REVIEW

Microbial mechanism of petroleum hydrocarbons degradation: An Environmental perspective

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Abstract: Petroleum hydrocarbon compounds are recognized to be neurotoxic and xenobiotic organic pollutants, because they are presently a large environmental issue as a result of the increased mining of petroleum compounds and similar products, both of which have important environmental consequences. Petroleum products include cancer - causing compounds which can have a range of impacts on ecology biotic and abiotic variables, and leakage is generally induced by mistakes in pumping, transportation, and refining. Physical and biological procedures are commonly cleaned to separate petroleum from polluted areas. Both methods are efficient but can be costly. Because it is not very costly and leads to complete mineralization, bioremediation is the best and most advanced method for treating these polluted sites. Another very significant and successful natural technique for eliminating petroleum hydrocarbon environmental contaminants is microbial decomposition. Hydrocarbon contaminants could be deteriorated by a variety of indigenous microbes in water and soil. A variety of limiting variables have been identified that impact petroleum hydrocarbon biodegradation. This study outlines the aerobic and anaerobic microbiological breakdown of organic compounds, as well as the different variables that influence the process. Microbial deterioration could be regarded a vital aspect in the cleaning approach for petroleum hydrocarbon recovery, it can be inferred.
Keywords: Hydrocarbon contaminants, bioremediation, aerobic and anaerobic degradation

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1 Introduction

Petroleum hydrocarbons (PHs) are considered the main energy source and materials for different industries (Varjani and Upasani, 2016). Many threats exist in the environment when hydrocarbons are used as energy sources. PAHs are major environmental pollutants generated by wide-scale production, transport, coastal oil refining, ship-ping activities, offshore oil production and accidental oil spilling (Arulazhagan et al., 2010). Human activities, like municipal run-offs and liquid release and industrial process cause PAHs pollution which impacts the environment and posses a direct or indirect health hazard to forms of life (Sajna et al., 2015). PAHs are toxic compounds classified as priority pollutants (Costa et al., 2012). Aliphatic and Aromatic hydrocarbons are two major PAHs components that have been reported. Till date, petroleum hydrocarbons are among the major and most commonly occurring environmental pollutants. The production of crude oil, its transportation, chemical processing and distribution are considered as the main sources of anthropogenic hydrocarbon pollution (Farhadian et al., 2008). It is of common knowledge that hydrocarbons are toxic substances that exert a negative impact on the ecosystems (Chen et al., 2015). The expansion of petroleum development into new frontiers, such as deep offshore waters and ice-dominated Arctic environments, and the apparently inevitable spillages which occur during routine operations which result the consequence of acute accidents and made a high research interest in this field. These contaminants are usually anthropogenic. They enter into the ecosystem, resulting to numerous environmental issues, ecological disasters and social catastrophes globally. Due to this problem scientific focus on cost-effective and environmental friendly strategies which would be faster, practical and adjustable in many physical settings for restoration and reclamation of the affected environments (Costa et al., 2012) have been studied. Bioremediation technology is believed to be non-invasive and relatively cost-eective (April et al., 2000) technique which relies on many microorganisms. Furthermore, despite the fact that the mechanisms of hydrocarbon biodegradation processes are known, there are still numerous misconceptions regarding the relation between microorganisms and hydrocarbons, which result in the lack of a uniform theory. In order to fully comprehend the depth of the interactions between microorganisms and hydrocarbons, it should be remembered that the history of petroleum trans-

