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# Review: Role of Micro-Organisms in Petroleum Hydrocarbon Degradation

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## ABSTRACT

**The discovery of crude oil has improved human life economically and has led human growth in a quick way and as also used as important accessible source of nonrenewable source of energy. These petroleum hydrocarbons are obtained from earth's crust by drilling and pumping and are major sources of energy for human life during its recovery and transportation contamination of fertile land occurs which leads to various pollution of petroleum hydrocarbons. The contamination fertile land can be reclaimed into clean and fertile land by proper remediation to remove petroleum hydrocarbon and can be done by various methods such as chemical, physical and biological. The biological remediation is most environmental friendly and these bioremediation can be achieved by environmental friendly non-pathogenic micro-organisms to remediate petroleum hydrocarbons contamination soils hence various observations resulted from experiment on degradation of petroleum hydrocarbon through bioremediation and their results are being reviewed and documented in the current write up.**

## INTRODUCTION

Natural product petroleum is a crude oil formed by conversion of biomass under high temperature and pressure million years ago. They are used in various fields such as industries transportation household activities or at work place various forms are gasoline, kerosene, fuel oil etc. when they are released or spilled leakage into the environment causing contamination in water, soil etc. Hydrocarbons are the world most common used primary energy and fuel resources. Due to the energy they produce apparently inevitable spillage, which follow during routine operations of crude oil production, refining distribution and as a moment of acute accidents, have engendered continuous research interest in this field **Okoh(2003**). Oil spills have become a global problem in industrialized and developing countries. The amount of natural crude oil seepage was expected to be 600,000 metric tons per year with a range of uncertainly of 200,000 metric tons per year **Kvenvolden (2003)**.These hydrocarbon contaminants are hazardous to the health of plants and are also carcinogenic, mutagenic, and potent immune-toxicants presence a serious threat to human and animal health **(Atlas, 1981; Zhou Crawford, 1995; Liebeg and cutright, 1999, Ting and Hutan, 1999)**. Petroleum product such as gasoline, kerosene, diesel oil and crude oil are a composite mixture of organic compound basically of paraffin, oleophilic and polycyclic aromatic hydrocarbons **Mittal and singh (2009); Singh and Lin (2008)**. Present of polycyclic aromatic hydrocarbons (PAHs) in soil and water are a foremost problem as environmental contaminants and most of these PAHs are intractable in nature. PAHs mean a prospective risk to the marine animals as well as to the human health as many of them are carcinogenic.Various techniques physical and chemical have been used to cleanup soil contaminated with hydrocarbons which are very expensive and does not results in complete breakdown of hydrocarbon and may cause secondary contamination bioremediation a biochemical ability of micro-organisms to degrade organic pollutants can be one of the promising technology to degrade petroleum hydrocarbon. It has various benefit over physical and chemical treatment as it is low cost effective quick compatible inside and Exide application a number of research work have been carried out to degrade petroleum hydrocarbon through bioremediation using hydrocarbon degrading bacteria. The biochemical abilities of micro-organisms are commonly used for one biological treatment of contaminated soils micro-organisms have unique ability to interact both chemically and physically with a wide range of organic hydrocarbons leading to complete degradation of the target molecule.

Lot of work has been done related of bioremediation of petroleum products and one enlisted as following:

**J. Aislabie *et al*. (2000**) isolated hydrocarbon-degrading bacteria from soil near Scott base, Antarctica and identified those using 16S r-DNA sequence analysis as *Sphingomonas or Pseudomonas spp*.

**Odokuma and Ibor (2002)** isolated nitrogen fixing bacteria that enhanced bioremediation of a crude oil polluted soil and recorded higher bioremediation rate than nitrogen fixing bacteria were used instead of inorganic nutrient.

**Saadoun (2002)** isolation and characterization bacteria from crude petroleum oil contaminated soil and recorded their potential to degrade diesel fuel. There results indicated that longer aged contaminated exhibited greater number of micro-organisms they mainly *genus Pseudomonas, Enterobacter, and Acinetobacter.*
**Banks *et al*. (2003**) reported a relationship between root acidation and bioremediation efficiency by micro-organisms from the Rhizosphere of Sorghum bicolor.

**Margesin *et al*. (2003)** characterized biodegradation of petroleum hydrocarbon in cold environment and reported no co-relation was found between the prevalence of hydrocarbon degradative genotypes and biological activities of soil micro-organisms.

**Sabate *et al.* (2003)** reported that biological treatment of contaminated soil as appropriate and can be evaluated by various condition and additives.

**Yerushalmi *et al*. (2003)** studied removal of total petroleum hydrocarbon in a bio-slurry process and reported that through bio-augmentation and bio-slurry treatment. The indigenous microbial population can help in treatment.

**Mehrasbi *et al.* (2003)** studied biodegradation of petroleum hydrocarbon in three different media and result revealed that within 5 months. Micro-organisms degraded petroleum hydrocarbon dehydrogenase activity related to the number of micro-organism and can be considered as an indicator for aerobic biodegradation of T.P.H.

**Salleh *et al*. (2003)** reported that due to the complexity of crude oil its biodegradation involved the interaction of many microbial spp. it is the effect of synergistic interaction among members of the consortium.

**Chaillan *et al*. (2004)** studied on tropical aerobic hydrocarbon degrading micro-organisms and reported their potential using 13 parameters and found no taxonomic trend between microbial phyla in terms of biodegradation activity.

**Ghazali *et al.* (2004)** studied effect of microbial consortium for their ability to degrade hydrocarbons in soil contaminated with diesel crude oil or engine oil.

