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PJBS

ISSN 1028-8880

Pakistan Journal of Biological Sciences

ANSInet
Asian Network for Scientific Information
308 Lasani Town, Sargodha Road, Faisalabad - Pakistan

Pakistan Journal of Biological Sciences 13 (15): 715-722, 2010
ISSN 1028-8880

A Review on the Phytoremediation of Petroleum Hydrocarbon

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Abstract: Oil spillage as a result of petroleum industry activities and pipe-line vandalization by saboteurs is a frequent occurrence in oil-producing regions of the world. Conventional oil spill clean-up techniques involve physical and chemical processes that do more damage to the aquatic ecosystem than the oil spill itself. Consequently, the need arises to evolve or develop a more environment-friendly technique that will not only clean-up the environment but also restore the aquatic ecosystem to its status before the oil spill. Phytoremediation, which involves the use of plant to detoxify polluted site, appears to be promising in this regard. It is environment-friendly as well as cost-effective but may take more time than the conventional methods because it is a natural process.

Key words: Oil spill, petroleum hydrocarbon, phytoremediation, environment-friendly, conventional methods

INTRODUCTION

It is estimated that between 1.7 and 8.8 million metric tons of crude oil are released into the world's water every year (National Research Council, 1985), of which more than 90% is directly related to human activities including deliberate waste disposal. Marine oil spills, particularly large-scale spill accidents, have received great attention due to their catastrophic damage to the environment. For example, the spill of 37,000 metric tons (11 million gallons) of North Slope crude oil into Prince William Sound, Alaska, from the Exxon Valdez in 1989 led to the mortality of thousands of seabirds and marine mammals, a significant reduction in population of many intertidal and subtidal organisms and many long-term environmental impacts (Spies *et al*., 1996).

An even more devastating spill occurred recently due to the explosion of the Transocean Deepwater Horizon rig on 20th April, 2010 killing 11 people and led to the British Petroleum (BP) oil spill that threatens coastal Louisiana, Gulf Coast fisheries, Gulf of Mexico ecosystems and perhaps the East Coast, as the spill reaches the loop current (The Daily Green, 2010). The British Petroleum oil spill has now obtained the dubious distinction of being the worst oil spill in United States history, surpassing the damage done by the Exxon Valdez tanker. Unlike the Exxon Valdez tragedy, in which a tanker held a finite capacity of oil, British Petroleum's rig is tapped into an underwater oil well and could pump more oil into the ocean indefinitely until the leak is plugged. About $2.65 billion have been spent on clean-up (The Daily Green, 2010).

Minor oil spills and oil contamination from non-point source discharges (e.g., urban run off and boat bilge) are no less threats to public health and the environment, although they have received much less attention in the past. According to the report of National Water Quality Inventory reports, non-point source pollution remains United State's largest source of water quality problems (United States Environmental Protection Agency, 1996, 2000). It is the main reason that approximately 40% of surveyed rivers, lakes and estuaries are not clean enough to meet basic uses such as fishing or swimming. However, in Nigeria, a major cause of oil spill is pipeline vandalisation by saboteurs (individuals or groups) seeking government attention to correct economic marginalization and ecological disaster occasioned by many years of unregulated crude oil exploration and exploitation by foreign companies in the Niger Delta.

Conventional oil spill countermeasures include various physical, chemical and biological methods. Commonly used physical methods include booming and skimming, manual removal (wiping), mechanical removal, water flushing, sediment relocation and tilling (Zhu *et al*., 2001). Physical containment and recovery of bulk or free oil is the primary response option of choice in most parts of the world for clean up of oil spills in marine and freshwater shoreline environments. Chemical methods, particularly dispersants, have been routinely used in many countries as a response option. However, chemical methods have not been extensively used in most parts of the world due to the disagreement about their effectiveness and the concerns of their toxicity and long-term environmental effects (United States Environmental Protection Agency, 1999). With the recent development of less toxic chemical dispersants, the potential for their application may increase. Some studies have also shown that some dispersant are not as toxic as crude oil (Ndimele *et al*., 2010).

