PHYTOREMEDIATION AND METHODS OF CONTROL FOR PCBS IN SOILS AND SEDIMENTS

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Abstract

Various remediation alternatives for PCB-contaminated soils and sediments are discussed including removal actions, containment strategies and sediment covers, dredging and placement of material in confined disposal facilities or hazardous waste landfills, soil washing, composting, and stabilization of soils by lime or other binding agents. One promising alternative is phytoremediation – using plants to help clean-up the environment. New results show that hybrid poplars can uptake, bind, and degrade PCB congeners found in Chicago air. Hybrid poplar trees can take-up and metabolize selected PCBs congeners in hydroponic systems through their roots, and also effectively scavenge airborne PCB congeners through their leaves and bark, especially for those congeners with more than two chlorine substitutions.

Introduction

There have been few full scale clean-up and control actions for PCB wastes in soils and sediments. These have been limited to dredging of sediments; excavation and removal of contaminated soils to incineration, hazardous waste landfill, soil washing or composting; and stabilization of contaminated soils with lime and kiln dust or other proprietary binding agents [1,2]. One promising alternative is phytoremediation of soils and sediments by engineering a system to cycle from anaerobic conditions (in which highly chlorinated congeners will be reductively dechlorinated by microbes in the root zone), followed by aerobic periods when lesser-chlorinated congeners will be oxidized and the biphenyl rings broken by soil microorganisms and the plants themselves. Such an engineered system could be accomplished using hybrid poplar trees (*Populus* spp.) whose roots can withstand low dissolved oxygen for extended periods of time (weeks to months) and which have been shown to uptake and degrade PCB congeners [3,4]. A dredging removal action is planned for the Indiana Harbor at East Chicago, Indiana, to be followed by disposal of contaminated sediments into a confined disposal facility in which hybrid poplar trees will be placed to scavenge volatile contaminants from air and degrade PCBs in the rhizosphere and root zone. In this paper, we report the results of uptake and degradation of semi-volatile (low molecular weight) congeners by hybrid poplar trees exposed to airborne mixtures of PCBs known to be present in Chicago air.

Materials and Methods

The fate of airborne volatile PCBs on hybrid poplar plants growing in hydroponic solution was studied. The poplars were exposed to semi-volatile PCB3, 15, 28, 52, and 77 through the air phase. The experimental system for exposure of the plants is shown in Figure 1. Compressed air flowed through a small screw-caped vial with 500μg of CB3, 200μg of CB15, 200μg CB28, 200μg of CB52, and 40μg of CB77 at 100 mL/min during exposure. The air flow blew PCBs into the upper flask of the system where PCBs could interact with the poplar. Glass rods were used as unplanted controls to check PCB volatilization loss and sorption to glass. Dead poplar controls were used to check the PCBs sorbed to the surface of (dead) poplar leaves and barks. After 10 days, all compartments of this system were sampled, extracted, and analyzed, including various poplar tissues, flasks, silicon sealant and septum, and the solution in order to obtain a mass balance.

Results ad Discussion

According to our results, almost all the CB3 (>99.5%), over 98% of CB15 and 28, 65% of CB15, and not more than 10% of CB77 were blown into the upper flask and became bound to poplar tissues in the aerial portion of the plant. The mass of each congener entering into the flask was related to its volatility from a mixed standard solution (Figure 1).

The mass balances and PCBs distribution (% of mass applied) in the exposed whole poplar, dead poplar controls and unplanted controls were calculated, and the results are expressed as the percent of PCB mass blown into the reactor for each congener. As shown in the table 1, leaves and barks captured a portion of the PCBs. The bark of the main stem and the secondary stems of either the dead or the live poplars, had a similar capability to capture PCBs. However, the live leaves captured significantly more CB15, 28, 52, and 77 than the dead leaves did, probably due to damage of the waxy layer in dead leaves. It was observed that PCBs could be taken up and transferred from leaves and the upper bark to the upper wood, but it did not translocate to the lower wood or to the roots of the live poplars. No hydroxylated metabolites were detected in the leaves during this brief experiment.

Due to the volatility and lipophilicity of the five PCB congeners, their affinities for the poplar tissues were different. As the most volatile analyte, a majority of CB3 was blown through the system and was not sorbed to the plants. However, over 50% of the CB15, 28, 52 and 77 which entered into the flasks were sorbed or taken up by the plants. In summary, hybrid poplar trees, as the candidate treatment system for uptake and remediation at dredged material disposal sites, not only can take up and metabolize such PCBs through their root systems, but also can effectively scavenge and take up airborne PCB congeners by sorption to leaves and bark, especially for those congeners with over two chlorine substitutions (3-4 chlorine substituents in this experiment).

