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Bioremediation of Petroleum and Other Inorganic Pollutants in Soil

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Abstract

Bioremediation has surfaced as a hopeful approach for cleaning up soil tainted by petroleum hydrocarbons and various inorganic pollutants. This process harnesses the natural metabolic capabilities of microorganisms to degrade and detoxify contaminants, thereby restoring soil quality and ecological balance. In the case of petroleum contamination, hydrocarbon-degrading bacteria such as *Pseudomonas, Bacillus*, and *Rhodococcus* species play a vital role in metabolizing complex hydrocarbons into simpler compounds. For inorganic pollutants like heavy metals, microbial processes such as biosorption, biotransformation, and precipitation contribute to remediation efforts. Metal-resistant bacteria like *Pseudomonas, Bacillus,* and *Klebsiella* species can sequester metals through extracellular polymeric substances (EPS) or enzymatic transformations, reducing their bioavailability and toxicity. Overall, bioremediation offers a sustainable and cost-effective approach to remediate soil contaminated with petroleum and inorganic pollutants, highlighting the importance of microbial diversity, metabolic pathways, and environmental factors in successful remediation outcomes.

Introduction

As the population is increasing, the demand for food, shelter and other lifestyle supporting things are increasing day by day. The surge in industrialization and the heightened demand for heavy metals in petrochemical goods have spurred unforeseen economic advancement. Our reliance on fossil fuels as the primary source for petroleum and other commodities has resulted in significant environmental problems in recent decades. Soil pollution caused by petroleum hydrocarbon has been of significant public and scientific attention now a days. In natural settings, the main biological damage occurs when the flow of water, nutrients, oxygen, and sunlight is disrupted, affecting soil fertility, the growth of plants, and their ability to sprout. This disruption also alters the composition and arrangement of soil microorganisms and structure by creating oil coatings and layers, which hinders the movement of oxygen and essential nutrients within the soil. Different environmentally conscious methods are utilized to clean up areas contaminated with petroleum substances.

Abundance and Variety of Microorganisms Using Petroleum

Numerous microorganisms have the capacity to decompose petroleum hydrocarbons, utilizing them as their exclusive carbon source for metabolic processes and generating energy. Among them, bacteria emerge as the most efficient agents in breaking down petroleum, serving as the primary decomposers of specific substances present in soil, water, and sludge. Microorganisms belonging to diverse genera have been recognized for their ability to degrade various fractions of petroleum-derived hydrocarbons, with numerous organisms isolated from both soil and aquifers.

Microbial Degradation of Petrogenic Hydrocarbons

Petrogenic hydrocarbons fall into four categories: the aliphatic fraction (saturates) the aromatic fraction, the asphaltene fraction (including phenols, fatty acids, ketones, esters, and porphyrins), and resins (comprising pyridines, quinolines, carbazoles, sulfoxides, and amides). Microorganisms are capable of metabolizing various organic pollutants as an energy source, transforming them into harmless byproducts such as carbon dioxide, water, and biomass. A variety of microbial groups are responsible for breaking down petroleum hydrocarbon compounds in environments contaminated with oil. Well-known microorganisms renowned for their ability to degrade hydrocarbons include species like *Pseudomonas, Rhodococcus, Sphingobium, Mycobacterium, Arthrobacter, Marinobacter, Achromobacter, Alcaligenes, Corynebacterium,* *Flavobacter, Micrococcus, Nocardia,* and others. Hydrocarbons of crude oil can be oxidized by the bacterial genera of *Bacillus, Dietzia, Gordonia, Halomonas species.*

Mycoremediation

Aspergillus, Penicillium, Fusarium, Saccharomyces, Amorphoteca, Syncephalastrum, Neosartorya, Phanerochaete, Paecilomyces, Talaromyces, and *Graphium sp.* demonstrate the capacity to break down hydrocarbons linked to petroleum through mineralization. Non-ligninolytic fungi can address petroleum hydrocarbons by employing the cytochrome P450 monooxygenase pathway, wherein the hydrocarbons are oxidized to arene oxides.White-rot fungi possess the ability to break down petroleum hydrocarbons by employing soluble extracellular enzymes like manganese peroxidase, laccases, and lignin peroxidase to mineralize them. Mohammadi-Sichani *et al*. (2019) observed the use of the white rot fungal species *Polyporus* sp. S133 in decomposing soil contaminated with crude oil. They utilized spent mushroom compost as an inoculant to remediate spills from oil-processing facilities. Composts containing white-rot fungi like *A. bisporus, P. ostratus,* and *G. lucidum* successfully broke down hydrocarbons associated with petroleum within a three-month time frame. The effectiveness of spent mushroom compost in degrading both high- and low-molecular-weight petroleum hydrocarbons suggests its potential usefulness in mycoremediation.

Natural attenuation

Natural attenuation represents a straightforward form of bioremediation where indigenous microbial populations, such as bacteria and fungi, play a vital role in reducing or neutralizing petroleum and other hydrocarbon contaminants that pose risks to human health and the environment. These microbes metabolize hydrocarbons through their natural pathways, converting them into less harmful forms and thus mitigating pollution at the affected site. This method requires minimal intervention and primarily involves monitoring the process, making it highly efficient. Hydrocarbon-degrading microorganisms present in the oil itself have the inherent ability to break down hydrocarbons without external stimulation. Yet, the efficiency of natural attenuation might be limited by factors like nutrient availability. In certain instances, the site may lack microbial communities with strong degradation abilities, or they may lack the specific genetic mechanisms necessary for fully breaking down the contaminants.

