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Review

Rhizospheric microorganisms as a solution for the recovery of soils contaminated by petroleum: A review

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ABSTRACT

Petroleum is currently the world's main energy source, and its demand is expected to increase in coming years. Its intense exploitation can lead to an increase in the number of environmental accidents, such as spills and leaks, and an increase in the generation of environmental liabilities resulting from refining. Due to its hydrophobic characteristics and slow process of biodegradation, petroleum can remain in the environment for a long time and its toxicity can cause a negative impact on both terrestrial and aquatic ecosystems, with the main negative effects related to its carcinogenic potential for both animals and humans. The objective of the present review is to discuss environmental contamination by oil, conventional treatment techniques and bioremediation an alternative tool for recovery petroleum-contaminated soils, focusing on the rhizodegradation process, plant growth-promoting rhizobacteria (PGPR), a phytoremediation strategy in which the microorganisms that colonize the roots of phytoremediatior plants are responsible for the biodegradation of petroleum. These microorganisms can be selected and tested individually or in the form of consortia to evaluate their potential for oil degradation, or even to measure the use of biosurfactants produced by them to constitute tools for the development of environmental recovery strategies and biotechnological application.

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1. Introduction

Among the numerous forms of energy, oil represents a considerable part of the world energy source. According to the International Energy Agency (IEA, 2017), in order to meet world demand, in 2015 97 million barrels of oil were needed per day, and it is estimated that 100 million barrels of oil per day will be needed up to 2021. At the same time, as the use of petroleum is of great relevance to society, numerous environmental accidents, such as spills and leaks, can be caused during exploration activities, and they can generate waste from refining, which can cause both

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terrestrial and aquatic ecosystems damages when they are not adequately treated (Wang et al., 2014).

Soil and water contamination caused by accidents can occur in several environmental compartments: groundwater (Liu et al., 2015), soils (Li et al., 2015), rocky shores (Kankara et al., 2016), sediments (Burnes and Jones, 2016) and oceans (Broszeit et al., 2016), causing impacts mainly from a toxicological point of view. In this way, the oil entry into ecosystems is one of the major environmental concerns. According to Vaziri et al. (2013), oil contamination can cause cancer in living beings, especially by their recalcitrant properties.

When the environment with petroleum is contaminated, it is necessary to use remediation techniques to recover the degraded area. Most of these techniques are not feasible due to the extent of the contamination. Therefore, it is necessary to search for alternative decontamination technologies namely biological technologies that, according to Shekoohiyan et al. (2016), are feasible, easy to apply, cost-effective, and according to García-Sánchez et al. (2018), are effective in remediation of environmental contamination.

Considering all these characteristics, phytoremediation stands out as a promising alternative in terms of biological treatment. Brzeszcz et al. (2016) and Seckin (2016) define phytoremediation as an alternative technology that involves the use of plants and microorganisms associated with their roots in order to reduce environmental impact. According to Alaribe and Agamuthu (2015) and Hanks et al. (2015), in the case of petroleum, these depollution agents are able to degrade toxic compounds when they use them as energy source, releasing substances, often less toxic for the environment.

Rhizoremediation, composed by the combined use of phytoremediation and bioremediation, has been proposed as a gentle remediation option to rehabilitate multi-contaminated soils (Lacalle et al., 2018). The rhizodegradation is a strategy for phytoremediation of polluted environments with petroleum and its derivatives. In this process, plants act indirectly in phytoremediation, since their presence in the environment provides favorable conditions for the growth of microorganisms in the rhizosphere region. These microorganisms are able to biodegrade the toxic compounds. The microorganisms commonly isolated from the rhizosphere of phytoremediation plants according to Rein et al. (2016), are bacteria, fungi and yeasts. Thus, the purpose of this review is to discuss about the environmental contamination by oil, the treatment techniques conventionally used, and alternative treatments, more specifically the rhizodegradation process, plant growth-promoting rhizobacteria (PGPR), advantages and limitations of rhizodegradation. For this purpose, the search for information in the Web of Science - WoS database was performed, in the online version. The search was carried out in English language works and covered the years from 2000 to 2018. The research was based on the search for articles that had as descriptors: petroleum, petrol derivatives, soil contamination, bioremediation, phytoremediation, rhizodegradation, rhizosphere, plant-microbe association, PGPR, and microorganisms.

