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4. Bioremediation and Its Applications

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Abstract:

Increase in pollution is posing new challenge to the environment day by day which is causing several harmful effect to flora and fauna. The techniqes are being evolved to mitigate the increased problem of pollutant and to reduce the harmful effect by pollutant. Bioremediation is a technique which uses microorganism for converting the harmfull pollutant to less harmfull compounds. In bioremediation Bacteria, Fungi and other similar organism are used for conversion of contaminants into less toxic compounds. There are two types of in situ Bioremediation and ex situ bioremediation. In situ Bioremediation the compounds are treated at the site itself while in exsitu the pollutants are are treated elsewhere. Bioventing, composting, bioaugmentation are some examples of Bioremediation.

4.1 Introduction:

Bioremediation is any process that uses organisms (microorganism, algae and plant) or their enzymes to return the polluted environment to its original condition. Use of living organisms (e.g., bacteria) to clean up oil spills or remove other pollutants from soil, water, and wastewater. (*Source: United States Environmental Protection Agency, Office of Compliance and Assurance)*. “Clean-up of pollution from soil, groundwater, surface water and air, using biological, usually microbiological processes”.

Biodegradation is the use of these organisms in the degradation of different pollutants. **Xenobiotic compounds** are chemical compounds found in an organism but it is not normally produced or expected to be present in it.

Cometabolism: in this process the microorganism produces an enzyme to utilizes its nutrients, but by chance this enzyme can degrade a pollutant. Bioremediation is a triple-corners process.

Bioremediation relies largely on the enzymatic activities of living organisms, usually microbes, to catalyze the destruction of pollutants or their transformation to less harmful forms.

A complex process depending on many factors including: ambient environmental conditions composition of the microbial community nature and amount of pollution present. What Makes Bioremediation a Promising Approach: permanence contaminant is degraded. Potentially low cost, 60-90% less than other technologies.

Bioremediation is described as the cycle whereby characteristic squanders are naturally corrupted under controlled conditions to an innocuous state, or to levels underneath obsession limits set up by managerial experts. Microorganisms are fit to the task of impurity destruction since they have proteins that license them to use natural pollutants as a food.

The purpose of bioremediation is asking them to work by giving ideal levels of enhancements and various fabricated materials fundamental for their absorption in order to spoil/detoxify substances which are unsafe to condition and living things. All metabolic reactions are mediated by impetuses.

4.2 Factors of Bioremediation:

The control and optimization of bioremediation processes is a complex system of many factors.

These factors include: the existence of a microbial population capable of degrading the pollutants; the availability of contaminants to the microbial population; the environment factors (type of soil, temperature, and pH, the presence of oxygen or other electron acceptors, and nutrients).

4.2.1 Microbial Populations for Bioremediation Processes:

Microorganisms can be isolated from almost any environmental conditions. Microbes will adapt and grow at subzero temperatures, as well as extreme heat, desert conditions, in water, with an excess of oxygen, and in anaerobic conditions, with the presence of hazardous compounds or on any waste stream. The main requirements are an energy source and a carbon source.

Types of treatment technologies are in use to remove contaminants from the environment.

Soil vapor extraction air sparging bioremediation thermal desorption soil washing. Chemical dehalogenation soil extraction *in situ* soil flushing.

4.3 Types of Pollutants:

Organic pollutants → catabolized

Naturally occurring

Xenobiotics - substances foreign to an entire biological system, i.e. artificial substances, which did not exist in nature before their synthesis by humans

