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Chapter

Bioremediation of Petroleum-Contaminated Soil

Raman Kumar Ravi, Shalini Gupta and Reeta Verma

Abstract

Petroleum is not only an important energy resource to boost economic development but also a major pollutant source of soil. Petroleum toxicity can cause an adverse impact on the environment, as well as has negative effects for both animals and humans due to its carcinogenic nature. Therefore, its removal from the environment becomes a matter of concern. Although a lot of techniques are in use for remediation of petroleum-contaminated soil, exploitation of fungal ability provides a sustainable solution for this due to their ability to survive in harsh environmental conditions. Mycoremediation is the bioremediation technique employed for the removal of toxic compounds using fungal biomass. The fungi have been proved as a potential biomass degrader for complex organic compounds, resulting in the production of versatile extracellular enzymes. In this chapter, we have highlighted the basic concept of mycoremediation, the enzymatic system involved in the degradation process, the mechanism of fungal degradation, and factors affecting the degradation process. The chapter also provides useful insight for greater future understanding and improvement of the technique towards solving the problem of petroleum-contaminated soils.

Keywords: bioremediation, mycoremediation, petroleum contaminated soil, enzymes, toxicity, degradation

1. Introduction

Petroleum is a vital resource that is dominating the world economy [1]. The petroleum is composed of a complex mixture of aromatic, aliphatic, heterocyclic hydrocarbons, asphaltenes, and non-hydrocarbon compounds, of which 60–90% are biodegradable [2]. In the past few decades, with the development of the petroleum industries, related activities like exploration, transportation, management, or storage and refining of hydrocarbons have caused contamination of soil environment and posed a serious global problem [3]. In view of the high toxicity, carcinogenicity, mutagenicity, and teratogenicity nature of petroleum compounds, their bioaccumulation in the food chain will interfere with the biochemical and physiological processes that directly or indirectly lead to human health [4, 5]. The petroleum contamination may induce oxidative stress. They may cause alteration in the soil’s chemical composition, its properties, and low nutrient availability, which leads to inhibition of seed germination. The petroleum compounds may cause various harmful effects on plants such as reduction of photosynthetic pigments, slowdown of nutrient assimilation, inhibition of root growth, foliar deformation and tissue necrosis, as well as destroy biological membranes, disturb the signaling
of metabolic pathways, and disrupting plant roots architecture [6–9]. The hydrocarbons with low-molecular weight can penetrate the plant cells causing plant death. Besides this, many petroleum compounds and their derivatives are carcinogens. It is also reported that petroleum contamination can cause the depression of the nervous system, narcosis, and irritation of the mucous membranes of the eyes in humans [10–13]. Therefore, nowadays, petroleum contamination becomes a global environmental issue. The petroleum compounds have not only adverse impact on plant growth and development but also on human and ecological health. Therefore, their removal becomes a necessity in the current scenario for a healthy environment. Bioremediation is one of the most reliable, environmentally friendly techniques for the removal of hazardous compounds using biological sources like plants and microbes or the metabolites obtained from them. The microbial communities ... play great role in the degradation of petroleum contaminants from the environment effectively. In this chapter, we have highlighted the microbial remediation of petroleum-contaminated soil for environmental clean-up. The chapter also discussed the different enzymes involved in bioremediation, mechanisms of petroleum compounds degradation, and factors influencing the bioremediation processes. This chapter may provide different clues for new research approaches for microbial-assisted methods of remediation.

2. Different sources of petroleum contamination

Petroleum comprises a number of aliphatic, branched, and aromatic hydrocarbons [14, 15] and several other organic compounds including some organometallic constituents [16]. The contamination of soil by petroleum hydrocarbons includes various sources such as the activities like industrial and municipal runoffs, effluent release, offshore and onshore petroleum industry activities as well as accidental petroleum spills (Figure 1). Most of them are toxic to human beings, animals, and vegetation [17–20]. The anthropogenic activities also lead to the release of petroleum hydrocarbons from oil and gas exploration and production units, tank leakages and overflow, petrochemical industry effluent discharge, accidental spills during loading and discharging, bunkering, oil tanker incident, transportation and storage, fugitive emissions, ballasting, and de-ballasting, burst in old underground

