Effects of Petroleum on Soil

Subjects: Ecology

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Petroleum is the most common global fossil fuel. It is a complex multi-component system mainly composed of various hydrocarbons such as alkanes, cycloalkanes, mono-, bi- and polyaromatic compounds, resins and asphaltenes. In spite of humanity's need for petroleum, it negatively affects the environment due to its toxicity. The ecological problem is especially serious at petroleum mining sites or during petroleum transportation. Since it is not possible to replace petroleum with less toxic fuel, ways to reduce the toxic impact of petroleum hydrocarbons on the environment need to be developed.

rhizodegradation microbial bioremediation biodegradation

1. Introduction

Environmental pollution by petroleum and its products has an anthropogenic origin. The main losses of petroleum occur during mining, transportation and storage and amount to millions of tons per year [1][2][3][4]. Currently, 1.2 million hectares of land in Russia are contaminated to various extents and need re-cultivation [5].

The petroleum toxicity to all life forms is long-known and is usually attributed to softening of the plasma membrane lipid bilayer in the presence of petroleum [6]. In addition to membranes, petroleum can also impair the genetic processes in a cell [7][8]. With the above in mind, petroleum is considered to be one of the most dangerous pollutants of the environment due to its high toxicity and presence in the biosphere in vast amounts. In terms of its negative impact, petroleum, its products and wastes are ranked second after radioactivity. Petroleum spills from mining and processing accidents do significant harm to the ecosystems. In such cases, soil is mainly affected, because it is able to accumulate large amounts of pollutants due to its enormous adsorbing surface area. Petroleum pollution negatively affects soil biocenosis, seriously changes the chemical composition, structure and properties of soil, and reduces soil fertility and arable value. The petroleum spills may turn soils into typical technogenic deserts that are practically absent of biological processes. Petroleum-polluted soils are not suitable for agricultural and recreational uses and are potential sources of contamination of surface and ground waters.

Self-restoration of soils may take a long period, of 10 to 30 years or longer, depending on the soil type [9][10]. Remediation of petroleum-contaminated land requires a series of measures to clean up and restore soil as a natural environment. The most common of these measures are currently classified as physical, physicochemical, chemical and biological measures. Sometimes, mechanical measures are used. Depending on the mechanism of action on the soil, the measures can be subdivided further (**Table 1**).

Table 1. Soil cleanup methods' classification.

	Methods of Cleanup	Mode of Action (Examples)
Mechanical	Mechanical	Mechanical removal
Physical	Hydrodynamic	Flushing, filtering
	Aerodynamic	Vacuuming, purging, extraction
	Thermal	Thermos-osmosis
	Electrical	Electrochemical bleaching, electric osmosis, electrophoresis, electromigration, electrodialysis
	Electromagnetic	Magnetic separation
Physico-chemical	Volatilization	Removal of volatile petroleum products
	Dissolution, diffusion	Dissolution, leaching, diffusiophoresis
	Ion exchange	
	Adsorption	
Chemical	Hydrolysis	
	Photolysis	
	Neutralization	Reagent leaching
	Oxidation	Oxidation
Biological	Phytoremediation	Phytodegradation, rhizodegradation, phytovolatilization, phytoextraction, rhizofiltration, phytostabilization
	Bioremediation	Oxidation, biosurfactant

The strategy for the cleanup of petroleum-contaminated soil is influenced by the scale of the particular spill, by the landscape and geographical zone of the spill, and by the cleanup measures available. However, many researchers note that the traditional recultivation measures used for restoration of petroleum-polluted soil ecosystems have a number of flaws; specifically, they do not always facilitate the soil and flora restoration and often do long-lasting harm to the environment [11]. Soil recultivation reduces the rates of petroleum decomposition. Removal of a contaminated soil layer produces new spots of secondary pollution. It is therefore advisable to finish soil recultivation by application of biological cleanup methods, that is, by bioremediation and phytoremediation.

2. Petroleum Composition and Its Effects on Soil

Petroleum is a complex multi-component system mainly composed of diversely structured hydrocarbons such as alkanes, cycloalkanes, aromatic compounds (benzene, toluene, ethylbenzene, xylene), polycyclic aromatics (naphthalene, phenanthrene, anthracene, benzo(a)pyrene), resins, asphaltenes and, in minor amounts, oxygen-, sulfur- and nitrogen-containing compounds. Depending on the source, crude oil consists of 82–85% carbon, 10–14% hydrogen, 0.01–7% sulfur, 0.02–2% nitrogen and 0.1–1% oxygen [2][12]. In terms of the petroleum composition, it can be classified as light (density 0.65–0.87 g/cm^3), intermediate (density 0.87–0.91 g/cm^3) or heavy (0.91–1.05 g/cm^3) [13]. This is an important parameter, which influences the impact of petroleum on the environment [14][15].

According to the literature, the major mechanisms of the negative effects of petroleum on living organisms are the direct toxicity of hydrocarbons from the light oil fractions, and the altered hydrophobicity and the other physical and chemical properties of soil, caused by heavy oil fractions [16][17][18][19]. The light oil effects on plants are stronger, but short-lived relative to the effects of heavy oil [20][21]. The light fractions of petroleum, however, are quickly degraded by microbial destructors or rapidly migrate from the soil; therefore, it is mainly the heavy fractions that negatively affect living beings, such as plants, animals and microbes, when the contamination is serious [22].

Soil contamination by petroleum and its products changes more or less all soil properties, including its physical, physicochemical and chemical properties [23][24]. The extent of such changes depends on the soil type, the soil's initial condition, and the type and concentration of contaminant. As a result of contamination and the petroleum film coating of soil particles, the color of the soil profile changes to grey and dark brown [25][26]. The soil surface color changes result in lower light reflective properties of soil [27]. The light reflective ability of polluted soil was found to proportionally grow with time because of the petroleum transformation. This effect facilitates more efficient heating of such soils. The soil particles coated by hydrophobic films of high molecular weight petroleum components lose their ability to absorb and retain moisture. This leads to a considerable loss of water conductivity and capacity. As a result of greatly increased hydrophobicity, the upper contaminated layers dry out, whereas the cleaner lower layers suffer from excessive moisture, leading to incorrect air and water conditions and the development of anaerobic processes [28][29]. The abnormal water conditions lower solubility and availability of micronutrients to plants, hence inhibiting nitrification and ammonification. The waters adjacent to petroleum were reported to be high in sodium. Sodium ions reach the soil sorbtion complex and replace its pH-balancing cations, thus elevating the soil pH [30][31]. Petroleum and its products change the redox properties of soil. Ineffective aeration and anaerobic conditions in the soil depth lower its redox potential and may result in pasting and even surface waterlogging. The petroleum contamination also changes soil chemical properties. Humus becomes poorer in humic and fulvic acids, and its organic carbon grows by 2–10 times. The higher carbon elevates the C:N ratio, and the concentrations of important elements such as phosphorus and potassium drop. In addition, all of the above factors adversely affect microbes and plants [9]. Petroleum products are bound by upper soil layers and extrude air from the soil, leading to incorrect air conditions in soil and plant hypoxia. Thus, petroleum and its products mainly cause negative changes in all soil properties, from the soil layer morphology to humic acid chemistry.

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