Metals from ore extraction and manufacturing

4.3.1 Biological Solution

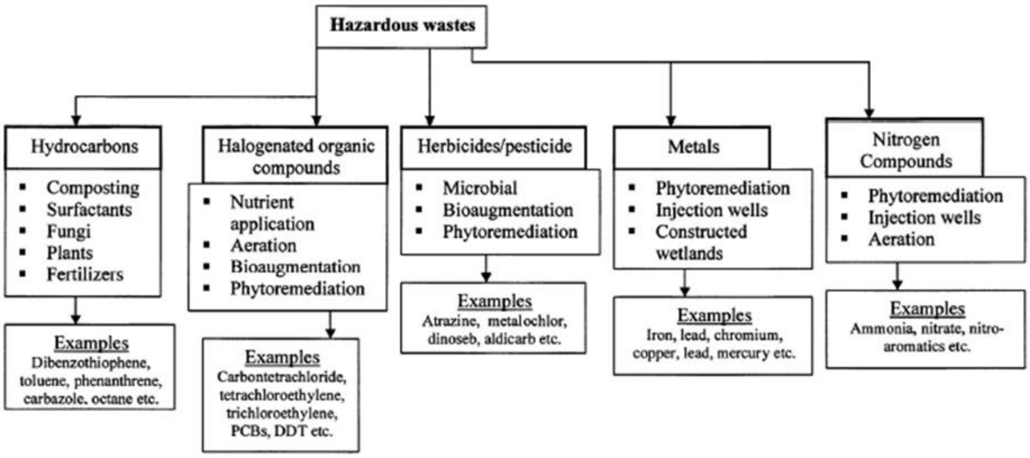

Figure 4.1: Summary of Different Bioremediation Strategies for Typical Hazardous Wastes

4.3.2 Fundamentals of Cleanup Reactions:

- **Aerobic Metabolism:** Microbes use O_2 in their metabolism to degrade contaminants
- **Anaerobic Metabolism:** Microbes substitute another chemical for O_2 to degrade contaminants. Nitrate, iron, sulfate, carbon dioxide, uranium, technicium, perchlorate
- **Co-Metabolism:** Bacterium uses some other carbon and energy source to partially degrade contaminant (organic aromatic ring compound)

4.3.3 Economics of *in-situ* vs. *ex-situ* remediation of contaminated soils

- Cost of treating contaminated soil in place \$80-\$100 per ton
- Cost of excavating and trucking contaminated soil off for incineration is \$400 per ton.
- Over 90% of the chemical substances classified as hazardous today can be biodegraded.

4.3.4 Bioremediation Techniques:

In situ bioremediation

Ex situ bioremediation

Phytoremediation

In situ bioremediation

It is approach in which there is a direct of microorganism with the contaminant.

a. Advantages:

- low cost
- Minimal site disruption
- Simultaneous treatment of soil and water
- Minimal exposure to public and site personnel

b. Disadvantages:

- Time consuming
- Seasonal variation
- Problematic addition of additives.

Two types

Intrinsic in situ bioremediation (or) Natural Attenuation

Engineered in situ bioremediation

Natural Attenuation is defined as the biodegradation, diffusion, dilution, sorption, volatilization, and or chemical stabilization of contaminants which reduces contaminant toxicity, mobility, or volume to a level that is protective of human health and the environment.

Biodegradation is considered destructive attenuation meaning it changes the chemical nature of the contaminant and the others are considered nondestructive forms of attenuation.

Natural attenuation referred to by several names:

Natural Attenuation

Passive Bioremediation

Intrinsic bioremediation

Natural Attenuation

Bioremediation Research

4.4 Bioaugmentation vs. biostimulation:

- **Biostimulation** involves the modification of the environment to stimulate existing microorganisms capable of bioremediation.

Indigenous populations may not be capable of degrading the xenobiotics or the wide range of potential substrates present in complex pollutant mixtures.

- **Bioaugmentation** is the introduction of a group of natural microbial strains or a genetically engineered variant to treat contaminated soil or water. Many factors control biodegradability of a contaminant in the environment. Before attempting to employ bioremediation technology, one needs to conduct a thorough characterization of the environment where the contaminant exists, including the microbiology, geochemistry, mineralogy, geophysics, and hydrology of the system

4.5 Phytoremediation:

- Phytoremediation is use of plants for accumulation, removal or conversion of pollutants.