Environmental pollution arising from oil spill is a multi-facet problem presently ravaging oil-producing communities all-over the globe; it causes loss of species diversity, loss of habitat, destruction of breeding grounds of aquatic organisms and sometimes death of organisms including man (Ndimele, 2008). The environmental degradation caused by oil spill affects the social and economic lives of the oil-producing communities because their rivers and other water bodies can no longer sustain aquatic life and so their primary source of livelihood is negatively affected. They also can't drink or swim in their rivers as they used to do before the oil pollution and so their social life is affected.

Oil spillage is a frequent occurrence in oil-producing regions of the world. Conventional oil spill clean-up techniques involve physical and chemical processes that do more damage to the aquatic ecosystem than the oil spill itself (Lin and Mendelssohn, 1998). Consequently, the need arises to evolve or develop a more environment-friendly technique that will not only clean-up the environment but also restore the aquatic ecosystem to its status before the oil spill. Phytoremediation, which involves the use of plant to detoxify polluted site, appears to be promising in this regard. It is environment-friendly as well as cost-effective but may take more time than the conventional methods because it is a natural process.

Background on phytoremediation: Remediation is a programme of activities designed to rehabilitate an impacted ecosystem. Phytoremediation is a form of bioremediation, which is the use of biological processes to detoxify polluted sites (Frick *et al*., 1999). Bioremediation can also be defined as the enhancing of rehabilitation of an impacted ecosystem by micro-organisms which have been described by Ekundayo (1978) as our unseen allies in fight against pollution. Phytoremediation specifically is the use of plants to remove pollutants from the environment or render them harmless (Raskin, 1996). Several species of plants have been shown to have the ability to grow in contaminated soils and actually extract the pollutant from the growth medium. These plants function in several different ways. Some plants can hyperaccumulate toxic heavy metals in their tissues (Ndimele, 2003). Others can converts the pollutants to less toxic compounds and volatilize them (Terry and Zayed, 1994; Brooks, 1998). Some aquatic plant roots can filter contaminants/pollutants from water (Brooks and Robinson, 1998).

Phytoremediators have been studied for use in cleaning up heavy metals like aluminium (Al), cadmium (Cd), chromium (Cr^{3+} and Cr^{6+}), copper (Cu), mercury (Hg), nickel (Ni), lead (Pb) and zinc (Zn). Phytoremediation has also been tested for clean-up of explosives like 2,4,6-trinitrotoluene (TNT), trichloroethylene (TCE) and other volatile organic chemicals and organic compounds such as petroleum compounds (Cunningham and Ow, 1996). If effective, phytoremediation can be an attractive alternative to current remediation methods because the treatment can be done *in situ*, the cost of plants is lower than most other current technologies and it is relatively environmentally safe. Using this technology lowers the total cost of the clean-up project and minimizes the disturbance the remediation will cause in the environment. Rock and Sayre (1998) estimated phytoremediation clean up costs as \$162 m^{-3} compare to \$810 m^{-3} for excavation and incineration.

There are limitations, however. One of the problems associated with phytoremediation is that the technology is still very new and is not completely understood. The use of chelators to mobilize the metal ions is necessary in some instances for uptake by plant roots and the results can be unpredictable (Zhu *et al*., 2001). Other major concerns regarding this technology include dissolution and migration of contaminants, limitation by the toxicity of the contaminated environments and it being a relatively slow process (Macek *et al*., 2000). Cunningham and Ow (1996) reported that a phytoremediation project may take several years to show results. Another challenge in phytoremediation is that the plants that are best hyperaccumulators are very small plants and do not produce high biomass (Banuelos *et al*., 1997).