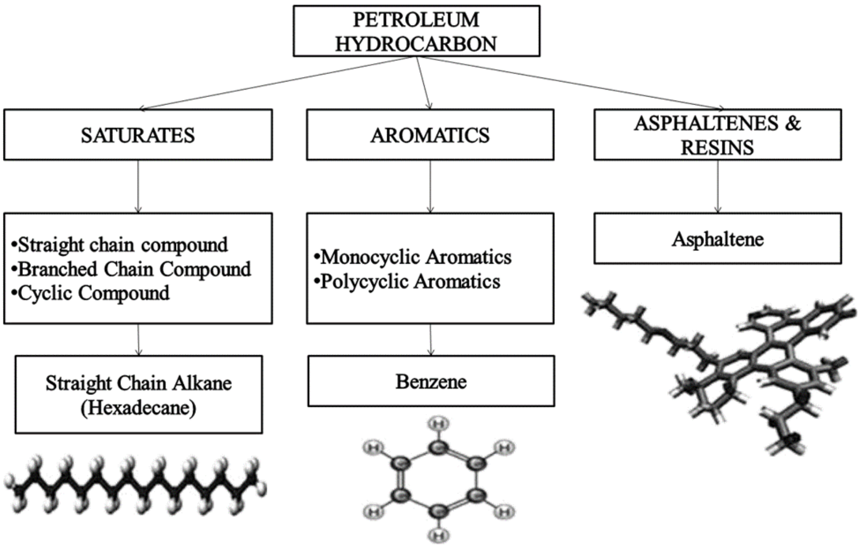

Figure 1. Types of petroleum hydrocarbon

gresses the issues of the modern world. Biodegradation by natural populations of microorganisms represents one of the primary mechanisms by which petroleum and other hydrocarbon pollutants can be removed from the environment and is cheaper than other remediation technologies.

Microbial degradation plays a major role in the weathering process. Biodegradation of petroleum hydrocarbons in natural ecosystems is complex. The evolution of the hydrocarbons mixture depends on the nature of the oil, the nature of the microbial community, and a variety of environmental factors which direct or indirect influence microbial activities. Most previous reviews concerning the microbiology of petroleum pollutants have been concerned with the marine environment. Biodegradation by indigenous microorganisms is a major mechanism and a reliable method that operates by biologically removing foreign contaminants, such as crude oil (Ghanavati et al., 2008). Bacteria, yeast and fungi can utilize PAHs (Haritash and Kaushik, 2009). Fungi such as *Aspergillus*, *Penicillium*, *Fusarium*, *Amorphotheca*, *Neosartorya*, *Paecilomyces*, *Talaromyces*, *Graphium Cunninghamella* are microorganisms which can degrade persistent pollutants. In recent years, the use of bacteria to deal with environmental pollutants has become a promising technology because of its low cost and eco-friendly nature (Guerra et al., 2018). The continuous advancement and enhancement of microbial remediation technologies has provided a new approach to remediate hydrocarbon contamination of petroleum, which has been received considerable attention (Dvŏrák, et al., 2017).

This review seeks to provide factual and recent advancement on microbial degradation including their mechanisms and the environmental factors which affect process of microbial degradation. This analysis also provides some recommendations for the potential development of petroleum hydrocarbons in bacterial remediation based on previously published recent studies relevant to developments in the field of bacterial hydrocarbon remediation.

2 Methods of Degradation of Hydrocarbon

The feasibility and location of the pollutants rely largely on a biological treatment process. Whether there is on-site care, the word "in situ" would be enough and if there is off-site treatment, then "ex situ" (Hamzah et al., 2013). For in situ and ex situ remediation, the methods of biological remediation have been shown remarkable results. Microorganisms can either remediate or degrade petroleum hydrocarbons in less hazards pollutants (Lim et al., 2016). When microbial growth conditions are favorable, biodegradation processes are started, it is known as natural attenuations (Benedek et al., 2011). The method to restore and clean up soil pollutants is easy, environmentally friendly, safe and economical. It includes the natural degradation of hydrocarbon petroleum pollutants, including natural microorganism found in soil like, bacteria, fungus, and yeast. They maintained the aerobic condition of soil through nutrient-supply and optimize limiting factors for its biological activities into non-toxic and other important compounds such as carbon (IV) oxide and water (Yanti, 2018).

Bioattenuation include the natural process of removing, processing, neutralize and reducing the mass, volume, levels of toxicity in contaminants . This is applicable for sites having low contaminant concentration and cannot be used for other methods of remediation.

Several stimulators have been used to enhance the rate of biodegradation as well as enzyme development (involve in bioremediation). It includes stimulants, bulking agents, nutrient modification agents, bio-surfactants, biopolymers and slow release fertilizers (Wu et al., 2016). Bioaugmentation requires the addition of exogenous microbial cultures, natives, and genetically modified microbes that have been "adapted and demonstrated to degrade pollutants to improve

