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Bioremediation: Environmental abatement by using microbes

Dr. Diptimayee Dash
Professor, Indira Gandhi Krishi Vishwa Vidyalaya, Raipur
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Bioremediation is a process that uses microorganisms to neutralize or eliminate pollutants from contaminated sites. It's an eco-friendly approach with applications in cleaning up oil spills, treating wastewater, and managing soil pollution. The world today is facing the problem of environmental pollution due to the intensification of in-organic agriculture and manufacturing industries which resulted in increased release of a wide range of xenobiotic compounds to the environment. The contamination of the environment by petroleum products, pharmaceutical compounds, chloro and nitrophenols and their derivatives, polycyclic aromatic hydrocarbons, organic dyes, pesticides and heavy metals is a serious problem. These pollutants enter the environment by different ways.

Microorganisms survive almost all environmental conditions due to an amazing metabolic activity. The biosphere is full of microorganisms as they can grow easily in a wide range of environmental conditions and are hence, widely distributed having an impressive metabolic activity. The biodegradation of pollutants can be carried out exploiting the nutritional versatility of microorganisms. Bioremediation uses microorganisms i.e. yeast, fungi or bacteria to clean up contaminated soil and water. In this process the microbes specifically break down the pollutants transforming them into less toxic or nontoxic elemental and compound forms. Bioremediation involves microorganisms helping in biodegrading the pollutants thereby removing them. The process in which certain microorganisms convert, modify and utilize toxic pollutants in order to obtaining energy and biomass production is termed as bioremediation.

Types of bioremediations

In situ bioremediation: Treatment of contaminants at the site without removal. These techniques are generally the most desirable options due to lower cost and less disturbance since they provide the treatment in place avoiding excavation and transport of contaminants. In situ treatment is limited by the depth of the soil that can be effectively treated. In many soils effective oxygen diffusion for desirable rates of bioremediation extend to a range of only a few cms to about 30 cm into the soil, although depths of 60 cm and greater have been effectively treated in some cases.

Bioaugmentation: Introduction of specific microorganisms to enhance degradation.

Biostimulation: Stimulating the growth of existing microorganisms through nutrient addition.

Bioventing: Stimulating the natural degradation of pollutants in the soil by enhancing microbial activity through increased aeration.

Ex situ bioremediation Removal of contaminated material for treatment elsewhere.These techniques involve the excavation or removal of contaminated soil from ground. Under the bioremediation processes, there are different types of treatment technologies or techniques.

Composting: Accelerating natural decomposition of organic contaminants through microbial activity in a controlled environment.

Biopiles: Similar to composting but involves creating piles of contaminated material with added microorganisms.

The basic bioremediation methods are: Biostimulation, bioattenuation, bioaugmentation, venting and piles. These are different types of treatment technologies or techniques under bioremediation processes.

Biostimulation

This kind of strategic is linked through the injection of specific nutrients at the site (soil/ground water) to stimulate the activity of indigenous microorganisms. The focus here is the stimulation of indigenous or naturally existing bacteria and fungus community. The first step is by supplying fertilizers, growth supplements and trace minerals. Then, by providing other environmental requirements like pH, temperature and oxygen to speed up their metabolism rate and pathway . So allow microbes to create the basic requirement for example, energy, cell biomass and enzymes to degrade the pollutant.

Bioattenuation [Natural attenuation]

Bioattenuation or natural attenuation is the eradication of pollutant concentrations from surrounding. It is carried out with biological processes it maybe includes (aerobic and anaerobic biodegradation, plant and animal uptake), physical phenomena (advection, dispersion, dilution, diffusion, volatilization, sorption/desorption), and chemical reactions (ion exchange, complexation, abiotic transformation). Terms such as intrinsic remediation or biotransformation are included within the more general natural attenuation definition.

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Bioaugmentation

The addition of pollutant degrading microorganisms (natural/exotic/ engineered) to augment the biodegradative capacity of indigenous microbial populations on the contaminated area these processes known as bioaugmentation to rapidly increasing the natural microorganism population growth and enhance degradation. This involves the addition of microorganisms indigenous or exogenous to the contaminated sites. Two factors limit the use of added microbial cultures in a land treatment unit: i) Nonindigenous cultures rarely compete well enough with an indigenous population to develop and sustain useful population levels ii) Most soils with long-term exposure to biodegradable waste have indigenous microorganisms that are effective degrades if the land treatment unit is well managed The collection of the microbes is done from the remediation site, separately cultured, genetically modified and returned to the site. The process of Bioaugmentation, involves adding engineered microbes in a system which act as bioremediators in order to quickly and totally eliminate complex pollutants.

Natural species are not fast enough to break down certain compounds so to facilitate must be genetically modified through DNA manipulation and highly compete with the indigenous species, predators and also various abiotic factors. Genetically engineered microorganisms have shown potential for bioremediation of soil, groundwater and activated sludge, exhibiting the enhanced degrading capabilities of a broad coverage of chemical and physical pollutants.

Genetically Engineered Microorganisms (GEMs)

Genetically engineered microorganism is a microorganism whose genetic material has been changed by artificial genetic exchange between microorganisms. This kind of scientific procedure is mainly termed as recombinant DNA technology. Genetically engineered microorganisms (GEMs) have shown potential for bioremediation applications in soil, groundwater, and activated sludge environments, exhibiting enhanced degradative capabilities encompassing a wide range of chemical contaminants.