**Meshreghi and Marialigeti (2005)** reported the biodegradative ability of bacteria isolated from contaminated soil and water and concluded that these isolated strains could be used for in-situ bioremediation of polluted sites.

**Hong *et al*. (2005)** reported diesel degrading bacterium (strain IU5) isolated from oil contaminated soil and identified at through 16s r DNA analysis as a strain of Pseudomonas aeruginosa which degrades 60 % of diesel in 13 days in a soil slurry phase with optimum conditions as pH-7 and temperature-30 degree they also observed that these strain was able to grow on crude oil gasoline, benzene, toluene, xylene and PAHs such as naphthalene, phenanthrene, and pyrene they concluded that P. aeruginosa is useful for bioremediation of soils and ground water contaminated with various hydrocarbons.

**Ahn *et al*. (2005**) monitored petroleum hydrocarbon degradative potential of indigenous micro-organisms and ozonated soil and reported that appropriate ozonation and subsequent biodegradation by indigenous micro-organisms could enhance remediation of petroleum hydrocarbon contaminated soil.

**Coral and Karagoz (2005)** reported phenanthrene-degrading bacteria from a petroleum refinery soil. They isolated 50 strains belonging to genus Pseudomonas and selected two best strains by selective enrichment culture and found there degrading ability they revealed the molecular size of plasmid involved referred to as PARP1 was estimated in about 26 kb.

**plaza *et al*. (2005**) isolated bacterial strains from petroleum hydrocarbon contaminated soils and screened for bio surfactants, bio emulsifiers under thermophilic conditions at ($37^0$C to $100^0$C) they reported six gram positive bacteria and evaluated its bio surfactant production at $45^0$C isolates were reported with emulsification abilities and can grow under extreme conditions which were in accordance with bodour and maier (2002)

**Meintanis *et al.* (2006**) isolated 150 different thermophilic bacteria from a volcano island and screened for alkane hydroxylase gene using degenerative primers 10 isolates carrying the alkJ gene was further characterized by 16S r-DNA gene sequencing nine out of ten isolates were phylogenetically affiliated with *Geobacillus spp*. and one isolate with Bacillus species. These isolates were able to grow in liquid cultures with crude oil as the sole carbon source and were found to degrade long chain crude oil alkanes in a range between 46.64% and 87.68%.

**Hubalek *et al.* (2006)** studied ecotoxicity of hydrocarbon contaminated soil during bioremediation from a brownfield under pilot tests and reported that highest toxicity to be detected in the first period of bioremediation.

**Ayotamuno *et al*. (2006)** highlighted the view that the availability of large amount of oxygen in the soil profile induces an accelerated biodegradation of petroleum hydrocarbons in a polluted agricultural soil and implies that regular tillage of contaminated soil in the presence of nutrients could achieve the decontamination of such soils.

**Hui *et al*. (2006)** conducted a laboratory experiment to study dynamic changes in microbial activity and community structure during biodegradation of petroleum compounds and recommended that decrease in urease activity as the most sensitive biochemical indicator of heavy diesel fuel contamination.

**Weid *et al*. (2006)** described that a novel strains of *Dietzia cinnamea* as a potential strains for bioremediation of oil contaminated soil.

**Embar*et al*. (2006)** examined the biodegradation capacity of indigenous bacterial and fungal population of crude oil in a desert soil. Maximal biodegradation 91% was obtained in soil containing the highest concentration crude oil (20%) supplemented with vermiculite were as only 74% of oil was degraded in samples containing crude oil but lacking vermiculite.

**Gallego *et al*. (2006)** studied biodegradation of oil tank bottom sludge using microbial consortia and reported significant effectiveness of consortia over individually strains.

**Roling *et al*. (2006)** reported that acidophilic microbial communities are associated with natural acidic petroleum seepage.

**Mohammed (2007)** reported that the indigenous enriched culture generally biodegraded the petroleum hydrocarbon to a greater extent than the commercial products and media controls early in the bioremediation process (0-5 days) however as time progressed the extents of biodegradation were not significantly different between treatments until late in the bioremediation process (after 18 days).

**Adoki and Orugbani (2007)** isolated 10 genera of *heterotrophic bacteria and fungi* and monitored removal of crude petroleum hydrocarbon amended with nitrogenous fertilizer plant effluents.

**Das and Mukherjee (2007)** reported the efficiency of *Bacillus subtilis DM04 and P. aeruginosa M and NM strains* isolated from petroleum contaminated soil sample from north east India and compared for the biodegradation of crude petroleum oil hydrocarbon in soil and sake flask study. The results showed that all the three strains are effective for in-situ bioremediation at highly contaminated with crude petroleum oil hydrocarbons they concluded that the thermophilic nature of these bacteria are advantages for use in bioremediation of petroleum contaminated soils in tropical countries.

**Olga *et al*. (2008)** studied the screening method for detection of hydrocarbon- oxidizing bacteria in the oil contaminated environment and modified solid media by adding triphenyltetrazolium chloride reagent as an indicator of the dehydrogenase activity to develop a simple screening method. They reported the four media MS, MST, T and TT to be suitable for practical work but MST media to be most appropriate for detecting hydrocarbon oxidizing bacteria.

**Ijah *et al*. (2008)** conducted comparative study of biodegradation of crude oil in soil amended with chicken droppings and NPK fertilizers and reported that they have potential for enhancing crude oil biodegradation.

