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Phytoremediation of Polychlorinated Biphenyls: A Brief Review.

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ABSTRACT

Polychlorinated Biphenyl (PCB) remediation has become a matter of concern since it is a biohazard. The review summarizes the phytoremediation technologies to clean up the PCB contaminated sites efficiently and economically. The physical and chemical properties of these chemicals were understood. Their ill effects to animals, plants and environment were compiled together and the treatment strategies with the use of mainly plants and micro-organisms were summarized using the latest researches about the remediation of these chemicals. Social and ecological issues relating to PCBs were discussed in this review as well. The advantages of phytoremediation technology over chemical remediation technology as well as the limitations have also been discussed. The limitations of the current phytoremediation technologies has given way to further discussion and research on this topic.

Keywords: Polychlorinated Biphenyls, Phytoremediation, xenobiotics, rhizodegradation, bio-augmentation.

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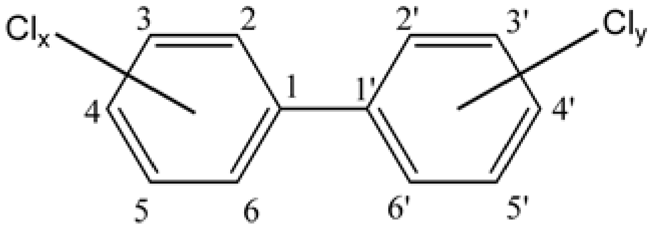
INTRODUCTION

Phytoremediation is the term used for the treatment of pollutant(s) by using mainly plants. There is an immediate need of efficient phytoremediation technology for the treatment of PCB contamination sites.

Polychlorinated Biphenyls (PCBs) are a class of Persistent Organic Pollutants (POPs) varying in the number of chlorine atoms (1-10) attached to their biphenyl rings [1]. They are represented by 209 individual derivatives with biphenyl rings chlorinated at different carbon atoms, known as congeners.



Due to their ability to enter food chains, volatility and other characteristics they constitute a substantial environmental and health risk for plants, animals and human beings [2].

Physical and Chemical properties

Polychlorinated Biphenyls have low solubility in water, are highly stable and tend to absorb on particulate phase. They are hydrophobic and lipophilic which makes it difficult for the plants to absorb them but they are susceptible to bio accumulate in animals especially in adipose tissues and breast milk [1]. They enter lipophilic membranes in the body and facilitate the absorption of hydrophilic toxic substances. Their toxicity levels differ with congeners. The aromatic ring stability is further increased due to the chlorine substitution; the degree of chlorination is inversely proportional to the solubility in water [3].

Uses and Occurrence

PCBs have been used as coolants in transformer oil, dielectric fluids and lubricants. Aroclor is the most common PCB commercially sold. These compounds, till today, have become a worldwide problem; they are omnipresent, including deep oceans and the atmosphere. Polychlorinated biphenyls (PCBs) contamination has resulted from mishandling and mal disposal practices of these chemicals. Moreover, they persist mainly with their ability to bio concentrate in the food chain which makes them a great hazard for environment and human health [4].

Ill-effects

PCBs are proved to cause reproductive, endocrine and neurological disorders, thyroid dysfunction, cognitive and motor deficits. Prenatal exposures are known to cause increased susceptibility to infectious diseases in early childhood [1]. Recent work by a group gathered by International Agency for Research on Cancer (IARC) identified PCBs as carcinogenic to humans.

Limitations

There are limitations in PCB phytoremediation

- Low bioavailability of PCB molecules due to their tendency to bind tightly to the soil organic matter, though use of fungal strains can help to overcome this limitation [9].
- The expression of catabolic genes leading to slowing down of biological degradation kinetic.
- Besides all the phytoremediation techniques which were found to be effective, the feasibility of large scale applications is limited because:
- PCB degrader microbes transfer to polluted soil is practically impossible because they are hydrophobic, use of transgenic bacteria may help in this case [22].

- Low level structural homologs like terpenes and phenolic compounds may be too little to facilitate the growth of the degrader micro-organism [23].

