Bioremediation of Xenobiotics: An Eco-friendly Cleanup Approach

Alok Bharadwaj

Abstract Xenobiotics are the chemicals, which are not found in nature and are said to be foreign substances in the atmosphere. These compounds are synthesized by human beings e.g. pesticides, that may be added in the soil to kill the harmful pests but in addition this, these pesticides also kill the beneficial microorganisms that are responsible for the fertility of soil. Moreover, these compounds can be accumulated in food chain and cause harm to the flora and fauna of such ecosystem. For the degradation of such xenobiotic compounds various physico-chemical and biological methods have been used but all these methods produce toxic by-products that are hazardous to the environment. Thus Bioremediation is a promising tool for the degradation of such compounds. In the present paper, we have emphasized on the remediation of xenobiotics by using microorganisms. Bacteria and Fungi play an important role in breaking down certain hazardous substances into simpler fragmented forms. Bacteria, which are used for bioremediation of xenobiotics includes aerobic, anaerobic, Methanotrophic, Methanogenic bacteria, Cyanobacteria and Sphingomonads. *Pseudomonas* species has been used for the degradation of several xenobiotic compounds. In addition to this, certain fungi such as *Aspergillus, Rhizopus, Botrytis, Neurospora* etc. have been used for the heavy metal biosorption. Hence we can say that fungi are one of the promising tools for the eco-friendly degradation of xenobiotic.

Keywords Xenobiotics · Microorganisms · Bioremediation

1 Introduction

The term 'bioremediation' means transformation of a chemical compound from highly complicated form (organic) to simple (inorganic) form through biological means. If we say a compound is biodegradable, it means that it can be converted

A. Bharadwaj (✉)
Department of Biotechnology, GLA University, Mathura, UP, India
e-mail: alok.bhardwaj@gla.ac.in

V. S. Parmar et al. (eds.), *Green Chemistry in Environmental Sustainability and Chemical Education*, https://doi.org/10.1007/978-981-10-8390-7_1

into various inorganic forms or can be mineralized i.e., possible to convert into carbon dioxide and water.

Xenobiotics are the chemical compounds, which are manufactured by human and their degradation is not possible. These are foreign compounds, when collected in the atmosphere pose dangerous effects on the atmosphere [1–3]. Examples of xenobiotics are pesticides, fuels, solvents, alkanes, polycyclic hydrocarbons (PAH's), antibiotics, synthetic azo dyes, pollutants, polyaromatic, chlorinated and nitro aromatic compounds [4]. Moreover, certain compounds are recalcitrant i.e. the compound are resistant to being broken down through chemical process because of the presence of halogen, nitro or sulphonyl groups.

The major examples of xenobiotics are DDT and halogenated aromatic compounds because they pose hazardous impact on the atmosphere. Although, many such compounds are highly beneficial to the humans but their long term presence in the environment cause deleterious effects.

Recalcitrant toxic pesticides such as BHC, PCBs, and DDT are not easily biodegraded and their concentration goes on increasing in the soil and water with time. For example, there is a continuous increase in the concentration of DDT at successive trophic levels in food chain. Model compounds of DDT such as diphenymethane and dichlorodiphenylmethane are biodegrade by various microbes. *Pseudomonas putida* converts DDT to several compounds under anaerobic conditions. In aerobic conditions, ring cleavage yield p-chlorophenylacetic acid that in turn served as a substrate for an *Arthrobactor* species. A number of reviews have been available on the bioremediation of xenobiotics [4–7].

2 Basis of Bioremediation

Microbes play the most important role in the process of biodegradation. Certain abiotic mechanisms and photo-oxidation also play an important role in the degradation of certain organic chemicals but such transformations are generally incomplete because these processes cannot convert the compound into inorganic form (Fig. 1).

