REVIEW ARTICLE

NANOPHARMACEUTICALS AND BIOREMEDIATION

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ABSTRACT

Usefulness of nanotechnology is exploring for producing safer and appealing pharmaceuticals. Those devising with said technology has specific surface chemistries and properties, for achieving wished novel physicochemical properties. These being manufactured nanomaterials presented as nanopharmaceuticals bearing dissenting biological and chemical properties comparing their macro form. Comparing natural nanomaterials, manufactured nanomaterials may act differently conferring potential and novel benefits and concurrently may peril. Their dispersion and shading into environment from the composite material may or may not associate with aging and degradation. Major concern bobbing up from their dispersal and shading is fate and ecological consequences and pollution of aquatic system. This may be periling diverse aspects of human life and environment, and causing ecotoxicological effects perilng environment and ecology. Diverse remediation process adopting for nullifying ecotoxicological effects of nanomaterials in aquatic system. However, biological systems are receiving attentions for remediating it and process is termed ‘bioremediation’. This process be exploiting to adsorb or sequester pollutants and to remove them. Bioremediation process is considering as novel, improved and efficient methods for degrading and sequestering pollutants of water, seeded nanomaterials. Available literatures are unable to provide insight on nanopharmaceuticals and their bioremediation. In this regard, information collected and presented as a handy reference. This insight features on bioremediation of nanopharmaceuticals and has applicability in nullifying their ecotoxicological effects.

Key Words: bioremediation, ecotoxicological, effects, nanomaterials, nanopharmaceuticals, nanotechnology.

INTRODUCTION

Global technological competition and breakthroughs driven by science and engineering had been resulting amalgamation of features of nature and science at nanoscale. This is bearing foundation of new knowledge, innovation, and integration of technology. It stemming in production of nanomaterials, the novel materials and devices whose properties never envisioned before. Nanomaterials are devising with nanotechnology have potential in rendering products with novel properties in diverse domain.¹⁴

Usefulness of nanotechnology is exploring for producing safer and appealing pharmaceuticals, safe and more nutritious and appealing foods, and for protecting or remediating environment. In remediation of environment is through pollution prevention, treatment, and cleanup; combating long-term problems at hazardous waste sites; and replacing current practices for site remediation.¹⁴

Nanotechnology-based products are marketing as electronic items, stain-resistant clothing, self-cleaning glass, paints, sports equipment, biotechnology products, nanopharmaceuticals, transparent sunscreens, and so on. Introduction potentially of nanomaterial bearing products is broadening gradually and having expectation for enhanced importance in near future.¹⁴

Nanopharmaceuticals are the manufactured nanomaterials designed with specific surface properties and chemistries for achieving wished novel physicochemical properties. These confer potential and novel benefits concurrently may peril, as these may act differently, comparing natural materials. Possible benefits over possible risks of them remain unclear. These may have differing biological and chemical properties comparing their macro form. Thus may be periling so many aspects of human life and environment and their consequences on human and environmental health became a concerns. Bearing of ecotoxicological properties and poorly understood potential risks might escort unintended consequences like irreversible damage.¹⁵

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Questions/concerns on the safety issues of nanopharmaceuticals include their fate in human, their fate and ecological consequences, and so on. Major concern bobbing out is ecological consequences followed to their dispersion and shading into environment from the composite material may or may not associate with aging and degradation. These upon dispersion and shading into aquatic system pollute it 1-4.

Ecotoxicological effects of dispersed and seeded nanomaterials from composite nanopharmaceuticals peril environment and ecology. Reports on ecotoxicological effects are available while concerns intensifying possible impact on plants, animals, microorganisms, and ecosystems 6-12.

Nowadays, diverse remediation process adopting for nullifying ecotoxicological effects of nanomaterials. Amongst them biological systems are receiving attentions for remediating aquatic system. Use of biological system in remediation process of environment is termed as ‘bioremediation’ 13.

Bioresidement process be exploiting to adsorb or sequester pollutants and to remove them from water. It is considering as novel, improved and efficient methods of water purification be using for degrading organic pollutants of water 13.

Present work is insights bioremediation of nanopharmaceuticals. Laid information has applicability in complying issues adjoining use of nanotechnology and pollution abatement of nanopharmaceuticals.