Phytoremediation of petroleum hydrocarbons: Various plants have been identified for their potential to facilitate the phytoremediation of sites contaminated with petroleum hydrocarbon. In the majority of studies, grasses and legumes have been singled out for their potential in this regard (Aprill and Sims, 1990; Qiu *et al*., 1997; Gunther *et al*., 1996; Reilley *et al*., 1996). However, Ndimele (2008) also reported that water hyacinth (*Eichhornia crassipes*) significantly accumulated petroleum hydrocarbon. Prairie grasses are thought to make superior vehicles for phytoremediation because they have extensive, fibrous root systems. Grass root systems have the maximum root surface area (per $m^3$of soil) of any plant type and may penetrate the soil to a depth of up to 3 m (Aprill and Sims, 1990). They also exhibit an inherent genetic diversity, which may give them a competitive advantage in becoming established under unfavourable soil condition (Aprill and Sims, 1990). Legumes are thought to have an advantage over non-leguminous plants in phytoremediation because of their ability to fix nitrogen; i.e., legumes do not have to compete with micro-organisms and other plants for limited supplies of available soil nitrogen at oil-contaminated sites (Gudin and Syratt, 1975). Water hyacinth (*Eichhornia crassipes*) would also be a good phytoremediation plant for petroleum hydrocarbon because it also possesses a fibrous root system like prairie grasses and floats in water where it can absorb the crude oil while it is still on the surface of the water. The need to test for the efficacy of a floating aquatic macrophyte like water hyacinth is important because most of the oil spills occur on water bodies and would need a floating aquatic plant to absorb the oil. The following is a brief summary of several studies on the use of plants in the phytoremediation of petroleum hydrocarbons.

Aprill and Sims (1990) established a mix of eight prairie grasses in sandy loam soil to determine whether the degradation of four PAHs (benzo (a) pyrene, benzo (a) anthracene, dibenzo (a, h) anthracene and chrysene) was stimulated by plant growth. The eight grasses included big bluestem, little bluestem, Indian grass, switch grass, Canada wide-rhy, side oats grama, blue grama and western wheat grass. The extent of PAH disappearance was consistently greater in planted units compared to unplanted controls, indicating that phytoremediation enhanced the removal of these compounds from contaminated soil. Apparent disappearance was greatest for benzo(a)anthracene followed by chrysene, benzo(a)pyrene and finally dibenzo(a,h)anthracene. This ranking correlated with the water solubility of the PAH compounds, i.e., the more water-soluble the compound, the greater its disappearance from the soil.

In a three year field plot study, Qiu *et al.* (1997) found that prairie buffalo grass accelerated the reduction of naphthalene in a clay soil compared to unplanted clay soil. The authors conducted a parallel experiment to assess the performance of 12 warm season grass species to remove various PAHs from contaminated soil. Results indicated that prairie buffalo grass, common buffalo grass, Meyer zoysia grass and Verde Klein grass accelerated the loss of the low molecular weight PAHs naphthalene, fluorine and phenanthrene compared to an unplanted control. However, only the Verde Kleingrass accelerated the loss of high molecular weight PAHs, such as pyrene, benzo(a)anthracene and benzo(a)pyrene compared to the unplanted control. Other authors that have investigated the potential of various plant species to absorb petroleum hydrocarbon are: Gunther *et al.* (1996) who worked on ryegrass (*Lolium perenne* L.), Reilley *et al.* (1996) on alfalfa (*Medicago sativa* L.), tall fescue (*Festuca arundinacea* Schreb.), Sudan grass (*Sorghum vulgare* L.) and Switch grass (*Panicum virgatum*) and Reynolds and Wolf (1999) on Arctared red fescue (*Festuca rubra* var.Arctared) and Annual ryegrass (*Lolium multiflorum*).

Yateem *et al.* (2000) investigated the degradation of total petroleum hydrocarbons (TPH) in the rhizosphere and non-rhizosphere soil of three domestic plants namely, alfalfa (*Medicago sativa*), broad bean (*Vicia faba*) and rayegrass (*Lolium perenne*). Although the three domestic plants exhibited normal growth in the presence of 1% TPH, the degradation was more profound in the case of leguminous plants. They found that the soil cultivated with broad bean and alfalfa was 36.6 and 35.8% respectively, compared with 24% degradation in case of rayegrass. Adams and Duncan (2002) found that the legume plant (*Vicia sativa*) was able to grow in soil contaminated with diesel fuel and the total numbers of nodules were significantly reduced in contaminated plants as compared to control plants, but nodules on contaminated plants were more developed than corresponding nodules on control plants. These authors found that the amount of diesel fuel remaining after 4 months in the legume plant *Vicia sativa* was slightly less than in the rayegrass planted soil.