Figure 1.
Different sources of petroleum contamination.
pipelines, war and political crisis, sabotage, and natural disasters. Such type of incidents has posed adverse impacts on terrestrial and marine biodiversity. The petroleum contamination directly or indirectly affects the wellbeings of all kinds of life inhabiting in the affected environment by altering population dynamics thereby interrupting the natural interaction among organisms at various trophic levels consequently misbalancing the natural community structure within the ecosystem ([17–20]; Belousova et al. 2001; Bejarano and Michel, 2010). In long term, this pollution affects the environment. Due to the adverse impact of these chemicals on human health and the environment, they are classified as priority environmental pollutants by the U.S. Environmental Protection Agency [21]. Wood fires or volcano eruptions account for the natural sources of petroleum contamination whereas major anthropogenic sources include industrial combustion processes, refining processes: coking (coal), cracking (petroleum products e.g., tar, waxes, oils) and fireplaces, tobacco smoke is categorized under indoor sources. Releasing hydrocarbon pollutants through spillages and leakage from underground tanks, steamers, unplugging of oil wells, or abandoned oil refinery sites causes contamination of surface soil, groundwater and ocean as well [20, 22–24].

3. Effect of petroleum contamination on the environment and human health

Contamination of soil by petroleum hydrocarbons can affect physicochemical properties of soil such as texture, compaction, structural status, penetration resistance, saturated hydraulic conductivity, mineral and heavy metal concentration (Hreniuc et al., 2015). The toxicity of petroleum compounds is of worldwide environmental concern and has an adverse effect on the environment and human health. The polyaromatic hydrocarbons (PAHs) are natural constituents of fossil fuels, coal, and petroleum comprising 0.2% and 7% PAHs [25]. The PAHs adsorb to dust or soot particles and enter into the atmosphere and are transported to far distances. Naturally, in a cyclic process, PAHs undergo a cycle of entry, deposition, and percolation. PAHs enter the environment via rain/fog thereafter get deposited on soil and plants and ultimately percolate in surface waters [26]. Dust produced by anthropogenic activities namely coal mining, automobile exhaust, transportation, and drilling of oil, stockpiles, and tailings is the major unnatural sources of PAHs that contaminate the various spheres of the atmosphere [27].

PAHs are present in all the spheres of the environment mainly evaporated into the atmosphere. Primarily when adsorbed on dust particles, PAHs undergo photolysis in the existence of sunlight. Upon oxidation, the complex structure of the compound can be broken in days or weeks [28]. The PAH compounds are hydrophobic in nature, immiscible in water; however miscible in other hydrophobic matter. PAHs can get easily adsorbed on dust particles as well as a precipitate on sediments of aquatic bodies. Therefore, these pollutants can easily mix with other hydrophobic matter and pollute the aquatic systems. Terrestrial and water system microbes possess the adaptability to degrade and mineralize PAHs over a longer or shorter time duration [29].

Under the influence of UV light, PAH metabolites produced are usually more toxic. PAHs in soil is unlikely to employ toxicity influence on terrestrial invertebrates [30]. In plants absorption of PAHs by roots from soils and thereafter translocated to other parts. Mobility of the absorbed contaminants is usually influenced by the dose, solubility, along other physicochemical properties of soil. The plant response against PAHs differs; certain plant species consist of components that may wear off a toxic consequence of PAHs; whereas, some plants have the ability
to synthesize PAHs and perform as growth hormones [29, 31]. PAHs are persistent organic compounds and have a longer half-life which accounts for the PAH bioaccumulation in terrestrial invertebrates (shellfish expected to consist much higher concentration of PAH than in the environment) observed. Nonetheless, the metabolism of PAHs is effective to preclude biomagnifications [32–35]. Organisms are adversely affected because of tumors, reproduction, growth development, and immunity. In mammals route to PAH absorption is by inhalation, dermal contact, and ingestion [31, 36, 37].

4. Strategies used for removal petroleum contamination from soil

The soil contamination by petroleum has drawn increasing attention to develop and implement innovative techniques to remove petroleum compounds from the soil in the past decades. Different strategies are being used for the removal of petroleum contamination from the soil that includes traditional physical and chemical remediation, which are less efficient. Bioremediation is one of the most reliable and efficient techniques used for the restoration of petroleum-contaminated soil in an eco-friendly way.

