MYCOREMEDIATION OF HEAVY METALS AND HYDROCARBONS CONTAMINATED ENVIRONMENT

Yosef Hamba[1*], Melkamu Tamiru[2]

[1]Africa-*ai*-Japan Project - JICA in Jomo Kenyatta University of Agriculture and Technology (JKUAT), Po Box 62000-00200, Nairobi, KENYA, [2]Collage of Natural and Computational Science, Stream of Microbial, Molecular and Cellular, Wollega University, ETHIOPIA.

[1] yosefhmb88@gmail.com

ABSTRACT

Biological treatment is the best method for remediating hydrocarbons and heavy metal contaminated environment by breaking down them into harmless substances. Mycoremediation is one of new technology which can be practiced with fungus for management of polluted environments. The apprehension over the perseverance, nature and presence of co-contamination of metals and polycyclic aromatic organic in the environment has increased due to their impact on the environment. Mixtures of harmful surplus are widely increased in the sites of unhygienic soil and groundwater that often varying concentrations. They are incorporated with brackish, carbon-based components, heavy metals, and dangerous compounds. There are various methods for the management of contaminated environment, these are: physical, chemical and biological. The main drawback of physicochemical approaches has been mainly owed to the high cost, low competence, limited versatility, and intrusion by other wastewater components and the handling of the excess generated. The biotic action of contaminated environment is an economically and ecologically attractive alternative to the present physicochemical methods of treatment. This review summarizes the recent developments, ideas on the mycoremediation of hydrocarbon and heavy metals contaminated environment that are environmental concern in risky places using fungi.

Keywords: Bioremediation, Bioaccumulation, Chromium, Fungi, Mush room

INTRODUCTION

Our biosphere is under constant threat from continuing man made activities which have negative effects over living and non-living on different natural eco-systems (Ramachandran and Gnanadoss, 2013). The exposed environment to heavy metals is hard for the life of living things because of their noxiousness, tenacious and non-degradable and continues contamination (Tam and Wong, 2000; Yuan et al., 2004). Industrial contaminants are produced from various processes, the amount and toxicity of waste released varies with its sources (Shen, 1999). According to Altaf et al., (2008) tannery sewages are categorized as the uppermost contaminants among all manufacturing wastes, for instance, Chromium (Cr) is very common contaminants. In India approximately 2000-3000 tonne of Cr discharges into the atmosphere once a year from tannery industries, with chromium concentrations ranging between 2000 and 5000 mg/l in the aqueous effluent equated to the recommended permissible discharge limits of 2 mg/l in public sewers (Ahameda and Kashif, 2014).

Unregulated waste of Cr-containing sewage both industrialized and non-industrialized countries has directed to the contamination of soil, sediment, surface and groundwater (Doenmez and Aksu, 1999). Heavy metals contamination is significantly affecting human being too the Ecosystems (Margesin and Schinner, 2001) and Petroleum hydrocarbons are mostly influencing due to the core sources of the energy, rapid industrialization, population growth and complete disregard for the environmental health. The population explosion in the world has brought unexpected soil and water pollution (Ricciardi, 1998) with the applications of new technology. However, it might be hard to have appropriate condition for life with the current and predicted trend of environmental pollution, if precise management is not applied (Kumar et al., 2011). The ultimate solution for pollution abatement is bioremediation which is the most efficient strategy to manage and recover the contaminated environment (Ahemad and Khan, 2011).

Biological remediation is the process of using living things (yeasts, fungi and bacteria) to depollute hazardous compounds (Vidali, 2001; Busetti, 2005; Strong and Burgess, 2008) and processed by microbial enzymatic actions to degrade the contaminants (Philip and Atlas, 2005 and Owabor et al, 2010). Though, characteristics, physical, chemical and environmental conditions; the component of the microorganisms' command the entire microbial degradation process (Oleszczuk and Baran, 2003).The merit of this technology is it uses relatively low cost, low-technology techniques (Abioye, 2011 and Sharma, 2012) and permanent solution as a result of complete mineralization of the pollutants (Perelo, 2010). It incorporates bio-stimulation, bio-augmentation, bioaccumulation, bio-sorption, phytoremediation and rhizo-remediation (Busetti, 2005; Rani et al., 2009; Zolgharnein et al., 2010; Akpoveta and Osakwe, 2010; Sharma, 2012).