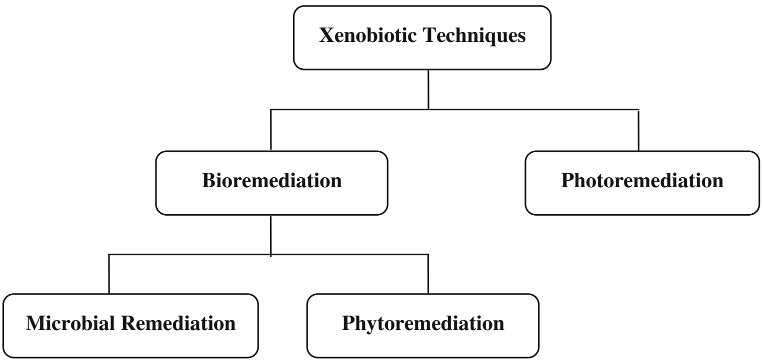

Fig. 1 Classification of different xenobiotic compounds

Before the industrialization, biosphere of earth remained constant because of more or less balanced biosynthesis and biodegradation reactions. During the course of evolution, a vast variety of chemical compounds are biosynthesized in nature and microbes were exposed to these compounds. For this millions of year's exposure, they have developed the capacity and mechanism to attack these compounds. Out of several chemical compounds synthesized by chemists, many have structural features and bonding similar to that of natural compounds, so can be biodegraded.

The xenobiotic compounds having recalcitrant characteristics have following features

(i) These compounds are not recognized by the microorganisms as substrate. So, can't be degraded by them.
(ii) For their transportation into the microbial cell, they do not have permease enzyme.
(iii) These are complex molecules. So, very difficult to enter inside the microbial cell.
(iv) These compounds are highly stable in the nature. In addition to this they are insoluble in water.
(v) Xenobiotic compounds are very poisonous in nature.

On the basis of chemical composition, the recalcitrant xenobiotic compounds can be divided into the following types (Fig. 2).

2.1 *Halocarbons*

These compounds are mainly used in the preparation of pesticides, insecticides etc. These are volatile, when free into the environment cause damage to the ozone layer and when gathered in soil, leading to biomagnifications.

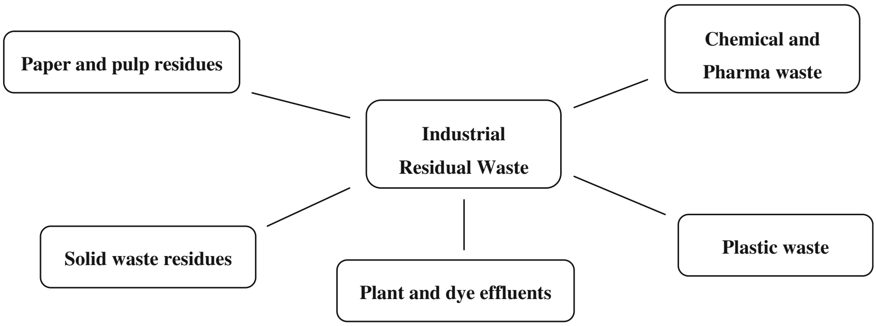

Fig. 2 Types of recalcitrant xenobiotic compounds

2.2 Polychlorinated Biphenyls (PCBs)

These compounds are inert in nature and are used in the manufacturing of plasticisers, insulator coolants in transformers etc.

2.3 Synthetic Polymers

These are high molecular weight compounds, which are insoluble in water and used in the manufacturing of plastics like polymer, polyvinylchloride.

2.4 Alkylbenzyl Sulphonates

These compounds are not degraded by microorganisms because of the presence of sulphonate group. They are used in the manufacturing of detergents.

2.5 Oil Mixtures

Due to accidental oil spilling in the ocean, oil spread over the water surface and its breakdown by microorganisms results ineffective. Oil is insoluble in water. So, it becomes recalcitrant.

From this discussion, it has been clear that the recalcitrant characteristic of a xenobiotic compound is directly connected with its complexity and it is also noted that recalcitrant property is enhanced as their complexity increased.