4.1 Bioremediation of petroleum-contaminated soil

Bioremediation is a process that naturally or artificially takes advantage of living organisms or their products to remove the pollutants of the contaminated environment [38]. Although it is time-consuming, due to their eco-friendly approach and very low cost, efficient and sustainable for restoring the contaminated soil in the context of sustainability, are extensively noticeable at present [39]. For this purpose, living organisms having the potential to grow under contaminated soil are usually used. The number of studies have revealed that selecting petroleum-tolerant plants for bioremediation in cases of soil petroleum pollution is a feasible and sustainable technology. Many plants like ryegrass, alfalfa, Mirabilis jalapa are capable to grow in petroleum stress conditions [40–42].

The microorganisms that are utilized in petroleum pollutants removal can be bacteria, fungi, or yeasts. These microbes are the essential component in soil that play a crucial role in the remediation of petroleum contamination [43, 44]. Some of them have a high capacity to degrade contaminants and are widely used for environmental clean-up [45]. In the bioremediation of petroleum-contaminated soils, the most widely used organisms are bacteria which have high frequency, rapid growth, and a broad spectrum of degradation of petroleum products [46]. The development of microbial biotechnology is beneficial for screening and identifying microorganisms from petroleum-contaminated soils [47]. Many microorganisms have been isolated and exploited for the bioremediation of petroleum hydrocarbons. A number of bacteria having the capacity to degrade petroleum hydrocarbons have been identified [48]. Furthermore, some microorganisms were crucial for petroleum hydrocarbons since the abundance of these microorganisms was dominant increased after petroleum contamination [49]. Different indigenous bacteria have different degrading enzymes, the blend of several efficient bacteria was employed to remediate the contaminated soils. The combined activity of indigenous bacterial consortium and exogenous bacteria can efficiently enhance the degradation of petroleum [50].

Biostimulation is a leading strategy of bioremediation to decontaminate petroleum polluted soil. It includes regulating various environmental conditions such as temperature, moisture, pH, redox potential, aeration, mineral nutrition, etc. to
increase the growth and the metabolic activity of microorganisms. Consequently, various hydrocarbons can be tolerated and utilized as a carbon source to fulfill its growth requirements [51]. Bioaugmentation is another strategy of bioremediation, which refers to the inoculation of exogenous microorganisms into the contaminated soils to degrade the target contaminants [52]. The inoculated microorganism can be one strain or a consortium of microbial strains with diverse functional degradation capacities [53]. Bioaugmentation was considered to be more effective for the degradation of the light fraction of petroleum hydrocarbons [54]. Besides this, the microbial electrochemical system was considered as an emerging technique for bioremediation, which integrates microbial and electrochemical processes to convert the pollutants to less-toxic or value-added products [55]. With numerous integral benefits, the microbial electrochemical system was frequently applied in the remediation of petroleum contaminants in soil. The microbial electrochemical system can be utilized for different contaminants owing to the oxidation and reduction transformation involved in remediation processes [56].

In the last decay, the role of fungi in bioremediation has been increasingly recognized [57, 58], in which mainly saprotrophic and basidiomycetes, groups of fungi are highlighted to degrade or to transform toxic compounds [59, 60]. Mycoremediation is the bioremediation technique that employs fungi in the removal of toxic compounds; it could be carried out in the presence of both filamentous fungi [61] and macrofungi such as mushrooms [62, 63]. Both classes possess enzymes for the degradation of a large variety of pollutants [64, 65]. Fungi are noted for their colonizing abilities. They can colonize and adapt in diversified heterogeneous environments including complex soil matrices at extreme environmental conditions. Furthermore, they can decompose the organic matter and easily colonize both biotic and abiotic surfaces [66, 67]. Filamentous fungi have shown some different characteristics that make them more preferable for soil bioremediation than yeasts and bacteria [66, 68]. The most important is the type of growth i.e., multicellular mycelial growth, suitable to soil colonization and translocation of nutrients and water, the production of many bioactive compounds and extracellular enzymes, and the unique capability to co-metabolize many environmental chemicals [69].