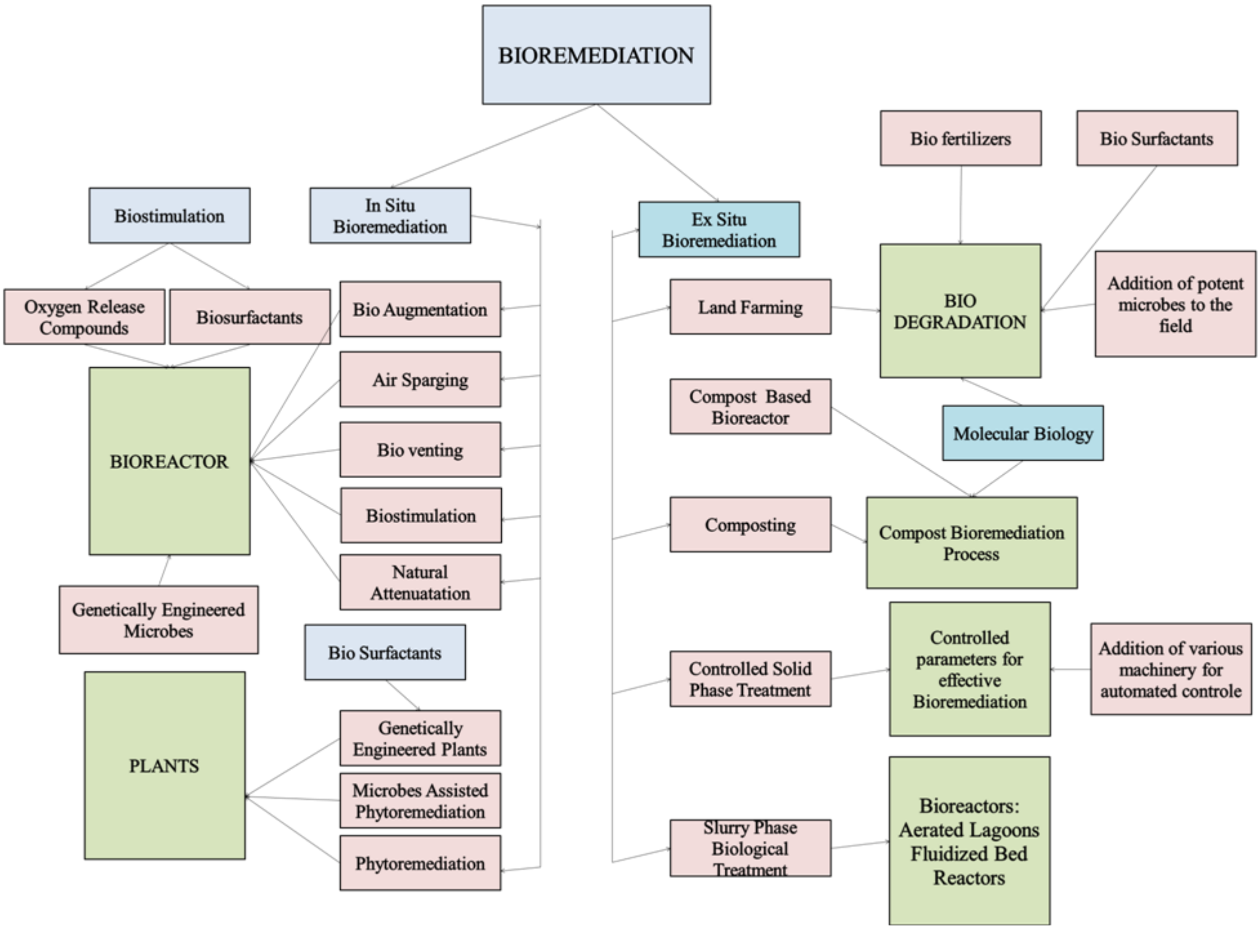

Figure 2. Methods of degradation of petroleum hydrocarbon

or boost the rate of degradation (Nwankwegu and Onwosi, 2017).

Bioventing injects air (oxygen) into the infected soil to improve in situ degradation and reduce volatile atmospheric pollutants (Trulli et al., 2016). Adding air to the ground promotes and improves aerobic development of indigenous microorganisms which enhance the catabolism of pollutants (Thomé et al., 2015). Similar assessment was also investigated by Kap et al., 2007. In their experiment the restoration and removal of diesel soil without any soil changes was 85% after 60 days.

Landfarming is the over ground remediation technology applies where the contaminated soil is hollow, added by the addition of microorganisms and nutrients to the soil surface or liner. By controlling the soil temperature and nutrients, the effectiveness of biodegradation can be improved. The degradation also increases the supplementation of co-substrates and anaerobic pre treatment of soil. This procedure has been used successfully conducted for benzene, toluene and xylene bioremediation (Sonawdekar, 2005). In regulated biologic composting process where microbial degradation of polluted materials is dominated by aerobic and thermophilic conditions results a stable end products.

