Biological Treatment of Contaminated Water with Petroleum Hydrocarbons: A Review

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Abstract

Petroleum pollution has developed into a significant environmental issue that could have a negative impact on both human health and the environment. Both artificial and natural sources contribute to environmental pollution. Numerous physicochemical and biological therapies were devised for the remediation of contaminated settings. The most fundamental and effective method of getting rid of toxins, notably petroleum and its refractory components, is bioremediation, which relies on the metabolic powers of microorganisms. It is a better solution than traditional remedial procedures. It has successfully applied several bioremediation strategies using bioaugmentation or/and biostimulation. Optimizing many factors to produce successful bioremediation methods has drawn more attention. In the study, the different treatment methods will be reviewed to remove hydrocarbons from the aquatic environment and focus on the efficiency of algae in removal, with a review of the most important factors affecting the removal process.

Keywords: Biological Treatment, Algae, Factors affected, Petroleum Hydrocarbons degradation

Introduction

Water plays a considerable role in every aspect of our lives. (Renuka and Karunyal, 2017). Water is the most important natural and vital source for the survival of life on Earth (Kristianto, 2017).

Water covers over 71% of the world's entire surface (Vaishnav *et al.*, 2017). It is well-known that water is a resource that can be used for various purposes, including drinking, irrigation, recreation, transportation, hydroelectric power, household, industrial, and commercial uses, as well as providing habitat for creatures crucial to the economy (Igwe *et al.*, 2017). Water is to be pure when it is clear, turbidity-free, and has a normal taste and fragrance and when water contains harmful chemicals, sewage from factories or homes, organic and inorganic materials, or microorganisms of human or animal origin, it is called contaminated water (Praveen *et al.*, 2016).

Water pollution is used to introduce harmful chemicals, physical impurities, radioactive materials, or pathogenic microorganisms into natural bodies of water (such as lakes, rivers, oceans, and groundwater) to change their composition. This harms any living thing that consumes, uses, or resides in the water. Most pollutants are produced by non-point sources of pollution activities, such as runoff from cultivated land, urban areas, industrial and construction sites, and malfunctioning septic tanks (Yohannes and Elias, 2017). Approximately 1500 substances have been identified as pollutants in freshwater ecosystems. A generalized list of pollutants includes acids and alkalis, anions (sulfide, sulfite, cyanide), detergents, household sewage and farm manure, water used in food processing, gases (chlorine, ammonia), heat, metals (cadmium, zinc, lead), nutrients (phosphates, nitrates), oil and oil dispersants, organic toxic wastes (Dwivedi, 2017).

Natural causes (weathering of soil and rock, erosion, forest fires, and volcanic eruptions), residential waste (sewage and laundry waste), agricultural waste, and industrial waste are other sources of water pollution (Karimi, 2017; Hassan *et al.*, (2017; Khatun, 2017). Industries are the main producers of all ecosystems, and different pollutants at different levels are directly or indirectly released into the environment (Abdel-Aziz *et al.*, 2017). Anthropogenic heavy metals in water are produced by industrial operations, including electroplating, mining, refining, smelting, and chemical production (Taamneh and Sharadqah, 2017). Organic and inorganic materials are often in variable amounts in chemical industry wastewaters (Awaleh and Soubaneh, 2014).

Many of the products used in the chemical industry are poisonous, mutagenic, carcinogenic, or almost nonbiodegradable. Although using organic manure and/or inorganic fertilizers in agriculture increases crop output and lower socioeconomic groups may afford food thanks to the inexpensive price of food, the overuse of nutrients can contaminate surface and groundwater (Krika and Krika, 2017). A continuous rise in metal contamination concentration in freshwater reservoirs due to water runoff might result from greater usage of metal-based fertilizers in the agricultural revolution (Alemu *et al.*, 2017). Water runoff from fields containing agricultural chemicals like herbicides (weed killers) and insecticides, which remain as residues on and in the soil, is one form of water pollution (Chaudhry and Malik, 2017).