3 Hazards from Xenobiotic Compounds

The impacts of xenobiotic compounds are very hazardous in nature. Their dangerous effect is not only on lower eukaryotes but higher eukaryotes are also affected. They are very toxic to human beings also. Their exposure may cause certain skin diseases and prolong exposure may cause cancer also. Because they posses recalcitrant property, they are not degraded in the nature and may remain persist for long time in the environment may result in the form of bioaccumulation or biomagnifications. In bioaccumulation or biomagnifications, they enter into the food chain and their concentration will increase with the increase in the trophic level of that ecosystem.

4 Removal of Xenobiotics

Unluckily, xenobiotics are used widely among the modern society. To survive the better life, many industries—manufactured different chemical compounds but majority of them are poisonous and toxic for the living beings. e.g. the use of plastics, pesticides, paints, textiles and pharmaceuticals can not be eradicated from our daily needs but now the time has come that we should aware to overcome this huge problem and protect our future from the curse of xenobiotics. One of the most efficient tools to get rid of this problem is the use of microorganisms that may degrade these toxic chemicals from the atmosphere. Because microorganisms are easily grow and multiply in laboratory. So, they can be a useful device for the degradation of such chemical compounds. The enzymes present in these microorganisms are able to degrade these chemical compounds. The enzymes present in these microbes are able to degrade these chemicals into harmless end products. Different types of microorganisms are used to degrade different type of waste but unfortunately there are some artificially human made chemical compounds, which are not degraded by the microorganisms because they are not able to break certain chemical bonds present in the chemical compounds.

One of the recent branches of the science i.e. genetic engineering makes it possible to construct such type of microorganisms, that able to degrade these xenobiotic compounds. Among such microorganisms *Pseudomonas* genus are mostly employed for their degradation. Such bacteria have extra chromosomal DNA i.e. TOL plasmid, that have the capacity to degrade toluene and xylene.

There is one more approach to degrade these xenobiotic compounds by using the combined efforts of human and microbial activity. In this technique the recalcitrant chemicals are first break into smaller parts and then subjected to microbial degradation. An example is the accidental oil spilling, which is very dangerous for the life of aquatic organisms. By the combining efforts of human and microbes, aquatic organisms may survive but if the area of oil spill is very vast, then the rate of oil degradation by microbes becomes very slow due to the toxicity of oil. But now, recently a chemical is used for solving this problem.

A chemical name SOT II (solid oil treatment) is an inorganic solid absorbent, which is chemically inert. Whenever a oil spill occurs, this chemical is spread over the oil spill area. Since it is a strong absorbent, it will compact in small particles with oil and sink at the bottom of the sea. Due to the property of strong absorbent SOT II particles can't leave the oil spill. As the superficial layer of oil has removed from the water, the living organism survives as they come in direct contact with oxygen and sunlight. The particles of SOT II with oil, which sinks at the bottom of sea will become the food of for oil degrading organisms i.e. bacteria, algae, fungi and protozoa. This process takes place rapidly at the bottom of the sea and within a week these oil degrading organisms degrade the oil with the production of end products i.e. water and CO_2.

This technique shows 99% success in the removal of oil from the sea and its degradation and elimination from the ecosystem.

As we all know, xenobiotics are the toxins and detoxification is a successful remedy to neutralize these toxins. In detoxification process, the negative impact of these toxins can be minimized by planning the detox diet. The main objective of detox diet is to eradicate these toxins because this diet contains 40% solid and 60% liquids. Solid food contains certain phytochemicals e.g. indole, flavanoids etc. e.g. pineapple contains bromelain. Papaya contains papain, which is a colon cleaner and improves immune system. Consumption of raw food such as sprouts, dried fruits, nuts, milk etc. are also the examples of detoxification because these foods contains antioxidants that enhance the immune system of our body.

5 Microbial Degradation of Xenobiotics

To overcome the needs of increasing population, the use of pesticide in modern agriculture is increasing day by day but the results are very dangerous because these pesticides persist in the ecosystem and don't undergo biological transformation (Table 1).