Generally, indigenous microorganisms are used for repository purpose and also waste is transformed into less complex or mass-decreasing products. The unloading of organic materials is mixed with polluted soils such as wood, plant and animal wastes to achieve greater efficiency. Aeration, temperature and humidity are in controlled condition. Thermofiltering has been carried out for a minimum of toxicity levels in terms of treatment of waste, diesel polluted soil, waste brewing, antibiotic fermentation and unit waste (Khan and Anjaneyulu, 2006).

The biopiling process includes combining landfill and composting of an engineered cell aerated to soil-adsorbed pollutants with blowers, vacuum pumps, irrigation and nutrient systems, and leachate collection systems (Kim et al., 2018). The technique consists of the piling of polluted soil and biostimulation and ventilation to improve degradation microbial activities. In an analysis shown by (Gomez and Sartaj, 2014), which conducted a 94-day biopiling treatment of polluted soil of petroleum hydrocarbon on a field scale, by a consortium of microorganisms and organic compost.

To improve biodegradation the windrows depend on the regular tilling and rotation of piled polluted soil by adding water to increase aeration and nutrient distribution. Microbial activity of indigenous hydrocarbons speeds up the rate of biodegradation, as well as biological transformation, assimilation and mineralization (Jiang et al., 2016).

Trichoremediation is used to remediate soil contaminated with petroleum hydrocarbons through the enzyme activities of keratinolitic and keratinophilic bacteria and fungi present on the keratine materials such as hair and keratin-containing fathers. In an analysis shown by (Njoku et al., 2017), who studied the bioremediation of petroleum soil polluted and used keratinolytic fungi as markers for the contamination of petroleum hydrocarbon.

The mycomediation process includes the use of fungal processes for the reduction or elimination of pollutants into less harmful or non-toxic forms (Kumar et al., 2018). In a similar study (Njoku et al., 2017) 62 days after incubation showed that 68.34 % of total petroleum hydrocarbons were removed in the soil at a concentration of about 10% and that the lowest removal rate in the soil was at 2.5% with 22.12% removal.

Phycoremediation is a sequestration, removal, degradation, biotransformation or metabolism of algal organisms (macroalgae, microcalgae) in a polluted aquatic setting (Phang et al., 2005). Kalhor et al. (2017) examined, after 14 days, Chlorella vulgaris' propensity for phycoremediation of the water polluted by crude oil.

Contaminants may be biodegraded to treat both solid and liquid wastes by massive bioreactors. Bioremediation of solids or liquids in specially constructed bioreactors is subject to regulated conditions. Variously different parameters are maintained under optimum conditions, Nutrient availability, temperature, aeration, humidity, and the relationship between contaminant and micro-organisms (Azubuike et al., 2016).

3 The Role of Microorganisms in Biodegradation of Petroleum Hydrocarbons

Petroleum hydrocarbon biodegradation is a complicated process that depends on its existence and its quantity. The hydrocarbons of oil can be classified into four categories: saturates, aromatic hydrocarbons, asphenols, fatty acids, ketones and esters, as well as resins (pyridines, quinolines, carbazoles, sulfoxides, and amides). Hydrocarbons are typically susceptible to microbial degradation as following: Linear alkanes > alkanes > aromatic little alkanes > cyclic alkanes (Atlas and Bragg, 2009). Hydrocarbons are mainly bacterial, yeast and fungal biodegraded in the ecosystem. The majority of petroleum hydrocarbons in the atmosphere have gradually been deteriorated or metabolised by indigenous bacteria, due to energy and the need to growth and reproduction of petroleum hydrocarbons. Many scientists have identified the need to reduce complicated hydrocarbon blends such as crude oil on soil by mixing populations with overall marine environments, large enzyme capacities.

4 Application

4.1 Bacteria

Bacteria are the most important agents for oil degradation and are the key environmental degraders for spilled oil (Rahman et al., 2003). Many bacteria are also known to only feed on hydrocarbons (Yakimov et al., 2007). Soil and water polluted with petroleum have recorded unique bacterial populations associated with different genera, e.g. "*Acinetobacter*, *Achromobacter*, *Alcaligenes*, *Arthrobacter*, *Bacillus*, *Burkholderia*, *Brevibacterium*, *Corynebacterium*, *Dietzia*, *Flavobacterium*, *Methylobacterium*, *Nocardia*, *Sphingomonas*, *Pseudomonas*, *Rhodococcus* and *Vibrio*" (Johnsen et al., 2005). Microbial consortium involving in the biodegradation of sugar cane waste soil are of 6 forms of bacteria belonging to the genera Pseudomonas, Klebsiella, and Serratia (Trejo-Hernandez et al., 2007).