**NANOPHARMACEUTICALS AND NANOTECHNOLOGY**

A material may have diverse optical, electrical, magnetic, mechanical and chemical properties at assorted size scales. Over past two decades, this desperate concept is stemming scientists and engineers in mastering the intricacies at nanoscale level. Manipulation of structures at the atomic level is developing newer technical methods for more precise and controlled production of novel materials and devices. These be terming as nanomaterials are devising with the nanotechnology. ‘Nanotechnology’ is the understanding and control of matter at dimensions between approximately 1 and 100 nanometres, where unique phenomena enable novel applications 1,4.

Integration of nanotechnology and pharmaceuticals synergizes effect of pharmaceutical mothering nanopharmaceuticals. The effort is to abreast improving performance of medications, cosmetics, delivery systems, and diagnostics. Improving performance is abreast in increasing efficacy, tolerability, specificity, stability, patient compliance, therapeutic index, and so on. In addition, it is in nullifying toxicities and improving marketability 1-4.

Enormous potential of nanotechnology bobbing up in devising nanopharmaceuticals is under extensive study. Pharmaceuticals containing nanomaterials presented as nanodoseage form, nanotherapeutics, and nanodevices. These having potential in revolutionising offering of device for drug targeting or site-specific controlled delivery, and presenting of differential device-activity in dissimilar physiological environments, under direction of an external operator or physician. In addition, efforts is presenting them as disinfectants, cosmetics, and biosensor or bio-tracer based diagnostic agent for detecting toxins, pathogens, volatile compounds, and organic components of body fluids; and for monitoring diseases 1-4.

Semi-biological nanodevices may be offering versatile therapeutic services demonstrating unitary biochemical activities. Nanodevices amalgamating imaging and therapeutic function can provide therapeutic intervention concurrent with prognostic information 1-4.

Novovesicles may be vesicular systems encapsulates drug in a cavity of polymeric membrane. Polymeric nanodevices with diverse functionality were being designing. Vesicular nanodevices have poor kinetic stability comparing nanoparticles 1-4.

Nanodevice systems are designing with diverse functionality. Type of process or technique and materials is bearing for wished physicochemical properties and wished therapeutic objective. Biodegradable and non-biodegradable polymers of natural or synthetic origin is using for deviseing them 1-4.

Adsorbing or grafting of molecules on surface of nanodevice modifies its surface property modifying interaction with intestinal mucosa. Ligand molecule like glycoproteins, antibodies or peptides confers targeting while hydrophilic molecules like polyethylene glycol improve transcytosis. Adsorbing, grafting, or coating of them with mucoadhesives improves gastric retention time 3,4,14-18.

**BEHAVIOUR OF NANOPHARMACEUTICALS**

Nanopharmaceuticals devised with specific surface properties and chemistries that were not likely to be observable with natural nanomaterials. Consensus on them is the engineered nanomaterials contained in it may act differently comparing natural one 1-6.

Entry of nanopharmaceutical in human body is through gastrointestinal (GI) -tract, skin and or lungs. Concern on their safety was rising with similar properties as comparable with pathogenic particles 12,15,20. Evidence exhibiting uptake and internalization of them by diverse type of mammalian cells, and their ability to cross the cell membrane are available 21-23. They were more likely to penetrate the skin unpredictably to significant extent 24.

Factors playing majorly in bearing of toxicity by nanopharmaceuticals are size dependency for their uptake, increased concentration and exposure time, and large surface area 25-28. In addition, their inhalation at elevated concentrations may cause inflammatory reactions in lungs and adverse effects in the nervous and cardiovascular systems 24.

Nanomaterials cause oxidative stress in the liver, harm the brain associated with higher Blood Brain Barrier permeability, and activate blood platelets leading to clot formation 27. Ferric oxide nanoparticles upon inhalation
may uptake by cells causing oxidative stress response at much higher level 29. While it upon internalization by cells leading to cell death and may persist in biological systems leading to potentially long-term effects. Possible long-term effects may due to mutagenic influence on organisms through DNA damage, lipid peroxidation, and in vivo oxidative protein damage 30.31. Internalization of dispersed C60 fullerenes results morphological changes in the vascular endothelial cells while at elevated concentrations could induce lethal effects and cytotoxic 32, 33.

Fate of nanomaterials in human was chiefly unknown 34. Amongst, paracellular or transcellular route, transport for particles across the epithelium of GI-tract, transcytosis involved in the uptake of them. Transcytosis is dependent on physicochemical properties of nanomaterials, physiology of the GI-tract, and animal model used for study 35. In addition, some aspects of GI environment and abrupt change in pH from stomach to intestine, disease state of the gut, and presence of other macromolecules in food may affect uptake of nanomaterials or possible toxicity 24.