Cadmium and Lead are not readily absorbed by microorganisms (Vidali, 2001); however, they can transfer the pollutants to another medium thus minimal exposure for living things (Gadd and White, 1993; Okoh and Trejo-Hernandez, 2006). Microorganisms can act on heavy metals by bio-sorption, bioleaching, bio-mineralization, intracellular accumulation, and redox-reactions (Nies, 1999; Lloyd, 2002; and Lloyd et al. 2005).

Heavy metals enter the environment by natural and anthropogenic means that includes: natural weathering of the earth's crust, mining, soil destruction, industrial expulsion, city overflow, sewages, and pesticide applications to plants and air pollution fallout (Ming-Ho, 2005). Large quantities of petroleum oils and petroleum products enter marine and terrestrial environments, causing serious long-term concern regarding all forms of life and natural resources. Petroleum hydrocarbons can enter the environment frequently and in large volumes via seepage from natural deposits that leads to the appearance of petroleum oil in marine environments, production, storage, and transportation, which involves a significant potential for the accidental release of petroleum hydrocarbons (Harbhajan, 2006). Petroleum and its product derived from petroleum used for different role in the life. Petroleum constitute the main source of energy for industry in and daily life, employed as a raw material in various products, such as cosmetics, paints, and plastics (Harayama et al., 1999).

Impacts of Hydrocarbons and Heavy Metals

Environmental contamination poses serious environmental hazards, including surface and groundwater impurity, and dangers to human health and safety (Balasubramaniam et al., 2007). Environmental contamination by heavy metals and hydrocarbons is consequently the most critical environmental problems as it poses significant impacts to the human health as well as the ecosystems (Adams et al., 2014). Intensification of agriculture and manufacturing industries has resulted in increased release of a wide range of contaminant compounds to the environment accordingly enforced for excess loading of hazardous waste has led to lack of clean water and turbulences of soil thus restricting crop production (Kamaludeen et al., 2003). Hydrocarbon that leaks in the form of petroleum products in to the environment and heavy metals from different sources have devastating effects on the biota of an environment through the food webs (Gibson and Parales, 2000).

Petroleum like all fossil fuels primarily consists of a complex mixture of molecules called hydrocarbons which are extremely poisonous to many organisms, including humans (Alexander, 1994). Oil tumbles and oil waste liquidated into the soils from different sources (refineries, factories or shipping contain venomous compounds) can be constitutes potential danger to plants and animals. According to the report of Clemente et al. (2001) hydrocarbon contamination of the air, soil, freshwater (surface water and groundwater) especially by PAHs (Polycyclic aromatic hydrocarbons/polyromantic hydrocarbons) has drawn public concerns because many PAHs are toxic, mutagenic, and carcinogenic. Some heavy metals are also dangerous to health or to the environment (e.g. mercury, cadmium, lead, chromium). They may cause corrosion (e.g. zinc, lead); some are harmful in other ways, for instance: arsenic may pollute catalysts (Thenmozhi, 2013). Some of these elements are actually necessary for humans in minute amounts (cobalt, copper, chromium, manganese, nickel) while others are carcinogenic, affecting, among others, the central nervous system (manganese, mercury, lead, arsenic), skin, bones, or teeth (nickel, cadmium, copper, chromium) (Abioye, 2011).

In the same to the heavy metal (mercury, lead, cadmium, copper), prolonged exposure to high oil concentration may cause the development of liver or kidney disease, possible damage to the bone marrow, and an increased risk of cancer (Lloyd. and Cackette, 2001 and Mishra, et al., 2001). Even though toxicity and the resulting threat to human health of any toxins are, of course, a function of concentration, it is well-known that chronic exposure to heavy metals and metalloids at relatively low levels can cause adverse effects (Castro and Méndez, 2008). According to Peterson the assessment of human exposure to contaminant chemicals in the environment can be measured by two major methods, each based on different data profiles, thus permitting the verification and validation of the information. The first approach involves environmental monitoring. That means, determining the chemical concentration scenario while the second methodology is based on estimations of exposure through the use of biomarkers (Peterson, 2007).