PCA hydrocarbons (naphthalene and phenanthrene) may be the single carbon source for bacteria belonging to the genus *Paenibacillen* recovered from the sediment polluted by petroleum (Riis et al., 2003). Biosufficiency improved with 75% hydrocarbon extraction by bioaugmentation of Antarctic contaminated soils using *Acinetobacter sp.* (Daugulis and McCracken, 2003). *Bacillius sp.* is able to displace crude oil, oil and other petroleum products, recovered from its storage and distribution facility (Sepahi et al., 2008). Estimates of potential biodegradation by hydrocarbons in microbiological hydrocarbons are *Gordonia sp.*, *Brevibacterium sp.*, *Aeromicrobium sp.* (Jain et al., 2010).

4.2 Fungi

Fungi have also a capacity to degrade petroleum hydrocarbons by implementing chemical modifications and thereafter improved contaminant availability. It contains different nonspecific enzymes which increase the process of degradation because the substrates are unspecific (Pinedo-Rivilla et al., 2009). Filamentous fungi may use mycelial production and protraction and catabolic enzymes with lower substrate specificities as only developmental substrates and with little contaminant dependence (Harms et al., 2011). Fungi may also be used as part of populations of bacteria, such as hydrocarbon biodegradation endo- or ectomycorrhizal associations (Khan and Anjaneyulu, 2006). *Mycoflora* has been widely tested and the most well known genera of fungal and yeast biodegrades have been used for biodegrading various products of petroleum: "*Pleurotus*, *Penicillium*, *Rhizopus*, *Polyporus*, *Rhodorula*, *Talaromyces*, *Saccharomyces*, *Torulopsis*, *Talaromyces*, *Torulopsis*, *Pichia* and *Aspergillus*, *Alternaria*, *Petalosporium*, *Candida*, *Fusarium*, *Cladosporium*, *Gliocladium*, *Geotrichum*, *Paecilomyces* and *Mucor*, *Rhodotorula* and *Talaromyces* (Gesinde et al., 2008). *Candida catenulate* CM1 was used as a 2% (w/w) diesel composting and petroleum-degrading yeast for amendments to petroleum-contaminated soil, which indicated an increase in disposal

Table 1. Microorganisms used for the degradation of petroleum hydrocarbon

Strains	Source	Fraction degraded	References
Leclercia adecarboxylata	Soil polluted with oily sludge, Digboi oil refinery, Assam, India	Polycyclic aromatic hydrocarbons	Sarma et al., 2004
S. marcescens *Bacillus pumilus* *B. carboniphilus* *B. megaterium* *B. cereus*	Naphtha-transporting pipeline, India	Naphtha	Rajasekar et al., 2010
Serratia marcescens *Bacillus sp.* *B. cereus* *B. subtilis* *Pseudomonas aeruginosa* *Klebsiella sp.* *Pseudomonas sp.* *B. litoralis*	Petroleum-transporting pipeline, India	Diesel	Singh, 2012
Micrococcus sp. *Pseudomonas* *Acinetobacter* *Proteus* *Bacillus* *Actinomyces* *Corynebacterium* *Enterobacter* *Brevibacteria* *Citrobacter*	Nigeria	Crude oil	Adoki and Orugbani, 2007
Sulfate-, nitrate-reducing bacteria and fermenting bacteria	Sediment, Southeast Louisiana, USA	Crude oil, BP oil Spill	Boopathy et al., 2012
Alcanivorax	Marine oil spills, Japan	Alkane	
Cycloclasticus	Oil-coated grain of gravel, Japan	Various aromatic hydrocarbons	
Pseudomonas putida *Sphingomonas sp.*	Oil refinery sludge, Spain	Polycyclic aromatic hydrocarbons	Pizarro-Tobías et al., 2015
Aspergillus sp. *Penicillium sp.*	Soil contaminated with oil spills, Madurai, India	Petroleum	Vanishree et al., 2014a, b
Pseudomonas aeruginosa *Bacillus subtilis*	Soil from gasoline stations, Madurai, India	Petrol	Darsa and Thatheyus, 2014