RESULTS AND DISCUSSIONS

PCB compounds are readily absorbed by soil and sediments. The critical factor affecting PCB remediation is the strong sorption of these molecules on soil and sediments. The ability to desorb these contaminants determines, in most cases, the effectiveness of remediation technologies [5]. Engineering based technologies are expensive so there is a need of remediation technologies which are environment friendly [4]. Established PCB treatment technologies such as incineration, landfill, and thermal desorption, and chemical dehalogenation can be costly (US $50–$1000 per ton) and usually involve dredging or excavation followed by disposal [6]. Plants run on solar energy and eradicate contaminants from soil and volatilize or utilize them thus making the remediation process very cost effective, much cheaper than chemical and physical means of remediation [7]. Recombinant DNA technology is used to express genes from heterotrophic organisms such as bacteria and mammals to increase plant tolerance and metabolism of organic chemicals [8]. E-waste dumped in land-fills constitutes towards pollution from PCBs which can be phytoremediated in the presence of methylated-cyclodextrins [6].

PCB degradation was tested in both vegetative as well as non-vegetative soil contaminated with PCBs. It was found that the level of PCBs was decreased a great deal in the vegetative soil. There are two main ways by which plants helps in biodegradation of PCB: 1. Rhizodegradation, i.e. the breakdown of organic contaminants by rhizosphere microbes, and 2. Uptake of PCB from soil with the help of roots and translocating to shoots.

The second process seems less significant due to low water solubility of PCB (high log ko/w rates, 5-7). The biomass of some plants rich in flavonoids and terpenes have been found useful as amendment to enhance PCB degradation in soil. PCB's water solubility decreases with increase in degree of chlorination. So only low chlorinated compounds will be translocated. Translocation rates depend on water solubility rather than their selective absorption by sprouts [9] and plant xylem system do not support active transport of PCB. Exceptions to low translocation rates have been identified by a Canadian research group in some weed species such as *Vicia cracca, Polygonum persicaria* and in zucchini, such as *Cucurbita pepo,* Huelster et al. have found a molecule that can increase the bioavailability of dioxins like PCB in both tissue and root exudates of zucchini by making them hydrophilic [10-14].

Phytoremediation enhances the presence of organic carbon in the soil and the degradation by rhizosphere is also increased. Soil micro biota especially rhizosphere microorganisms play an important role in soil-plant interaction [15]. Carbon sequestration, soil stabilization are other benefits of phytoremediation [7]. It is well known that the PCB-degrading bacteria do exist in contaminated soil environments, but the persistence of PCBs in soil indicates that bacteria are capable of metabolizing them only. The symbiosis between plant roots and rhizosphere (i.e., bacteria and fungi that are associated with the plant or soil) helps in removing PCBs from soil [2]. In plants, rate of metabolism is limited, the biphenyl ring is not cleaved and the final products have a tendency to accumulate in the cells or vacuoles. So the metabolic process for plants is not effective for phytoremediation. Although bacteria degrade the plant-derived monohydroxylated PCB metabolites, the trans-diols resulting from P450 oxygenation are less prone to bacterial degradation than the cis-diols deriving from bacterial aryl-hydroxylating deoxygenase reaction. Accumulation of toxic metabolites in plants and release of trans-diols hampers the efficient removal of PCBs by combined plant–rhizobacteria metabolism. Transgenic plants producing bacterial PCB degrading enzymes can be an effective option [16]. Plants also have a positive effect on the micro organisms' ability to degrade organic pollutants since it enhances the rhizosphere which is a favourable habitat for micro-organisms [17]. Some willow species like *Populus* were found efficient in absorbing heavy metal ions, organic compounds [PAH, PCB, TPH]. Studies show that salix [18], rice, alfalfa, and ryegrass tall fescue [6] can be a good tool for the remediation of soil. Use of ectomycorrhizal fungi has been effective in remediation of PCBs [4].

