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Remediation Technologies for Soils Contaminated by Polychlorinated Biphenyls (PCBs): A Review

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Abstract

PCBs can be present in degraded soils and sediments when they have been specifically regulated for use. Because of their perceived value and outstanding physical-chemical properties, some 1.2 million tons of overall PCBs have been developed and commonly used in production such as coolants, transformer lubricants, pesticides, etc. This natural for PCBs to cause a number of individual, livestock, food, and laboratory harmful reactions in organisms. Microbes are the main players of PCB depletion, carried out under both aerobic and anaerobic conditions. Microbes and plants communicate strongly inside the rhizosphere. Microbes may promote plant growth under stressful conditions that are characteristic of contaminated soils. This study discusses the new insights that continue to arise from recent studies, especially regarding both the capacity for rhizosphere in bioremediation of PCBs and the deployment of simultaneous aerobic and anaerobic degradation processes.

Keywords: Phytoremediation; Contaminated soils and sediments; Polychlorinated Biphenyls (PCBs); Remediation technologies; *In situ*; *Ex situ*; Rhizoremediation

Introduction

Polychlorinated Biphenyls (PCB) are common chemical contaminants used from the 1930s to the 1980s globally. PCBs may be found in polluted soils and sediments, although their use has been strictly controlled. The most widely practiced abatement approaches are "cut and burn" and "find and incinerate," but different techniques are now emerging and may be more efficient alternatives. Remedial action is important for management of Polychlorinated Biphenyls (PCB) contaminated areas. Massive amounts of treatment techniques employed globally could be separated into two basic categories: incineration and non-incineration Polychlorinated Biphenyls (PCBs) is recognized as one of the first historically, and most common plastic contaminants (POPS) which were environmentally widespread [1].

Because of their appropriateness and excellent physical-chemical character traits, some 1.2 million tons of total PCBs were produced and widely used in industry, such as refrigerants, transformer lubricants, dielectric condensers, insecticides, etc. [2]. However, if most policymakers stopped their PCB production of old electricity and transformer systems by the late 1980s, it nevertheless persisted. More than half of those PCBs were computed to be still in use, encrypted or accumulated in dumping site. Close to one third were discharged into the environment in general, and only a little was destroyed. By bioaccumulation in plants and animals and bio magnification in the food supply chain, PCBs discharged from evaporation, spillage, illegal reusing, unsuitable removal and accidents posed high harmful effects to humans.

Due to their lifespan in the ecosystem, levels of PCBs will hardly decrease without remediation measures in most contaminated sites. Organizing PCB polluted sites and PCB-containing pollutants would be a central issue in the coming years because a large amount of PCBs that have ever been produced would remain in network, storage, or dumpsites [3]. Polychlorinated Biphenyls (PCBs) are a type of Persistent Organic Contaminants (POPs) that vary in the sum of chlorine atoms (1-10) connected with their biphenyl chains as shown in Figure 1.

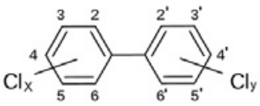

Figure 1: Chemical structure of Polychlorinated biphenyls.

Physicochemical properties of polychlorinated biphenyls

PCBs are highly difficult to extract from the soil and sediment matrices because of their good molecular stability, poor water solubility and high propensity to adsorb at particulate level. Their hydrophobicity and lipophilicity make them poorly taken in by plants but susceptible to animal aggregation, especially up breast milk and adipose tissue. PCB binding proteins vary in chemical, physical and toxicological properties, depending on the chlorine content and location. Using chlorine further stabilizes the aromatic frame by displacing electrons and increasing oxidation state. The more the molecule is chlorinated, the less water-soluble and responsive it gets. As shown in Table 1.

