growth and activity of specific indigenous microbial populations. (eg. Bioventing, biobarriers).

Bioaugmentation - addition of exogenous, specialized microorganisms with enhanced capabilities to degrade the target pollutant.

In situ biological treatment

The most common approaches:

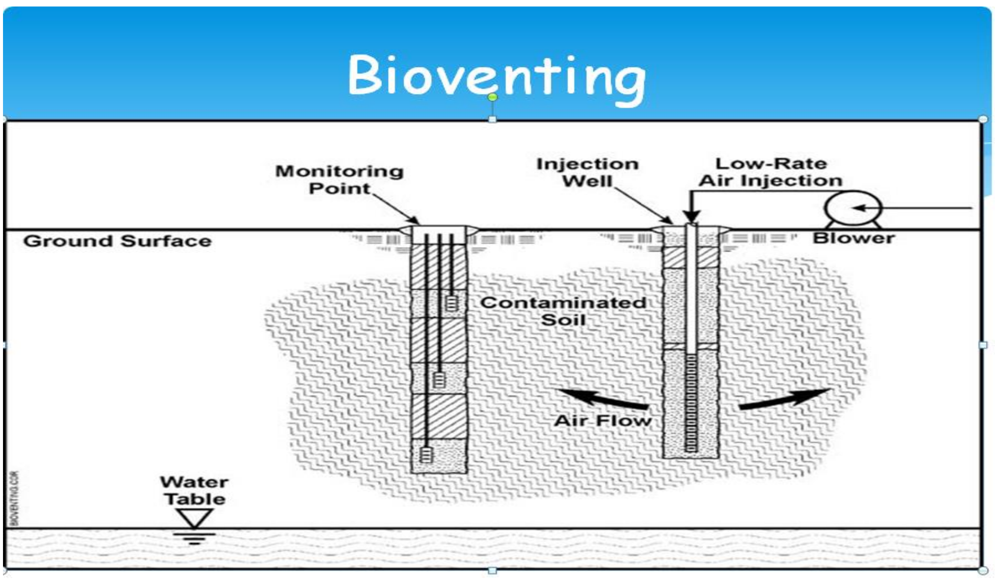
- Bioventing
- Water circulation systems
- Air sparging
- Biobarriers

Bioventing

1. In situ bioremediation that uses indigenous microbe to biodegrade organic constituents adsorbed to soil in the unsaturated (vadose) zone.

2. Activity of indigenous bacteria is enhanced by inducing slow air flow into the unsaturated zone commonly by using vacuum pumps that pull air through the contaminated soil.

3. Nutrients are added if necessary.



Water recirculation systems (WRS)

Applicable to the saturated zone.Also known as Raymond process (Richard Raymond-pioneer 1974).Contaminated groundwater is extracted and treated aboveground.The treated groundwater is ammended with nutrients and reinjected into the aquifer to biostimulate the contaminated zone.

1. Most versatile: attempt to handle contamination above and below the water table
2. Can be used and modified to inject microbe, electron acceptor delivery system to enhance bioremediation.
3. However, recovery of all recirculating water requires aboveground treatment
4. Time required: 6 months to 5 years.
5. Problems:
    a. clogging of wells by oxides and bacterial growth.
    b. Monitoring and maintenance needed.

Air sparging

Involved injection of compressed air into the contaminated subsurface to deliver oxygen and strip the contaminant (volatile organic compounds) into a vapor-capture system. Remediate contamination in the saturated zone of a groundwater aquifer, as well as to remediate portions of the unsaturated zone.

* This system is also known as in situ air stripping or in situ volatilization.
* Effectiveness depends on 2 factors

* Partitioning characteristics of the contaminants (vapor, dissolved, sorbed phases).

* Permeability of soil (rate air can be injected)

* This determine the mass transfer rate of the contaminants from dissolved to vapor phase.

Air sparging with soil vapor extraction (soil venting) process

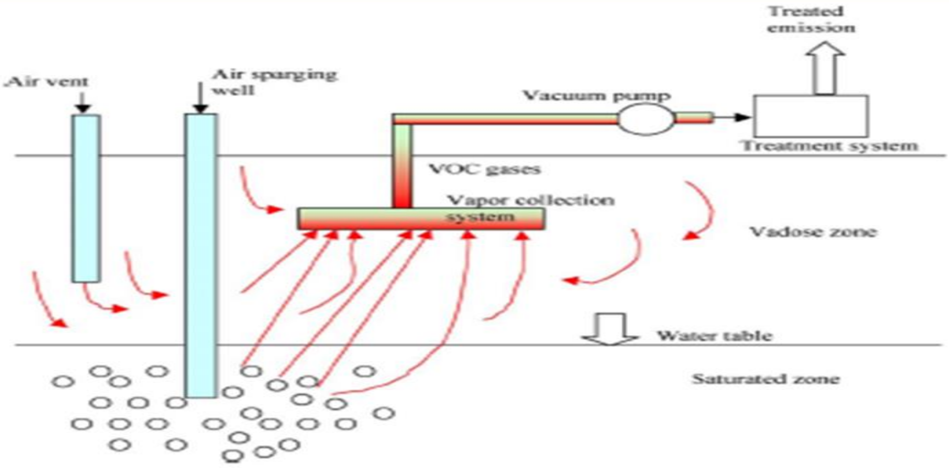


Fig. 1. Air sparging with soil vapor extraction process.