Though some heavy metals (Cu, Zn, Cr, Ni and Fe) are essential for the growth of microorganisms in trace amounts but they are toxic at high concentrations. Their addition in soil has been known to inhibit soil respiration, nitrogen mineralization and nitrification (Sobolev and Begonia, 2008). Heavy metals have also been implicated in the reduction of degradation of vegetable materials and can potentially limit the biodegradation of organic contaminants in the environment (Atagana, 2010)

Mycoremediation of Heavy Metals and Hydrocarbons

Mycoremediation is a process of using fungi to return an environment (usually soil) contaminated by pollutants to a less contaminated state (Asiriuwa et al., 2013). This new technology held promise for removing heavy metals and hydrocarbon contaminants from the land by channeling them to the fruit bodies for removal (Barbara, et al., 2010 and Okhuoya, 2011). Fungi are a diverse group of organisms and are ubiquitous in the environment. They have contributed a lot toward shaping human welfare since the beginning of civilization with their involvement ranges from natural ecology to industrial use.

ISSN: 2186-8476, ISSN: 2186-8468 Print
www.ajsc.leena-luna.co.jp
Leena and Luna International, Chkusei, Japan.
(株) リナアンドルナインターナショナル,筑西市,日本

Fungi are one of nature's most adaptable organisms in their structure, metabolism, ecology, and genomics. They are capable to grow under environmental conditions of stress; for instance: environment with low pH values, poor in nutrients and with low water activity. One of the primary roles of fungi in the ecosystem is decomposition, which is performed by the mycelium (Lawton and Jones, 1995) that mycelium conceals extracellular enzymes and acids that breakdown lignin and cellulose, the two main building blocks of plant fiber.

The key to mycoremedation is determining the right fungi species to target a specific pollutant (Harbhajan, 2006). It was evaluated as a waste management approach for Chromated copper arsenate (CCA) and Alkaline copper quaternary (ACQ)-treated wood waste using wood degeneration fungi that are major degraders of lignocellulose (Lamar et al. 1994). Fungi are the major degraders of the lignocellulose and hemicellulose components of woody biomass on the forest floor and wood structures. Wood decay fungi secrete enzymes and metabolites that degrade environmental contaminants. Mycoremediation is a cost effective technique, a natural process and does not usually produce toxic by-products and a permanent solution as a result of complete mineralization of the contaminants in the environment (Barbara, et al., 2010 and Thenmozhi, et al., 2013).

Fungi have proven to modify soil permeability and soil ion exchange and to detoxify contaminated environment. They have also demonstrated the removal of metals, degradation and mineralization of phenols and chlorinated phenolic compounds, petroleum hydrocarbons, polycyclic aromatic hydrocarbons, polychlorinated biphenyls, chlorinated insecticides and pesticides, dyes, biopolymers, and other substances in various matrices (Lloyd, 2002). The fungal mycelia have an additive advantage over single cell organisms by solubilizing the insoluble substrates through producing extracellular enzymes. Normally, fungi are capable of influencing metal transformation in several types of media such as industrial wastes, low grade ores and metal bearing minerals (Gadd, 2001). They have the ability to mineralize, release, and store various elements and ions and accumulate toxic materials (Irwin, 1996).

Many hydrocarbon-contaminated environments are characterized by low or elevated temperatures, acidic or alkaline pH, high salt concentrations, and high pressure (Margesin and Schinner, 2001). The extent of hydrocarbon biodegradation by bacteria, yeasts, and fungi is a function of the ecosystem and local environmental conditions. Bacteria and yeasts are predominant hydrocarbon degraders in the aquatic ecosystems, while fungi and bacteria are the main degraders in soil environments. White rot fungi are increasingly investigated and used in bioremediation because of their ability to degrade an extremely diverse range of very persistent or toxic environmental pollutants (Barr and Aust, 1994). They have been applied for biotransformation of pesticides, degradation of petroleum hydrocarbons and *lignocellulolytic* wastes in the pulp and paper industry (Adenipekun and Lawal, 2012). Yateem et al. (1998) reported that three white-rot fungi: *Phanerochaete chrysosporium, Pleurotus ostreatus, and Coriolus versicolor* were shown to have the ability to degrade oil in contaminated soil. The white-rot fungi are also efficient in polyethylene-degradation (Iiyoshi et al., 1997). *Schizopora paradoxa KUC8140* is a white rot wood degrader which has been reported as the tolerance of heavy metals and polycyclic aromatic hydrocarbons and dye de-colorization activity make this strain a potential candidate for mycoremedation commonly found in Korea (Min et al. 2015).