Bioaugmentation

This process involves introducing either native or genetically engineered microorganisms into polluted areas, establishing ideal conditions to accelerate the removal of undesirable compounds.The microorganisms are sourced from environments contaminated with petroleum hydrocarbons. *Bacillus sonorensis* strain was employed under ideal conditions for this purpose. An immobilized bacterial consortium composed of *Flavobacterium johnsoniae* and *Shewanella baltica* strains demonstrates the highest degradation efficiency for soil contaminated with polyaromatic hydrocarbons. *Pseudomonas aeruginosa* NCIM 5514, isolated from soil contaminated with petroleum, exhibits the capability to degrade hydrocarbons and can be employed for both ex situ and in situ mineralization of petroleum hydrocarbon contaminants.

Biostimulation

Biostimulation is a frequently used bioremediation method that aims to boost the growth and functionality of naturally existing microorganisms at contaminated sites by supplementing nutrients.This accelerates the natural process of biodegradation. Bacterial species like *Proteobacteria, Bacteroidetes,* and *Actinobacteria* play crucial roles in petroleum degradation. In bioremediation initiatives targeting oil-contaminated desert soil, a range of materials including organic wastes, spent mushroom compost, poultry manure, and urea are employed. *Firmicutes, Actinobacteria, and Proteobacteria* are identified as the key bacterial populations accountable for breaking down petroleum pollutants in soil during biostimulation-driven decontamination procedures. Biostimulation entails adding both organic and inorganic substances such as nutrients, surfactants, fresh and composted sewage, sludge, and manure to boost microbial activity and aid in degradation processes.

Factors Influencing Biodegradation of Hydrocarbons

The effectiveness of bioremediation in soil hydrocarbon degradation depends on environmental and biological factors, which can differ significantly from one site to another. These factors encompass the nature and concentration of pollutants, soil composition and structure, the presence and durability of contaminants, and the abundance and viability of degrading microorganisms.

Environmental circumstances

Several environmental factors, including soil pH, oxygen levels, nutrient availability, temperature, and the accessibility of hydrocarbons to microorganisms, impact the effectiveness of bioremediation. Limited bioavailability can hinder hydrocarbon degradation rates, reducing the efficiency of the process. The interplay among hydrocarbon-degrading microbes, soil composition, and contaminant presence is crucial in bioremediation. Soil organic matter plays a crucial role in mediating interactions between soil and organic pollutants. The proportion of soil organic matter dictates how petroleum hydrocarbons are distributed into the organic soil fraction and influences the extent of sorption, thus impacting degradation rates.

Rate of degradation of petroleum contaminants

In the initial phase, the degradation rate is higher when petroleum pollutants are readily bioavailable. Yet, during the second stage of remediation, bioavailability becomes restricted as hydrocarbons are sequestered. Once this stage is reached, further degradation halts for the remainder of the remediation process. Additionally, the aging of polluted soil can impact the degradation of petroleum-associated hydrocarbons. Contaminants can be divided into the soil organic matter fraction or penetrate into small pores, diminishing their accessibility to microbes. This obstacle is more prominent in soils rich in organic matter compared to those with lower organic content. Additionally, the properties of hydrocarbons vary between newly spilled petroleum products and aged ones.

Advantages of Bioremediation

Bioremediation is straightforward to implement, cost-effective, environmentally friendly, and suitable for application over extensive areas. It facilitates the thorough elimination of various contaminants, requiring minimal equipment and labor. Petroleum hydrocarbon contamination can be remediated through the utilization of a diverse array of microorganisms. Customizing microbes to target particular hydrocarbon pollutants can notably boost the efficiency of remediation processes.

Constraints of Bioremediation

The treatment duration tends to be lengthy due to the reliance on microbes for degradation. Bioremediation effectiveness is heavily influenced by site-specific factors like soil type, climate conditions, and the concentration of the contaminant. There is a risk of incomplete degradation, potentially leading to the introduction of harmful chemicals into the environment. Environmental factors and chemical composition of petroleum hydrocarbons also affect the bioremediation process. The efficiency is unpredictable.

Conclusion

The use of petroleum products for energy has resulted in oil spills in the environment, creating difficulties in cleaning up polluted sites. Bioremediation has emerged as a promising and sustainable approach to mitigate the impact on soil ecosystems. Microbial consortia, comprising both bacteria and fungi, play crucial roles in degradation processes. These mechanisms showcase the effectiveness and variety of biological processes in breaking down intricate hydrocarbons. Approaches like bioaugmentation and biostimulation provide promising paths for expediting the degradation of petroleum hydrocarbons and customizing solutions to particular contamination scenarios. Moreover, combining bioremediation with other technologies such as phytoremediation or chemical treatments, as well as employing integrated remediation methods, enhances the cleanup of petroleum-related hydrocarbons.

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