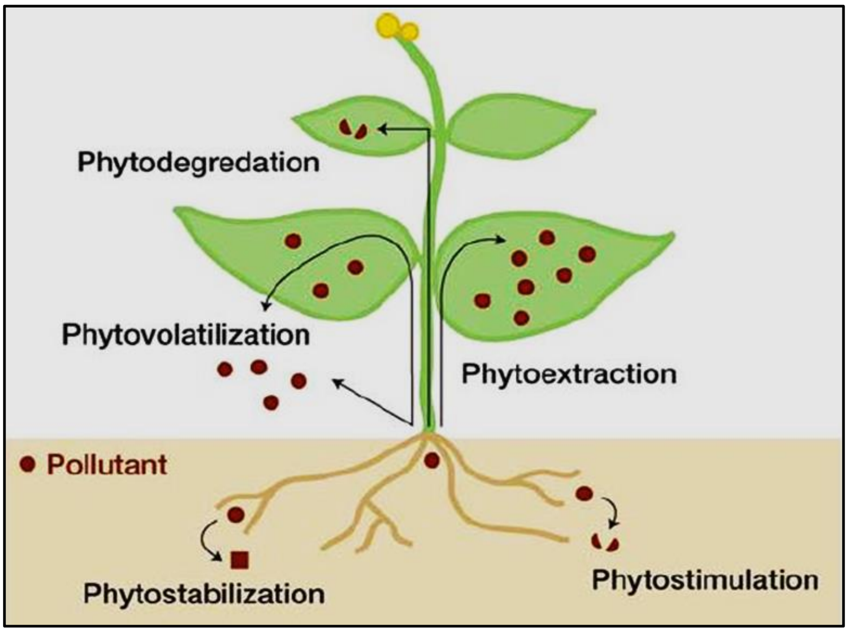

Figure 4.2: Phytoremediation Process

- Approximately 400 plant species have been classified as hyperaccumulators of heavy metals, such as grasses, sunflower, corn, hemp, flax, alfalfa, tobacco, willow, Indian mustard, poplar, water hyacinth, etc.

4.5.1 Technology that use plants to clean up contaminated sites.

- Green technology that uses plants systems for remediation and restoration.
- Encompasses microbial degradation in rhizosphere as well as uptake, accumulation and transformation in the plant.

4.5.2 Current Methods:

- Current methods mainly remove and transport to RCRA land fill or pump and treat type systems.
- Many sites are large and pollution is not high but still violates standards.
- For secondary or tertiary treatment of waste water.

4.5.3 How does it work?

Plants in conjunction with bacteria and fungi in the rhizosphere transform, transport or store harmful chemicals. Plants attributes make them good candidates. Root system surface area to absorb substances and efficient mechanisms to accumulate water, nutrients and minerals. Selectively take up ions. Developed diversity and adaptivity to tolerate high levels of metals and other pollutants.

4.5.4 Mechanisms:

Phytotransformation/ Phytodegradation:

- Pollutant is taken up by the plant and transformed in plant tissue (to be effective must be transformed to a less toxic form).
- Trichloroethylene (TCE), a prevalent ground water contaminant, transformed to less toxic metabolites by using hybrid poplar tree.
- Air Force facility in Texas using cottonwoods to treat a large ground water plume of TCE.
- EPA research lab using parrot feather (a common aquatic weed) for TNT treatment.

4.6 Phytoextraction:

- Uptake of chemical by the plant.
- Works well on metals such as lead, cadmium, copper, nickel etc.

4.6.1 Detroit lead contaminated site was removed with Sunflower and Indian mustard.

Recently researchers at the University of Florida have determined that a species of fern, native to the south east, stores high concentrations of arsenic in its fronds and stems more than 200 times the concentration in the soil.

4.6.2 Phytostabilization:

Vegetation holds contaminated soils in place: root system and low growing vegetation prevent mechanical transportation of pollutants from wind and erosion. Trees transpire large quantities of water (more than 15 gal/day) so pumping action prevents contaminants from migration into the water table.

4.6.3 Rhizofiltration:

Use the extensive root system of plants as a filter. 1995, Sunflowers were used in a pond near Chernobyl approx. 1 week they had hyperaccumulated several thousand times the concentration of cesium and strontium. Hyper accumulation can contain 100 times or more of contaminant than normal plant.

4.6.4 Rhizosphere Bioremediation:

Increase soil organic carbon, bacteria, and mycorrhizal fungi, all factors that encourage degradation of organic chemical in soil. The number of beneficial bacteria increase in the root zone of hybrid poplar trees an enhanced the degradation of BTEX, organic chemical, in soil.