Leena and Luna International, Chikusei, Japan.
(株) リナアンドルナインターナショナル,筑西市,日本
ISSN: 2186-8476, ISSN: 2186-8468 Print
www.ajsc. leena-luna.co.jp

Figure1: Branched Oyster Mushroom: Role of fungi: breaking down plant and woody material; carbon based plant cell structures, such as cellulose and lignin, saprophytic fungi use their digestive enzymes to break down chemicals like hydrocarbons and pesticides; larger hydrocarbon chains into smaller pieces; extract and hyper-accumulate heavy metals, concentrating them in the fruiting body of the fungi (We can see the picture of mushroom).

Source: Leila Darwish:

http://earthrepair.ca/resources/bioremediation-types/mycoremediation/#prettyPhoto

Most studies (Singh and Gauba, 2014) have revealed that mushrooms can bioaccumulation heavy metals from metal contaminated soils and they are purifier of oil contaminated soils (Emuh, 2010), for instances, effective mush rooms with the heavy metals they can remove: *Galerinavittiformis* (Cu, Cd, Cr, Pb and Zn); *Marasmiusoreades species* (bismuth and titanium) and *Hypholomacapnoides* (Ti, Sr and Mn). *Phanerochaete chrysosporium*, *Agaricus bisporus*, *Trametes versicolor* and *Pleurotus ostreatus* amongst many mushrooms have been described in the decontamination of polluted sites; also *Lentinus squarrosulus*, *Pleurotus tuber-regium*, *P. ostreatus* and *P. pulmonarius* have been employed in bioremediation of contaminated soils both *in-situ* and *ex-situ in Nigeria (*Adenipekun and Lawal, 2012). *Phanerochaete chrysosporium NRRL 6361* and *Pleurotus pulmonarius CBS 664.97* were confirmed for their ability to grow under nonsterile conditions and to degrade various aromatic hydrocarbons in an aged contaminated soil that also contained high concentrations of heavy metals (D'Annibale et al., 2005).

ISSN: 2186-8476, ISSN: 2186-8468 Print
www.ajsc.leena-luna.co.jp
Leena and Luna International, Chkusei, Japan.
(株) リナアンドルナインターナショナル,筑西市,日本

Table 1. Removal/Degradation of Pollutants by Biomass of Mushrooms

Mushroom species	*Pollutants*	*Comments*	*References*
Pleurotus ostreatus	Cadmium	It possess biosorption capacity and mechanism of biosorption was observed	Tay et al. 2011
Fomes fasciatus	Copper (II)	Mushroom is efficient in biosorption of Cu (II) ions and hotalkali treatment increased their affinity for Cu(II) ions	Sutherland and Venkobachar, 2013
Pleurotus tuberregium	Heavy metals	Biosorb the pollutant of heavy metals from the soil artificially contaminated with some heavy metals	Oyetayo et al. 2012
Flammulina velutipes	Copper	Mushroom compost used as biosorbent for removing copper ions from aqueous solution	Luo et al. 2013
Pleurotus sajorcaju	heavy metal Zn	They biosorb the heavy metals	Jibran and Milsee Mol, 2011
Agaricus bisporus, Lactarius piperatus	Cadmium (II) ions	Wild *L. piperatus* showed higher removal efficiency on Cd(II) ions compared to the cultivated *A. bisporus*	Nagy et al. 2013
Pleurotus platypus,Agaricus bisporus,Calocybe indica	Copper, Zinc, Iron, Cadmium, Lead, Nickle	They are effective biosorbent for the removal these ions from aqueous solution	Lamrood and Ralegankar, 2013
Jelly sp., *Schizophyllum commune* and *Polyporous* sp	malachite green	99.75% (*Jelly* sp.), 97.5% (*Schizophyllum commune*), 68.5% (*Polyporous* sp.2) dye was degraded in 10 days	Rajput et al. 2011
Lentinula edodes	2,4dichlorophenol	Mushrooms degraded 2,4 dichlorophenol (DCP) by using vanillin as an activator	Tsujiyama et al. 2013
Coriolus versicolor MKACC 52492	PAH	Mushroom possesses ability to degrade PolyR 478 which decide its suitability to degrade PAH. *Ligninmodifying enzymes laccase, manganese* dependent *peroxidase* (MnP), and *lignin peroxidase* (LiP)was found to produce for degradation	Jang et al. 2009
Pleurotus ostreatus	Oxo Biodegradable plastic	Mushrooms degraded the plastic and grew on it.	da Luz et al. 2013
Pleurotus pulmonarius	crude oil	crude oil was degraded	Olusola and Anslem, 2010
Pleurotus pulmonarius	Radioactive Cellulosic based waste	Waste containing mushroom *mycelium* was solidified with Portland cement and then this solidified waste act as first barrier against the release of radio-contaminants	Eskander et al. 2012