Bioventing

Bioventing is the most common in situ treatment and involves supplying air and nutrients through wells to contaminated soil to stimulate the indigenous bacteria. Bioventing is involved in venting of oxygen through soil to stimulate growth of natural or introduced bacteria and fungus in the soil by providing oxygen to existing soil microorganisms; indeed, it is functional in aerobically degradable compounds. Bioventing uses low air flow rates to provide

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only enough oxygen to sustain microbial activity. Oxygen is most commonly supplied through direct air injection into residual contamination in soil by means of wells.

Biopiles

Excavated soil contaminated with aerobically remediable hydrocarbons, can be treated in "biopiles". Biopiles are a hybrid of landfarming and composting. Essentially, engineered cells are constructed as aerated composted piles. Biopiles (also known as biocells, bioheap, biomounds and compost Piles) are used to reduce concentrations of petroleum pollutants in excavated soils during the time of biodegradation. In this process, air is supplied to the biopile system during a system of piping and pumps that either forces air into the pile under positive pressure or draws air through the pile under negative pressure. The microbial activity is enhanced through microbial respiration resulting in high degradation of adsorbed petroleum pollutant. Biopiles provide a favorable environment for indigenous aerobic and anaerobic microorganisms.

The advantage of Bioremediation

- It is a natural process, microbes able to degrade the contaminant and increase in numbers when the contaminant is present. When the contaminant is degraded, the biodegradative population become declines. The residues for the treatment are usually harmless product including water carbon dioxide and cell biomass.
- It requires a very less effort and can often be carried out on site, often without causing a major disruption of normal activities. This also eliminates any threats to human health and the environment that can arise during transportation.
- It is applied in a cost-effective process as it cost less than the other conventional methods (technologies) that are used for clean-up of hazardous waste. Important method for the treatment of oil-contaminated sites.
- It does not use any dangerous chemicals. Nutrients especially fertilizers added to make active and fast microbial growth.
- Simple, less labor intensive and cheap due to their natural role in the environment.
- Eco-friendly and sustainable.
- Relative ease of implementation.

The disadvantage of Bioremediation

- It is limited to those compounds that are biodegradable. Not all compounds are susceptible to rapid and complete degradation.
- There are some concerns that the products of biodegradation may be more persistent or toxic than the parent compound.

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- 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.
- It is difficult to extrapolate from laboratory studies to full-scale field operations.
- Research is needed to develop and engineer bioremediation technologies that are appropriate for sites with complex mixtures of contaminants that are not evenly dispersed in the environment. Contaminants may be present as solids, liquids and gases.

Factors affecting microbial bioremediation

The efficiency of bioremediation depends on many factors; including, the chemical nature and concentration of pollutants, the physicochemical characteristics of the environment, and their availability to microorganisms. These factors are included here:

- ➢ Monitoring and Control: Regular monitoring of microbial activity and adjusting environmental conditions as needed ensure the success of bioremediation efforts.
- ➢ Microbial Diversity: The presence of diverse microbial communities enhances the range of contaminants that can be targeted.
- ➢ Environmental Conditions: Factors like temperature, pH, and moisture levels significantly impact microbial activity and effectiveness.
- ➢ Contaminant Characteristics: Different microbes specialize in breaking down specific types of pollutants, and their efficiency varies accordingly
- ➢ Nutrient Availability: Microorganisms require nutrients for growth and pollutant degradation, so adjusting nutrient levels can optimize the process.
- ➢ Oxygen Levels: Aerobic (oxygen-dependent) and anaerobic (oxygen-free) microorganisms play distinct roles; hence, oxygen availability is crucial.

Advanced Techniques:

Genetic Engineering: Modification of microorganisms' genetic makeup to enhance their ability to degrade specific contaminants.

Creating synthetic biology approaches for custom-designed microbes optimized for environmental cleanup.

Nano-Bioremediation: Integration of nanoparticles with microbial activity to enhance the efficiency of pollutant degradation.

Utilizing nanomaterials for targeted delivery of nutrients or electron shuttles to microorganisms.

Metagenomics: Studying the genetic material directly from environmental samples to understand the diversity and functions of microbial communities involved in bioremediation.

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Allows for a comprehensive analysis of microbial populations and their potential for pollutant degradation.

Applications:

Oil Spill Cleanup: Microbes break down hydrocarbons in oil, aiding in the recovery of affected ecosystems.

Wastewater Treatment: Microorganisms help break down organic pollutants in wastewater, making it safer for discharge.

Soil Decontamination: Bioremediation can be used to treat soil contaminated with various chemicals, pesticides, or heavy metals.

Challenges:

Slow Process: Bioremediation is often slower compared to other methods.

Complexity: The success of bioremediation depends on a myriad of factors, making it challenging to predict outcomes accurately.

Conclusion

Despite challenges, bioremediation remains an eco-friendly and sustainable approach to address environmental contamination. Biodegradation is very fruitful technique to remediating, cleaning, managing and recovering for solving polluted environment through microbial activity. Key factors influencing bioremediation success include microbial activity, environmental conditions, and the type of contaminant. Overall, it's a promising and sustainable method for environmental cleanup. As bioremediation can be effective only where environmental conditions permit microbial growth and activity. Bioremediation has been used in different sites globally within varying degrees of success. Mainly, the advantages is greater than that of disadvantages which is evident by the number of sites that choose to use this technology and its increasing popularity through time. Bioremediation's advanced applications and emerging technologies highlight the dynamic nature of this field, offering innovative solutions for challenging environmental problems.

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