Advantages:

- Cost effective when compared to other more conventional methods.
- “nature” method, more aesthetically pleasing.
- Minimal land disturbance.
- Reduces potential for transport of contaminants by wind, reduces soil erosion
- Hyperaccumulaters of contaminants mean a much smaller volume of toxic waste.
- Multiple contaminants can be removed with the same plant.

Disadvantages:

- Slow rate and difficult to achieve acceptable levels of decontamination.
- Potential phase transfer of contaminant.
- Possibility of contaminated plants entering the food chain.
- Disposal of plant biomass could be a RCRA regulated hazard substances.
- Possible spread of contaminant through falling leaves.
- Decrease in action during winter months when trees are dormant.
- Trees and plants require care.
- Contaminant might kill the tree.
- Degradation product could be worse than original contaminant.
- Much testing is needed before a procedure can be utilized (EPA approval)

4.6.5 Aquatic Plants for Wastewater Treatment:

Aquatic plants are chosen for absorb particular nutrient and to remove pathogens, metals and other contaminants from wastewater. Aquatic plants have been shown to be very effective as a secondary or tertiary state for water treatment and nutrient removal.

Water Lily has an extensive root system with rapid growth rates, but is sensitive to cold temp, it is an idea plant for water treatment in warm climates.

Duckweed (Lemna spp.) has greater cold tolerance and a good capacity for nutrient absorption.

Penny wort (Hydrocotyl spp) is relatively cold tolerant with a very good capacity for nutrient uptake. Water hyacinth uptake of heavy metal eg. Pb, Cu, Cd, Hg from contaminated water.

Table 4.1: Function of Plants in Aquatic Treatment

Plant Parts	Functions
◆ Roots and/or stem in water column	◆ Uptake of pollutants ◆ surfaces on which bacteria grow ◆ media for filtration and adsorption of solids
◆ Stem and/or leaves at or above water surface	◆ Attenuate sunlight, thus can prevent growth of suspended algae. ◆ Reduce effects of wind on water ◆ Reduce transfer of gases and heat between atmosphere and water.

Table 4.2: Contaminant Removal Mechanisms

Physical	Chemical	Biological
Sedimentation	Precipitation	Bacterial metabolism
Filtration	Adsorption	Plant metabolism
Adsorption	Hydrolysis reaction	Plant absorption
Volatilization	Oxidation reaction	Natural die-off

4.7 Rhizofiltration:

4.7.1 Applicability:

A suitable plant for rhizofiltration applications can remove toxic metals from solution over an extended period of time with its rapid-growth root system. Various plant species have been found to effectively remove toxic metals such as Cu^{2+}, Cd^{2+}, Cr^{6+}, Ni^{2+}, Pb^{2+}, and Zn^{2+} from aqueous solutions. Low level radioactive contaminants also can be removed from liquid streams.

4.7.2 Limitations:

Rhizofiltration is particularly effective in applications where low concentrations and large volumes of water are involved.

Rhizofiltration may not succeed for a number of reasons, including mortality of plants for reasons such as management, weather extremes, soil conditions or pest.

4.7.3 Field Studies:

Field studies are required before full-scale application. Specific information includes rates of remediation, irrigation requirements, rates of soil amendments, and plant selection. Formulating clear objectives, appropriate treatments, experimental units and planning are important considerations in field studies.

4.7.4 Economic:

This technique should be less cost than traditional technologies such as excavation, thermal desorption, landfilling etc.

4.8 Conclusion:

Phytoremediation will clearly play some role in the stabilization and remediation of many contaminated sites. The main factor driving the implementation of phytoremediation projects are low costs with significant improvements in site aesthetics and the potential for ecosystem restoration.

Bioremediation is a long way greater low priced than distinct improvements which can be regularly used to tidy up risky waste. There are numerous cost or effectiveness possibilities to bioremediation which may be applied in zones which can be tough to attain with out removal. Biodegradation is extremely productive and alluring choice to remediating, cleaning, overseeing and recuperating procedure for unraveling dirtied condition through microbial movement.

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