In the degradation of xenobiotics compounds, the role of microorganisms is very important because these microorganisms degrade the xenobiotics into the simpler or non hazardous compounds. Among these microbes, bacteria have the noble detoxifying abilities. Examples of aerobic and anaerobic xenobiotics degradative

Table 1 Duration of persistence of insecticides and herbicides in soil

Biocides	Time taken for 75–100% disappearance
A. *Chlorinated insecticides*	
DDT (l,l,l-trichloro-2,2-bis-(p-chlorophenyl) ethane)	4 years
Aldrin	3 years
Chlordane	5 years
Heptachlor	2 years
Lindane (hexachloro-cyclohexane)	3 years
B. *Organophosphate insecticides*	
Diazinon	12 years
Malathion	1 week
Parathion	1 week
C. *Herbicides*	
2,4-D (2,4-dichlorophenoxyacetic acid)	4 weeks
2,4,5-T	30 weeks
Atrazine	40 weeks
Simazine	48 weeks
Propazine	1.5 years

Source [8]

bacteria are *Pseudomonas, Gordonia, Bacillus, Moraxella, Micrococcus, Escherichia, Sphingobium, Pandoraea, Rhodococcus*, and anaerobic xenobiotics degradative bacteria are *Pelatomaculum, Desulphovibrio, Methanospirillum, Methanosaeta desulfotomaculum, Syntrophobacter, Syntrophus* [6, 9]. Among them, *Pseudomonas* species and *Bacillus* species have been the most widely studied. Many other bacterial species which assist in degradation of recalcitrant xenobiotic compounds are listed in Table 2.

Table 2 List of xenobiotic compounds degraded by microorganisms

Xenobiotic compounds	Microorganisms degrading xenobiotics	Isolated sites	References
Petroleum hydrocarbons: crude oil, engine oil, petrol, diesel, brake oil	*Bacillus* sp. S6 and S35	Soil samples from storage and distribution centre of oil products in Tehran refinery and Siri Island	[10]
	Pseudomonas sp., PSI, PSII, PSIII	Soil samples from pil production site of ONGC (Lingal oil field project) and from local areas in Haridwar, India	[11]
	Pseudomonas putida (strain G1) and *Pseudomonas aeruginosa* (strain K1)	Soil samples from abandoned coal power plant (PHC) at Ijora-Olapa, Lagos	[12]
	Bacillus subtilis	Soil samples from automobile workshops and petrol bunks, Madurai, India	[13]
	Consortium 1: *Pseudomonas aeruginosa* strains S4.1 and S5 and *Bacillus* sp. strain S3.2 Consortium 2: Consortium 1 and *Bacillus* sp. strains 113i and O63 and *Micrococcus* sp. strain S	Bacterial strains purchased from centre for research in enzymes and microbiology, Malaysia	[14]
	Pseudomonas sp., *Vibrio* sp., *Bacillus* sp., *Corynebacterium* sp. and *Klebsiella* sp.	Soil samples from Missa Kaswal and Rajian oil fields, Gojar Khan and Chakwal districts	[15]
	Pseudomonas sp., *Vibrio* sp., *Bacillus* sp., *Corynebacterium* sp., *Flavobacterium* sp., *Micrococcus* sp. and *Morexella*	Soil samples from various gasoline and diesel spilled gas stations, Coimbatore, India	[16]
	Bacterial diversity	Soil samples from storage and distribution centre for oily products in south of Iran	[17]

(continued)

Table 2 (continued)

