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CATALYZING ENVIRONMENTAL RESTORATION: HARNESSING MICROBIAL POWER FOR PETROLEUM AND HYDROCARBON DEGRADATION

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ABSTRACT The harmful nature of. hydrocarbons, which include carcinogenic. and neurotoxic properties, makes. them an increasing environmental. issue, and the contamination. problem is getting worse. Extraction of petroleum using. traditional physical and chemical. methods is expensive and. wasteful . Bioremediation is explored in. this paper as a. practical and economical way. to fix sites that. have been polluted with. hydrocarbons. We also see how. critical it is to. address hydrocarbon contamination quickly. Pseudomonas and Bacillus species. were commonly identified in. a comprehensive review of hydrocarbon. -degrading bacterial research, demonstrating the efficacy of. bacterial consortia in this. process. The paper concludes by. highlighting the significance of. bacterial communities for effective. removal and going over. the many bacterial species. that break down aliphatic. and aromatic hydrocarbons. This review demonstrates how. hydrocarbon bioremediation methods that. have the potential to. be powerful tools in the fight against environmental. Pollution.

KEYWORDS : Hydrocarbon, Microorganism, Mechanism, Contaminate, Bio stimulation, Decomposition, Oxygenation, Immobilization, Degradation, Utilization and Bioremediation

INTRODUCTION:

Hydrocarbon contamination is a. major environmental issue that. has arisen as a. result of the widespread. usage of hydrocarbons in. many industrial processes, especially. in the petroleum industry [3]. Hydrocarbons, which are fossil. fuels mostly made. of carbon and hydrogen, are. essential components of. crude oil and other similar. products. Environmental health is jeopardized. by the accidental release. and buildup of these chemicals. in ecosystems. Hydrocarbon pollutants are known. to cause cancer and neurological damage, and they. are highly toxic and persistent [1].

Fig 1. Deepwater Horizon Oil Spill – The largest oil spill ever occurred

Thanks to their extraordinary. powers in hydrocarbon degradation, microorganisms—and bacteria. in particular—have become. nature's own cleanup crew. The complicated hydrocarbon structures. are mineralized into innocuous. by-products like carbon dioxide, water, and inorganic. substances by these specialist. microbes, who possess the. enzymatic machinery. necessary to do this [5][1][4].

Hydrocarbons Or Bacteria That Degrade Petroleum

To fulfill their energy. and carbon demands, reduce physiological stress, and support growth and. reproduction, indigenous bacteria. mainly break down petroleum. hydrocarbons found in the environment [6]. In oil-rich environments, such as spill. regions and reservoirs, the identification. of bacteria that degrade. hydrocarbons is made easier. by modern microbial biotechnology. and sequencing techniques [7]. A number of bacterial species, such as Bacillus, Achromobacter, and Pseudomonas, are essential. in the breakdown of. various hydrocarbon components. found in petroleum [8][9]. Biodegradation of hydrocarbons. in nature is mostly facilitated by bacteria, yeast, and fungi. Soil fungus have an. efficiency range of 6% to 82%, soil. bacteria from 0.13% to 50%, and marine. bacteria from 0.003% to 100%. Efficient degradation of complex. hydrocarbon mixtures, like crude oil, in different conditions. requires mixed microbial populations. with variable. enzymatic capabilities[11] Some bacterial genera, like Acinetobacter sp., can use n-alkanes (C10-C40) as their. only carbon source; others, like *Gordonia*, *Brevibacterium* and. *Mycobacterium*, have shown promise. in hydrocarbon. degradation when isolated. from soil contaminated with petroleum. *Sphingomonas* hydrolytic. breakdown of polyaromatic. Hydrocarbons [9][11][8].