The widespread water contamination seriously threatens the environment and human health with

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petroleum oil and its constituents, particularly hydrocarbons, in oil-producing and industrialized nations worldwide (Al-Baldawi *et al.*, 2015).

Previous studies showed that a complex mixture of hydrocarbons and other organic components makes up petroleum (Van Hamme et al., 2003). However, petroleum hydrocarbons are one of the environment's most prevalent classes of persistent organic pollutants (El–Sheekh and Hamouda, 2013).

Several oil spills are reported on an average day due to rising petrochemical and petroleum exploration activity worldwide. Spills can happen in the sea, estuaries, rivers, lakes, or land; they can impact living things and put people, wildlife, and communities at risk of suffocation, hydrocarbon toxicity, hypothermia, and other chronic, long-term impacts. Hydrocarbons are thought to contain some organic contaminants that are both carcinogenic and neurotoxic (AL-Obaidy *et al.*, 2017).

Das and Preethy Chandran (2011) reported that Petroleum-based goods constitute the main energy source for industry action, production, refining, transportation, and storage of petroleum and petroleum products; leaks and unintentional spills frequently happen (Das and Preethy Chandran, 2011).

There are many ways to treat water polluted with oil derivatives and hydrocarbons, including mechanical and chemical processes and physical methods, which include landfilling, evaporation and removal. Still, these methods are often expensive and may lead to partial or incomplete decomposition of these hydrocarbons (Patowary *et al.*, 2016; El Mahdi *et al.*, 2016).

One of the effective ways to treat pollution with petroleum hydrocarbons is biological treatment methods that can transform toxic hydrocarbons into non-toxic by microorganisms, referred to as biological treatment (Azubuike *et al.*, 2016). There are three types of treatment: physical, chemical, and biological treatment (Table 1).

Table 1: Types of treatment (Bhargava, 2016; Guo *et al.*, 2017; Zajda and Kwaterczak, 2019)

Treatment types	Description
Physical treatment	filtration, flotation, sedimentation, and screening detachment of the membrane Comminution, equalization of flow, and granular-medium
Chemical treatment	Other chemical uses include coagulation, chemical precipitation, ion exchange, adsorption, neutralization, solvent extraction, disinfection, and chlorination.
Biological treatment	Anaerobic digestion, Activated sludge process, aerated lagoon, trickling filters, rotating biological contactors, stabilizing of ponds, biological nutrient removal

The current study aims to review the treatment methods to remove petroleum hydrocarbons, and biological treatment is one of the treatment methods.

2. Biological Treatment

It is well known that many microorganisms, including algae, bacteria, fungi, and yeast, can grow and qualify them for the biological treatment of contaminated water; biological treatment methods are affordable and efficient ways to remove harmful chemicals and environmental pollutants (Roy and Saha, 2021).

Biological treatment processes were characterized over several years with clear results, where bacteria and fungi were the biological factors that were the most used in recent studies. Still, using microalgae to treat water pollution with hydrocarbons is very important as they can feed on these hydrocarbons differently from the rest. (Sayed *et al.*, 2021).

2.1. Algae as agents of biological treatment

Within aquatic ecosystems, algae are the main source of biomass. Algae use the bio-absorption, bioaccumulation, and biodegradation processes to remove organic and inorganic contaminants, including heavy metals and hydrocarbons. Microalgae have a photosynthetic effect that is 40 times greater than terrestrial plants, allowing them to create valuable biomass and efficiently deplete nutrients for a brief period. The biomass can be used downstream processes to make various products, such as biofuels (bioethanol, biodiesel), animal feed, and other high-value goods like astaxanthin and carotenoid (Ahmadi *et al.*, 2021).

Some varieties of algae may oxidize and break down various kinds of hydrocarbons into less dangerous parts. This refers to their capacity to reform crude oil (EL-Sheekh *et al.*, 2014).