Dispersal and shedding potential of nanopharmaceuticals depends on its dissolution potential. Said potential is influencing by not only properties of dissolution media but also quality and quantity, size or surface area, surface energy, surface morphology, and aggregation of nanopharmaceuticals. The characteristics of exposed environment, and the biochemical, physiological, and behavioural traits of the exposed organism and adsorbing species determines their biological and ecological fate and effects 36-38.

Environmental fate of seeded nanomaterials depends on their potentiality for aggregation-segregation and adsorption-desorption occurring during interaction among themselves and or with natural nanomaterials or macromaterials 39,41. Their aggregation potential in natural systems depends upon their particle size and physical processes like Brownian diffusion, fluid motion, and gravity. This potential also determines efficiency of their removal from environment 42.

The surface charge of nanomaterials plays dominantly in their adsorption processes that consequently modifies their nature 43-45. Their mobility can be modifying with coating and environmental conditions. Environmental conditions like composition of groundwater and hydrologic conditions responsible for facilitation or inhibition of contaminant transport bears for increasing/decreasing toxicity of transported contaminants 14-18, 46-50.

Proponents of nanotechnology and nanopharmaceuticals were reviewing concerns along with difficulties referring reliability on assessing potential utility and safety prior to their continuances. However, proponents on promising beneficial properties could hostile governments, damage ecology and environment leading to wreak havoc, and are becoming a hot topic 12, 51-53.

ECOTOXICOLOGY OF ENGINEERED NANOMATERIALS

Nanomaterials seeded from nanopharmaceuticals may accumulate in the environment can scupper negatively affecting stability of many aquatic ecosystems. In addition, can be peril human health and the environment. Human activities, use, industrial discharges, domestic effluents, and improper waste disposal practices are seeding nanomaterials from composite nanopharmaceuticals 14.

Seeded nanomaterials pollute the aquatic ecosystems and may be persistent. Persistency processes involves processes of their adsorption, desorption, immobilization and accumulation, and transformation and activation. Persistency can made them available to benthic organisms as well as organisms in the water column 54. Their persistence can scupper health and safety of human and wildlife 55-57.

Reports on ecotoxicological effects of manufactured nanomaterials were available 7. In addition, lab-scale report on uptake of some manufactured materials by fish, Daphnia magna, copepods, and other organisms were available. Raising peril being on reactivity of nanomaterials might affecting plants, animals, microorganisms, and ecosystems making up the basis of food chains 8-12. Some nanomaterial scupper humans and or environment may have damaging potentiality. Knowledge on impact of nanomaterials in the environment and on human health was still scarce 7, 56-58.

Nanopharmaceuticals high in lipids serve as the base of both pelagic and benthic food chains are categorised as persistent organic pollutants (POPs). POPs peril if persistent and enter the food chain may be carcinogenic. These pollutants may be classing as polycyclic aromatic hydrocarbons (PAHs), short and long chain alkanes, and Polychlorinated biphenyls (PCBs) 56-59.

Shorter and longer chain alkanes (< C10 and C20–C40 respectively) and PAHs are difficult to degrade 60. Phenanthrene (PHE) and fluoranthene (FLA) highly toxic pollutant belongs to PAHs 61. Nonchlorinated aliphatic and aromatic hydrocarbons are hydrophobic and pass very slowly to the aqueous phase liquid where microorganisms are active and use them as carbon source 62. The asphaltene of complex hydrocarbons contain nitrogen, sulphur and oxygen, are very resistant to microbial degradation 63, 64.

PCBs a worst pollutant is toxic and carcinogenic, widely distributed and slowly biodegraded in the environment. Their degradation is complex as many are of different forms. Some of monohydroxylated PCBs are potent endocrine disrupters. Whilst some metabolites of PCBs having a hydroxy group at meta or para position reported to be involved in developmental neurotoxicity 54, 65, 66.

Studies emphasizing peril of nanomaterials on health and environment, and assessing their life cycle were very infancy. Lack of data on said issue is detracting consensus. Their damaging potentiality may inaccessible due to lack of knowledge on dosage and follow-up of traditional risk analysis models. However, their unique physicochemical property complicates environmental risk assessment 67, 68.
Size-dependent adsorption reactivity of crystalline iron-oxide nanomaterials is responsible for conveying adsorbed pollutants like copper, mercury, and silver. Consequently is eliciting toxicity on algae, fungi, flowering plants, and phytoplankton.

**BIOREMEDIATION**

Bioremediation is a waste management technique involving use of organisms in removal or neutralization of pollutants from a contamined site. Alternately is a "treatment that uses naturally occurring organisms to break down hazardous substances into less toxic or non toxic substances".