Xenobiotic compounds	Microorganisms degrading xenobiotics	Isolated sites	References
	Pseudomonas sp., *Acinetobacter* sp., *Bacillus* sp., *Corynebacterium* sp. and *Flavobacterium* sp.	Soil samples from automechanic workshops at Mgbuka-nkpor, Nigeria	[18]
	Pseudomonas aeruginosa PDKT-2, Bacillus licheniformis PDKT-5 and *marcescens PDKT-1 (HM998315*	Soil samples from auto mobile workshops, Pudukottai, Tamil Nadu, India	[19]
	Pseudomonas sp., *Arthrobacter* sp. and *Mycobacterium* sp.	Soil samples from garage area of heavy vehicles in Tehran-Saveh road, Iran	[20]
	Pseudomonas aeruginosa, Alcaligenes faecalis, Bacillus sp. and *Serratia* sp.	Soil samples from automechanic workshops at Ota, Western Nigeria	[21]
	Acinetobacter, Alcaligenes, Bacillus, Corynebacterium, Flavobacterium, Micrococcus and *Pseudomonas*	Higher purity n-alkane, cycloalkane, and aromatic HCs were obtained from Farmex Nigeria Limited, Sango-Otta	[22]
	Bacterial strains (RP1, RP2, RP4, RP12, DE5, DE7ii, DE8ii, OW13 and OW14)	Oil contaminated soil samples were collected from the oil production sites of Essar Oil LTD., Vadinar-Jamnagar and from Oil and Natural Gas Corporation (ONGC) Point (Gujarat-India)	[23]
	Micrococcus sp.	Soil samples were collected from automobile workshops in Mayiladuthurai	[24]
	Pseudomonas aeruginosa	Isolated from some crude oil flow stations' saver pit effluent in the Niger delta area of Nigeria	[25]
	Micrococcus and *Pseudomonas*	Soil samples contaminated with spent engine oil were collected from a mechanic workshop along Opopo gbooro, Iworoko Road, Ado-Ekiti	[26]
	Bacterial strains MJH1101, MJH1102, MJH1103, MJSH1104,	Soil samples were collected from two different oil contaminated sites: (A) Popular Service Garage, city station,	[27]

(continued)

Table 2 (continued)

Xenobiotic compounds	Microorganisms degrading xenobiotics	Isolated sites	References
		Lucknow, (B) Rajesh Garage, Jama masjid, Lucknow	
	Proteus vulgaris SR1	Bacterial strain was isolated from newly killed fish samples collected close to the point of spill in the Niger Delta region in Nigeria	[28]
	Pseudomonas sp., *Achromobacter* sp., *Bacillus* sp. and *Flavobacterium* sp.	Soil samples were obtained from a Judy Creek area of north-central Alberta, from a diesel fuel spill near Salmon Arm, British Columbia	[29]
	Flavobacterium sp., *Acinetobacterium calcoaceticum* and *Pseudomonas aeruginosa*	Soil samples collected from ENGEN, Amanzimtoti, South Africa	[30]
	Bacterial isolates SP4, SP5, SP6, SP7	Soil samples were collected from contaminated sites of Barmer near Mangala oil well, Rajasthan	[31]
	Arthrobacter, Halomonas, Pseudomonas, Bacillus, Klebsiella, Proteus	Soil samples from oil fields of ONGC sites located in Gujarat	[32]
	Pseudomonas alcaligenes LR14, Bacillus coagulans CR31, Klebsiella pneumonia CR23, Klebsiella aerogenes CR21 and Pseudomonas putrefacience CR33	Rhizosphere soil contaminated with spent engine oil in Sokoto, Nigeria	[33]
	Acinetobacter iwoffii, Aeromonas hydrophila, Pseudomonas aeruginosa, Pseudomonas putida	Soil samples from two oil refineries in Malaysia	[34]
Pesticides: Glyphosate	*Pseudomonas putida, P. aeruginosa and Acinetobacter faecalis*	Agricultural soil polluted with glyphosate in Osogbo Osun State, Nigeria	[35]

(continued)

Table 2 (continued)

Xenobiotic compounds	Microorganisms degrading xenobiotics	Isolated sites	References
Organochlorine-DDT	*Pseudomonas aeruginosa, P. putida, Stenotrophomonas maltophilia, Flavimonas oryzihabitans,* and *Morganella morganii*	Green bean coffee (Coffea arabica) from Veracruz was supplied by the Mexican Coffee Council	[36]
Tetrachlorvinphos	*Stenotrophomonas malthophilia, Proteus vulgaris, Vibrio metschinkouii, Serratia ficaria, Serratia* spp. and *Yersinia enterocolitica*	Tetrachlorvinphos contaminated agricultural soil, Mexico	[37]
Chlorpyrifos	Bacterial strains	Rhizospheric andnon-rhizospheric soil contaminated with organophosphorous pesticide	[38]
Organophosphorous pesticide - malathion	*Staphylococcus aureus*	Strain obtained from National Collection of Industrial Microorganisms, Pune	[39]
Atrazine	*Enterobacter* spp., *Bacillus* spp., *Providencia* spp. and *Pseudomaonas* spp.	Soil contaminated with atrazine in Egypt and Saudi Arabia	[40]
Organochlorine	Actinomycetes	Organochlorine contaminated soil	[41]