Leena and Luna International, Chikusei, Japan.
(株) リナアンドルナインターナショナル,筑西市,日本
ISSN: 2186-8476, ISSN: 2186-8468 Print
www.ajsc. leena-luna.co.jp

Aspergillus flavus colonized and degraded chitosan-graft poly-methyl methacrylate film by 45% during 25 days of aerobic cultivation as the report of Prashanth et al., (2005). *Phanerochaete chrysosporium* attached to fibers of polyamide-6 and reduced 50% of the polymer's molar mass after 3 months (Klun et al., 2003). Of 15 species of white- and brown-rot fungi, Resinicium bicolor was shown to be the most effective fungus for the detoxification of ground waste tire rubber material prior to de-vulcanization (Bredberg et al., 2002).

Filamentous fungi are known to possess higher adsorption capacities for heavy metal removal (Singh and Gauba, 2014). Amongst the filamentous fungi Trichoderma and Mortierella species are the most common fungi isolated from the soil and *Aspergillus and Penicillium species* have frequently been isolated from marine and terrestrial environments have the ability to remediated contaminated environment (Thenmozhi, R., et al., 2013). Polyethylene, with a molecular weight of 4000 to 28 000, is degraded by the cultivation of *Penicillium simplicissimum* YK (Yamada et al., 2001). Enzymes of Mucorrouxii NRRL 1835 and Aspergillus flavus have produced changes in the mechanical properties and weight of disposable polyethylene bags (El-Shafei et al., 1998).

CONCLUSION

Remediation of hydrocarbon and heavy metals contaminated environment is a necessity in order to have a safe and healthy environment. Biological remediation of hydrocarbon and metal contaminated environment offers a better and more environmentally friendly technique. The biological treatment of contaminated environment has become an economically and environmentally attractive alternative as it does not leave behind daughter compounds which are more toxic to the environment than the parent compounds when compared to the physicochemical methods of treatment. Microorganisms play a crucial role in bioremediation of heavy metals from contaminated soils since they are easy to operate, do not produce secondary pollution and show higher efficiency at low metal concentrations. Fungal species can grow in different hazard condition that can enable them to remediate the environment that may not allow the growth of other organisms. Therefore, It is very important to screen fungal species which are effective to remediate soil and water environment contaminated with hydrocarbons and heavy metals. Also researchers should focus on the right fungi species by targeting on a specific pollutant to remediate the heavy metals and hydrocarbons contaminated environments.

REFERENCES

[1]. Abioye, O. (2011). Biological Remediation of Hydrocarbon and Heavy Metals Contaminated Soil, *Inst. Biol. Sc.*, Kuala Lumpur, Malaysia

[2]. Adams, G. O., Tawari-Fufeyin, P., Igelenyah, E., & Odukoya, E. (2014). Assessment of heavy metals bioremediation potential of microbial consortia from poultry litter and spent oil contaminated site. *Int. J. Env. Bioremed. & Biodegr., 2*(2): 84-92.

[3]. Adenipekun, C. O., & Lawal, R. (2012). Uses of mushrooms in bioremediation: A review *Biotechnology and Molecular Biology Review* Vol. *7*(3), pp. 62-68, online at *http://www.academicjournals.org/BMBR DOI: 10.5897/BMBR12.006 ISSN 1538-2273.*

[4]. Ahameda, M. N., & Kashifb, P. M. (2014). Safety disposal of tannery effluent sludge: challenges to researchers-*a review*. *5*(10): 0975-9492.

[5]. Asiriuwa, O.D., Ikhuoria, J.U., & Ilori, E.G (2013). "Myco-Remediation potential of

heavy metals from contaminated soil." *Bulletin of Environment, Pharmacology and Life Sciences*, *2* (5), 16-22

[6]. Akpoveta, O.V., & Osakwe, S.A. Determination of heavy metal content in refined petroleum products sold in Agbor metropolis, Delta state, Nigeria. *33rd International Conference of the Chemical Society of Nigeria*. Kuto, Abeokuta, Ogun State, Nigeria. 2010 pp10-16

[7]. Alexander, M. (1994). Biodegradation and Bioremediation. *Academic Press*, New York, 692.