The technologies of bioremediation can generally be classifying as in-situ or ex-situ. In-situ technology involves on-site treatment of pollutants, while ex-situ involves their removal from the site followed by off-site treatment.

Process of bioremediation may occur on its own calling natural attenuation or intrinsic bioremediation. Alternately may only effectively is occurring through addition of fertilizers, oxygen, etc. Added materials encourage growth of the pollution-eating microbes within the medium terming as biostimulation.

Worldwide the trees, grasses, herbs, and associated fungi and microorganisms have been using increasingly for remediating polluted sites. Phytoplankton critically controls the fate of POPs in the water column as are high in lipids and serve as the base of both the pelagic and benthic food chains. In some cases these uses to detoxify organic compounds.

Bioremediation using plants is ‘Phytoremediation’ and that using fungi is ‘Mycoremediation’. Phytoremediation ‘on the brink of commercialization’ is proposing often for bioaccumulation of metals. In Europe its market potential is still emerging and increasing rapidly while in United States the revenues progressing.

Mycoremediation follows decomposition of pollutant is performing by the mycelium of fungi. Mycelium reduces toxins in-situ by stimulating microbial and enzyme activity. Some fungi are hyperaccumulators, capable of absorbing and concentrating heavy metals in their fruit bodies. Microbial consortia exploited for degrading PAHs.

Oyster mushrooms reduce PAHs to non-toxic components in the mycelial-inoculated plots. Wood-decay fungi are more effective in degrading aromatic pollutants, as well as chlorinated compounds, components of certain persistent pesticides.

The algae is exploring in controlling and biomonitoring of organic pollutants in aquatic ecosystems. Green algae are investigating for bioaccumulation/biodegradation of organic xenobiotics. The algae are effective in hyperaccumulation of heavy metals as well as degradation of xenobiotics. Application of benthic microalgae in restoration of organic-polluted aquatic environment (sediments) is in primary stage.

Higher plants and bacteria are exploiting for bioextraction and bioremediation of heavy metals and organic pollutants. Bacteria, fungi, algae producing enzymes are capable of degrading harmful organic compounds by attacking and utilising them. They are effective in remediating pollutants of hydrocarbon unless polluted medium contains limiting nutrients like nitrate, phosphate, and microelements.

Some microorganisms can be degrading PCBs aerobically or anaerobically under diverse conditions. Dioxigenases aerobiocally degrade lower chlorinated PCBs via co-metabolism resulting complete mineralization through ring cleavage. However, orthochlorinated PCBs inhibit and inactivate dehydroxybiphenyl oxygenase, a key enzyme in the degradation pathway.

Brown algae *Caepidium antarcticum* and *Desmaretdia* sp. having ability to associate their exudates with PCBs. Uptake of PCBs congener 2,2',6,6'-tetrachlorobiphenyl, lipid assimilation, by *Stephanodiscus minutilus* (a phytoplankton) significantly altered by nutrient availability which subsequently affects transfer to *Daphnia pulecara* (a zooplankton). Exudates from brown algae *Ascophyllum nodosum* and *Fucus* sp. are able in incorporating organic compounds like amino acids, sugars and fatty acids in their lipid stores.

Some microalgae producing enzymes are capable of degrading harmful organic compounds transforming them into low toxic one. Benthic microalgae can remediate organically enriched sediments. *Scenedesmus obticus* GH2 (a microalgae) is used to construct an artificial microalgal-bacterial consortium. This isolated microbial consortium upon mixing with asphaltenes fastens and improves oxygen consumption degrading crude oil and asphaltenes. In addition, this in different amendments enhances significantly degradation efficiency of both aliphatic and aromatic hydrocarbons of crude oil. Another consortium of pre-isolated oil-degrading bacteria in association with three species of plants effectively remediates hydrocarbon.

Several microorganisms can metabolise the nonchlorinated aliphatic and aromatic hydrocarbons as sources of carbon, but due to their hydrophobicity they pass very slowly to the aqueous phase liquid where microorganisms are active. Marine organisms including phytoplankton can uptake and accumulate several chlorinated hydrocarbons. Consensus is that in bioremediation of organic contaminants such as PAHs oxygen plays key role and can proceed under aerobic and anaerobic conditions.