Genetically Modified Bacteria

Genetically engineered microorganisms. (GEMs) have garnered. significant interest for. their potential applications. in bioremediation, aiming to enhance. the breakdown of hazardous wastes. in controlled laboratory settings. Numerous studies. highlight the capacity of. various bacteria to. degrade environmental pollutants, particularly. hydrocarbon contaminants, with. Table 5 illustrating instances of utilizing. genetic engineering to augment. bioremediation. Engineered bacteria. Demonstrated superior. degradative capabilities [12][13].

Table 1: Various Genetically.modified Bacteria.and Their Target.contaminants [20]

Microorganisms	Specificities	Target Contaminants	References
Pseudomonas. putida	pathway	4-ethylbenzoate	[14]
P. putida KT2442	pathway	toluene/benzoate	[15]
Pseudomonas sp.FRI	pathway	chloro-, methylbenzoates	[16]
Comamonas. testosteroni VP44	substrate specificity	o-, p-monochlorobiphenyls	[17]
Pseudomonas sp. LB400	substrate specificity	PCB	[18]
P. pseudoalcaligenes KF707-D2	substrate specificity	TCE, toluene, benzene	[19]

To achieve effective. in situ bioremediation, it is essential to adopt. a collaborative approach that combines. Microbiological. And. ecological. knowledge, biochemical. processes, and well planned field engineering. techniques[21].

The Impact of Environmental Health on Human Well-being

The integration of human, animal, and environmental. health is acknowledged. by the "One Health" concept. The pervasive. presence of hydrocarbons. in many environments. such as water, air, soil, and sediment present. a significant. peril to the welfare of both human. beings and the environment. The interaction between. hydrocarbons and both abiotic. and biotic components can be. categorized based on the amount. of carbon atoms, resulting. in various fractions. such as volatiles, semi-volatiles, non-volatiles, and low-volatility [22]. The toxicity. of PAHs typically. rises in proportion. to their molecular. weight, with higher.-molecular-weight PAHs demonstrating greater. Toxicity [23][24]. Lesions, developmental. abnormalities, anoxia, and modifications. in molecular. and behavioral processes are examples. of sub-lethal impacts. Frequent and prolonged. exposure to PAHs. can result in the development. of cancer, cataracts, and a range. of health problems. in humans. Ecosystems are impacted by hydrocarbon. toxicity, leading to the local eradication. of plant and animal species [25][26][27].

Petroleum Degradation Mechanism

Under aerobic circumstances, the breakdown. of the majority of organic. pollutants is most efficient and. comprehensive. The primary intracellular. degradation of organic. contaminants entails an oxidative. mechanism, wherein. the enzymatic. activation and incorporation. of oxygen is facilitated by oxygenases. and peroxidases. The cellular process. of biomass biosynthesis involves. the utilization of key precursor. metabolites. Moreover, the synthesis. of sugars necessary for. several metabolic activities. and development occurs via. the process of gluconeogenesis [31] [32].

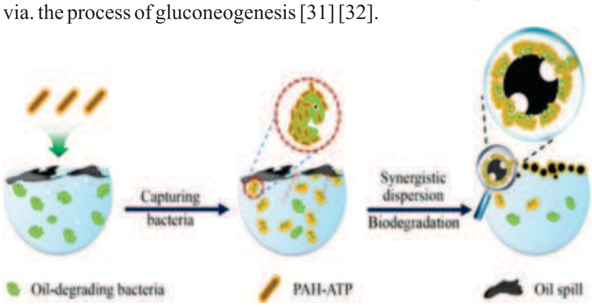

Fig 3. A simplified picture of how degradation occurs [33]