Rosado and Pichtel (2004) studied the decomposition of used motor oil in soil as influenced by plant treatment. Soil contaminated with used motor oil (1.5% w/w) was seeded with soybean (*Glycine max*), green bean (*Phaseolus vulgaris*), sunflower (*Helianthus annuus*), Indian mustard (*Brassica juncea*), mixed grasses/maize (*Zea mays*) and mixed clover (*Trifoleum partense*, L. *Trifoleum repense*). After 150 days in the clover treatment, the added oil was no longer detected. A total of 67% of the oil was removed in sunflower/mustard and with addition of NPK fertilizer, the oil was completely removed. The grass/maize treatment resulted in a 38% oil reduction, which increased to 67% with fertilizer application. Based on oil residue and biomass results, the clover and sunflower/mustard treatments are considered superior to other plant treatments in terms of overall phytodegradation of used oil hydrocarbons.

Table 1 is a list of plants that have potential to phytoremediate petroleum hydrocarbon while Table 2 is a list of plant with a demonstrated potential to tolerate petroleum hydrocarbons. They are mostly grasses and legumes. The uniqueness of these grasses in phytoremediation stem from the fact that they have a fibrous root system which increases their contact with the pollutant because of increase in surface area (Aprill and Sims, 1990). The legumes are also a good option for phytoremediation because of their ability to fix atmospheric nitrogen. Therefore, they do not compete for

Table 1: Plants with a demonstrated potential to phytoremediate petroleum hydrocarbons

No.	Details
1	Western wheatgrass (*Agropyron smithii*)
2	Big bluestem (*Andropogon gerardi*)
3	Side oats grama (*Bouteloua curtipendula*)
4	Blue grama (*Bouteloua gracilis*)
5	Common buffalograss (*Buchloe dactyloides*)
6	Prairie buffalograss (*Buchloe dactyloides* var. Prairie)
7	Bell rhodesgrass (*Chloris gayana*)
8	Bermuda grass (*Cynodon dactylon* L.)
9	Carrot (*Daucus carota*)
10	Canada wild-rye (*Elymus canadensis*)
11	Tall fescue (*Festuca arundinacea* Schreb)
12	Arctared red fescue (*Festuca rubra* var. Arctared)
13	Soybean (*Glycine max*)
14	Duckweed (*Lemna gibba*)
15	Annual ryegrass (*Lolium multiflorum*)
16	Ryegrass or perennial ryegrass (*Lolium perenne* L.)
17	Alfalfa (*Medicago sativa* L.)
18	Verde kleingrass (*Panicum coloratum* var. Verde)
19	Switchgrass (*Panicum virgatum*)
20	Bush bean (*Phaseolus vulgaris* L.)
21	Poplar trees (*Populus deltoides x nigra*)
22	Winter rye (*Secale cereale* L.)
23	Little bluestem (*Schizachyrium scoparius*)
24	Indiangrass (*Sorghastrum nutans*)
25	Sorghum (*Sorghum bicolor*) or sudangrass (*Sorghum vulgare* L.)
26	Meyer zoysiagrass (*Zoysia japonica* var. Meyer)
27	Sudangrass (*Sorghum vulgare* L.)

Source: Frick *et al.* (1999)

the limited nitrogen in the soil with micro-organisms and other plants and so can grow and have enough biomass which will enhance their capability to phytoremediate.