Biobarriers

Also known as biowalls, trench biosparge, microbial fences, bubble curtains, air curtains, bioscreens and sparge curtains.

Alternative to traditional impermeable barriers (containment tools designed to prevent or control groundwater from flowing into, through or from a certain location).

Biobarriers are permeable barrier that allow contaminants to flow through it where contaminants will be degraded.

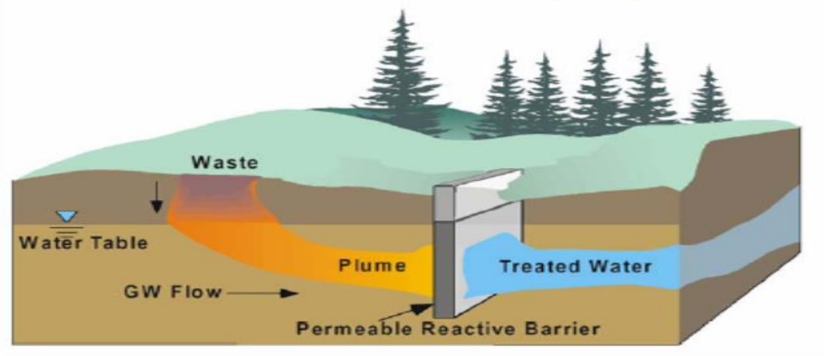
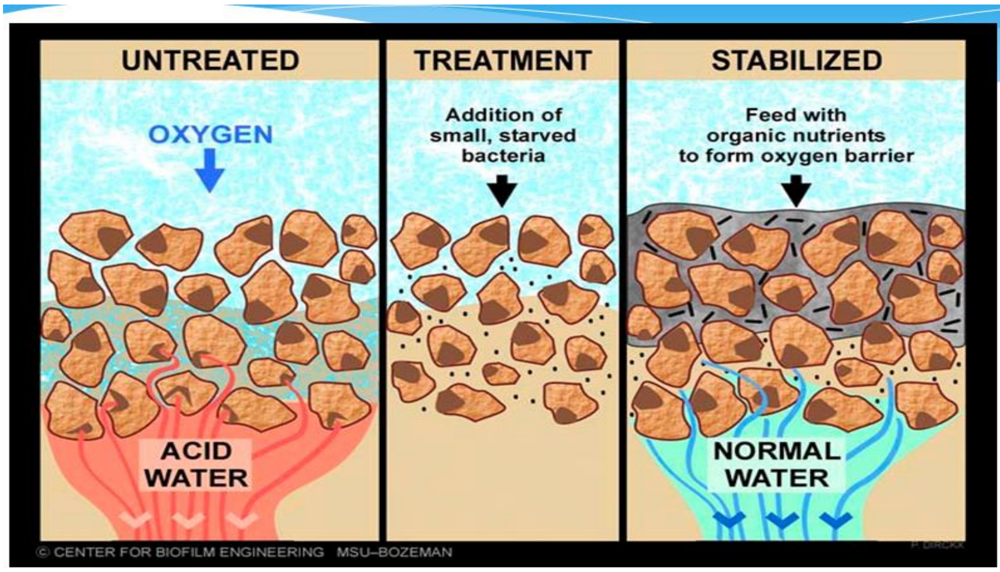


Figure 1. Schematic representation of a permeable reactive biobarrier.

* **Biobarriers aims is to**
  * establish and maintain a biological treatment system with a high density of competent microorganisms under a controlled process that protects specific degraders and prevents their loss under environmental stress conditions
* **Simple example of biobarriers:**
  * Dig a trench and fill it with crushed stone, which serves as a medium for biofilm growth.
  * Oxygen introduced by air sparging to form an air curtain.
  * Nitrate is also introduced as another electron acceptor
  * Specialized microorganisms that can degrade the contaminants could also be injected.



Microorganisms used for bioaugmentation

- Enrichment cultures
  - Enrichment of indigenous microbes isolated from contaminated area.
- Pure cultures specific for contaminants
  - Culture isolated and studied earlier on specific contaminants.
  - Eg: *Dehalococcoides ethenogenes* to remove TCE
- **Commercially available cultures.**
  - Available as freeze-dried cultures (mixed and pure)

Genetically modified microorganisms (GMOs).

- Not yet apply for in situ treatment

* Long term effect not fully studied
* Genetic drift across species
* If applied, will give lots of advantages and also create worries to public.