Cyanobacteria is a gram-negative bacteria characterized by being the only bacteria capable of carrying out the process of photosynthesis of oxygen. It is among the oldest forms of life, as it was found more than 3.5 billion years ago on Earth, but due to the difficulty of finding its cellular structure, it was considered one of the organisms of the beginning of the nucleus. It is noted that these bacteria grow near oil spills and oil refineries or inside oil pipeline filters, where they are completely resistant to contamination with oil derivatives (Zahra *et al.*, 2020).

Factors affected Petroleum Hydrocarbon Degradation

A biotic factor like oil degradation, which is a biotic factor, can determine the presence of petroleum hydrocarbon in the environment, factors that impact our ecology, the environment, and the proliferation of analyzers, an enzyme that affects petroleum-related pollution directly on hydrocarbon mixture quality, amount, and properties. Petroleum-derived hydrocarbons infiltrate our environment immediately upon the occurrence of situations that are entirely hydrocarbons biodegrade in just a few hours or days (Truskewycz *et al.*, 2019). Several factors determine how quickly petroleum hydrocarbons degrade shown below:

3.1 Chemical and the Physical State of Oil

Petroleum hydrocarbons' susceptibility to microbial degradation varies according to their chemical makeup. Long chain alkanes are naturally hydrophobic solids and are difficult to break down because of their limited water solubility. Shorter chain compounds are more hazardous than longer chain compounds, such as n-alkanes of medium length (C10-C25) (Abu and Ogiji, 1995). Branched-chain alkanes and cycloalkanes deteriorated more slowly over time than ordinary alkanes (Adebusoye *et al.*, 2007). The surface area for microbial assault rises when petroleum hydrocarbons are dispersed in a liquid column (Abu and Ogiji, 1995; Radwan *et al.*, 2002). A high concentration of hydrocarbons may be associated with the creation of thick rafts which may prevent microbial Biodegradation by reducing oxygen levels (Cerniglia *et al.*, 1983; Supriya *et al.*, 2019).

3.2.Temperature

The temperature significantly impacts the Biodegradation of petroleum hydrocarbons in two ways: first, by directly affecting the chemistry of the pollutants, and second, by influencing the physiology and variety of the microbial environment, the characteristics of spilled oil and the activity or population of microorganisms are both impacted by the ambient temperature of a place (Okoh, 2006). Among the physical factors, temperature is the most important factor in determining the survival of microorganisms and the composition of the hydrocarbons (Das and Chandran, 2011). In cold environments such as the Arctic, oil degradation via natural processes is very slow and puts the microbes under more pressure to clean up the spilled petroleum. The sub-zero water temperature in this region causes the transport channels within the microbial cells to shut down or even freeze the entire cytoplasm, thus rendering most oleophilic microbes metabolically inactive (Macaulay, 2014; Yang *et al.*, 2009). The optimal temperature for biological enzymes involved in the breakdown pathway varies with temperature, and their metabolic turnover will differ.

Furthermore, a certain temperature is required to break down a particular chemical. Due to its profound influence on microbial physiological features, the temperature can also hasten or slow down the bioremediation process. The rate of microbial activity rises with temperature and reaches its peak at an ideal temperature; with each subsequent rise or fall in temperature, it abruptly begins to plummet until it ends once the temperature reaches a certain point (Abatenh *et al.*, 2017).

3.3. pH

The pH of a substance, which refers to its acidity, basicity, and alkalinity, affects the metabolic activity of microbes and how quickly waste is removed (Asira and Enim Enim, 2013). Higher or lower pH values produced worse outcomes because metabolic processes are extremely sensitive to small pH changes (Wang *et al.*, 2011). When developing new biological treatment techniques, the pH might be very variable, and enzyme activity, as well as functions like catalytic reaction balance and cell membrane trafficking, are all impacted by the pH of the environment (Al-Hawash, 2018).