Mechanisms for the phytoremediation of petroleum hydrocarbons: There are 3 primary mechanisms by which plants and micro-organisms remediate petroleum contaminated soil and ground water. These mechanisms include:

- Degradation
- Containment and
- Phytovolatilization (Cunningham *et al*., 1996)

Degradation: Degradation is the breaking down of a hitherto harmful substance to less harmful or harmless substances. In petroleum hydrocarbon degradation, plants and micro-organisms are involved, both directly and indirectly. Some of the end-products are: alcohol, acids, carbon dioxide and water and these are generally less toxic and less persistent in the environment than the parent compounds (Eweis *et al*., 1998). Though plants and micro-organisms can degrade petroleum hydrocarbons independently of one another, Atlas and Bartha (1998) suggests that it is the interaction between plants and micro-organisms (i.e., the rhizosphere effect) which is the primary mechanisms responsible for petrochemical degradation in phytoremediation efforts.

Table 2: Plants with a demonstrated potential to tolerate petroleum hydrocarbons

No.	Details
1	Crested wheatgrass (*Agropyron desertorum*)
2	Tilesy sage (*Artemisia tilesii*)
3	Oat *(Avena sativa)*
4	Canola (*Brassica rapa*)
5	Water sedge (*Carex aquatilis*)
6	Round sedge (*Carex rotundata*)
7	Rock sedge (*Carex rupestris*)
8	Carrot (*Daucus carota*)
9	Bering hairgrass (*Deschampsia beringensis*)
10	Quackgrass (*Elytrigia repens or Agropyron repens*)
11	Tall cotton-grass (*Eriophorum angustifolium*)
12	Soybean (*Glycine max*)
13	Sunflower (*Helianthus annuus*)
14	Barley (*Hordeum vulgare*)
15	Birdsfoot trefoil (*Lotus corniculatus*)
16	Black medick (*Medicago lupulina*)
17	Alfalfa (*Medicago sativa* L.)
18	*Melilotus altissima*
19	Reed canary grass (*Phalaris arundinacea*)
20	Reed grass (*Phragmites australis*)
21	Jack pine (*Pinus banksiana*)
22	Field pea (*Pisum arvense*)
23	Alpine bluegrass (*Poa alpina*)
24	*Psoralea bituminosa*
25	*Robinia pseudacacia*
26	Arctic willow (*Salix arctica*)
27	Snow willow (*Salix reticulata*)
28	Three-square bulrush (*Scirpus pungens*)
29	*Senecio glaucus*
30	*Spartina alterniflora*
31	*Spartina patens*
32	Alsike clover (*Trifolium hybridum*)
33	Red clover (*Trifolium pratense*)
34	White clover (*Trifolium repens*)
35	Wheat (*Triticum aestivum*)
36	Cattails (*Typha latifolia*)
37	Fababean (*Vicia faba*)
38	*Vicia tetrasperma*
39	Maize (*Zea mays* L.)

Source: Frick *et al.* (1999)

The rhizosphere effect: The rhizosphere is the region of soil closest to the roots of plants and is, therefore, under the direct influence of the root system (Frick *et al*., 1999). Plants provide root exudates of carbon, energy, nutrients, enzymes and sometimes oxygen to microbial populations in the rhizosphere (Cunningham *et al*., 1996). Root exudates of sugars, alcohol and acids can amount to 10-20% of plant photosynthesis annually (Schnoor *et al*., 1995) and provide sufficient carbon and energy to support large numbers of microbes (e.g., approximately 10^8-10^9 vegetative microbes per gram of soil in the rhizosphere; Erickson *et al*., 1995). Due to these exudates, microbial populations and activities are 5 to 100 times greater in the rhizosphere than in bulk soil (i.e., soil not in contact with plant roots) (Atlas and Bartha, 1998; Gunther *et al*., 1996). This plant-induced enhancement of the microbial population is referred to as the rhizosphere effect (Atlas and Bartha, 1998) and is believed to result in enhanced degradation of organic containment in the rhizosphere.

However, Frick *et al.* (1999) noted that a few experiments suggest that the degradation of petroleum hydrocarbons from soil may not be enhanced by the rhizosphere effect. Ferro *et al.* (1994) reported that crested wheat grass (*Agropyron desertorum* (Fisher ex Link) Schultes) had no effect on either the rate or extent of mineralization of the (^{14}C) phenanthrene when planted and unplanted systems were compared. For this experiment, the authors speculated that rapid mineralization of the (^{14}C) phenanthrene by microbes prior to the establishment of the plant root systems and, therefore, prior to the presence of a rhizosphere effect in the soil may have resulted in the lack of significant difference between mineralization in planted and unplanted systems.