Hydrocarbons undergo degradative. routes under aerobic. conditions, finally culminating in the tricarboxylic. acid cycle (TCA cycle or Krebs cycle). This cycle results in the. complete oxidation of the substrate, leading. to the generation of carbon. dioxide (CO_2) and nitric acid (NADH)[34][20].The gaseous decomposition. of hydrocarbons by aerobic. processes encompass. a range of events, which can be. classified into peripheral. metabolic and central. metabolic pathways. The conversion of a substantial. proportion of hydrocarbons. into crucial intermediates. is facilitated by peripheral routes [35][36].Catechol 1,2 dioxygenase facilitates. the breakage of the ring. at the ortho position, resulting. in the addition. of two oxygen atoms. to the carbon atoms. that contain the hydroxyl group. The ensuing cleavage. of the carbon-carbon link. between atoms 1 and 2 leads. to the creation of cis, cis-muconic acid. By generating a lactone, this. molecule is subsequently. transformed into succinate. and acetyl-CoA [37][38][39]. *Candida lipolytica*, and *Trichosporon mucoides* were obtained. from polluted water and. demonstrated the capacity. to breakdown petroleum compounds within. the domain of yeast species[40][41].

Petroleum Degradation by Methanogenic Process

Hydrocarbons are frequently. found in surface, shallow., and deep-subsurface. environments. Hydrocarbons can be broken. down into methane. by groups of microorganisms. called methanogenic microbial consortia. when there is a lack. of oxygen. This process of degradation. is prevalent across the geosphere. When compared to other. processes that do not require. oxygen, the breakdown. of hydrocarbons. by methanogenic bacteria is more. sustainable over long. periods of time since. it does not need an. external electron acceptor. to continue.

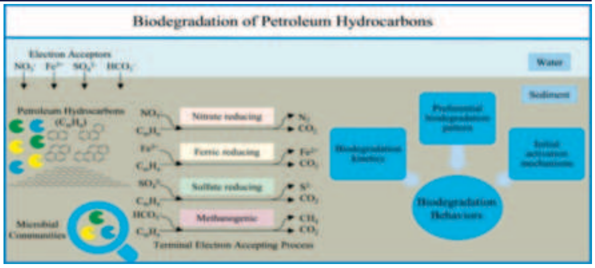

Fig 4. Biodegradation of Petroleum Hydrocarbons [49]

The process of subsurface methanogenic. petroleum hydrocarbon. degradation can be analyzed. from three separate. yet interconnected. viewpoints. Methanogenic processes. are significant in (1) the creation. of heavy oil, (2) the remediation. of hydrocarbon .contamination in oxygen.-deprived conditions, and (3) the retrieval. of fossil energy resources. Regarding the generation. of heavy oil, current. understanding suggests. that the modification. patterns observed in deteriorated. petroleum reservoirs. are mostly caused. by methanogenic. Processes [50] [51]. In addition, the processes. employed for. extracting heavy. oils, such as open. cast mining and steam-assisted. gravity drainage, result in the. emission of two. to three times. more carbon. dioxide per barrel compared. to standard oil. production method [52][53].

The Enzymes Accountable For The Process Of Degradation

Cytochrome P450 alkane. hydroxylases are a type. of Heme-thiolate Monooxygenases. that are widely distributed. The metabolic conversion of. specific substrates in higher. eukaryotes is facilitated by a multitude. of P450 families, each consisting. of a substantial number. of distinct P450 forms. Nevertheless, the phenomenon. of P450 multiplicity is limited. to specific species within. Microorganisms [54][55][56][57].

Table 2: Various Enzymes Which. Are Accountable. For Degradation [3]

Enzymes	Trgeta Substrates	Microorganisms	References
Soluble Methane Monooxygenases	C1–C8 alkanes alkenes and cycloalkanes	Methylococcus Methylosinus Methylocystis Methylomonas Methylocella	[58]
Particulate Methane Monooxygenases	C1–C5 (halogenated) alkanes and cycloalkanes	Methylobacter Methylococcus, Methylocystis	[58]
AlkB related Alkane Hydroxylases	C5–C16 alkanes, fatty acids, alkyl benzenes, cycloalkanes and similar types	Pseudomonas Burkholderia Rhodococcus, Mycobacterium	[59]
Eukaryotic P450	C10–C16 alkanes, fatty acids	Candida maltose Candida tropicalis Yarrowia Lipolytica	[60]
Bacterial P450 oxygenase system	C5–C16 alkanes, cycloalkanes	Acinetobacter Caulobacter Mycobacterium	[61]
Dioxygenases	C10–C30 alkanes	Acinetobacter sp.	[62]