of 84% of petroleum-hydrocarbon (Baheri and Meysami, 2002). *Cladosporium resinae* has been responsible for 20 to 40 per cent of petroleum degradation from the first filamentous fungi (Joo et al., 2008). A collection of *cephalosporium*, *aspergillos* and *penicillium* has also been disclosed which have also been observed as potential users of crude oil hydrocarbons(Adenipekun and Isikhuemhen, 2011). *Pleurotus tuberregium* has reported that it raises its soil nutrient content in soils that are saturated with engine oil up to 40%, reducing heavy metal levels after a six-month incubation period. In a comparison study, *Lentinus squarrosulus*, white red fungus, was also discovered to be able to increase nutrient levels and accumulation of Fe, Zn & Ni at an acceptable concentration in the same oil-polluted ground (Hidayat and Tachibana, 2011). Macot agar medium-sized and solar-polluted soil samples aggregated with Capek's petroleum stations are Absidia, Alternaria, Chrysosphorium (1%). Isolated kerosene-polluted *Aspergillus terreus* found that lipase production and the potential for oil degradation is high and suggested it might be advisable for researchers looking for high lipase and crude oil extraction fungi in insulated hydrocarbon-polluted soils (Mahmoud et al., 2015a, b).

4.3 Algae

These are regarded as key representatives in aquatic and terrestrial ecosystems with microbial consortia. However, there is no evidence of algae depletion in the natural environment of oil contaminants. Petroleum oil, different substrates of hydrocarbons, nisoalcanes and aromatic hydrocarbons, which were considered as the hydrocarbon achlorophyll algal were used as the Prototheca zopfii chlorophyll. The naphthalenium oxidisation of seven cyanobial bacteria, namely *Agmenellum sp.*, *Amphore Sp.*, *Aphanocapsa sp.*, *Chlamydomona sp.* and *Coccochloris sp.* was observed by several researchers in *Scenedesmus Platydiscus*, *Chlorella vulgaris*, *S. capricornutum* and *S. quadri-Cauda* for their important role in habitats with fresh algal biodegradation of PAHs (Abdel-Shafy and Mansour, 2016). Phenanthrene biodegradation as algal-bacterial microcosms by the use of *Pseudomonas migulae* and *Sphingomonas yanoikuyae* was studied (Haritash and Kaushik, 2009). Conversely, Efficacy of Chlorella vulgaris in pyrene, fluoranthene, and their blended effects has been examined by *Scenedesmus platydiscus*, *S. quadricauda* and *Selenastrum capricornut* (Ueno et al., 2008).

4.4 Protozoa

Protozoa was described in comparison with the bacteria, algae and fungi as a poor agent of biodegradation. The numerical values of bacteria ready for hydrocarbon removal, however, were significantly reduced in their populations. This shows that it does not benefit from biodegradation within the ecosystem (Stapleton and Singh, 2012). Bacteria, however, feed protozoa on organic pollutant degradation. The reciprocal activity between protozoa and bacteria therefore definitely would influence the bacteria's biodegradation. A model was developed for food series (Mattison et al., 2005) to assess the effect on bacteria leading to degradation of benzene and methylbenzene by flagellate heteromita globosa from protozoa.

5 Mechanism of Hydrocarbon Substance Degradation by Microorganisms

In ordinary habitat, bacteria, yeast, and fungi with varying degradation levels are biodegraded in an aerobial or anaerobial way (Guarino et al., 2016). There are different metabolic limitations in the presence or absence of oxygen in mixed populations (consortias) considered fundamental to degrading complex petroleum hydrocarbon mixtures, such as oil in soil, dwelling and marine environments. Several detailed studies have shown that the potential for degradation of petroleum carbon is linked to a microbial degra. In general, aerobic restriction has resulted in biodegradation that happens very quickly and entirely for most organic pollutants. Via the centrally regulated metabolity like the tricarboxylic acid cycle, the environmental pathways for biodegradation are eventually transforming such organic pollutants into fragments. A metabolism such as acetyl-CoA, pyruvate and sucinate of the central precursors mainly results in the biological synthesis of the celled mass. In addition, the gluconeogenesis process synthesis sugars required for different biological syntheses (Fritsche and Hofrichter, 2000).

