Biodegradation of Petroleum Hydrocarbons in Soil Environment

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ABSTRACT

Environmental pollution with petroleum and petrochemical products has been recognized as a significant and serious problem. Several physico-chemical of decontaminating the environment have been estabilished and employed. Bioremediation by microbial degradation of petroleum hydrocarbons like anthracene, pyrene, phenanthrene is one of the major practices in natural decontamination process which is considered a non-destructive, cost-effective, and sometimes logistically favourable cleanup technology, which attempts to accelerate the naturally occurring biodegradation of contaminants through the optimization of limiting conditions. The most commonly reported genera of hydrocarbon-degraders include Pseudomonas, Acinetobacter, Nocardia, Vibrio and Achromobacter. This paper will review the biodegradation of petroleum contaminated soil and their adverse effect on environment and the subsequent development of health effects.

Keywords: Petroleum hydrocarbons, environmental pollution, microbial degradation, bioremediation

1. INTRODUCTION

Hydrocarbon compounds for instance petroleum are essential elements of life. Since they do not naturally come about in the forms most useful to humans, they can be hazardous. Fuel and lubricating oil spills have develop into a major environmental hazard to-date [1]. Contaminated soils are menace to the human and the ecosystem. Biodegradation of such contaminated soils is requisite by convention method that is affordable and eco friendly [2,3]. Microorganisms have the competence to degrade majority of hydrocarbon components, the saturated and unsaturated alkanes, monoaromatic and low molecular weight polycyclic aromatic hydrocarbons (PAHs). The organism ought to be in contact with their substrate to utilize and degrade the hydrocarbon. Limited quantity of hydrocarbon substrates can be metabolizes by individual microorganisms, So the mixed cultures of microorganisms are essential to increase the rate of petroleum biodegradation [4]. When the organism grows in the contaminated soil, they utilize these constituent hydrocarbons as substrates. Such hydrocarbon utilizing microorganism shows emulsifying activity [5,6].

Hydrocarbons contamination causes extensive damage of local system since accumulation of pollutants in animals and plant tissue may cause death or mutations. These oil spills can even cause damage to the sea and shoreline organisms [7]. The other sources of contamination incorporate service stations, garages, scrap yard, waste treatment plants and saw mills etc. Consequently with the expansion of petroleum industry, one cannot ignore the inevitable spillage and significant contamination occurring during operations and transportation [8,9]. A better approach than these traditional methods is to entirely destroy the pollutants if possible, or at least to transform them to innocuous substances. In vision of this bioremediation is becoming an increasingly accepted technique for cleaning up the contaminated sites. The present study was aimed to investigate the potential for reduction of petroleum hydrocarbons concentration in contaminated soil by the use of microorganisms and their activities for removal of soil pollution also leading to the recommendation of possible processes to improve soil biotreatability.

1.1.Historical Perspective

Biodegradation of hydrocarbons by the process of bioremediation was invented by George M. Robinson. Throughout the 1960s Robinson pioneered the initiative of making custom mixtures of dried bacteria cultures for commercial use. His "bug-brew" recipes subsequently gained approval and notoriety after numerous well publicized demonstrations [10] Later the first marketable in situ bioremediation system was installed in 1972 to cleanup a Sun Oil pipeline spill in Ambler, Pennsylvania [11].

In 1979, for the first time Anand Mohan Chakrabarty, an India borne American scientist obtained a strain of Pseudomonas putida that contained the XYL and NAH plasmid as well as a hybrid plasmid derived by CAM and OCT (these are incompatible and cannot co-exist as separate plasmids in the same bacterium) [10] Considering this in mid-1980s prominence went on bioengineering organisms for bioremediation. But this technology did not manufacture better results. So by 1990s scientists switched to greater confidence on natural microorganisms and techniques to boost their performance.

1.2. Petroleum Hydrocarbons

Petroleum refinery is an industrial process plant where crude oil is processed and refined into more useful products such as petroleum naphtha, gasoline, diesel fuel, asphalt base, heating oil, kerosene and liquefied petroleum gas. Petroleum and petroleum products are highly intricate and varied mixtures. When petroleum compounds such as crude oil are unconstrained into the environment, the compounds go through physical, chemical, and biological changes communally referred to as weathering. The extent to which various types of petroleum hydrocarbons degrade under these changes depends on the physical and chemical properties of the hydrocarbons [12].

