ECG Environmental Brief No. 27 ECGEB No. 27

Microbially-enhanced bioremediation of organic contaminants

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Petroleum contamination is the most persistent environmental threat resulting from oil and gas operation. The slow rate of natural attenuation necessitates the development of enhanced remediation approaches. One strategy is the use of bacterial consortia with the environmental adaptability and metabolic capacity for hydrocarbon degradation. In this Environmental Brief, we examine the rational for this strategy and potential biotechnological applications.

Environmental contamination by petroleum and its products is the most persistent environmental menace resulting from oil and gas operations. Spills have occurred in terrestrial and aquatic environments as a result of human error, corrosion and equipment failure (*1*). This has become a major threat to human and animal lives and the environment because of the toxicity of petroleum hydrocarbons (*2*). Consequently, there is an urgent need for effective remediation.

Bioremediation options

Because of the diversity of petroleum contaminants, a number of different remediation options have been investigated. These are classified into two major groups namely, *ex situ* and *in situ*. *Ex situ* techniques involve the excavation and relocation of contaminants for off-site treatments (*3*). As a result, *ex situ* techniques are very expensive and environmentally unfriendly. In contrast, *in situ* remediation involves the on-site treatment of contaminants, and *in situ* methods are both eco-friendly and cost-effective. The United States Environmental Protection Agency (US EPA) indicated that implementing *in situ* remediation of petroleum contaminated sites will result in cost savings of 50 to 80% over traditional methods such as excavation and landfill incineration (*4*).

An *in situ* method that has proved relatively effective for hydrocarbon remediation is phytoremediation, which is the use of plants to clean up contaminated sites. This technique relies on the use of plant interactions (physical, biochemical, biological, chemical, and microbiological) in polluted sites to mitigate the toxic effects of pollutants (*5*).

This technique has advantages in that carefully selected plants with fibrous roots serve as a natural host for hydrocarbon-degrading microorganisms. At the same time, extensive rooting systems make it possible for air to penetrate the rhizosphere, thus serving as natural bioventing system, leading to increased biodegradation of pollutants. Notwithstanding the merits of this technique, its longer remediation time, slow growth rate, and slow metabolic activity limit its application. To address this shortfall, there is increasing interest in the isolation of different microbial consortia for enhanced remediation of environmental contaminants. This approach, known as microbially-enhanced bioremediation, offers great potential for effective reclamation of hydrocarbon contaminated sites.

Microbial-enhanced bioremediation

Bioremediation of petroleum hydrocarbons relies primarily on biodegradation by microorganisms through a series of complex processes. Recent studies have shown that the inoculation of petroleum-contaminated soils with hydrocarbon-degrading bacterial consortia or isolates, a technique known as bioaugmentation, can enhance the effectiveness of bioremediation (*6*). The consortia can be used as a stand-alone inoculum, or in synergism with plants (**Figure 1**).

In addition, some of the inoculated microbes enhance the growth of host plants through processes such as nitrogen fixation, and phosphate and potassium solubilisation.

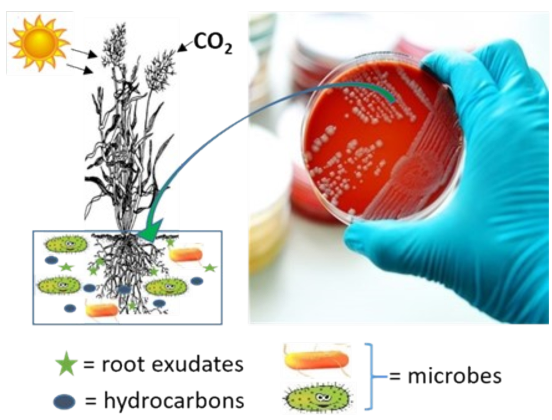

Figure 1. Microbial-enhanced rhizomediation.

In turn, the root exudates released by the host plants provide nutrition to the associated bacteria, enabling continuous biodegradation of contaminants by the rhizobacteria. This synergistic relationship has been described as the ecological driver of rhizoremediation (*7*). As such, it is important to identify novel microbes that can serve as inocula for enhanced bioremediation of organics.

Microorganisms present in contaminated environments hold the key to unlocking most of the challenges associated with bioremediation since they possess both the environmental adaptability and metabolic capacity for contaminant degradation (*8*). These organisms can be isolated from the contaminated environment through successive enrichments using the contaminant of interest as the sole carbon and energy source. This is followed by metagenome functional analysis of the isolated consortium to enable the assessment of its potential to activate and carry out complex processes involved in the degradation of organic contaminants. In aerobic degradation of hydrocarbons, oxygen is both the terminal electron acceptor and a necessary reactant for activating hydrocarbons by converting them into oxygenated intermediates (*9*). This process is orchestrated by monooxygenases and dioxygenases that incorporate oxygen atoms, forming alcohols. The central metabolism of aromatic hydrocarbons involves ortho- and meta-cleavage of catechol and alkylcatechols (*9*). Further oxidation results in the formation of oxoadipate and aldehydes, with the former being metabolised via succinyl-CoA and the latter via acetyl-CoA and propanoyl-CoA (*10*). The inoculation of petroleum contaminated soils with microbes having the ability to perform these complex reactions may speed up the biodegradation of organic pollutants. This is a novel technology, with only a few studies carried out so far, and a handful of inocula developed. Nevertheless, the results of these studies have shown that microbially-enhanced bioremediation is a promising technology with many potential biotechnological applications. Therefore, there is a growing need for more research in this direction.

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Conclusions

The pollution of the environment by petroleum hydrocarbons poses serious risks, because of the toxicity of these organics. As a remediation strategy, plant-based techniques offer an eco-friendly and cost-effective alternative over traditional methods. However, slow metabolic activity limits their effectiveness. The development of oil-degrading microbial consortia appears to address this shortfall.

These consortia are capable of initiating and speeding up the degradative processes. This is a promising technology capable of enhancing rhizoremediation, since rhizoremediation relies on biodegradation of pollutants by root-associated microbes. The biotechnological application of this remediation approach could speed up the reclamation and restoration of contaminated sites.

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