**Beak *et al*. (2008**) evaluated the activity and abundance of the crude oil degrading bacterium Nocardia spp. H17-1 during bioremediation of oil contaminated soil using real time PCR. The total petroleum hydrocarbon degradation rate constants of the soils treated with and without H17-1 were 0.103 $d^{-1}$ and 0.028$d^{-1}$ respectively. These results indicated that H17-1 is a potential candidate for the bio-augmentation of alkane-contaminated soil; overall they evaluated the abundance and metabolic activity of the bioremediation strain H17-1 using real-time PCR, independent of cultivation.

**Plaza *et al*. (2008)** investigated biodegradation of crude oil and 7 different distillation products by *Ralstonia picketti* (SRS) and *Alcaligenes piechaudii* SRS they reported degradation of light boiling fraction to be 80-100 % and degradation of heavy high boiling fractions to be lower between 10-81% the mixture of isolates enhance degradation efficiency of crude oil distillation products. They concluded that there is no evidence that bio surfactant produced are involved in the degradation of crude oil and its distillates.

**Obayori *et al.* (2008)** studied the microbial population dynamics on the soil contaminated with crude petroleum with tropical agricultural soil they reported the physicochemistry of control and contaminated soil to differed significantly at ($P<0.05$).They revealed that natural population is able to degrade crude oil present in the soil.

**S. Obayori *et al*. (2008**) studied four hydrocarbon degraders from enriched oil and asphalt contaminated soils and demonstrated that *Pseudomonas putida P11* has strong ability to degrade kerosene, gasoline, diesel, engine oil and crude oil while *P. aeruginosa BB3* exhibited fair degradative ability on crude oil, gasoline, engine oil, anthracene and pyrene but weak on kerosene, diesel and Di-benzothiophene.

**Li *et al*. (2009)** revealed that the low concentration of polycyclic aeromatic hydrocarbon by microbial consortium can be achieved by bioaugmentation and can be used in the field as bioremediation.

**Mohsen (2009)** studied biotreatment of Phenantrene using indigenous bacteria isolated from petroleum contaminated sites in Iran. They revealed a significant relationship between concentration and type of microbial consortium with the removal efficiency of phenanthrene over the time P value less than 0.001 microbial analysis using confirmative series tests and analytical profile index (API) kit tests showed the *Pseudomonas fluorescence, serratia liquefaciens, Bacillus and Micrococcus* strains as dominant bacteria in the mixed cultures.

**Molina *et al*. (2009)** reported the potential use of isolated bacterial consortium for the bioremediation of PAH polluted areas with a significant decrease in toxicity.

**Ahmed *et al*. (2010)** isolated and characterized 20 different petroleum hydrocarbon contaminated samples and isolated and characterized microbes from sheep breaking yards at vatiary and kumira coast in chittagong. The rate of degradation by the isolated was estimated and they observed the highest (96.8%) degradation of diesel was shown by B. brevis, followed by 92%, 88.8%, and 84.8% of diesel degradation by the strains of P. alcaligenes, B. cirroflagellosus and C. freundii, respectively.

**Mrozik and Seget (2010)** reported strategy to be developed for cleaning up of soil contaminated with aromatic compounds to successful technologies by the use of genetically engineered they stated to study habit at distribution population dynamic potential effect and knowledge of generation sequencing technology at the field scale level with the involvement of immobilized micro-organisms in activated soil through gene bio-augmentation.

**Benedek *et al.* (2010)** investigated hydrocarbon degrading micro-organisms from contaminated areas and determined there degradative capacity using "Biometer flasks". They identified strength showing great degradation efficiency based upon the 16S rDNA technology. They identified four strains out of 30 as *Rhodococcus erythropolis, Micrococcus luteus, Bacillus cereus and Bacillus subtilis*.

**Mirdamadian *et al*. (2010)** isolated five bacterial strains from petroleum contaminated soil and investigated there biodegradation ability in mineral basic media supplemented with light oil, crude oil, aniline plus catechol aniline toluene naphthalene. They also determined plasmid profile of the strains so as to co-relate biodegradation ability to plasmid related.

**Tang *et al.* (2010)** reported ecotoxicity of petroleum hydrocarbon contaminated soil by using earthworm plant and luminescent bacteria the results suggests higher toxicity of petroleum on bacteria activity lowers where as wheat is tolerant to petroleum contamination as compare to earthworm and bacteria.

**Rahim *et al*. (2010)** examined a strain of Pseudomonas alkanolitica to degrade oil spill in surface water and result showed. An extent of biodegradation more than 90% can be achieved within 10 days using this strain.

**Sun *et al*. (2010)** screened polycyclic aeromatic hydrocarbon degrading bacterial consortium from contaminated soil and reported that these consortium could utilize and degrade several HMW-PAHs, including pyrene, fluorenthene, and banzo pyrene efficiently. Its community structures at different transfers were analyzed by construction of 16S-r RNA sequence gene libraries.

**Onuoha *et al.* (2011)**isolated 27 bacteria on mineral salt medium from oil polluted environment belonging to gram positive actinobacteria group. The screened the isolates for hydrocarbon degradation by gas chromatography and found that corynebacterium spp. Is the highest ability to degrade motor oil and has highest emulsification ability also and suggested it to be used as potential isolate for bioremediation of contaminated environment.

**Malik and Ahmed (2011)** prepared consortium of 15 bacteria and investigated the metabolic capability of bacteria crude oil degradation by shek flask transformation in mineral salt medium with 2% crude oil at $37^0$C for 24 days. They reported removal of 94.6% aliphatic hydrocarbons and 93.75% aeromatic hydrocarbons the ability of degrading long chain n-alkanes and crude oil at high concentration makes the consortium potentially useful for bioremediation and microbial enhanced oil recovery.