4.1.1 Mycoremediation of petroleum-contaminated soils

Mycoremediation offers an alternative environmentally friendly technique for remediation of contamination in environmental matrices [70–73]. Different species of fungi have been used for the remediation of petroleum-contaminated soils. These include microfungi such as Arbuscular mycorrhiza and yeast [74–76] as well as Penicillium and Aspergillus species [77, 78]. Mycoremediation with macrofungi (mushrooms) is also identified [79, 80]. Abioye et al. [76] reported crude oil degradation by yeast Saccharomyces cerevisiae. It was inoculated in a sterile mineral salt media containing 1 g of crude oil under control conditions at 30°C for 28 days. Obire et al. [81] recognized micro-fungal communities were actively involved in the remediation potentials of cow & poultry compost on petroleum polluted soil sites. Isolated yeasts and molds from cow dung comprised of Alternaria sp., Aspergillus sp., Cephalosporium sp., Cladosporium sp., Geotrichum sp., Moniliasp., Mucor sp., Penicillium sp., Rhizopus sp., Sporotrichum sp., Thamnidium sp., Candida sp., Rhodotorula sp., and Torulopsis sp., Saccharomyces spp (Yeast) has also been revealed to transform polycyclic aromatic hydrocarbons (PAHs) into eco-friendly products [82].

One significant class of fungi, which demonstrate mycoremediation of petroleum-contaminated soils are the ligninolytic mushrooms such as white rot
fungi [83–85]. Lebo et al. [86] and Fetzer [87], identified that white rot fungi are able to degrade recalcitrant organic pollutants, the fact is mushroomed naturally feed on and degrade lignin, a substance with the similar monomeric unit to organic contaminants. Stamets [73], validated up to 99% degradation of naturally diesel-contaminated soils at 20,000 parts per million concentration of PAHs after 8 weeks using the white rot mushroom i.e., *P. ostreatus*. Kristanti et al. [88], reported that up to 93% degradation of crude oil in the soil can be obtained using the white rot mushroom *Polyporus* sp. SI33 pre-grown on the wood meal. It has been established that the litter decomposing mushroom i.e., *Stropharia coronilla*, can metabolize PAHs such as benzo[a]pyrene at 200 μM and this activity could be increased up to 12 times in presence of supplementary Mn2+ as electron acceptor. Mohammadi-Sichani et al. [89], reported that the litter decomposing mushroom *A. bisporus* can yield a higher ability to degrade total petroleum hydrocarbons in soils than white rot mushroom such as *Pleurotus ostreatus* and *Ganoderma lucidum*.

The most suitable fungal genera used for remediation of hydrocarbon contaminated soil are the basidiomycetes group [90]. The saprotrophic basidiomycetes, utilize dead organic substances as a carbon source, consist of the wood-degrading fungal groups. Overall, white-rot fungi are reflected for a prominent role in the biodegradation of petrochemicals [91]. These fungi can degrade efficiently both lignin and cellulose biopolymers till the complete mineralization [92], by producing an extracellular enzymatic complex, which comprehends lignin peroxidases (LiPs), manganese-dependent peroxidases (MnP), versatile peroxidases (VPs), laccases, H2O2-generating oxidases and dehydrogenases, produced during the idio-phase, usually under nitrogen depletion. The most common example of white rot fungi, that are capable to degrade pollutants, include *Phanerochaete chrysosporium*, *Pleurotus ostreatus*, *Trametes versicolor*, *Bjerkandera adusta*, *Lentinula edodes*, *Irpex lacteus*, *Agaricus bisporus*, *Pleurotus tuber-regium* and *Pleurotus pulmonarius* [93, 94]. Among these fungi, *Phanerochaete chrysosporium* has been the most investigated for its ability to degrade toxic or insoluble compounds to CO2 and H2O, more efficiently than other fungi.