Two algal species, *Nitzschia* sp. and *Skeletonema costatum*, accumulates and biodegrades two typical PAHs, PHE and FLA. Accumulation and degradation abilities of *Nitzschia* sp. is more to *S. costatum*. Degradation of FLA by these species was slower making it more recalcitrant PAH compound. Removal efficiency of PHE-FLA mixture by these species is comparable or more comparing that of PHE or FLA alone.

An algal-bacterial consortium, *Chlorella sorokiniana* and *Pseudomonas migulae* (a PHE-degrading strain), degrades PHE under photosynthetic conditions without needing external supply of oxygen. This suggests...
microalgal populations driven by algaecide simultaneously. The marine diatom Monoraphidium braunii is of follow order and assimilate three pesticides copper sulphate, fluzasulfuron and dimethomorph and endosulfan ether. This suggests ability to oxidize naphthalene is widely distributed amongst the algae. Once in the aquatic environment, antimicrobials could cause up to one million intoxication cases and up to 20,000 deaths per year. Phyto remediation of pesticides using transgenic plants is emergent nowadays. Aquatic plants, Leman minor, Elodea canadensis and Cabomba aquatic can remove and assimilate three pesticides copper sulphate, fluzasulfuron and dimethomorph. Their uptake capacity is of follow order Lemma minor > Elodea Canadensis > Cabomba aquatic. Scenedesmus quadricauda is more effective in the removal of dimethomorph and pyrimethanil and isoproturon. The marine diatom Amphora coffeiformis consumes mesotriene resulting increase in its cellular density. Algae of Chlorococcus sp. and Scenedesmus sp. degrade α-endosulfan to endosulfan sulfate and endosulfan ether. The first is major metabolite and latter a minor metabolite. Freshwater systems located in urban or agricultural areas exposes microalgae to a multitude of toxicologically different pesticides. This could hypothesize in the appearance of resistant mutants. Thus will simultaneously determine arose of new morphological populations driven by algaecide-resistant clones.

BIOREMEDIATION BY GENETIC ENGINEERING

Nowadays genetic engineering had been using for improving bioremediation of heavy metals and organic pollutants. Expression of metal-binding proteins or peptides in plants and microorganisms enhances heavy metal accumulation and/or tolerance. Said ability of expression has great potential in removing heavy metals from contaminated aquatic ecosystems. In this regard, the plants either with bacterial or animal xenobiotic degrading genes has been successfully tried a transgenic approach of engineering. Genetic engineering can be creating genetically modified organism, potentially degrading diverse POPs and removing diverse toxic compounds.

Transgenic plants and associated bacteria constitute a new generation of genetically modified organisms for bioremediation. These transgenic organisms are developing to degrade or modify POPs. Transgenic algae and microorganisms mutated with bioluminescence genes could be using in biomonitoring of organic and inorganic pollution. Expression of the catalytic genes of PCB-degrading microorganisms is a key factor for biodegradation of PCBs. Transgenic plants expressing the bacterial xenobiotic degradation genes combine the advantages of both the systems. Firstly, more ability of biodegradation by bacteria secondly is high biomass and stability of plants for having an ideal system for in situ bioremediation of contaminants.

Transgenic Chlamydomonas cells express metallothionin, a metal binding protein. These cells grow at normal rates in the presence of lethal concentrations of cadmium accumulating five-fold more cadmium comparing wild type cells. Mixotrophy in cyanobacteria and microalgae can provide many competitive advantages over bacteria and fungi in degrading POPs. Bioremediation of pharmaceuticals, pesticides, and petrochemicals also done with gomeya/cow dung. Bioremediation of industrial pharmaceutical drugs had also been devised.

DEALING WITH THE UNCERTAINTY AND PERIL OF NANOTECHNOLOGY

Introduction and continuances of nanopharmaceuticals requires reviewing of its proponents. Their potential risks understood poorly. Underestimations of this might escort to unintended consequences like irreversible damage. However, advocated promising beneficial effect of nanopharmaceuticals could hostile governments or angry individual and damage humans and environment leading to wreak havoc and become a hot topic presently. Unavailability of data relating toxicity, exposure, and life cycle of their applications regulatory decisions were in a state of ambiguity. This level of uncertainty may be resulting in either forgoing benefits of nanopharmaceuticals bearing from too much regulation or scupper damages bearing from relaxed regulation. Contradictory reports highlighting toxicity, gaps in research, and possible testing strategies for nanomaterials were publishing. Contradicting opinions bearing with scarce scientific evidence based harmful/hazardous effects is the elimination for need to regulate these by
regulatory bodies and industry, and adoption of more proactive risk management strategies advocating by non-government organizations.  