Properties of the most common PCB commercial mixtures and single congeners	
Physical states	Oil, viscous liquid, sticky resin
Water solubility (mg/L)	0.0027 (Aroclor 1260)-0.59 (Aroclor 1221)
Octanol-water partition coefficient (log ko/w)	4.7 (Aroclor 1221)-6.8 (Aroclor 1260)
Bio Concentration Factors (BCFs) in aquatic organisms	60 (penta-and esa-CBs in Ciliate protozoa)-274,000 (tri- and tetra-CBs in the freshwater fish feated minnow)

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Toxic Equivalency Factor (TEF) for mammals	0.00001 (2,3_4,4_5,5_-HexaCB)-0.1 (3,3_4,4_5-PentaCB)

Table 1: General Properties of Common PCBs.

At the moment PCBs are still a global issue. Because of their capacity to absorb soil, their poor solubility in water, their significant cohesion in the human tissues, environment, and their toxicity, they cause an environmental threat. They are becoming omnipresent environmental have never been used, such as deep oceans and polar regions [4]. Despite the overwhelming exposure to these substances, the possible effects of even small impact on human health are significant. PCBs have been shown to induce neurological, fertility, renal, dermal diseases as well as several different illnesses that can be related to rising immune responses. Epidemiological research indicates most of these symptoms are due to chronic PCBs use.

Further, the prospective neurotoxicity of PCBs in humans and in animals has been thoroughly researched. Access to some organochlorine compounds, like PCBs, can result in motor and cognitive deficits, in general participation in focus and concentration of problems, as well as inattention and impulsive symptoms during pre-adolescence, and in certain deficiency in motor development.

Impacts of PCBs on ecosystem and humans

It is very popular for PCBs to provoke a variety of human, wildlife, plant, and laboratory toxic reactions in animals. It could perforate the human body through skin exposure, PCB vapor inhalation and PCB-contaminated food ingestion [5]. The consumption of PCB infected foods, in particular fish, meat and other poultry products, remains the primary source of pollution while amounts of PCBs in foods have been diminished [6]. Which is further explained in Figure 2.

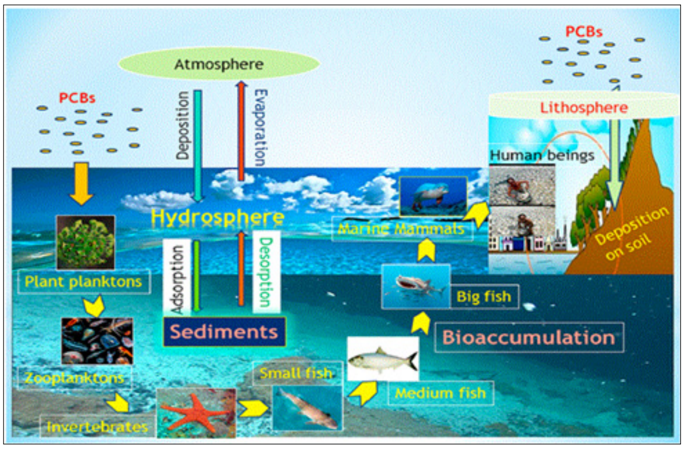

Figure 2: Transmission routes of PCBs in the ecosystem.

Remediation strategies for PCBs

Strong removal efficiency of such molecules is the significant factor affecting soil and sediment remediation of PCBs. In other cases the ability to desorb these contaminants suggests the efficacy of the treatment methods. PCB concentration levels in degraded soils/sediments are usually comparatively small, with the exception of heavily polluted area, generally less than 1% of the contaminated surface. For the treatment of large volumes, most traditional remediation techniques for PCB soil pollution and sediments, such as solvent extraction, land farming, temperature reduction or thermal alkaline decay, are unfit [7].

PCBs Sampling from Different Sources

PCBs were recognized in nonlinear sample matrices, for example in air, aquatic mammals, birds, benthic animals, water, dirt, sediments, trees, adipose human tissue, and much more. That is why it is important to collect the most suitable samples for each field assessment which should not be ignored. During field processing, pollution can occur, in particular from PCBs used in electrical equipment and construction materials. Similar methods are therefore needed to collect data from various sites. Assessment of PCBs in water is very difficult owing to their powerful tendency to move to the fatty environment and their lower solubility in soil [8]. Consequently, the amounts of PCBs identified in water samples are very low, and background pollution may impede the study, which requires careful prudence during sample extraction to increase its concentration.