5.1 Aerobic degradadtion

The most rapid and complete method is aerobic degradation to eliminate petroleum-hydrocarbon hazards, particularly for aromatic forms, in the environment. Various pathways and enzymes have been found responsible for degradation of petroleum hydrocarbons, such as the P450 cytochrome family and the monooxygenase alkane, related to petroleum pathways (Van Beilen et al., 2006; Van Beilen et al., 2007). The oxygen involvement on the route characterises aerobic degradation (Rojo, 2010). Monooxygenase which adds one oxygen to hydrocarbons is used for the majority of reactions to aliphatic and aromatic hydrocarbons. In aromatic molecules, dioxygenase may add one or two oxygen atoms. In the aquatic world, unbranched alkanes are depleted fast. This decrease is effective for long and small carbon chains, but shorter chains deteriorate more rapidly. First, most alkanes are converted into alcohol by bacteria. Aldehydes or carboxylic acids can be present in these alcohols. In certain cases alcohol is secondary, and a ketone rather than carboxylic acid is formed in the next step. Carbon Acid can further degrade by oxidation of β to produce two atoms smaller in the carbon chain than the initial molecule and acetyl coenzyme A. Mineralization of the organic soil material using microbes with a nitrogen content of more than 4 percent was shown to be stifled. Another research has shown that biodegradation of petroleum petroleum oil in polluted soil by gasoline is the most rapid when 8% of the oxygen intake is in O_2. The depletion rate was more than double that of almost atmospheric O_2 at 8 percent of O_2 (18 percent O_2). As shown, a level of 5 percent or less of oxygen was limited from the former gasworks to soil biodegradation.

5.2 Anaerobic degradation

Anaerobic microorganism degradation of hydrocarbons is regarded as an environmental significance technique for petroleum hydrocarbon microbial degradation; oxygenases are not used as in aerobic species. Aromatic benzoate, halobenzoate and chlorophnol microbial degradation occurs at zero oxygen concentrations. In anaerobic environment, the molecular oxygen (in breathing), and various hydrocarbons in the oil plumes of groundwater, for example, were substituted for manganese, nitrate, sulphate, and iron. Anaerobic bacteria are classified into two classes: rigid and optional anaerobic bacteria. Strict anaerobics are the majority of sulphate reducing bacteria. But optional anaerobic bacteria have the choice between oxygen- or hydrocarbon degradation. Sulfur or nitrogen anaerobic oxidation requires bacteria. Bacteria degrade Alkanes and other fatty acids to form petroleum aromatic contents. In this degradation the process begins with the free radical mechanism of the principal carbon chain.

6 Use of Genetically Engineered Microorganism for bioremediation

Genetically engineered micro-organisms (GEMs) applications in bioremediation have gained much attention to enhance the laboratory degradation of dangerous waste. These issues need to be resolved before GEM can have a cost-

Table 2. The adsorption effects of various biochar on different heavy metals

Name of the microorganisms	Source	Hydrocarbon degradation(%)	References
Microcosm of six microbes (names not mentioned)	Contaminated oil refinery plant in China	63.2 ± 20.1%	Ma et al., 2015
Alkanindiges sp., Arthrobacter sp., Pseudomonas sp., Mycobacterium sp. and Rhodococcus sp.	Contaminated soils of Northern China	-	Sun et al., 2014
Alternaria alternata, Cladosporium sp., Aspergillus terreus, Eupenicillium hirayamae, Sphaerospermum sp. and Paecilomyces variotii	Contaminated mangrove sediments from Red Sea coast of Saudi Arabia	28-56%	Ameen et al., 2015
Stenotrophomonas sp., Pseudomonas sp.	Dredged sediments of a river estuary in Italy	43-95%	Gregorio et al., 2016
Nocardia otitidiscaviarum	Contaminated desert soil of Iran	-	Zeinali et al., 2007
Mycobacterium sp.	Soil	-	Miller et al., 2004
Mycobacterium sp.	Uncontaminated Natural Park Soil of Schwa of Germany	-	Kim et al., 2005
Acinetobacter sp., Aeromonas sp., Alcaligenes sp., Bacillus sp., Kocuria sp. (Micrococcus), Ochrobactrum sp., Pseudomonas sp. and Xanthomonas sp.	Contaminated Patagonian soil	0.028-100%	Peressutti et al., 2003
Rhodococcus sp. and Pseudomonas sp.	Contaminated soils of Kaluga, Kirov, Moscow	0-95%	Baryshnikova et al., 2001
Not defined	Uncontaminated soils of Western Siberia (Arctic region)	3.8-51.2%	Belousova et al., 2002
Alcanivorax borkumensis	North Sea, Atlantic Ocean, Mediterranean Sea, Sea of Japan, South China Sea and the Antarctic	80-90%	Golyshina et al., 2003
Nocardia otitidiscaviarum	Soil contaminated with Waste water of a petroindustrial site in Iran	10-55%	Zeinali et al., 2007
Afipia sp., Janthinobacterium sp., Leptothrix sp., Massilia sp., Methylobacterium sp., Rhizobium sp., Sinorhizobium sp. and Thiobacillus sp.	Uncontaminated soil of Arizona	88%	Bodour et al., 2003
Mucor mucedo	Uncontaminated soils of Shenfu irrigation area, China	87%	Jia et al., 2016
Haloarcula sp., Haloferax sp. (*the first report on the potential role of halophilic archaea belonging to the genera Haloarcula and Haloferax)	Uncontaminated pond water of Camargue, France	32-95%	Tapilatu et al., 2010
Marinobacter sp., Pseudomonas sp., Halomonas sp., Hahella sp. and Alcanivorax sp.	Contaminated sediments from coastal region in Oman	67%	Abed et al., 2014
Pseudomonas sp. and Variovorax sp.	Contaminated soils from Station Nord (St. Nord) in Greenland high Arctic region	70%	Sorensen et al., 2010