3.4. Nutrient

Nutrients, including nitrogen, and phosphorus, are significant in Biodegradation. By sanitizing contaminated surroundings, nutrients are needed to initiate the biodegradation process (Alotaibi *et al.*, 2021).

Previous research has shown that nutrients are essential for boosting Biodegradation through the biomass of microbes. The leakage of liquid petroleum hydrocarbons causes oil degradation into the environment, which results in an increase in carbon and a decrease in phosphorus or nitrogen quality. Nitrogen and phosphorus in freshwater and seawater generate nutrient-deficient areas, forcing plants to consume massive amounts of nutrients. The amount of nutrients needed to degrade oil pollution must be increased. The process of Biodegradation occurs while there is a high concentration of nutrients. Numerous researchers who have studied nutrient levels have found that high levels of NPK (nitrogen, potassium, and phosphorus) are particularly harmful when aromatic hydrocarbons are present. The kind and quality of nutrients primarily influence the Biodegradation of hydrocarbons (Singh, 2020).

Numerous studies show that the decomposition of petroleum hydrocarbons is slowed when there is an adequate supply of nutrients. The numerous nutrients aerobic microorganisms use during deterioration include sulfur, manganese, nitrogen, a little phosphorus, and iron. For the natural breakdown of hydrocarbons, phosphorus and nitrogen are crucial nutrients; their absence slows down the process. These nutrients are present in seawater in small amounts. Calcium phosphate, a type of phosphorus, is present in saltwater. Seawater's phosphorus and nitrogen compounds depend on temperature, ranging from 0 to 0.7 mg/l and 0.1 to 1 mg/l, respectively. If there are insufficient nutrients for Biodegradation, fertilizer is used to supply nutrients (Goveas, 2020).

3.5. Oxygen

For the Biodegradation of hydrocarbons, oxygen is the most crucial ingredient. When oxygen is present, petroleum deterioration begins, and oxygen is a crucial component in the entire degradation process. Oxygen is sufficient for the destruction of hydrocarbons since it is used in large quantities in aerobic circumstances and in smaller quantities by soil bacteria during the overall degradation pathway for respiration to convert 1 ml of hydrocarbon into water and carbon dioxide, 3–4 ml of oxygen are typically used because petroleum contains a considerable amount of carbon and hydrogen but little carbon dioxide, Biodegradation requires a lot of oxygen (Kanwal *et al*., 2022).

3.6. Toxic compounds

Some hazardous pollutants might harm microorganisms and delay decontamination when present in high concentrations. Specific toxicants, their concentrations, and the microorganisms exposed all influence the extent and mechanisms of toxicity. Certain organic and inorganic substances poison the intended life species (Abatenh, 2017).

3.7. Salinity

Salinity significantly impacts the biodegradation and remediation processes, as well as microbial diversity and growth (Al-Hawash, 2018). Some important enzymes complicated in the process of hydrocarbon breakdown are adversely affected by salinity (Ebadi et al., 2017). The impact of salinity on microbial decomposition is briefly discussed in a few research studies. The microorganisms that live in the world's seas often adapt to a wide variety of salinities. There is little evidence, such as salt in petroleum resources, that hypersaline conditions influence bacteria. Because the salinity of oil wells differs from that of seas, estuaries have formed a special condition. A microorganism's compatibility with the saline amount, such as the capacity of archaeal to function in crude oil's hypersaline environment, is known to exist in a deteriorating environment, the Kalamkass oil field in Kazakhstan uses n-alkenes and isoprenoids to degrade hydrocarbons while consuming 10–25 percent salt from brine, Halococcus, Haloferax, and Halobacterium halophilic strains were discovered in salt media through more than 26 percent NaCl, and oil vapor is used as a carbon source (Maheen, 2022). The temperature in the Arabian Gulf's hypersaline region is 40–45 °C. in high Microbes in areas with high salinity utilize aliphatic and aromatic hydrocarbons as energy as well as carbon sources (Cao, 2020). Studies show that only a small number of fungus species contribute to salt decomposition in environments with high salt concentrations. Only Papulaspora spp., Fusarium lateritious, and Drechsler spp. have a role in deterioration. In the desert of Kuwait, where salinity ranges from 5 to 10%, saltmarsh serves as a carbon source by digesting crude oil, However, even at high salinity levels, bacteria, eukaryotes, and archaea break down crude oil (0-30 percent), all archaea (halococcus, haloferax, and Halobacterium) and eubacteria (Actinopolysporaspp., Streptomyces Albiaxialis, MarinobacterAquaeolei) work at 20–30% salinity, and these organisms are used to clean up oil damage in hypersaline environments because natural attenuation is slow under these circumstances (Camacho et al., 2021).