The role of plants in degradations

Direct degradation: There is paucity of information on the direct degradation of petroleum hydrocarbon by plant (Frick *et al.*, 1999). Durmishidze (1977) reported that corn seedlings, tea and poplar shoots were able to metabolize methane into various acids. The ability to assimilate n-alkanes and liberate $^{14}CO_2$ was identified in leaves and roots of both whole and cut plants. The general pathway of conversion for alkanes in plants was generalized as:

$$\text{n-alkane} \rightarrow \text{Primary alcohols} \rightarrow \text{Fatty acids} \rightarrow \text{acetyl-COA} \rightarrow \text{various compounds}$$

Indirect degradation: In contrast to the limited information available on the direct degradation of petroleum hydrocarbon by plants, there is a considerable body of information available regarding the indirect roles played by plants in the degradation of petroleum hydrocarbons. These include:

- The supply of root exudates that cause the rhizosphere effect and enhanced cometabolic degradation
- The release of root-associated enzymes capable of transforming organic pollutants
- The physical and chemical effects of plants and theirs root system on soil conditions (Gunther *et al.*, 1996)

Root exudates: Root exudates are the link between plants and microbes that leads to the rhizosphere effect (Frick *et al.*, 1999). The type and quantity of root exudate are dependent on plant species and the stage of plant development. For example, Hegde and Fletcher (1996) found that the release of total phenolics by the roots of red mulberry (*Morus rubra* L.) increased continuously over the life of the plant with a massive release at the end of the season accompanying leaf senescence. The type of root exudate is also likely to be site and time specific (Siciliano and Germida, 1998). Site and time factors include variables such as soil types, nutrient levels, pH, water availability, temperature, oxygen status, light intensity and atmospheric carbon dioxide concentration- all of which significantly affect the type and quantity of root exudates (Siciliano and Germida, 1998).

Cometabolism: Cometabolism is the process by which a compound that cannot support microbial growth on its own can be modified or degraded when another growth- supporting substrate is present (Cunningham and Berti, 1993).

Organic molecules, including plant exudates, can provide energy to support population of microbes that co-metabolize petroleum hydrocarbons. For example, Ferro *et al.* (1997) reported that plant exudates may have served as co-metabolites during the biodegradation of (^{14}C) Pyrene in the rhizosphere of crested wheatgrass.

Plant enzymes involved in phytoremediation: The release of enzymes from roots is yet another indirect role that plants play in the degradation of petroleum hydrocarbons. These enzymes are capable of transforming organic contaminants by catalyzing chemical reaction in soil (Frick *et al.*, 1999). Schnoor *et al.* (1995) identified plant enzymes as the causative agents in the transformation of contaminants mixed with sediment and soil. Isolated enzymes systems included dehalogenase, nitroreductase, peroxidase, laccase and nitrilase. These findings suggest that plant enzymes may have significant spatial effects extending beyond the plant itself and temporal effects continuing after the plant has died (Cunningham *et al.*, 1996).

The role of micro- organisms in degradation: Bioremediation is the use of micro - organisms to destroy or immobilize organic contaminants in the absence of plant (Frick *et al.*, 1999). It is important to look at the role of micro-organisms in the degradation of petroleum hydrocarbons in the presence of plants - a mechanism of Phytoremediation. Issues to be considered include the types of micro-organisms involved in phytoremediation, reasons for microbial degradation, differences in degradation by various micro-organisms, characteristics of microbial communities involved in degradation, and the role micro-organisms play in reducing phytotoxicity to plants.