1.3 Types of Petroleum Hydrocarbons

Aliphatics and Aromatics are the two major groups of petroleum hydrocarbons, Aliphatics include alkanes that contain single bonds between carbon atoms and have formulas of C_nH_{2n+2}, alkenes, which include one or more double bonds between atoms and have formulas of C_nH_{2n}, and cycloalkanes, which include carbon atoms in cyclic structures. Aromatics have one or more benzene rings as component of their structure. Monoaromatics are aromatics with one benzene ring as element of their structure, polycyclic aromatic hydrocarbons (PAHs) are aromatics with two or more fused benzene rings. Monoaromatics, such as benzene, toluene, ethylbenzene, and xylenes (BTEX), are some of the most widespread aromatic compounds in petroleum. Crude oil contains less BTEX than gasoline. On average, crude oil contains approximately 1% PAHs. Numerous aromatic hydrocarbons are known or suspected human carcinogens, and are classified as priority pollutants regulated by the U.S. Environmental Protection Agency (USEPA) [13].

1.3.1 PAHS in the Environment

The chemical properties, and so the environmental fate, of a PAH molecule are reliant in part upon both molecular size, i.e., the number of aromatic rings, and molecule topology or the pattern of ring linkage. Ring linkage patterns in PAHs may occur such that the tertiary carbon atoms are centers of two or three interlinked rings, as in the linear kata-annelated PAH anthracene or the pericondensed PAH pyrene. In general, an increase in the size and angularity of a PAH molecule results in a concomitant increase in hydrophobicity and electrochemical stability. PAHs are also known to wield acutely toxic effects and possess mutagenic, teratogenic, or carcinogenic properties [14].

1.3.2 High Molecular Weight (HMW) PAHS Biodegradation

PAH molecule stability and hydrophobicity are two primary factors which contribute to the persistence of HMW PAHs in the environment. Due to their lipophilic nature, PAHs have a high potential for biomagnification through trophic transfers.

2. PRINCIPLES OF BIOREMEDIATION

Bioremediation is the use of microorganisms to degrade the environmental contaminants into less toxic forms. It engage the use of naturally occurring bacteria and fungi or plants to degrade or detoxify substances hazardous to human health and the environment. As mentioned prior contaminant compounds are transformed by living organisms all the way through reactions that take place as a part of their metabolic processes. So for bioremediation to be effective it is very important that these organisms supposed to be metabolically active and should carry different enzymes essential for the biodegradation. One can run the method aerobically or anaerobically as per the selection of the microorganism [15].

3. STRATEGIES AND TECHNIQUES USED FOR MONITORING BIODEGRADATION

Bioremediation can be approved using in situ bioremediation, ex-situ bioremediation or phytoremediation [16].

3.1 IN-SITU BIOREMEDIATION OF SOIL

In-situ techniques are less expensive, create less dust, and cause less release of contaminants than ex-situ techniques as they do not require excavation of the contaminated soils. In-situ techniques, however, may be slower than ex-situ techniques, may be difficult to deal with, and are most efficient at sites with permeable soil. The major types of in-situ bioremediation are as specified below (Tab.1)

Table 1: In-situ hydrocarbons bioremediation [17]

Treatment	Description	Applicable to	Advantages
Biostimulation	The addition of oxygen, water and mineral nutrients (usually combinations of nitrogen, phosphorous and trace metals)	Groundwater, soils	Acceleration by as much as 100 fold of reproduction of indigenous organisms.
Bioventing	Combines conventional soil venting with biodegradation. The less volatile compounds are biodegraded and the volatile components are vented off in conventional venting.	Soils	Addresses full range of petroleum hydrocarbons. Effective method of supplying indigenous microorganisms with oxygen to support degradation.
Bioaugmentation	Direct application of microorganisms originating from (a) remediation site (b) an off site vendor (c) genetic engineering.	Groundwater, soils	One of the most effective bioremediation techniques. The microorganisms have been cultured and adapted and their degrading capacity can be enhanced for specific contaminats and site conditions.

Surfactants	Synthetic or biogenic substances are used to increse the aquous solubility of solid hydrocarbons and emulsify liquid hydrocarbons.	Solid and liquids, aromatic, aliphatic hydrocarbons	Enhancement of contaminant accessibility to microorganisms, nutrients and possibly oxygen.
Fertilizer Application	To stimulate microbial metabolism by supplying indigenous oil-degraders with nutrients (N,P,K etc)	Soil, groundwater, sediments	Acceleration of natural biodegradation process, especially in nutrients deficient areas.