Additionally, after the sampling, accumulation of PCBs in air can be assessed using filters or sampling devices. After that, the sediments and biota in the samples obtained for PCB study are the most preferably tested matrices.

Soil sampling of PCBs

Marine sediments can build up considerably higher quantities than surrounding water, especially with high organic carbon, PCBs and other hydrophobic compounds. The sampling strategy essentially varies with the intention to observe and the natural state of the area to be investigated. PCB sampling approaches involve fixed stratified sampling, fixed station sampling, and stratified random sampling. Ideally suited for controlling biological pollutants are muds or swampy sediments containing large proportion of refined products. Variety of grab samplings for sediment collection [9].

The concentration of PCBs in sediments generally shows the uneven distribution and thus could be mixed into pooled sediment with the overall number of grabs collected at a single location. Containers of stainless steel in catch samplers must be used to prevent potential damage from synthetic products that include plasticizers such as phthalates. Grab samplers usually capture the samples from the greater tiers of the sediments but as they move down they may scatter the unconcentrated flocks at the location between sediment and water. Multiple dulled arrays of shallow coring systems are required to collect the flocs.

Treatment Techniques for Remediation of PCBs

Remediation techniques and technologies are generally classified as *in-situ* and *ex-situ* techniques. Different physicochemical, natural attenuation, thermal and other combined methodologies are classified under these two techniques. As shown in Figure 3.

***Ex-situ* treatment techniques**

Biological techniques for treatment: A process of treatment with bioremediation is land farming, carried out at *ex-situ* sites within cells for bio treatment. Contaminated soil, mud, or loam are integrated into