[8]. Atagana, H. (2010). Bioremediation of co-contamination of crude oil and heavy metals in soil by phytoremediation using C*hromolaena odorata* (L) King and H.E. Robinson. *Earth and Environ. Sc., 215*: 261-271.

[9]. Balasubramaniam, A., Boyle, A., & Voulvoulis, N. (2007). Improving petroleum contaminated land remediation decision making through the MCA weighting process. *Chemosphere*, *66*: 791-798.

[10]. Barr, D., & Aust, S. (1994). Mechanisms of white rot fungi use to degrade pollutants. Environmental Science and Technology, *28*: 78 - 87.

[11]. Busetti, A., Heitz, M., Cuomo, S., Badder, P., & Traverse, M. (2005). Polycyclic aromatic hydrocarbons in aqueous and solid samples from Italian Wastewater Treatment Plant. *J Chrom. Chem. 11*(2):104-109

[12]. Castro, G., & Méndez, A. (2008). Heavy metals: Implications associated to fish consumption. *Environ. Toxic. and Pharm., 26*:263-271

[13]. Clemente, A., Anazawa, T., & Durrant, L. (2001). Biodegradation of polycyclic aromatic hydrocarbons by soil fungi. Brazilian Journal of Microbiology, 32:255-261.

[14]. Da Luz, J.M.R., Paes, S.A., Nunes, M.D., da Silva, M.C.S., & Kasuya, M.C.M. (2013). Degradation of Oxo-Biodegradable Plastic by *Pleurotus ostreatus*. *PLoS ONE*. *4*(8):69386.

[15]. D'Annibale, A., Ricci M., Leonardi V., Quaratino D., Mincione E., & Petruccioli M. (2005): Degradation of Aromatic Hydrocarbons by White-Rot Fungi in a Historically Contaminated Soil, *Biotechnology and Bioengineering, Inter-Science (www.interscience.wiley.com). DOI: 10.1002/bit.20461*

[16]. El-Shafei, H., El-Nasser, N., & Kansoh, A. (1998). Biodegradation of disposable polyethylene by fungi and Streptomyces species. *Polymer degradation Stabilization, 62*: 361-365.

[17]. Gadd, G. (2001). Metal transformation. In: Fungi in Bioremediation. Gadd G.M (Eds.) Cambridge University Press. Cambridge, 358-383.

[18]. Emuh, F. N. (2010). Mushroom as a purifier of crude oil polluted soil. *Inter. J. Sci. Nat*, *1*(2): 127-132.

[19]. Eskander, S.B., Abd El-Aziz, S.M., El-Sayaad, H., & Saleh. H.M. (2012). Cementation of bio-products generated from biodegradation of radioactive cellulosic-based waste simulates by mushroom. *ISRN Chemical Engineering, doi:10.5402/2012/329676.*

[20]. Gibson, D., & Parales, R., (2000). Aromatic hydrocarbon dioxygenases in environmental biotechnology. *Current Opinion in Biotechnology*, *11*: 236-243

[21]. Iiyoshi, Y., Tsutsumi, Y., & Nishida, T., (1997). Polyethylene biodegradation by white rot fungi. *In: Proceedings of the Ninth International Symposium on Wood and Pulping Chemistry, Montreal, Canada*, *38*:1-4.

[22]. Irwin, P.(1996). To clean up environmental spill, know your medium. Electrical World 37-40.

[23]. Jang, K.Y., Cho, S.M., Seok, S.J., Kong, W.S., Kim, G.H., & Sung. J.M. Screening of biodegradable function of indigenous ligno-degrading mushroom using dyes. Mycobiology. 2009; 4:53–61. doi: 10.4489/MYCO.2009.37.1.053. doi:10.4489/MYCO.2009.37.1.053

[24]. Jibran, A.K., & Milsee, Mol, J.P. (2011). *Pleurotus sajor-caju* Protein: A potential biosorptive agent. *Adv Bio Tech.*; *4:25*–27.

[25]. Kamaludeen, S., Arunkumar, K., Avudainayagam, S., & Ramasamy, K. (2003). Bioremediation of chromium contaminated environments. *Indust. J. Exper. Biol., 41:* 972-985.