3.2 EX-Situ Bioremediation of Soil

These techniques involve the excavation or removal of contaminated soil from land. Ex situ bioremediation can be alienated into two main types: Solid phase and Slurry phase ex-situ bioremediation which can be further divided as follows [18]

3.2.1 Landfarming

A simple technique in which contaminated soil is excavated and spread above a prepared bed and from time to time turned over until pollutants are degraded. The goal is to stimulate indigenous biodegradative microorganisms and facilitate their aerobic degradation of contaminants. Usually, the practice is inadequate to the treatment of superficial 10–35 cm of soil.

3.2.2 Composting

A technique that involve combining contaminated soil with nonhazardous organic amendants such as manure or agricultural wastes. The presence of these organic materials supports the development of a rich microbial population and elevated temperature characteristic of composting.

3.2.3 Biopiles

Biopiles is a hybrid technique of land farming and composting. Fundamentally, engineered cells are constructed as aerated composted piles. Biopiles provide a favorable environment for indigenous aerobic and anaerobic microorganisms.

3.2.4 Bioreactors

A type of slurry phase treatment, Slurry reactors or aqueous reactors are used for treatment of contaminated soil and water pumped up from a contaminated plume as it is a containment vessel and apparatus used to create a three-phase (solid, liquid, and gas) mixing condition to increase the bioremediation rate of soil bound and water-soluble pollutants as a water slurry of the contaminated soil and biomass (usually indigenous microorganisms) capable of degrading target contaminants.

4. CHARACTERSTICS THAT LIMIT THE BIODEGRADATION PROCESSES

As the process of biodegradation of petroleum hydrocarbons using microorganisms does not remove all quantity of contaminants, Substantial gaps exist in the understanding of microbial ecology, physiology, genetic expression, site expression and site engineering. Some of the characterstics that limit the biodegradation processes are mention below (Tab.2)

Table 2 : Characterstics that limts the process of biodegradation [19]

Limiting Characterstics	Reasons for potential effects	Action of minimize effects
Variable sediment composition	Inconsistent biodegradation caused by variationsin biological activity	Dilution of contaminated sediments; increased mixing or blending of sediments
Non uniform particle size	Minimizes the contact with microorganims	Physical separation to remove coarse-grained material prior to bioremediation, particularly for bioslurry
Water solubility	Contaminants with low solubilityare harder to biodegrade	Addition of surfectants or other emulsifiers
Biodegradability	Low rate of destruction inhibits the process	Addition of microbial culture capable of degrading particularly difficult compounds or longer residence time
Temperature outside 15-20^{o}c range	Less microbial activity outside the range	Temperature monitoring and adjustments
Nutrient Deficiency	Lack of adequate nutrients for biological activity	Adjustment of carbon/nitrogen/phosphorous ratio
Oxygen Deficiency	Lack of oxygen is rate limiting	Oxygen monitoring and adjustments
Insufficient mixing	Inadequate microbe/solids/organic compound contact	Optimization of mixing characterstics ; increasing permeability

pH outside 4.5-8.8 range	Inhibition of biological activity	Sediment pH monitoring; addition of acidic or alkaline compounds
Microbial population	Insufficient populations results in low biodegradation rates	Addition of culture strains
Water and air emissions discharges	Potential environmental and/or health effects	Post treatment emissions collection and treatment processes
Presence of elevated, dissolved concentrations of: heavy metals, highly chlorinated organic compound, Inorganic salts.	Can be highly toxic to microorganisms	Pretreatment processes and dilution with amendments to reduce the concentration of toxic compounds in the constituentsin sediment to non toxic range

5. CONCLUSION

The quality of life on earth is extremely related with its environment. For life to protract it is very imperative that the environment should remain clean and healthy. In recent times due to the increase in industrialization and utilization of petroleum related products not to forget negligence using them, the environment is getting damaged. Microbial degradation processes assist the elimination of spilled oil from the environment, together with various physical and chemical methods. This is feasible because microorganisms have enzyme systems to degrade and utilize different hydrocarbons as a source of carbon and energy. If the challenges of bioremediation, particularly of in situ techniques, can be overcome, bioremediation has potential to provide a low cost, non-intrusive, natural method to render toxic substances in soil less harmful or harmless over time. Presently, research is being conducted to improve and conquer limitations that hinder biodegradation of petroleum hydrocarbons. On a broader scale, much research has been and continues to be developed enhance perceptive of the essence of microbial behavior as microbes interact with various toxic contaminants. As these innovative techniques are brought into commercial practice, the importance of these methods for evaluating biodegradation using microorganisms will increase. And that will help to create a better and cleaner environment.

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