Several government and non-government organizations had identified health risks and potential environmental consequences, and the importance for assessing it. Environmental consequences determine hazardous effects, fate and transport, and bioaccumulation of released/dispersed nanomaterials.  

Comparing other pharmaceuticals, nanopharmaceuticals have differing material, size, surface, and shape. Therefore, general claims cannot be making on associated health and other risks. Consequently, suggestions had been making to assess their risk and toxicity on case-by-case basis.  

Many factors can be influencing the bioremediation of PAHs includes temperature, oxygen, pH, seeding potential and ecotoxicity. Temperature considerably affects ability of the in situ microorganisms to degrade them. In most situations, contaminated sites will not be at the optimum temperature for bioremediation throughout the seasons of year. The solubility of PAHs increases with an increase in temperature. Their degradation potentiality is dependent on availability of optimum pH of contaminated sites.  

Combination of microbiological and ecological knowledge, and biochemical mechanisms are the essential elements for successful in situ and ex situ bioremediation using transgenic bacteria and microalgae. Molecular methods and metabolic and genomic information will help in identification and selection of mixotrophic species of cyanobacteria and microalgae with capabilities to degrade organic pollutants. In addition, also this will help in monitoring efficiency of bioremediation.  

CONCLUSION  

REFERENCES  

8. Lovern SB, Strickler JR, Klaper R, Behavioral and physiological changes in Daphnia magna when exposed to nanoparticle suspensions (titanium dioxide, nano-C60, and C60HxC70Hx), Environmental Science & Technology, 2007, 41(12), 4465-4470.  


Lyng SG, Price DJ, Birge WJ, Kilham SS, Effect of nutrient availability on the uptake of PCB congener 2,2',6,6'-tetrachlorobiphenyl by a diatom (Stephanodiscus michaudii) and transfer to a zooplankton (Daphnia pulicaria), Aquatic Toxicology, 2007, 83(1), 24-32.


Burrtt DJ, The polycyclic aromatic hydrocarbon phanathrene causes oxidative stress and alters polynuclear aromatic metabolism in the aquatic liverwort Riccia fluitans L, Plant, Cell & Environment, 2008, 31(10), 1416-1431.


Cummings SP, Bioremediation: methods and protocols, New York, United States: Humana Press; 2010.


Wu M, Chen L, Tian Y, Ding Y, Dick WA, Degradation of polycyclic aromatic hydrocarbons by microbial consortia enriched from three soils using two different culture media, Environmental Pollution, 2013, 178, 152-158.


Abhilash PC, Jamil S, Singh N, Transgenic plants for enhanced biodegradation and phytoremediation of organic xenobiotics, Biotechnology Advances, 2009, 27(4), 474-488.

Davies JS, Westlake DW, Crude oil utilization by fungi, Canadian Journal of Microbiology, 1979, 25(2), 146-156.


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ISSN: 2250-1177

CODE (USA): JDDTAO
Bioaccumulation

The role of algae in

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Water, Air, and Soil

for PAHs

Phenanthrene,

112.

109.

108.

106.

101.

100.

98.

Alli

Zhang S, Qiu CB, 

suspensions, Chemosphere, 2010, 79(2), 117

and removal of

Olette R, Couderchet M, Toxicity

and Phytoremediation of Pesticides: Recent Advances,

Hussain S, 

Durán

organochlorine contamination in the global environment.

Loganathan BG, Kannan K, Time perspectives of

General Microbiology, 1980, 116, 495

naphthalene by cyanobacteria and microalgae, Journal of

Biochemical and Biophysical Research Communications

degradation in soil,

Al

Soil Pollution, 2002,

and optimization of PAH

degradation by an algal

Muñoz R, Guieysse B, Mattiasson B 

Pollution Bulletin, 2008, 56(8), 1400

enriched from a mangrove aquatic ecosystem, Marine

Biotechnology


Hong YW, Yuan DX, Lin QM, Yang TL, Accumulation and biodegradation of phenanthrene and fluoranthene by the algae enriched from a mangrove aquatic ecosystem, Marine Pollution Bulletin, 2008, 56(8), 1400-1405.


Cerniglia CE, Gibson DT, Baalen CV, Algal oxidation of aromatic hydrocarbons: Formation of 1-naphthol from naphthalene by Agmenellum quadruplicatum, strain PR-6, Biochemical and Biophysical Research Communications 1979, 88(1), 50-58.


Seger M, Hernández M, Méndez V, Ponce B, Córdova M, González M, Bacterial degradation and bioremediation of