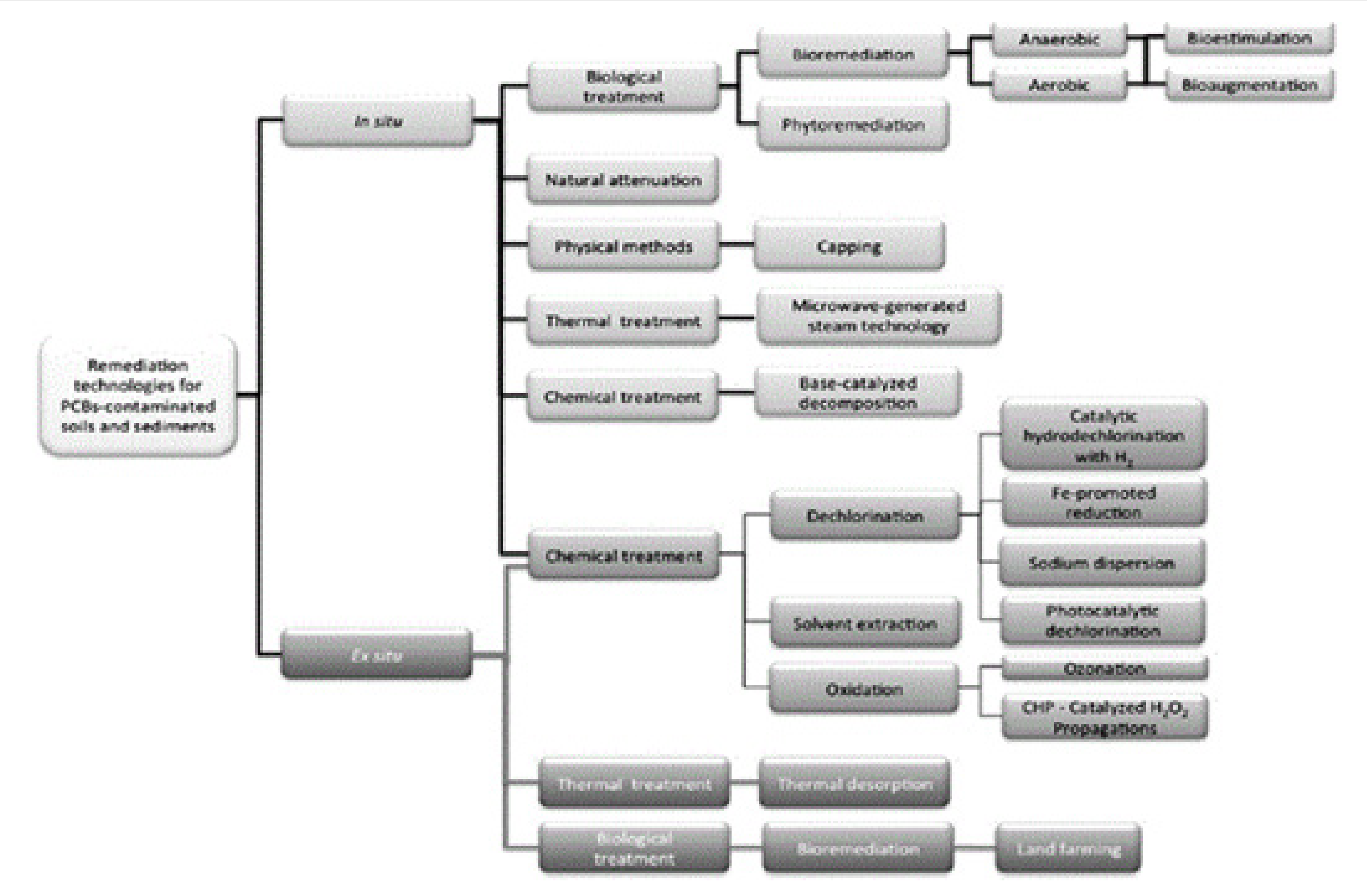

Figure 3: Remediation Techniques for Soils Contaminated with PCBs.

the surface of the soil and regularly transformed to aerate a combination.

Thermal techniques for treatment: Thermal desorption is an environmental cleanup technique which uses heat to improve the mobility of pollutants from the sample substratum (typically dirt, sludge, or filter cake) and extract it. As low heat thermal desorption at around 400 °C is used to treat moderate and high organic distillate pollutants such as solvents, diesel, gasoline, and greasing oils [10]. Polluted material is continuously pumped into a rotary kiln heating it to levels that are adequate to evaporate and ignite the toxins, removing these contaminants from the surface. The pollutants that become volatilized are then severely degraded thermally.

Chemical based treatment techniques: A catalytic method of hydrogenation i.e. Base-Catalyzed Decomposition (BCD) is used where chlorine ions are stripped from molecules then substituted by hydrogen atoms. Contaminated soil is blended with sodium hydroxide or sodium bicarbonate coupled with carrier oil that behaves both as a channel of suspension and a donor of hydrogen (Table 2). The mixture is heated in a rotary reactor for about 200 °C-400 °C, degrading significant percentages of the PCBs by trying to promote the hydrogenation of chlorines coupled with hydrogen separated from the carrier or donor oil [3].

***In-situ* treatment techniques**

Biological treatment techniques: Microbial PCB degradation is known to occur through two major routes: anaerobic and aerobic.

Technology	Development stage	Field testing	Cost indication	Clean up time	Effectiveness	Social Acceptability	Major Advantages	Possible disadvantages
Biological treatment Land farming	Practical stage	Limited	Moderate	Fast	Variable	Moderate	Biological process Amendments can be added to speed the degradation of the contaminants	Need to control soil conditions to optimize the rate of contaminant degradation.
Thermal treatment Thermal desorption	Practical stage	Substantial	High	Fast	High	Moderate	The efficiency of desorption can be greater than 99%. It is insensitive to contaminant concentration levels in the soil	Special equipment and conditions can be necessary to prevent formation of dioxins and furans

Table 2: *Ex-situ* Remediation Technologies.

Under anaerobic environments strongly chlorinated PCB can be de chlorinated to form lower chlorinated congeners that are more vulnerable to degradation and often recognized as the Pathway to Biphenyl Degradation. This involves insertion of O2 into the less chlorinated structure at adjoining unsubstituted carbons, accompanied by ring to create chlorinated benzoate [11].