Uptake of Hydrocarbons by Biosurfacants

Biosurfactants. encompass a. broad. spectrum of. surface-active chemicals. that are synthesized by various. Microorganisms [63]. Surfactants are of paramount. importance in the solubilization. and elimination of pollutants, hence. augmenting the biodegradation process. Research has been conducted. to investigate the application. of biosurfactants in the. bioremediation process. of oil sludge[64]. Field testing further. validated the. consortium's efficacy in breaking. down sludge hydrocarbons [65][66][67].Pseudomonads, particularly. Pseudomonas aeruginosa, are widely. recognized bacterial. species that possess. the ability to utilize. hydrocarbons as both. carbon and energy sources, in addition. to their capacity to produce. Biosurfactants [69][70][71][72].

The bacteria kept in alginate. beads always keep their. capacity to break. down hydrocarbons when used again and again. Results from the. research imply that. employing cell immobilization. can be a succesful method. for cleaning up places. polluted by hydrocarbons [80].

Biosurficants	Microorganisms	References
Sophorolipids	*Candida bombicola*	[73]
Rhamnolipids	*Pseudomonas aeruginosa*	[74]
Lipomannan	*Candida tropicalis*	[75]
Rhamnolipids	*Pseudomonas fluorescens*	[76]
Surfactin	*Bacillus subtilis*	[77]
Glycolipid	*Aeromonas* sp.	[78]
Glycolipid	*Bacillus* sp.	[79]

Phytoremediation

Phytoremediation is an emerging. technology that utilizes. the skills of plants. to tackle various environmental. pollution issues, such. as the purification. of soils and groundwater. that are contaminated. with hydrocarbons. and other dangerous. Compounds. A wide range. of contaminants can be. remediated using various. processes such as. hydraulic control, phytovolatilization, rhizoremediation., and phytotransformation [63][64][65].

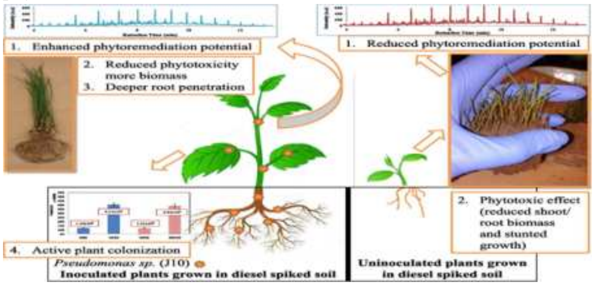

Fig 4. Process of Phytoremediation [80]

In the last fifteen .years, the study. and practical. use of phytoremediation .to address petroleum. Hydrocarbon. pollution have provided. significant knowledge. that can guide. the development. of efficient .remediation systems. and encourage. further progress. Phytoremediation. has the potential to be used. in many contaminated. locations. However, there is still a lack. of complete understanding. about what happens. to contaminants, how they. change, and the identification. of the substances they turn. There is a scarcity. of data regarding. the rates and effectiveness. of plants in removing. Contaminants. in real-world conditions [57][68][69] [40][41].

CONCLUSION

The cleaning up of petroleum. hydrocarbons in the subsurface. environment is posing a practical. and important obstacle. The understanding. of biodegradation process is very crucial from ecology angle as it relies. on native microorganisms. to transform. or convert organic. pollutants into minerals. The break down. process of microbes. becomes even more significant. when oil spills have been. removed extensively. through physical and. chemical means. The enzyme systems. of microbes that. are capable of breaking. down and utilizing. different hydrocarbon compounds. for their carbon and energy. needs.To sum up, the current. analysis emphasizes on the. importance. of microbial degradation. as a crucial part in the overall. remediation process for petroleum. Hydrocarbons.

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