Table 3 shows a list of bacteria and fungi that can degrade petroleum hydrocarbon. Generally, degradation

Table 3: Genera of hydrocarbon-degrading microorganisms isolated from soil

List	Detail
(A) Bacteria	
1	*Acidovorax*
2	*Alcaligenes*
3	*Arthrobacter*
4	*Mycobacterium*
5	*Pseudomonas*
6	*Rhodococcus*
7	*Sphingomonas*
8	*Xanthomonas*
9	*Achromobacter*
10	*Micrococcus*
11	*Acinetobacter*
12	*Norcardia*
13	*Bacillus*
14	*Proteus*
15	*Brevibacterium*
16	*Sarcina*
17	*Chromobacterium*
18	*Serratia*
19	*Corynebacterium*
20	*Spirillum*
21	*Cytophaga*
22	*Streptomyces*
23	*Erwinia*
24	*Vibrio*
25	*Flavobacterium*
(B) Fungi	
1	*Cunninghamella*
2	*Fusarium*
3	*Penicillium*
4	*Phanerochaete*
5	*Acremonium*
6	*Monilia*
7	*Aspergillus*
8	*Mortierella*
9	*Acremonium*
10	*Monilia*
11	*Aspergillus*
12	*Mortierella*
13	*Aureobasidium*
14	*Paecilomyces*
15	*Beauveria*
16	*Phoma*
17	*Botrytis*
18	*Rhodotorula*
19	*Candida*
20	*Saccharamyces*
21	*Chrysosporium*
22	*Scolecobasidium*
23	*Cladosporium*
24	*Sporobolomyces*
25	*Cochliobolus*
26	*Sprotrichum*
27	*Cylindrocarpon*
28	*Spicaria*
29	*Debaryomyces*
30	*Syncephalastrum*
31	*Geotrichum*
32	*Tolypocladium*
33	*Gliocladium*
34	*Torulopsis*
35	*Graphium*
36	*Trichoderma*
37	*Humicola*
38	*Verticillum*

Source: Frick *et al*. (1999)

occurs as result of these organisms using the organic contaminants for growth and reproduction. The organic contaminants provide the micro-organisms with the carbon and electron used by the orgamism to obtain energy (Frick *et al*., 1999).

Containment: Containment can be direct or indirect. Direct containment involves the accumulation of contaminants within the plants, adsorption of contaminants onto roots and binding of contaminants in the rhizosphere through enzymatic activities (Cunningham *et al*., 1996; Frick *et al*., 1999). Containment involves using plants to reduce or eliminate the bioavailability of contaminants to other biota. Contaminants are not necessarily degraded when they are contained. Indirect containment involves plants supplying enzymes that bind contaminants into soil organic matter (or *humus*) in a process called *Humification* and by increasing soil organic matter content, which allows for humification (Cunningham *et al*., 1996).

Transfer of petroleum hydrocarbons to the atmosphere (phytovolatilization): The natural ability of a plant to volatilize a contaminant that has been taken up through its roots can be exploited as a natural air-stripping pump system. Phytovolatilization is most applicable to those contaminants that are treated by conventional air-stripping i.e., contaminants with a Henry's constant KH >10 atm m^3 water· m^{-3} air, such as BTEX, TCE, vinyl chloride and carbon tetrachloride. Chemicals with KH < 10 atm m^3 water· m^{-3} air such as phenol and PCP are not suitable for the air-stripping mechanism because of their relatively low volatility (Zhang *et al*., 2001).

CONCLUSION

Phytoremediation have shown great promise in the clean up of aquatic environment polluted with crude oil. Though in its infancy and not fully understood yet, it is one remediation strategy that holds tremendous prospects for the future. It will clean up the environment without any of those negative impacts that is associated with physical and chemical processes of oil spill remediation. However, a lot of studies still need to be done on areas like: the mechanisms of phytoremediation by plants as this may vary, site specificity of phytoremediation techniques, the influence of microbial population, the use of genetically modified plants that has greater speed of crude oil absorption.

ACKNOWLEDGMENT

The author is grateful to Dr. Adetola Jenyo-Oni of Department of Wildlife and Fisheries Management, Faculty of Agriculture and Forestry, University of Ibadan, Nigeria for her constructive criticisms of the original manuscript.

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