Phytoremediation: Phytoremediation is based on plant use for the extraction, sequestration and/or detoxification of toxins from polluted site. Also in context of PCB there are three major processes involved: soil ingestion and aggregation in tissues of leaves and stems, phytodegradation i.e. enzymatic transition and rhizoremediation crop improvement of microbial function in the root region, increase of bioremediation, development of secondary metabolites such as carbohydrates, proteins, organic acids, different exudates and microbial vegetation [12]. Table 3 briefly summarizes these techniques.

Rhizosphere degradation

A root in the rhizosphere activates a multitude of microbial processes.

Technology	Development stage	Field testing	Cost indication	Clean up time	Effectiveness	Social Acceptability	Major Advantages	Possible disadvantages
In situ methods								
Biological treatment Bio remediation	Initial stage	Limited	Low to Moderate	Long	Variable	High	Natural process. Improves the overall quality and texture of soils. Different technologies are available and enhancements can be made to improve efficiency of nutrients phosphorus, chloride etc.	The rate of PCB removal may be orders of magnitude slower in nature than as established in laboratory because of mass transfer limitations

Phytoremediation	Practical stage	Substantial	Low to Moderate	Long	Variable	High	Natural process. Improves the overall quality and texture of soils. Plants provide groundcover and minimize soil erosion	Bioaccumulation depends on soils properties, including carbon content, soil pH and nutrient levels.
Natural Attenuation	Practical stage	Substantial	Low	Long	Variable	High	Natural biological, physical and chemical processes. It can be carried out with little or no site disruption	Intensive and long lasting Monitoring. It often requires more time to cleanup than others.

Table 3: *In-situ* remediation technologies.

The use of this stimulating action to improve the deterioration of various pollutants has been described as "rhizodegradation", "phytostimulation", "rhizoremediation" or "plant-supported bioaugmentation". Multiple plant species will thrive on PCB-contaminated soils and some species adjust the bacterial community composition in favor of PCB deteriorating indigenous communities with high degradation capacity (Figure 4).

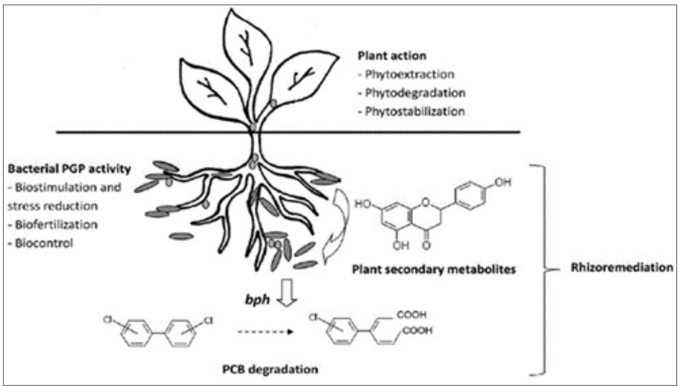

Figure 4: Interaction of Bacterial Species in PCB Contaminated Soil.

Implementation of Remediation Technologies

Since the technologies mentioned aim to kill or transform PCBs, function in somewhat specific ways and therefore have varying clean up periods, prices, product breakdowns and the climates trikes. They also have site-specific efficacy, since each technique focuses on the pollutants (mostly a mixture of them green and inorganic contaminants, particularly though they are polluted just because of specific congener mixtures of PCBs), age of the waste, soil type and geomorphological conditions, and other polluting variables.

Biological therapies typically, such as bioremediation; phytoremediation and natural attenuation are long-term techniques that have lower atmospheric costs and consequences than chemical, functional or thermal processes, and greater societal support. Its effectiveness is also less foreseeable. Life Cycle Assessment (LCA) demonstrates that bioremediation has little impact on PCB-polluted soil combustion, with the lowest environmental footprint for electrical filtration, particularly in terms of climate change and depletion of abiotic resources [13]. Biological therapies are conveniently paired with other methodologies for remediations. For example, it is of interest to combine phyto-extraction with several other soil therapies in "treatment trains" (use of different technologies whether simultaneously or sequentially); what can be helpful in situations where mixed pollutants necessitate more than one methodology to effectively mitigate sites [14].