During rhizodegradation, plants sustain fungal and bacterial degrading activity through following processes:

- Plants diffuse oxygen in soil promoting the growth of aerobic microbes. Soil aeration is also improved by formation of air channels when roots die and decay and by direct root oxygen release.[19-21]

- Energy (for aerobic metabolism) and electrons (for anaerobic metabolism) is provided by sugars, alcohols and organic acids and thus plants can sustain bacterial communities.
- Phenolic compounds and terpenes in root exudates are structural analogues of PCB and can induce PCB degradation. [23]
- Biological surface active agents enhance pollutants' mobility [24].

Root filaments create micro zones with redox conditions to allow growth of both aerobic and anaerobic microbes together. Some mycorrhizal fungi such as *Radiigera atrogleba* and *Gautiera crispa* degrade PCB directly [25]. The size of a root system and its release capacity determines the sphere of influence of a plant species. It is preferred to use plants like willows and poplars with well-developed roots.

For organic compounds phytoremediation considers all processes related to plant metabolism that leads to diminishing pollutant concentration. Organ-o-chlorine pesticides can be phytoremediated by (a) phytoremediation in root zone through the activity of excluded enzymes or rhizopheric microorganisms, (b) Plant uptake and then metabolism or accumulation within the plant xylem or other tissues, and (c) volatilization of parental compounds and their metabolites. Willow and poplar trees have the required properties such as large biomass yield, extended and deep roots, high transpiration rates that make them proper for phytoremediation purpose [26].

So the PCB biodegradation can be enhanced by

Inducers employed in aerobic degradation

Xenobiotic metabolizing genes have developed into microbes which capable of metabolizing plants derivatives with a structure similar to PCB [27]. Thus the plant compounds which have structural similarity to xenobiotics could possibly provide an alternative to biphenyl hence enhancing the rate of PCB aerobic removal. Aerobic PCB biodegradation is also enhanced by plant terpenes such as carvone, limonene, flavonoids and salicylic acid [28-35].

Carbon sources and electron donor

The microbes require energy to degrade PBC. So the degradation can be enhanced by adding to cell culture specific organic substrate that provide dechlorinator microbes with suitable carbon source, as the main source of energy for aerobic microbes is carbon. For example: biphenyl, glycerol, xylose, glucose, pyruvate, methanol and acetone [36, 37]. In the case of anaerobic microbes, in PCB de-chlorination the loss of a chlorine substituent and its replacement by hydrogen enhances PCB degradation [38].

Mobilizing agents

To increase the bioavailability, some mobilizing agents can be added to the polluted soil. A promising approach is carried out in which selection and engineering of plants and microbial strains are done which are able to modify solubility and transport of organic materials in-situ, through exudation of bio surfactants.

Bio-augmentation

This refers to the addition of exogenous microbes in PCB contaminated soil and sediments. The cultures generally tend to lose their ability to de-chlorinate PCBs when transferred to another medium [39], and thus is not a very efficient method. The soil is repeatedly inundated with an active inoculum to improve the effectiveness of bio-augmentation and it also helps in aeration.

CONCLUSION

The use of PCBs can be reduced but cannot be stopped completely. They can cause various physical as well as genetic disorders in humans (being carcinogenic) which has become a matter of concern. Their property to biomagnify in the food chain and accumulate in adipose tissue can create conditions toxic conditions. The remediation techniques' effectiveness depend on the level of chlorination of PCB.

The phytoremediation process of PCBs in soil can be brought about by plants in three different ways: 1. Rhizodegradation - Degradation of PCBs by rhizosphere microorganisms especially bacteria and fungi which are found in the roots of plants, 2. Translocation by xylem tissues along with water to the shoot system and storage in plant vacuoles, 3. Xenobiotics - Molecular compounds found in the plant root which are analogous to PCBs and can induce biodegradation of PCBs. For these processes to be more effective, bioavailability of PCBs must be increased in soil as well as proper conditions must be maintained for the proper and continuous growth of the microorganisms (whether aerobic or anaerobic). Though limitations still exist, phytoremediation is considered a better and more environment friendly process for degradation of PCBs than other chemical and physical processes.

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