Mostly the biodegradation studies at the laboratory & pilot scale are covered micro-fungi, but in last year, much attention has been given to mushrooms which are frequently present in soil and also easily cultivated [95]. Bioremediation by macro-fungi basidiomycetes is advantageous because, simultaneous remediation process, and soil enrichment with organic matter, nutrients and result in enhanced plant growth. Macro-fungi are potent degraders due to secretion of the similar intracellular enzymes (LiP, MnP, and laccase) labeled for the lignin-degrading fungi thus are attention-grabbing in the field of bioremediation. Altogether, they grow to a great extent and produce high biomass, when cultivated on carbon sources, like stubble or sawdust [79]. The mushroom biomass can be a protein source or can contain biologically active compounds such as phenols with antioxidant activity [64, 96]. Furthermore, mushroom biomass can be applied in biosorption treatment thanks to its ability to accumulate ions and xenobiotics from contaminated soils [97].

Different types of petroleum compounds such as phenanthrene, naphthalene, anthracene, pyrene, benzo[a]pyrene, fluoranthene, acenaphthene, etc. are earlier reported to be degraded by fungal biomass (*Table 1*). Phenanthrene can be degraded by *Pleurotus ostreatus* [98], *Phanerochaete chrysosporium* [99–101], *Phanerochaete sordida* [100, 102], *Ganoderma lucidum* [103], *Trametes versicolor* [104]. Naphthalene is degraded by *Penicillium oxalicum* [105], *Penicillium* sp. [106], *Penicillium fastigiata*, and *Penicillium digitatum* [107]. Govarthanana et al. [106] also reported degradation of acenaphthene and benzo[a]pyrene by
Penicillium sp. Similarly, fungus *Phanerochaete sordida* is reported to degrade fluoranthene [100, 102]. The petroleum compound like anthracene is reported to be degraded by various fungal species such as *Aspergillus fumigatus* [108], *Stropharia coronilla* [109], *Pleurotus ostreatus* [100]. The earlier study revealed the *Fusarium solani* and *Mucor* sp. can degrade benzo[a]pyrene [110, 111], while pyrene is degraded by *Trichoderma harzianum* [112], *Penicillium janthinellum* [113] and *Penicillium* sp. M 1 [114].

### 5. Mechanism of petroleum hydrocarbon degradation

Fungal genera catabolize hydrocarbons to intermediates analogous to those formed by a mammalian enzymatic system via Cytochrome P450 [115]. Whereas, several mechanisms have been proposed includes both direct and indirect oxidation of the organic molecule by the fungal enzymes namely Lignin peroxidase, Manganese Peroxidase, versatile peroxidase, and Lacasses (Figure 2) [116–118]. The promising combination of multi enzymatic mechanisms could play a key role in the degradation process [119]. Radical mediated reaction initiated by manganese peroxidase involves indirect oxidation of benzene rings with hydroxyl group may be led to spontaneous ring opening. Produce derivatives like muconic acid and carbon dioxide by decarboxylation of carboxyl groups [120, 121].
5.1 Enzymes involved in biodegradation of petroleum contamination

Most of the enzymes are extracellular and allow to attack and then degrade large molecules into smaller units which can enter the cells for further transformations [122]. Extracellular laccases start ring cleavage in the biodegradation of aromatic compounds [61]. Laccase are multicopper oxidases with low substrate specificity & could act on o- and p-phenols, phenylenediamines via four-electron transfer from the target organic substrate to molecular oxygen [123]. Fungal peroxidases generate oxidants that initiate substrate oxidation in the extracellular environment [61]. They belong to the class II peroxidases [124] & catalyze the oxidation of various organic substrates by utilizing peroxide (H₂O₂) as an electron acceptor. Lignin peroxidase (LiPs), Manganese peroxidase (MnP), and Versatile or non-specific peroxidase (VPs) are the leading fungal high redox class II peroxidase enzymes as reported earlier. These intracellular enzymes are convoluted in the biodegradation process of the complex lignocellulosic structure and, subsequently, could biotransform various organic substrates into inorganic substrates [125]. Some reported fungal genera could also secrete the dye-decolorizing peroxidase (DyPs), which have the ability to oxidize and hydrolyze phenolic and non-phenolic compounds [126]. Heme-thiolate peroxidase (HTPs) allocates peroxide-oxygen, from H₂O₂/R-COOH to organic substrate; in this group chloroperoxidases (CPOs) and aromatic peroxygenase (APOs) are involved. APOs can mainly be active on heterogeneous substrates via aromatic preoxygenation, epoxidation, or hydroxylation of aliphatic organic compounds [124].