In the present scenario, the problem of xenobiotics remediation can be sorted out by the use of microorganisms that play a key role in the degradation of these xenobiotic compounds. An example of xenobiotics degradation is pentachlorophenol (PCP) that is a broad spectrum biocide, which has been used as fungicide, insecticide, herbicide, algicide, disinfectant and antifouling agent.

Bioreactors containing alginate immobilized along with Polyurethane foam immobilized PCP degrading *Flavobacterium* (ATCC39723) cells have been used to remove PCP from contaminated water. Absorption of PCP by Polyurethane immobilized matrix plays a role in reducing the toxicity of PCP (Fig. 3).

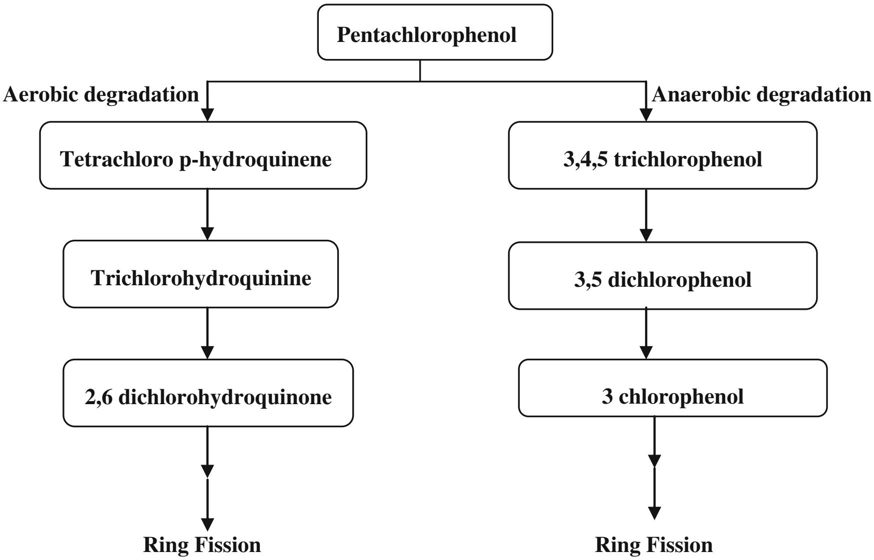

Fig. 3 Outline of aerobic and anaerobic degradation of pentachlorophenol

6 Conclusion

Xenobiotic compounds present a big problem in the environment but microorganisms play an important role in their bioremediation. From this paper, it has been clear that oil spilling is the world's greatest problem but with the help of genetically modified microorganisms, these oil spills can be cleaned up within few days. So, from this review, it may be concluded that microbial degradation is an important tool for the remediation of different xenobiotic compounds.

Acknowledgements Author would like to thanks Prof. A.K. Bhatia, HOD and Prof. Anoop Gupta, Director, Dept. of Biotechnology, GLA University to encourage during this work.

Conflicts of Interest Author declares no conflict of interest.