[26]. Lamrood, P.Y., & Ralegankar, S.D. (2013). Biosorption of Cu, Zn, Fe, Cd, Pb and Ni by non-treated biomass of some edible mushrooms. *Asian J Exp Biol Sci*., *4*:190–195.

[27]. Luo, D., Yf, X., Tan, Z.L., & Li, X.D. (2013). Removal of Cu^{2+} ions from aqueous solution by the abandoned mushroom compost of *Flammulina velutipes*. *J Environ Biol*. *4*:359–365.

[28]. Min, B., Park, H., Jang, Y., Kim, J. J., Kim, K. H., Pangilinan, J., & & Choi, I. G. (2015). Genome sequence of a white rot fungus Schizopora paradoxa KUC8140 for wood decay and mycoremediation. *J.Biotech.*, *211*, 42-43.

[29]. Okhuoya J.A, (2011). Mushrooms: what they are and what they do. Inaugural Lecture Series 114, University of Benin.

[30]. Olusola, S.A., & Anslem, E.E. (2010). Bioremediation of a crude oil polluted soil with *Pleurotus Pulmonarius* and*Glomus Mosseae* using *Amaranthus Hybridus* as a test plant. *J Bioremed Biodegrad.*; 4:111.doi:10.4172/2155-6199.1000113.

[31]. Oyetayo, V.O., Adebayo, A.O., & Ibileye, A. (2012). Assessment of the biosorption potential of heavy metals by*Pleurotus tuber-regium*. *Int J Advanced Biol Res.*; *4*:293–297.

[32]. Kumar.A, Bisht.B., Joshi, V., & Dhewa, T. (2011). Review on Bioremediation of Polluted Environment: A Management Tool, *Int. J. Environ. Sc., 1*(6):0976 -4402

[33]. Lamar, R.T., Davis, M.W., Dietrich, D.M., & Glaser, J.A. (1994). Treatment of a pentachlorophenol-and creosote-contaminated soil using the lignin-degrading fungus *Phanerochaete sordida*: a field demonstration. *Soil Biol. Biochem*. *26*:1603-1611.

[34]. Lawton, J.H., & Jones, C.G. (1995). Linking species and ecosystems: organisms as ecosystem engineers. In: Linking Species and Ecosystems, C.G. Jones and J.H. Lawton, eds. Chapman & Hall, New York, pp. 141-150

[35]. Lloyd, J., Anderson, R., & Macaskie, L. (2005). Bioremediation of metals and radionuclides. In: Bioremediation: Applied microbial solutions for real world environmental cleanup. Atlas, R. and Philp, J. (eds). *ASM* Press, ISBN 1-55581-239-2, Washington, D.C. 294.

[36]. Lloyd, J. (2002). Bioremediation of metals: The application of microorganisms that make and break minerals. *Microbiology Today*, *29*:67-69.

[37]. Lloyd, C., & Cackette, T. (2001). Air and waste Management Association, *51*:805-847

[38]. Mishra, S., Jyot, J., Kuhad, R. C., & Lal, B. (2001). Evaluation of inoculum addition to stimulate in situ bioremediation of oily-sludge-contaminated soil. *Applied and environmental microbiology*, *67*(4), 1675-1681.

[39]. Margesin, R., & Schinner, F. (2001). Biodegradation and bioremediation of hydrocarbons in extreme environments, *Applied Microbiol. and Biotech.*, *56*:650-663

[40]. Ming-Ho, Y. (2005). Biological and Health Effects of Pollutants, Chap.12, CRC Press LLC, ISBN 1-56670-670-2, 2nd Edition, *Environmental Toxicology: Boca Raton*, USA.

[41]. Nagy, B., Măicăneanu, A., Indolean, C., Mânzatu, C., & ilaghi-Dumitrescu, M.C. (2013). Comparative study of Cd(II) biosorption on cultivated *Agaricus bisporus* and wild *Lactarius piperatus* based biocomposites. Linear and nonlinear equilibrium modelling and kinetics *J Taiwan Inst Chem E*. doi:10.1016/j.jtice.2013.08.013.

[42]. Okoh, A., & Trejo-Hernandez, M. (2006). Remediation of petroleum polluted systems: Exploiting the bioremediation strategies. *Afr. J. of Biotech.*, *5*(25): 2520-2525.