Biodegradation by intracellular enzymatic pathway includes a class of cytochrome P450 monooxygenase and glutathione transferase, mainly possessed by lignocellulosic and plant litter fungi [125]. These enzymes show a functional role in the primary and secondary metabolism of fungi. Cytochrome P450 monooxidase, heme-thiolate containing oxidoreductase, could act on numerous organic substrates in stereo- and region selective manner, requiring molecular oxygen for the reaction initiation. These enzymes are triggered via reduced heme iron and single molecular oxygen to a substrate. Hydroxylation, epoxidation, sulfoxidation, and dealkylation intermediate reactions can occur and entail NADPH as electron donor [127]. Glutathione transferase enzyme is positioned in different cellular partitions and catalyze the nucleophilic attack of carbon, nitrogen or sulphur atom in non-polar compounds by reducing
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6. Factors influencing bioremediation of petroleum contaminants

Bioremediation is a technique to remove the contamination in a cost-effective and environment-friendly way. The remediation of contaminants depends on various factors like availability of contaminants for microbes, temperature, pH, relative humidity etc.

6.1 Availability of contaminants

Solubility and bioavailability are important factors in the bioremediation of petroleum-contaminated soils. Boopathy and Manning [129], stated that the rate of contaminant conversion during bioremediation depends on their uptake and metabolism rate and the rate of contact with the cells of the organism. Mannig et al. [130] reported that activities that result in the homogenous spread of contaminants in soils can drastically stimulate their biodegradation. Singh and Agarwal [131], demonstrated that the bioavailability of organic contaminants decreases with time. According to Boopathy and Manning [129], some physicochemical progressions such as sorption, desorption, diffusion and dissolution stimulate contaminants bioavailability. So, these elements must be measured during planning for bioremediation of petroleum-contaminated soil. The use of surface-active agents (surfactants) could aid to combat the contaminants bioavailability issue during the remediation process [129].

<table>
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<td>Manganese peroxidase</td>
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<td>Extracellular peroxidases</td>
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<tr>
<td>Monooxygenase; epoxide hydrolase</td>
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Table 2. Major enzymes involved in petroleum compounds degradation.

Glutathione. These enzymes consist a wide range of substrate specificity and involved in the detoxification of several endogenous or exogenous toxic metabolites [128]. Major enzymes involved in petroleum compounds degradation are summarized in Table 2.
6.2 Temperature

Temperature plays a critical role in bioremediation processes [132]. It has been reported that the rate of degradation of organic contaminants is comparably higher at higher temperatures [133]. Higher rates of degradation of organic contaminants are also reported in tropical soils compared to soils from temperate regions [134, 135]. Dimond and Owen [136], stated that temperature affects the half-life of organic contaminants which increases with lowering temperatures. Hong et al. [137], demonstrated that a temperature range of 20–40°C was optimal for degradation of the contaminant fenitrothion. Siddique et al. [132] further demonstrated that the highest degradation of Hexachlorocyclohexane in water and a soil slurry was achieved at an incubation temperature of 30°C.

6.3 pH

The soil environment is contaminated with different types of organic compounds that are causing an adverse effect on the soil microbial diversity. The pH of the soil is highly mutable and ranges from 2.5 to 11 which may significantly affect the biodegradability of hydrocarbons. The aptness of a pH range in any bioremediation process is site-specific, & swayed by the complex relation among the organism, contaminant, and soil properties. The pH range may also affect the solubility and availability of contaminants in soil. The organic contaminant present in the soil is degraded at high pH because of the increased solubility [138]. The study carried out by Owen et al. [135], demonstrated faster degradation of organic contaminants in alkaline soil pH compared to in acidic soil. The report also suggested that at low soil pH of 4.5 to 4.8, degradation of organic contaminants is inhibited [139]. Nash et al. [140], reported the effects of pH on the stability of DDT and observed maximum degradation in both moist and dry soils were obtained at pH values above 7. In another study, Hong et al. [137] reported bioremediation of fenitrothion-contaminated soil using *Burkholderia* sp. FDS-1 with an optimal degradation at a slightly alkaline pH of 7.5. Thus, pH is one of the factors that should be considered in the bioremediation of petroleum-contaminated soils.