**Dongfeng *et al*. (2011)** isolated and identified hydrocarbon degrading bacteria KL2-13 from oil contaminated soil in the karamay oil field. On the basis of morphological, physiological and 16S r-DNA sequence as Bacillus fusiformis they reported influence of pH and concentration of metal ions responsible for degradation ability.

**Scherr *et al*. (2011**) studied changes in bacterial communities from anaerobic digesters during petroleum hydrocarbon degradation and reported that anaerobic digester can adapt to and degrade petroleum hydrocarbons. The decontamination of PHC-containing waste via fermentative treatment appears possible.

**Cerqueira *et al.* (2011)** analyzed the biodegradation capacity of aliphatic and aeromatic hydrocarbon of petrochemical oil oily sludge in liquid medium via bacterial consortium. The result indicated that the bacterial consortium has potential to be applied in bioremediation of petrochemical oily sludge contaminated environment. Favoring the reduction of environmental passives and increasing industrial productivity.

**Kumar *et al*. (2011**) isolated four bacteria from petroleum sludge and investigated for invitro degradation of flurothene.

**Erdogan *et al*. (2011)** isolated 33 strains of bacteria from the contaminated soil in turkey they reported that these bacterial isolates have catabolic capabilities for the degradation of petroleum hydrocarbons. The strains identify were *as Pseudomonas spp., Paucimonas lemoignei, Stenotrophomonas maltophilia, Eschericha spp.Enterobacter spp. Citrobacterkoseri, Acinetobacter spp., Aeromonas caviae, Sphingobacterium mutivorum, Klebsiella pneumonia, Pseudomonas arugenosa, Pseudomonas putida* respectively.

**Alkhatib *et al*. (2011)** isolated crude oil utilizing bacteria from crude oil contaminated soil and tested their ability to degrade crude oil contaminated soils they isolated 50 strains and selected 20 strains by monitoring in shake flask using minimal salt medium with crude oil as sole carbon source out of these. They selected 12 best strains to form four bacterial consortiums each containing three strains. The bioremediation experimental result revealed that as compared with natural attenuation and bio stimulation the removal of crude oil was achieved in less time by bioremediation.

**Moneke and Nwangwu (2011)** reported ability of four bacterial spp. to utilize kerosene, engine oil and automotive oil and MSM under aerobic conditions they reported variation between the efficiency of single and mixed bacterial cultures showed more growth on the substrate tested of the four spp. tested Pseudomonas spp. utilize the hydrocarbon better than the other bacterial spp.

**Malik and Ahmed (2012)** isolated 15 bacteria by enrichment technique from oil contaminated soil and mixed consortium was used with crude oil for study of metabolic capabilities of bacteria they reported that the consortium shows the degradation of n-alkanes up to $C_{16.}$ The ability of degrading long chain n-alkanes and crude oil at high concentration mix the consortium potentially useful for bioremediation and microbial enhanced oil recovery.

**John *et al.* (2012)** isolated (PAH) Polycyclic aeromatic hydrocarbon degrading bacteria from Aviation fuel contaminated soil at Nigeria Alcaligenes faecalis exhibited best growth with strong PAH degrading potentials are recommended for bioremediation of PAHs in aviation fuel-contaminated sites in the tropics.

**John and Okpokwasili (2012)** reported the high crude oil utilization of the mixed culture implies that nitrifying bacteria isolated from contaminated ecosystem are excellent crude oil degraders and can be harnessed for bioremediation purposes.

**Xu*et al*. (2012)** studied growth characteristic of seven hydrocarbon degrading active bacteria isolated from oil contaminated soil and reported that the presence of metal ions, such as $Ni^{2+}$ and $Co^{2+}$ in soil decreased the crude oil degradation efficiency of these strains, while metal ions, such as $Fe^{2+}$ and $Mn^{2+}$ did not affect the oil degradation activities.

**Mathe *et al.* (2012)** studied diversity activity antibiotic and heavy metal resistance of bacteria from hydrocarbon contaminated soils located in Harghita country (Romania). They reported the genes Pseudomonas have the highest heavy metal tolerance and antibiotic resistance was isolated from heavy metal tolerance/ antibiotic resistance hydrocarbon degradation ability of isolates from Balan.

**Lotfinasabasl *et al*. (2012)** assessed petroleum hydrocarbon degradation from soil and tarbal samples collected from mangrove forest Maharashtra India by fungi they isolated four fungi and assessed for their degradation capability. They reported the bioremediation of 20% oil contaminated soil by different fungi observed that a mix culture consisting of *Penecillium sp, Rhizopus sp and Aspergillus terreus* showed highest growth diameter.

**Lawson *et al*. (2012)** studied microbial degradation potential of some Ghanaian soils contaminated with diesel oil. This study revealed that the main factors responsible for differences in degrading abilities of these soils are presence of large populations of hydrocarbon utilizing bacteria availability of organic carbon, nitrogen and phosphorus.

**Bacosa *et al.* (2012)** studied preferential degradation of aromatic hydrocarbons by a microbial consortium and related it with bacterial community dynamics these work provided an alternative way to explain the contribution of different microbial species in the degradation of the hydrocarbon fraction. The behavior of the consortium is of interest in the context of the bioremediation of the more toxic aromatic hydrocarbons in environments contaminated by petroleum products.

**Chikere *et al*. (2012**) examined bacteria population dynamics during bioremediation of an African soil with Arabian light crude oil result indicated that nutrient-amended of oil contaminated soil selected and enriched the bacterial communities of *Actinobacteria* capable of surviving in toxic contamination with biodegradation of hydrocarbons they concluded that bacterial population changes as a result of biostimulation nutrients input aeration and watering.