Table 3. Genetic modification for biodegradation of hydrocarbons

Microorganisms	Modification	Contaminants	Reference
Pseudomonas. putida	Pathway	4-ethylbenzoate	Wasilowski et al., 2012
P. putida KT2442	Pathway	toluene/benzoate	Vinothini et al., 2015
Pseudomonas sp. FRI	Pathway	chloro-, methylbenzoates	Das and Chandran, 2011
Comamonas. testosteroni VP44	substrate specificity	*o*-, *p*-monochlorobiphenyls	Panel et al., 2020
Pseudomonas sp. LB400	substrate specificity	PCB	Vinothini et al., 2015
P. pseudoalcaligenes KF707-D2	substrate specificity	TCE, toluene, benzene	Sarma and Joshi, 2015

effective clean-up operation. Genetically modified microorganisms have been created and the metabolic potential of microbiological organisms have been intensively studied (GMMs) (Urung-Demirtas et al., 2006). GMMs are an alternative remedy for microorganisms' wild strains, which slowly or not degrade pollutants. The first two genetically engineered strains were patented in the United States in 1987 (Davison, 2005). The "two strains are *Pseudomonas aeruginosa* (NRRL B-5472) and *Pseudomonas putida* (NRRL B-5473) with genes that give naphthalene," salicylate, and camphor degradation capacity . The findings for the biodegradation of genetically engineered petroleum hydrocarbons were similar to the results of bacterial strains extracted from the reservoirs. Two metagenomic clones were obtained 31% and 47% for saturated hydrocarbons, while natural bacteria were obtained at 99%. For aromatic hydrocarbon, metagenomic clones were degraded more (94%) than "natural strains (63%-99%) . Limitations in operation in the ecosystem of GEMs are due to the ambiguities in species classification, possible gene transfer and co-release of antibiotic resistance markers into other microorganisms." The environmental and health issues restrict research in real fields through the use of GEMs. Bioremediation control, strain monitoring, stress response, end-point analysis and toxicity evaluation have been used for genetically engineered bacteria. Combining micronuclear and ecological expertise, omic technology, biochemical processes and field engineering are key to effective in situ bioremediation using genetically modified substances (Urung-Demirtas et al., 2006).

7 Conclusion

There is clearly a link between hydrocarbons and microorganisms developed over millions of years. Therefore, among microbial communities the capacity to degrade hydrocarbons is widespread. The high toxicity of oil hydrocarbons for human and environmental health makes them one of the worst contaminants to produce. Petroleum degrading bacteria are commonly considered an environmentally safe and efficient technology for bioremediation. A significant number have been used and used in bioremediation with bacterial species of petroleum hydrocarbon degrading ability. During the practical application, however, different problems were identified that slowdown biodegradation effects. Several techniques have been researched and implemented, including controlling environmental variables and optimising microbial inoculants.

It's important that we continue to develop a low-cost, easy to manage and feasible technology that will clean up oil spills and other congenital environments. The following can be completed in the following way: (1) To address obstacles to micro-based use of the petroleum hydrocarbons continues on the theoretical basis of the interfacial process between bacteria and petroleum carbons; (2) Compare isolated strain output or efficiency; (3) To improve interaction between bacteria and petroleum hydrocarbons create new biocompatible surfactants; (4) Exploring undiscovered petroleum-bacterial resources through modern biotechnology, for example, through a high-throughput screening process to improve and enrich bacterial functional resources; (5) Optimize further the strategic approach of artificial microbial consortia by enriching and developing preferable consortia.

Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of this article.

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