6.4 Relative humidity

Relative humidity is an important parameter in the removal of contaminants from the soil. In bioremediation of contaminated soils, generally more than 60% relative humidity is maintained [141, 142]. Several studies have been reported a different range of relative humidity. The utilized relative humidity for bioremediation of contaminated soil was 70% [142] and 60% [141], while it was between 60 and 70% [143]. The relative humidity values up to 85–95% have also been reported for remediation of contaminated soil [116]. The growth of mushrooms and their fruiting is also reported at a relative humidity of 70–80% [144].

7. Conclusion

Bioremediation could serve as a sustainable alternative for complex pollutant clean-up. Though this technique has been explored and studied for years. But still, it is not been maximized for practical solutions and field-scale application for the treatment of petroleum-contaminated soil. Hence, it is necessary to carry out an assessment of microbes for bioremediation of petroleum-contaminated soil site and its evolvement, limitations, and perspectives in the field. Present literature provides
an understanding of bioremediation for petroleum-contaminated soils, in which different types of fungi, mechanisms of the technique are highlighted. The findings offer mycoremediation is capable of providing reliable options for the treatment of petroleum-contaminated soils. This is because fungi can provide cheaper and safer means for the simultaneous degradation of organic contaminants for environmental clean-up.

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References


Bioremediation of Petroleum-Contaminated Soil
DOI: http://dx.doi.org/10.5772/intechopen.100220


[69] Harms H, Schlosser D, Wick LY. Untapped potential: Exploiting fungi in
bioremediation of hazardous chemicals. Nature Reviews Microbiology. 2011;9:177-192. DOI: 10.1038/nrmicro2519


[80] Rhodes CJ. Mycoremediation (bioremediation with fungi)—Growing mushrooms to clean the earth. Chemical Speciation and Biology. 2014;26(3):196-198


[85] Isikhuemhen OS, Anoliefo GO, Oghale Ol. Bioremediation of crude oil polluted soil by the white rot fungus, Pleurotus tuberregium (Fr.) Sing. Environmental Science and Pollution Research International. 2003;10(2):108-112


Bioremediation of Petroleum-Contaminated Soil
DOI: http://dx.doi.org/10.5772/intechopen.100220


[100] Pozdnyakova NN. Involvement of the ligninolytic system of white-rot and litter-decomposing fungi in the degradation of polycyclic aromatic hydrocarbons. Biotechnology Research International. 2012


[112] Saraswathy A, Hallberg R. Degradation of pyrene by indigenous
fungi from a former gasworks site. FEMS Microbiology Letters. 2002; 210:227-232


Mannig JF, Boopathy R, Kulpa CF. A Laboratory Study in Support of the Pilot Demonstration of Biological Soil Slurry Reactor. Argonne, IL: Argonne National Laboratory; 1995


Siddique T, Okeke BC, Arshad M, Frankenberger WT. Temperature and pH effects on biodegradation of hexachlorocyclohexane isomers in water and a soil slurry. Journal of Agricultural and Food Chemistry. 2002; 50(18): 5070-5076


Dimond JB, Owen RB. Long-term residue of DDT compounds in forest soils in Maine. Environmental Pollution. 1996; 92:227-230

Hong Q, Zhang Z, Hong Y, Li S. A microcosm study on bioremediation of fenitrothion-contaminated soil using Burkholderia sp. FDS-1. International Biodeterioration and Biodegradation. 2007; 59(1):55-61


Andrea MM, Tomita RY, Luchini LC, Musumeci MR. Laboratory studies on volatilization and mineralization of 14c-p, p'-DDT in soil, release of bound residues and dissipation from solid surfaces. Journal of Environmental Science and Health Part B. 1994; 29(1):133-139

Nash RG, Harris WG, Lewis CC. Soil pH and metallic amendment effects on DDT conversion to DDE. Journal of Environmental Quality. 1973; 2:390-394