Bioaugmentation for in situ reductive dechlorination

* Location: The aquifer underlying Dover Air Force Base, Delaware, US.
* Contaminants: TCE and degradation metabolites.
* First phase of pilot study: biostimulation: addition of nutrient and substrate (sodium lactate).
* Second phase: bioaugmentation: addition of specific microorganisms.

Results:

* The biostimulation alone (addition of lactate) was not sufficient to dechlorinate TCE to cis-DCE.
* Indigenous microflora unable to degrade cis –DCE.
* When bioaugmentation was carried out, vinyl chloride and ethene were observed in monitoring wells.

Cometabolism

The term cometabolism indicates that transformation of the contaminants is a secondary reaction whereby.

The microbes consume a hydrocarbon, such as butane for their energy needs. In the process, they produce enzymes that unexpectedly degrade other compounds such as TCE.

- Based on location where the bioremediation process occurs, bioremediation can be classified as:
  - ***Ex situ*** involves the use of aboveground bioreactors to treat contaminated soil or groundwater that has been extracted from the contaminated site- off site
  - ***In situ*** occurs below the ground surface, where the contaminated zone becomes the bioreactor- on site

***In situ* bioremediation**

Can be aerobic or anaerobic:

- Aerobic
- supplying oxygen by:
  - Addition of oxygen using air spargers.
  - Hydrogen peroxide dissolved in nutrients.
  - Oxygen releasing compound buried in contaminated zone.
- Anaerobic:
  - Organic substrates or hydrogen gas can be injected as electron donors (lactate, acetate, methanol or hydrogen gas).

***Ex-situ* bioremediation**

- Generally selected for the treatment of highly contaminated material.
- Applicable when :
  - contaminants has been extracted from source zone

* hydrophobic pollutants (PAHs and PCBs) are not effectively removed in situ due to low availability.
* Rapid removal of contaminants is required

Advantages of in situ bioremediation to *ex-situ*

* No remediation wastes are produced because treatment occurs below ground. Eliminates transportation costs and disposal charge.
* Minimum land and environmental disturbance.
* treat large volumes of contaminated soil and groundwater
* attack hard-to- withdraw hydrophobic pollutants that may be located at depths that prohibit excavation.

Disadvantages of *in situ*

* In situ treatment is slower than ex-situ treatment due to inefficiencies in distributing stimulary substrates throughout the contaminated zone.
* Difficulties to overcome mass transfer through mixing or surfactant addition, therefore slow degradation of hydrophobic pollutants.
* Difficult to implement highly stratified soils that hinder the vertical distribution of injected air or gases through the contaminated zone

Advantages of bioremediation

Bioremediation is a natural process and is therefore perceived by the public as an acceptable waste treatment process.

* Relies on natural biodegradation processes that can be faster and cheaper

* Instead of transferring contaminants from one environmental medium to another, for example, from land to water or air, the complete destruction of target pollutants is possible.

1) Minimum land and environmental disturbance
2) Bioremediation is less expensive
3) Used in conjunction with (or as a follow up to) other treatment technologies.

Disadvantages of bioremediation

* Bioremediation is limited to those compounds that are biodegradable.
* There are some concerns that the products of biodegradation may be more persistent or toxic than the parent compound.
* It is difficult to extrapolate from bench and pilot-scale studies to full-scale field operations.
* Bioremediation often takes longer than other treatment options.
* Biological processes are often highly specific.
* Important site factors required for success include the presence of metabolically capable microbial populations.
* suitable environmental growth conditions, and appropriate levels of nutrients and contaminants.
* May require extensive monitoring.
* Certain wastes such as heavy metals, are not eliminated by biological processes (they can be bioreduced or biooxidized to less toxic and less mobile forms.
* High concentration of contaminants will inhibit microorganisms

Table 4 Summary of bioremediation strategies.

Technology	Examples	Benefits	Limitations	Factors to consider
In situ	*In situ* bioremediation Biosparging Bioventing Bioaugmentation	Most cost efficient Noninvasive Relatively passive Natural attenuation processes Treats soil and water	Environmental constraints Extended treatment time Monitoring difficulties	Biodegradative abilities of indigenous microorganisms Presence of metals and other inorganics Environmental parameters Biodegradability of pollutants Chemical solubility Geological factors Distribution of pollutants
Ex situ	Landfarming Composting Biopiles	Cost efficient Low cost Can be done on site	Space requirements Extended treatment time Need to control abiotic loss Mass transfer problem Bioavailability limitation	See above
Bioreactors	Slurry reactors Aqueous reactors	Rapid degradation kinetic Optimized environmental parameters Enhances mass transfer Effective use of inoculants and surfactants	Soil requires excavation Relatively high cost capital Relatively high operating cost	See above Bioaugmentation Toxicity of amendments Toxic concentrations of contaminants