In terms of phytoremediation, the ideal plant should have many characteristics: fast growing, solid biomass, deep roots, easy to harvest and should resist (and accumulate) toxins in its aerial and harvestable parts. It is crucial to use crops for organic pollutants such as PCB which enhance phytodegradation rather than phytoextraction and accumulation, given the concerns about transfer of pollution, crop degradation and the possibility of building up in the trophic chain. If the biomass produced from phytoremediation projects, e.g. as bioenergy, is valued, then one major downside (the long remediation period required) is less important and faster phytoremediation strategies could be envisaged, focused on incremental amplification of the pollutants rather than on short-term imposed removal. Further work on possible environmental impacts of genetically modified usage is required for PCB phytoremediation techniques.

Recommendations

During the past couple of years basic science work on PCBs has made many surprising findings. Primarily, ambient amounts of PCBs are no longer declining but are instead rising in certain regional areas. PCBs have discovered some unidentified frameworks to potentially cause health effects, instead of the regulatory variations developed. For over years toxicity work on PCBs highlights the need to update traditional perception of the public safety threats associated with PCBs. Taking into account inhalation as the second crucial route of exposure, the presumption of diet as the primary routes of reconfiguring exposure to PCBs. To date, a number of abatement systems have been developed in different forms to reduce prices, disposal times, degradation materials and environmental impacts. Every emerging technology effectiveness is site-specific, because it focuses on aging depletion, the form of soil or sediment, and geomorphological factors and other environmental impacts. Nevertheless, PCBs are complex toxins, so a detailed understanding of their physio-chemical properties is necessary in order to properly grasp their nature so transportation from which to choose the most suitable remediation strategies.

More recently, the use of multiple technologies has brought remarkable results in reducing PCBs. Accordingly, the active management of PCBs recognized not only by the introduction of appropriate remediation methods, but also by the general recognition that endorses the impacts of the respective remediation technology on human and environmental safety, which have not yet been achieved. Hence finding effective approaches to remediation is another key problem. To effectively destroy PCBs *in-situ* and *ex-situ* to assess their environmental impacts and risks related to the implementation technology, respectively [15].

Conclusion

Due to their toxicity, resilience and potential to bio accumulate, PCBs are the most important environmental dangerous pollutants governed by the Stockholm Convention and classified for priority action in the OSPAR List of Chemicals. PCBs obviously infest the environment through a variety of human activities, but it is difficult to identify its sources of emissions and transport media. Intake of infected biota PCBs introduces PCBs into the food chain. They easily sorped mineral and organic matter (solid phases) after PCB entry into the soil system. In certain instances, the potential to desorb such chemicals dictates the efficiency of the remediation methods. Successful findings were obtained under standardized laboratory conditions in bench-scale experiments. Most developments are still in the early stage of growth, and some deployment problems need more study. Further field results and tests on a pilot scale are important for assessing the feasibility of such techniques. There seems to be no single, portable technique relevant in contaminated soils and sediments for both *ex situ* and *in situ* techniques of PCBs. Increasing situation are special, so it has to weigh many factors.

The effective treatment of a location depends on the appropriate mitigation selection, design and adjustment technique based on the soil characteristics and system performance of the congeners present. More recent times, using remedial work in combination the so-called recovery trains and innovations are a positive solution to chronic pollutants present. Likewise, further research is needed to better understand the potential advantages and risks of these ecological biotechnologies, to assess the optimal conditions leading to careful implementation of PCB-remediation, and to resolve the issue of co-contamination. Important discoveries begin to evolve from recent studies, particularly concerning both PCB bioremediation rhizosphere capability and concurrent aerobic and anaerobic processes of deterioration. Though production of PCBs has been banned in most countries, there has been and still is substantial environmental pollution.

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