**Omotayo *et al*. (2012)** isolated four bacteria from soil composts and analyzed there crude oil degradation capacity results revealed that micrococcus variance has the highest degradation rate followed by *Bacillus radius Corynebacterium ulcerans and Corynebacterium amycolatum* respectively.

**Jayashree *et al*. (2012)** isolated bacterial spp. from oil contaminated sites and reported there degradation capability with solvent extraction method and confirmed by FT-IR analysis results revealed that *Psedomonas spp*. and were followed by *Bacillus serratia* and *Staphylococcus* respectively where as mixed culture showed maximum efficiency in degradation that is 97% of oil components during 30 days of incubation.

**Asquith *et al.* (2012)** compared bioremediation of petroleum hydrocarbon contaminated soil by biostimulation, bioaugmentation and surfactant edition using to commercially available petroleum hydrocarbon degrading microbial cultures they reported that bio stimulationbio augmentation and surfactant edition all together can enhance the removal of petroleum hydrocarbon with it in the selected soil.

**Mandal *et al*. (2012)** studied the microbial consortium isolated from various oil contaminated sites of India which could biodegrade different fractions of TPH (total petroleum hydrocarbon) they reported that bio remediated soil has less TPH content and was found to be non- toxic to the environment and the time for bioremediation was within 2-12 months the bio remediated soil has adverse effects on seed germination.

**Maqbool *et al.* (2013**) evaluated the phytoremediation potential of Sesbania cannabina for the remediation of crude oil contaminated soil and concluded that the organisms had greater degradation capability and combine affect of plant and microbes of the key factors involved in higher TPH degradation in planted pots.

**Agamuthu *et al*. (2013)** studied bioremediation of hydrocarbon contaminated soil using organic wastes and recorded that organic matter enhance the multiplication of indigenous microbes enabling rapid biodegradation of the contaminated in the soil.

**Kumari *et al*. (2013)** isolated identified and characterized oil degrading bacteria from the contaminated sites of Barmer Rajsthan they isolated at and after screening selected four isolates for oil degrading capacity.

**Varjani and Upasani (2013)** carried comparative studies on bacterial consortia for hydrocarbon degradation with physic-chemical methods they reported that bacterial consortia prepared showed faster utilization of DCPIP as compare to physico-chemical methods.

**Geetha *et al.* (2013**) isolated and characterized 14 different bacteria from various petroleum contaminated sites using enrichment technique and studied for utilization of various hydrocarbons they found bacterial isolates RP-12 to be the best isolates growing on majority of hydrocarbons and degrading diesels.

**Varjani *et al*. (2013**) isolated oil degrading micro-organisms from oil polluted sites isolated 69 oil degrading micro-organisms and screened for their hydrocarbon degradation capacity and six isolates were selected which showed maximum utilization of hydrocarbons for further preparation of consortium.

**Patel and Hardik (2013**) isolated bacteria from soil near kadi region Gujrat (ONGC well) and screened all the ten isolates for biodegradation of hydrocarbons and reported that KO1 isolates degraded 70% of hydrocarbon belong to genus *Psedomonas* where as other isolates showed biodegradation in the range of 30-55%.

**Hesnawi *et al*. (2013)** reported that mesophilic temperature was more beneficial for biodegradation than thermophilebio augmentation of indigenous bacteria in the presence of nutrients enhanced TPHs removal and addition of activated sludge had no significant effect on biodegradation.

**Dadrasnia and Agamuthu (2013**) studied the dynamics of diesel fuel degradation in contaminated soil using organic wastes the results showed there is potential for soy cake, potato skin and tea leaf to enhance biodegradation of diesel in oil-contaminated soil.

**Peyda *et al.* (2013)** studied for petroleum hydrocarbon reduction and clay soil through polymer partitioning approach and reported that polymer extraction followed bioremediation sorbaants and TPB can be applicable to treat crude oil contaminated with kaolin

**Pham *et al.* (2014)** isolated 14 strains from oil degrading efficiency by TPH degradation analysis three strains of Pseudomonas displayed complete degradation (100%) this study suggests that these isolates can be effectively utilized in the treatment of oil contaminated soil in land farming, especially during winter.

**Ichor *et al*. (2014)** isolated bacteria for crude oil contaminated brackish water of Bodo and analyzed biodegradation of TPH by aerobic heterotrophic bacteria the results showed the growth of bacteria cells increased progressively with decrease in TPH implying that the bacteria were responsible for biodegradation. Further application of bioremediation strategies in Bodo Greek for bio stimulation of crude oil biodegrading bacteria for reclamation and restoration of an efficient ecosystem structure and function is suggested.

**Chandankere *et al*. (2014)** studied the properties and characterized bio surfactant and crude oil degradation with the help of bacterium Bacillus strains Methylotrophicus the bio surfactant did not exhibit inhibitory effect to various vegetables, however strong antibiotic activity against gram positive and gram negative bacteria was observed. The study suggests application of the USTBa bio surfactant as an appropriate candidate for bioremediation of crude oil contaminants.

**Darsha *et al.* (2014)** determined efficiency of isolated strains by analyzing the parameters pH, Optical density, and $co_2$ released during petrol degradation and reported that *Bacillus subtilis* has the ability to tolerate petrol concentration can grow on them enhance used in cleaning oil polluted sites. They confirmed the degradation by HPLC analysis.