Moisture

The abiological process that moves waste materials, nutrients from food, and microorganisms depend on moisture, water surface moisture, lake moisture, and ocean moisture exist without issue; however, soil moisture speeds up soil deterioration when soil re-aeration is hampered by more water, anaerobic conditions result because of the location and soil type, the ideal range of soil moisture, according to some research, this is between 30 and 990 percent. Still, in other studies, it is between 12 and 32 percent. Based on the soil's water holding capacity, the ranges for aerobic processes are between 50 and 70 percent. At the same time, rain is vital for oil deterioration by transferring oxygen and moisture to microorganisms, and tides and waves are significant in water transmission to marches and beaches (Tran *et al*., 2021).

Discussion

Since the development of petroleum oil extraction and its associated products, which have serious ecological problems, hydrocarbon compounds have been known to belong to the family of neurotoxic and xenobiotic organic pollutants. At present, petroleum hydrocarbon compounds are a major natural concern. Petroleum products include carcinogenic and mutagenic substances, affecting biotic and abiotic ecosystem components. Oil seepage often results from mistakes made during the pumping, transporting, and refining. Two principal approaches include mechanical Hydrocarbons that may be removed from polluted areas using both physical and chemical procedures, which are effective but costly. Because it is quite inexpensive and will result in complete mineralization, bioremediation is the best and most advanced approach for treating these polluted sites.

Several factors determine how quickly petroleum hydrocarbons degrade, such as chemicals and the Physical State of Oil. Then petroleum hydrocarbons' susceptibility to microbial degradation varies according to their chemical makeup. Temperature significantly impacts the Biodegradation of petroleum hydrocarbons in two ways: first, by directly affecting the chemistry of the pollutants, and second, by influencing the physiology and variety of the microbial environment.

The pH might be very variable. Enzyme activity, as well as functions like catalytic reaction balance and cell membrane trafficking, are all impacted by the pH of the environment.

Nutrients, including nitrogen and phosphorus, are significant in Biodegradation; sanitizing contaminated surroundings requires nutrients to initiate Biodegradation.

The Biodegradation of hydrocarbons also depends on oxygen, as oxygenases are responsible for the initial attack on the hydrocarbon chain.

Toxic compounds and some hazardous pollutants might harm microorganisms and delay decontamination when present in high concentrations.

Salinity significantly impacts the biodegradation and remediation processes, as well as microbial diversity

and growth.
The abiological process that moves waste materials, nutrients from food, and microorganisms depend on moisture.

Conclusion

Biotreatment is the main natural mechanism that can clean up petroleum hydrocarbon pollutants from the environment. This research is a review of the methods of biological treatment. Many organisms were reviewed, including algae, where it was found through previous research and studies that they give good results in their use in biological treatment and rid the aquatic environment of petroleum hydrocarbons. Several influencing degradation factors have been identified to reduce the toxicity of oil contamination in the environment by removing, degrading or transforming contaminants. Therefore, a successful bioremediation treatment requires understanding factors like chemical and the physical state of oil, temperature, pH, nutrient, Oxygen, Toxic compounds, Salinity and moisture.

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