[43]. Oleszczuk, P., & Baran, S. (2003). "Degradation of individual polycyclic aromatic hydrocarbons (PAHs) in soil polluted with aircraft fuel." *Polish J. of Environ. Studies*, *12*: 431-437.

[44]. Owabor, C.N., Ogbeide, S.E., & Susu, A.A. (2010). "Degradation of polycyclic aromatic hydrocarbons: Model simulation for bioavailability and biodegradation". *Canad. J. Chem. Eng.*, *88* (2), 268-276.

[45]. Peterson, P. (2007). Assessment of Exposure to Chemical Pollutants in Food and Water, In: Mineral Components in Foods, Szefer P. and Nriagu J.O. (Eds), 413-431, *Taylor and Francis Group*, ISBN 978-0-8493-2234-1,

[46]. Boca, R., & Perelo, L. (2010). In situ and bioremediation of organic pollutants in aquatic sediments. Review: *J. of Hazardous Mater.*, *177*: 81- 89.

[47]. Philp, J., & Atlas, R. (2005). Bioremediation of contaminated soil and aquifers. In: Bioremediation: Applied Microbial Solution for Real- World Environmental Clean Up. Atlas, R. M., and Jim, C. P. (ed.) ASM Press, ISBN 1-55581-239-2, Washington, D.C., 139.

[48]. Prashanth, H., Lakshman, K., Shamala, T., & Tharanathan, R. (2005). Biodegradation of chitosan-graft polymethylmethacrylate films. *Int. Biodeterioration and Biodegradation*, *56*:115-120.

[49]. Rajput, Y., Shit S., Shukla, A., & Shukla, K. (2011). Biodegradation of malachite green by wild mushroom of Chhatisgrah. *J Exp Sci.*; *4*:69–72.

[50]. Singh A., & Gauba P. (2014). Mycoremediation: A Treatment for Heavy Metal Pollution of Soil, *Journal of Civil Engineering and Environmental Technology*, *1*(4), 59 – 61

[51]. Sobolev, D., & Begonia, M. (2008). Effects of heavy metal contamination upon soil

Leena and Luna International, Chikusei, Japan.
(株) リナアンドルナインターナショナル, 筑西市,日本
ISSN: 2186-8476, ISSN: 2186-8468 Print
www.ajsc. leena-luna.co.jp

microbes: lead-induced changes in general and denitrifying microbial communities as evidenced by molecular markers. *Int. J. of Environ. Res. Public Health, 5*(5):450-456.

[52]. Strong, P., & Burgess, J. (2008). Treatment methods for wine related ad distillery wastewaters: a review. *Bioremed. J., 12*: 70-87.

[53]. Sutherland, C, Venkobachar, C (2013). Equilibrium modeling of Cu (II) biosorption onto untreated and treated forest macro-fungus *Fomes fasciatus*. *Int. J. of Plant, Animal and Environment Sc.; 4*:193–203.

[54]. Tay, C.C., Liew, H.H., Yin, C.Y., Abdul-Talib, S., Surif, S., Suhaimi, A.A., & Yong, S.K.(2011). Biosorption of Cadmium ions using **Pleurotus ostreatus**: Growth kinetics, isotherm study and biosorption mechanism. *Korean J. Chem. Eng.; 4*:825–830.

[55]. Thenmozhi, R., Arumugam, K., Nagasathya, A.,Thajuddin, N., & Paneerselvam, A. (2013). Studies on Mycoremedation of used engine oil contaminated soil samples. *Adv. in Applied Sc. Res., 4*(2):110-118

[56]. Tsujiyama, S., Muraoka, T., & Takada, N. (2013). Biodegradation of 2, 4-dichlorophenol by shiitake mushroom (*Lentinula edodes*) using vanillin as an activator. Biotechnol Lett. ; 4:1079–1083. doi: 10.1007/s10529-013-1179-5. doi:10.1007/s10529-013-1179-5.

[57]. Yamada, O., Mukumoto, H., & Katsuyaya, Y., (2001). Degradation of polyethylene by a fungus, *Penicillium simplicissimum* YK. *Polymere degradation Stabilization, 72*:323-327.

[58]. Yateem, A., Balba, M., & Al-Awadhi, N., (1998). White rot fungi and their role in remediating oil-contaminated soil. *Environ. Int., 24*: 181-187.