**Zafra *et al*. (2014)** studied on microbial consortium isolated from crude oil contaminated soil and reported so fungal and bacterial isolates from the soil they evaluated individual bacterial and fungal isolates for their potential to tolerate high concentration of PAHs this is the 1st study which evaluated the microbial tolerance to extreme concentration of PAHs they highlighted the potential use of identified micro-organisms for the bioremediation of soils impacted by petroleum hydrocarbons.

**Hesham *et al*. (2014)** studied biodegradation ability of Sphingomonas koreensis strain ASU-06 isolated from Egyptian oily soil and its catabolic genes and reported that the strain utilized the compounds via two main pathway the thilate was the major products and catabolic genes were with specific primers alkB, $alkB_1$, nahAC, cl20, and $C_230$ .

**Gao *et al*. (2014)** studied affect of different remediation treatment including nitrogen addition, Suaeda salsa planting, and arbuscular mycorrhiza fungi inoculation individually or combined, on crude oil contaminated saline soil were assessed using a microcosm experiment. The results showed that different remediation treatments significantly affected the physicochemical properties oil contaminant degradation and bacterial community structure of the oil contaminated saline soil.

**Guo *et al.* (2014)** evaluated the coupling interactions between bioremediation and electrokinetics in the remediation of total petroleum hydrocarbons by using bio-electrokinetics with a rotatory 2-D electric field. The results demonstrated an obvious positive correlation between the degradation extents and TPH and electric intensity both in the EK and Bio-KE tests.

**Suja *et al*. (2014)** investigated factors enhancing the performance of the bioremediation in crude oil contaminated soil in laboratory and field. The kinetic analysis study of the microcosm tank showed that a combination of both bio stimulation and bio augmentation in the soil column achieved the fastest rate constant of 0.0390 $day^{-1}$.

**Pacwa-Plociniczak *et al*. (2014)** isolated Pseudomonas spp. from newly petroleum hydrocarbon contaminated soil and characterized them. They found the presence of gene-encoding enzymes responsible for the degradation of alkanes and naphthalene in the genome of the P-1 strain was reported. The results of this study indicate that the P-1 and bio surfactant produced by this strain have the potential to be used in bioremediation of hydrocarbon – contaminated soils.

**Darsa and That heyus (2014)** determined the biodegradation of petrol by *Pseudomonas aeruginosa* isolated from petrol contaminated soil and confirmed degradation of petrol by HPLC they analyzed pH, optical density and release of CO2 during petrol degradation and reported increase in optical density during the initial treatment period where as $CO_2$ production showed a linear increase with increasing petrol concentration.

**Sharma *et al*. (2014)** studied biodegradation of diesel by bio augmentation of Pseudomonas aeruginosa and revealed that bio augmentation of Pseudomonas aeruginosa to be a better approach in which 66% diesel degradation was observed during incubation period of 30 days which were confirmed by FTIR and Gas chromatography analysis.

**Allamin *et al*. (2014)** reported occurance of hydrocarbon degrading bacteria covering petroleum exploration station in kukawa Nigeria they studied 19 bacterial spp. for their potential to degrade hydrocarbon which were confirmed by GC-MS analysis.

**Borah and Yadav (2014**) optimized growth conditions for efficient degradation of complex petroleum hydrocarbon by newly isolated Bacillus cereus strain DRDU1 from an automobile engine. The strain was found to degrade 99%, 84%, and 29% of diesel crude oil and used engine oil under optimized condition which was confirmed by GLC analysis.

**Ismail et al. (2014)** investigated biodegradation of spent engine oil by bacteria isolated from the rhizosphere of Cajan Cajan and Lablab Purpureus five bacterial spp. were isolated and degraded the oil at the rate of 68% 62% 59% 58% and 45% confirmed by Chromatographic analysis using GC-MS study.

**Chikere and Ekwuabu (2014)** characterized microbial communities in selected crude oil polluted sites in Bodo community Nigeria. The bacterial isolates belong to genus *Bacillus, Proteus, Pseudomonas, flavobacterium, corynebacterium serratia, Micrococcus, klebsiella, Enterobacter and Azotobacter*.

**Omoni *et al*. (2015)**studied the potential of plantain and banana agrowaste for enhanced biostimulation of hydrocarbon utilizing bacteria in soil contaminated with spent engine oil as an alternative to inorganic fertilizer they reported higher THBC (total heterotrophic bacterial count) and HUB (hydrocarbon utilizing bacteria) count day 28 and day 42 plantain treatment showed higher percentage of degradation 95% than banana pill treatment.

**Chirwa and BeZZa (2015)** reported a significant degradation of creosote PAHs and the production of biosurfactant with important emulsification activities during the bioremediation process.

**Wu et al. (2015)** showed that biostimulation and bioaugmentation promoted 60% and 34% degradation of the TPH after six weeks of incubation the population of TPH degraders in soil were positively related to TPH degradation efficiency during bioremediation of petroleum polluted soils.

**Akpe *et al.* (2015)** studied the bacterial degradation of petroleum hydrocarbons in crude oil polluted soil amended with cassava peels (CP) (an organic waste) for eight weeks. Results showed that CP contained appreciable amounts of some biodegradation enhancing elements/nutrients such as nitrogen (2.37%), potassium (7.13 meq/100g), phosphorus (0.78 mg/kg) and organic carbon (2.37%). The soil samples used for the study were composed of 81.6% clay, 16.4 % sand and 2% silt.

**Kogbara *et al*. (2015)** investigated the effect of different soil texture on biodegradation of petroleum hydrocarbon during a six week period the results suggests that higher sand than clay content of soil favours faster hydrocarbon bioremediation.