2. Environmental contamination by oil and negative impacts to environmental compartments

Several studies in recent years involve the analysis of environments contaminated by different pollutants from industrial activities. Among the most studied contaminants, pesticides, chlorophenols and heavy metals can be highlighted, and the same importance is verified when the pollutant is petroleum (Pi et al., 2016; Shahi et al., 2016; Shekoohiyan et al., 2016; Venkidusamy et al., 2016; Wang et al., 2016; Zhang et al., 2016).

Due to the technological development and capital accumulation, occurred the world trade's expansion and dependence on oil and its derivatives (Carneiro and Gariglio, 2010), since they are the main products used in both domestic and industrial activities (Andrade et al., 2010).

Petroleum is composed of a complex mixture of aliphatic, aromatic and heterocyclic hydrocarbons (Falkova et al., 2016), formed by biogeochemical processes and its found at varying depths in the subsoil. Depending on its origin, most of its components (from 60% to 90%) are classified as biodegradable and the smallest part (from 10% to 40%) is characterized as crude or recalcitrant; in other words, not biodegradable, resulting in a delay to disappear from the environment.

The problems commonly associated with the disposal of petroleum in the environment involve accidental spills during the transport, management or storage of hydrocarbons in underground deposits, distribution pipes, or refining processes (Das and Chandran, 2010; Smith et al., 2015). Around these refineries and near the transport facilities, the impacts comprise a challenge of managing the oil production chain (Olajide and Ogbeinfun, 2010; Vaziri et al., 2013).

Mena et al. (2016) report that when there is an oil spill, the contaminant fills the pores of the soil and it is rapidly adsorbed by its particles, moving vertically with capillary forces with the aid of gravity, altering the chemical, physical and biological compositions of the soil. The oil penetrates the soil easily until it reaches groundwater, which changes its ecological and geochemical states.

An initial modification occurs in the availability of oxygen, because oxygen is an electron acceptor molecule that stimulates the degradation of petroleum hydrocarbons (Ramiréz-Pérez et al., 2015). Under reduced or absent oxygen conditions, aerobic microorganisms present in contaminated soil have their metabolism partially interrupted, which directly interferes with microbial activity, thus affecting ecosystems, causing negative impacts due to their toxic properties (Chen et al., 2015).

The negative impacts on different ecosystems include the impairment of altered biotic and abiotic conditions, mainly reflecting loss of habitat and serious consequences on biodiversity. According to Nardeli et al. (2016), the most common impacts related to the presence of petroleum in the environment include abiotic stresses such as heat, hypoxia, oxidative and osmotic stresses. Gargouri et al. (2015) mention that in general, the pollution of natural resources with petroleum hydrocarbons and their derivatives cause soil's impermeabilization and imbalance in the groundwater's quality. According to Abbasian et al. (2016), and Andreolli et al. (2015), changes in soil microbial composition and inhibition of activity are also highlighted, as a consequence of the alteration in soil's chemical composition and low nutrient availability.

In plants, the negative effects occur in the growth and development stages, in other words, from seed germination to reproduction. The presence of petroleum in the soil induces oxidative stress, which reduces growth and causes foliar deformation and tissue necrosis, as well as disturbances in the signalling of metabolic pathways of oxygen reactive species and responses related to defense against pathogens (Nardeli et al., 2016).

The animals are also harmed due to damaging to the conditions of their habitat, a fact that can lead to the development of cancer and other diseases, as well as imbalances in the food chain. Insufficiency in reproductive capacity and bioaccumulation in the food chain at levels that disturb biochemical and physiological processes are also reported. The sum of these environmental imbalances leads directly or indirectly to human health, since oil contamination has high toxicity and carcinogenic, mutagenic and teratogenic potential, as affirmed by Chen et al. (2015), and Rein et al. (2016). Depression of the nervous system, narcosis and irritation of the