References

1. Gursahani YH, Gupta SG (2011) Decolourization of textile effluent by a thermophilic bacteria *Anoxybacillus rupiensis*. J Pet Environ Biotechnol 2:111
2. Sridevi V, Lakshmi MVVC, Swamy AVN, Rao MN (2011) Implementation of response surface methodology for phenol degradation using *Pseudomonas putida* (NCIM 2102). J Bioremed Biodegrad 2:121

3. Kumar KK, Prasad MK, Sarma GVS, Murthy CVR (2009) Removal of Cd(II) from aqueous solution using immobilized *Rhizomucor tauricus*. J Microbial Biochem Technol 1:015–021
4. Sinha S, Chattopadhyay P, Pan I, Chatterjee S, Chanda P, Bandyopadhyay D, Das K, Sen SK (2009) Microbial transformation of xenobiotics for environmental bioremediation. Afr J Biotech 8(22):6016–6027
5. Agarwal N, Shahi SK (2015) An environmental cleanup strategy—microbial transformation of Xenobioti compounds. Int J Curr Microbiol Appl Sci 4(4):429–461
6. Varsha YM, Naga Deepthi CH, Chenna S (2011) An emphasis on xenobiotic degradation in environmental cleanup. J Biorem Biodeg 11:1–10
7. Janssen DB, Dinkla IJT, Poelarends GJ, Terpstra P (2005) Bacterial degradation of xenobiotic compounds: evolution and distribution of novel enzyme activities. Environ Microbiol 7:1868–1882
8. Madigan MT, Martinko JM, Parker J (1997) Biology of microorganisms, 8th edn. Prentice Hall, Englewood Cliffs
9. Chowdhury S, Mishra M, Adarsh VK, Mukherjee A, Thakur AR, Chaudhuri SR (2008) Novel metal accumulator and protease secretor microbes from East Calcutta Wetland. Am J Biochem Biotechnol 4:255–264
10. Sepahi AA, Golpasha DI, Emami M, Nakhoda MA (2008) Isolation and characterization of crude oil degrading *Bacillus* spp. Iran J Environ Health Sci Eng 5(3):149–154
11. Mittal A, Singh P (2009) Isolation of hydrocarbon degrading bacteria from soils contaminated with crude oil spills. Ind J Exp Biol 47:760–765
12. Salam LF, Obayori OS, Akashoro OS, Okogie GO (2011) Biodegradation of bonny light crude oil by bacteria isolated from contaminated soil. Int J Agric Biol 13:245–250
13. Darsa KV, Thatheyus AJ, Ramya D (2014) Biodegradation of petroleum compound using the bacterium *Bacillus subtilis*. Sci Inter 20–25
14. Ghazali FM, Abdul Rahman RNZ, Salleh AB, Basri M (2004) Biodegradation of hydrocarbons in soil by microbial consortium. Int Biodeterio Biodegrad 54:61–67
15. Raza C, Billal A, Jahan N (2010) Evaluation of biodegradation potential of bacteria in crude oil contaminated soil. Biologia 5(1&2):77–85
16. Sathishkumar M, Binupriya AR, Balk S, Yun S (2008) Biodegradation of crude oil by individual bacterial strains and a mixed bacterial consortium isolated from hydrocarbon contaminated areas. Clean 36(1):92–96
17. Khashayar T, Mahsa T (2010) Biodegradation potential of petroleum hydrocarbons by bacterial diversity in soil. Worl Appl Sci J 8(6):750–755
18. Mbachu AE, Onochie CC, Agu KC, Okafor OI, Awah NS (2014) Hydrocarbon degrading potentials of indigenous bacteria isolated from auto-mechanic workshops at Mgbuka-Nkpor, Nigeria. J Global Biosci 3(1):321–326
19. Thenmozhi R, Nagasathya A, Thajuddin N (2011) Studies on biodegradation of used engine oil by consortium cultures. Adv Env Biol 5(6):1051–1057
20. Namazi BA, Shojaosadati SA, Najafabadi HS (2008) Biodegradation of used engine oil using mixed and isolated cultures. Int J Env Res 2(4):431–440
21. Umanu G, Akpe AR, Omoikhudu AR (2013) Oil degradation assessment of bacteria isolated from used motor oil contaminated soils in OTA, Nigeria. Int J Adv Biol Res 3(4):506–513
22. Adebusoye SA, Ilori MO, Amund OO, Teniola OD, Olatope SO (2006) Microbial degradation of petroleum hydrocarbons in a polluted tropical stream. J Am Sci 2(3):48–57
23. Geetha SJ, Joshi SJ, Kathrotiya S (2013) Isolation and characterization of hydrocarbon degrading bacterial isolate from oil contaminated sites. In: 4th international conference on environmental science and development—ICESD, APCBEE Procedia, Elsevier
24. Santhini K, Myla M, Sajani S, Usharani G (2009) Screening of *Micrococcus* sp. from oil contaminated soil with reference to bioremediation. Bot Res Inter 2(4):248–252
25. Okoh AI (2003) Biodegradation of Bonny light crude oil in soil microcosm by some bacterial strains isolated from crude oil flow stations saver pits in Nigeria. Af J Biotech 2(5):104–108
26. Jesubunmi CO (2014) Isolation of oil—degrading microorganisms in spent engine oil—contaminated soil. J Biol Agric Healthcare 4:191–195