**Sharma *et al*. (2015)** isolated 348 microbial strains from petroleum hydrocarbon contaminated soil and selected five for their ability to produce bio surfactant based on screening assay they reported that *pseudomonas aeruginosa (DSVP-20*) has the ability to degrade Eicosane pristane and fluoranthene and biosurfactant produced by these isolates have the potential role in bioremediation of petroleum hydrocarbon contaminated soil.

**Maddela *et al.* (2015)** isolated soil micro-organisms from Ecuadorian are amazon oil field and tested capability of micro-organisms removing TPHs by the use of 16/18S rDNA sequence analysis the isolates were identified as *Bacillus cereus*, *Bacillus thuringiensis*, *Geomyces*, *Pannorum and Geomyces spp.*

**Varjani *et al*. (2015)** studied ex-situ bioremediation of crude oil by halotolerant bacterial consortium of indigenous strains isolated from onshore sites of Gujrat India and reported ex-situ bio augmentation for affective in-situ bioremediation of hydrocarbon contaminated sites as well as management of sea surface oil spills.

**Adeleke *et al*. (2015)** studied cow dung as inoculum carrier for the biodegradation of crude oil and isolated microbes from cow dung and tested there efficiency for crude oil degradation and found degradative potential in order of *E.coli> P. pseudomallei> B. subtilis> S. hominis* followed by *P. citrium* showed the highest efficiency of crude oil degradation.

**Chikere *et al*. (2016**) reported microbial community profiling of active oleophilic bacteria involved in bioreactor based crude oil polluted sediment treated with poultry droping cow dung NPK fertilizer and urea fertilizer. They isolated 24 hydrocarbon utilizing bacterial spp. Depositedin gene bank identified as *Brevundimonas naejangsanensis, Pseudomonas pseudoalcaligenes, Pseudomonas spp. Aquitalea magnusonii, Achromobacter spp., Halomonas lutea, Pseudomonas aeruginosa Shewanella spp. Achromobacter spp., Gordonia sp., Sphingobacterium spp., and Bacillus spp.*

**Kawo and Bacha, (2016)**isolated *Bacillus and Micrococcus* species from soil compost in Kano Nigeria. The isolates showed appreciable degree of degradation of the crude oil micrococcus had 93.7 % degradation rate there as *Bacillus species* showed biodegradation rate of 87.5% and they concluded that bioremediation of crude oil polluted field could ba achieved using indigenous hydrocarbon utilizers.

**Cueva *et al.* (2016)** studied the changes in microbial population dynamic during bioremediation of soil contaminated with petroleum hydrocarbons and reported that as microbial genera decreases TPH biodegradation decreases the co-relation between TPH biodegradation and microbial population dynamic explains time required for bioremediation and can facilitated action for increasing bioremediation efficiency.

**Fuentes *et al.* (2016)** studied dynamic of soil microbial communities in response to hydrocarbon polluted and different bioremediation treatment. They reported rare to dominant bacterial shieft as reservoir of ecological functions in high diversity environment which illustrated the potential role of rare biosphere phasing drastic environmental disturbances in support the concept of “conditionally are taxa”.

**Pratiusha *et al.* (2016)** isolated seventeen bacteria characterized and studied petroleum hydrocarbon degradation by terbidomatry and DCPIP method they selected six isolates to prepare a consortium which utilizes maximum hydrocarbon.

**Chen *et al*. (2016**) reported ozonation resulted in four fold increases in biodegradation of heavy hydrocarbon and has negligible effect on indigenous bacteria as they survived after ozonation.

**Patowary *et al.* (2016)**developed efficient bacterial consortium isolated from contaminated sites for potential remediation of degradation of hydrocarbons showing up to 84.15 % of degradation after 5 weeks of incubation.

**Criste *et al*. (2016)** isolated and characterized microbial load soil contaminated with petroleum using selective enrichment technique. They reported the largest group of microorganisms present in the oil contaminated soil sample was the nitrous nitrifying bacteria followed by nitrate bacteria.

**Bahobail *et al*. (2016**) isolated 23 bacterial isolates from petroleum sludge at refinery waste plant Jdda K. S. A. and selected 12 out of them for efficiency of biodegradation on complex mixture of hydrocarbons the results indicated three isolates have in remarkable multiple degradation potential with fast reaction rate by partial 16S r-RNA sequencing. They confirm the isolates as*Pentoea agglomerans, Acinetobacter lwoffii and Bacillus thuringiensis* respectively.

**Verma *et al*. (2017**) performed study on bioremediation of soil contamination with petroleum sludge using Bacillus pumilus of TPH. The treatment resulted in 97% removal of TPH in 12 days in bacteria mixed contaminated soil as compare to 12 % removal of TPH in uninoculated contaminated soil.

**Chikere (2017)** studied biodegradation potential of indigenous bacteria isolated from crude oil polluted soil site in Bodo Waste. They isolated 30 HUB isolated an sequence 15 those showing strong crude oil degradation potential and concluded be explained for future bioremediation studies In the polluted sites.

**Muthukamalam *et al*. (2017**) isolated and characterized deoxygenates and bio surfactant produced by crude oil degrading soil bacteria and subsequently identified them by 16S r RNA gene sequence analysis as *Corynebacterium aurimucosum, Acinetobacter baumannii and microbacterium hydrocarbonoxydans* respectively.

**Dwivedi *et al*. (2017)** focused on petroleum hydrocarbon degradation ability of mutant strain as compare to three wild strains using UV-radiation and reported that study reflects that gene specific mutation enhanced the degradation ability of bacteria and can be used in bioremediation of petroleum hydrocarbons in soil and water.

**Baoune *et al*. (2017)** isolated endophytic Streptomyces sp. From plants grown in contaminated soil of southern Algeria and accessed the ability to degrade crude petroleum as well as produce plant growth promoting rates. They highlighted that the endophytic *actenobacter* can improve phytoremediation efficiency of petrol contaminated soil as well as attributes to plant growth promotion.

**Wemedo *et al.* (2018**) studied biodegradative potential of chyseobacterium sp. And *Lysinibacilus fusiformis* isolated from crude oil site in Gokana LGA of rivers state and result showed a study decline in pH mixed culture *L. fusiformis* had greater capacity to degrade crude oil followed by the mixed culture and lastly *chryseobacterium sp*.

**R. Bajagain *et al.* (2018)** studied feasibility of oxidation-biodegradation serial foam spraying for total petroleum hydrocarbon removal without soil disturbance. They evaluated this technology to delivered chemical oxidation and oil degrading microbes to unsaturated soil for 30 days which resulted and revealed the effectiveness of serial foam followed by bio augmentation. The foam spraying technique employing oxidation biodegradation serial application clearly increased the TPH removal efficiency and resulted in a final TPH concentration near the residential regulatory limit.

**Lustosa *et al*. (2018)** isolated mangrove bacteria for petroleum hydrocarbon degradation and there invitro study evaluated the degrading potential of mangrove bacteria. Results showed the potential application of these bacteria in bioremediation process due to their metabolic and adaptive capacity to grow enrich hydrocarbon medium.

**Liu *et al*. (2018)** explored the affects of mechanisms of petrol contaminated soil bioremediation using aged refuse (AR) from land field they recommended that AR amendment is a cost effective easy to use method facilitating into large scale applications for recycling huge amounts from land fields.

**Xu *et al*.** (**2018**) analyzed petroleum hydrocarbon degrading bacteria for the remediation of oil pollution under aerobic conditions and referred to the uses of bacteria as biodegradation regarding the implementation of this microbial technology discussed its barriers and provides suggestions for further development.

**Essabri *et al*. (2019)** studied bio augmentation and bio stimulation of total petroleum hydrocarbon degradation in a petroleum contaminated soil with fungi isolated from olive oil effluent. They reported the efficiency of these *fungal strains* and found that *Aspergillus niger* has highest percentage degradation that is 71.19% as compare to *Penicillium ochrochloron, and Trichoderma viride*.

**Zhang *et al*. (2019)** investigated a new highly affective bio char to remediate contaminated soil there results highlight the potential of applying immobilized micro-organisms on bio char for accelerating the biodegradation of petroleum and maintaining the balance of the soil ecosystem, which may be ascribed to the synergistic effect of bio stimulation and bio augmentation.

**Al-Dhabaan (2019**) studied morphological biochemical and molecular identification of petroleum hydrocarbon biodegrading bacteria isolated from oil polluted soil in Dhahran saud Arabia 16S r DNA sequencing fingerprinting results confirmed they bacterial identification as *Bacillus subtilis, Pseudomonas aeruginosa*, and *Bacillus cereus*. Distinguishable capability for hydrocarbons degradation was evaluated for three isolates which reflected varied degradation rate % patterns.

**Sari *et al*. (2019**) isolated and identified indigenous bacteria from TPH polluted soil of indonasia the results showed that the strains of bacteria are *Bacillus sp*. And *B. cereus* with probability of 72.00 and 77.00% , respectively. These strains potentially acted asbio surfactant producers and hydrocarbon degraders. Thus bio stimulation could be implemented to reduce the TPH levels in polluted soil at Wonocolo public oilfields.

**Sun *et al.* (2019)** studied the effect of temperature, pH value and TPH concentration on the biodegradation of *Enterobacter sp.* S-1 contaminated soil. It was found the TPH degradation rate was more significantly affected ($P<0.0006$) by temperature compared with other two parameters. In the temperature of $30^0$C, pH value of 7.14 and TPH concentration was 4.83 g/L, The best degradation rate was 81.63%.

**Choudhary *et al.* (2019**) suggest that the removal of mid-length, non-volatile hydrocarbons in affected by the population of biodegradation and the nutrients used in the process of remediation. A combinatorial approach, including biostimulation and bioaugmentation, could be used to effectively remove large quantities of aliphatic hydrocarbons persisting for a longer period in the soil.

**Phulpoto *et al*. (2020**) studied affect of natural microbiom and culturable biosurfctant producing bacterial consortia of fresh water lake demonstrated >80% contribution in the total petroleum hydrocarbons degradation by the natural micro biome of the ecosystem.

**Novianty *et al.* (2021**) studied the diversity of fungi consortium isolated from polluted soil for degrading petroleum hydrocarbon the results showed that consortium II (KF-II) has the highest potential to degrade petroleum hydrocarbon (50.61%).

**Hossain *et al.* (2021**) isolated bacteria present in the oil contaminated soil characterized them by morphological biochemical and molecular tools through 16S r-RNA sequence analysis. Revealed that the isolates are closely related to *Pseudomonas sp., Acinetobacter sp., Enterobacter sp*. respectively. All the isolates showed their degradation efficiency in 4% v/v diesel oil and in 8% v/v burned engine oil.

**Popoola *et al.* (2022**) investigated bio augmentation and bio stimulation process parameters influence on bio augmentation effectiveness of bacteria isolates in a crude oil polluted soil for 60 days. Bio stimulation was highly significant on the percentage of TPH biodegraded as revealed by experimental results the model developed was effective for future prediction with better correlation between experimental and predicted values. Conclusively bacteria isolates from native polluted site could be applied as effective scavenger for hydrocarbons in crude oil contaminated soil.

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