27. Khan JA, Rizvi SHA (2011) Isolation and characterization of micro-organism from oil contaminated sites. Adv Appl Sci Res 2(3):455–460
28. Olajide PO, Ogbeifun LB (2010) Hydrocarbon biodegrading potentials of a *Proteus vulgaris* strain isolated from fish samples. Am J Appl Sci 7(7):922–928
29. Jobson A, Cook FD, Westlake DWS (1972) Microbial utilization of oil. Appl Microbiol 23:1082–1089
30. Mandri T, Lin J (2007) Isolation and characterization of engine oil degrading indigenous microrganisms in Kwazulu-Natal, South Africa. Af J Biotech 6(1):23–27
31. Kumari N, Vashishtha A, Saini P, Menghani E (2013) Isolation, identification and characterization of oil degrading bacteria isolated from the contaminated sites of Barmer, Rajasthan. Int J Biotech Bioeng Res 4(5):429–436
32. Sunita VJ, Dolly PR, Bateja S, Vivek UN (2013) Isolation and screening for hydrocarbon utilizing bacteria (HUB) from petroleum samples. Int J Curr Appl Sci 2(4):48–60
33. Ismail HY, Ijah UJJ, Riskuwa ML, Allamin II (2014) Biodegradation of spent engine oil by bacteria isolated from the rhizosphere of legumes grown in contaminated soil. Int J Env 3 (2):63–75
34. Hamzah A, Rabu A, Farzarul R, Yussoff NA (2010) Isolation and characterization of bacteria degrading Sumandak and South Angsi oils. Sains Malaysiana 39(2):161–168
35. Olawale AK, Akintobi, OA (2011) Biodegradation of glyphosate pesticide by bacteria isolated from agricultural soil, vol 3(1), pp 124–128. http://www.sciencepub.net
36. Barragan-Huerta BE, Costa-Perez C, Peralta-Cruz J, Barrera-Cortes J, Rodriguez-Vazquez Esparza-Garcia F (2010) Biodegradation of organochlorine pesticides by bacteria grown in microniches of the porous structure of green bean coffee. Int Biodeter Biodegr 59:239–244
37. Ortiz-Hernández ML, Sanchez-Selinas E (2010) Biodegradation of the organophosphate pesticide tetrachlorvinphos by bacteria isolated from agricultural soils in Mexico. Rev Int Contam Ambient 26(1):27–38
38. Hindumathy CK, Gayathri V (2013) Effect of pesticide (Chlorpyrifos) on soil microbial flora and pesticide degradation by strains isolated from contaminated soil. J Biodegr Biorem 4(2):1–6
39. Akilandeswari K, Sona V (2013) Efficiency of *Staphylococcus aureus* in the degradation of an organophosphorous pesticide, malathion. J Pharm Sci Innov 2(6):13–21
40. El-Bestawy E, Sabir J, Mansy AH, Zabermawi N (2014) Comparision of the efficiency of different bioremediation technologies of Atrazine-contaminated soils. J Biorem Biodegr 5:237–243
41. Feuntes MS, Benimeli CS, Cuozza SA, Saezl JM, Amorosa MJ (2010) Microorganisms capable to degrade organochlorine pesticides. Curr Res Tech Educ Top Appl Microbiol Microbiol Biotech 1255–1264