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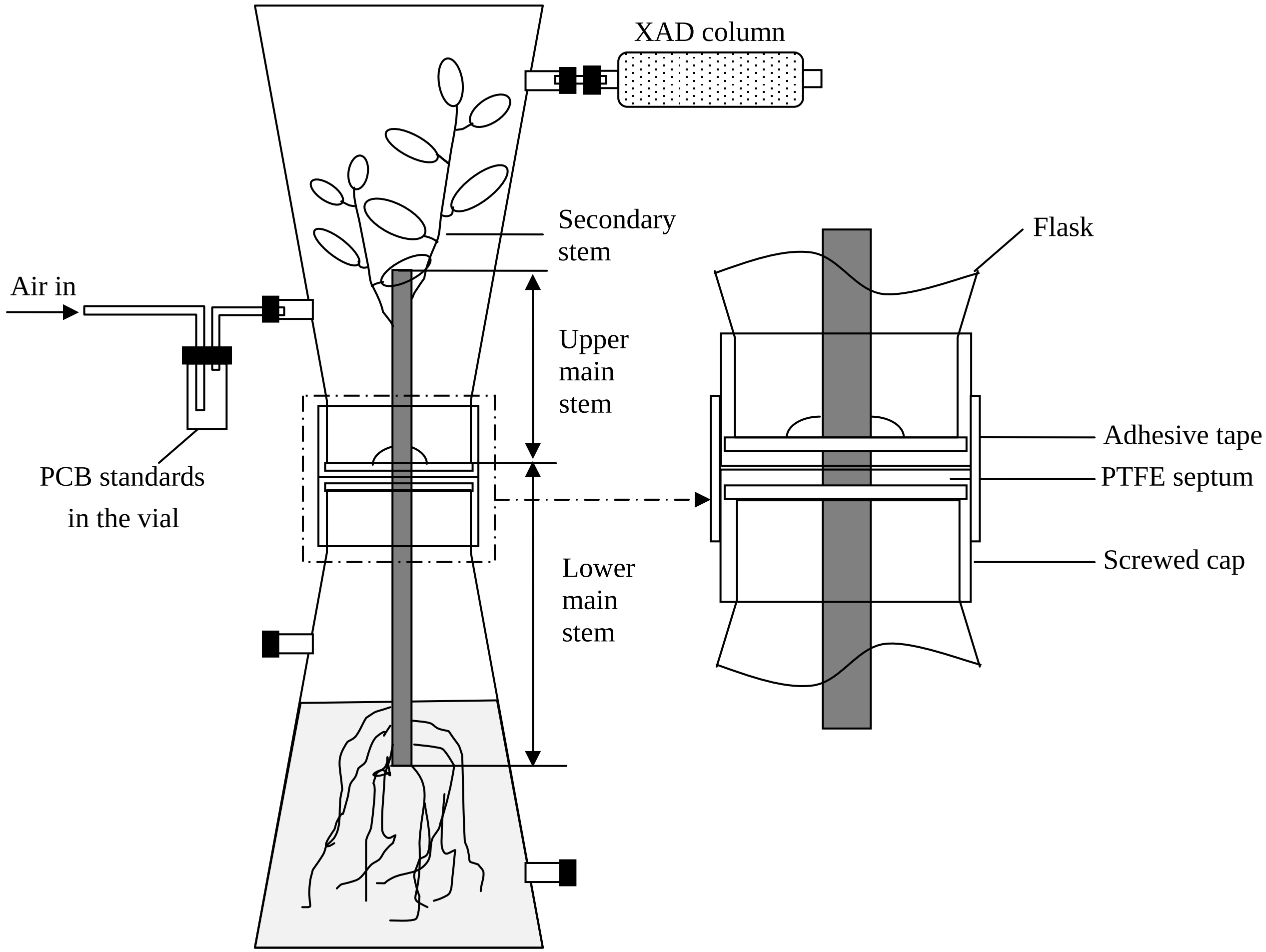

Figure 1. Experimental system for exposing hybrid poplar plants to airborne PCB congeners

Fig 1

Table: Mass balances and PCBs distribution (% of mass applied) in the Exposed Whole Poplar (EWP), Dead Poplar Controls (DPC) and Unplanted Controls (UPC) after 10 days[a].

Compound & Reactors	XAD	Glass	Silicon sealent	Solution	Leaves	Secondary stem	Upper bark	Upper wood	Lower bark	Lower wood	Roots	Total PCBs recovered [b]
PCB 3 EWP	76±10 [c]	n.d. [d]	5.6±2.9	n.d.	3.4±1.8	2.4±1.2	1.9±0.7	0.40±0.12	0.021±0.022	0.018±0.044	n.d.	89±12
DPC	61±3	n.d.	8.1±0.7	n.d.	6.9±3.2	1.6±0.4	5.4±0.6	n.d.	0.046±0.039	0.0033±0.0057	n.d.	83±5
UPC	96±13	0.025±0.050	2.0±0.8	n.d.								98±13
PCB15 EWP	22±5	0.10±0.10	2.2±2.2	n.d.	51±7	10±4	11±3	1.0±0.3	n.d.	0.069±0.170	n.d.	98±6
DPC	45±5	0.059±0.058	4.0±1.6	n.d.	25±5	9.1±1.5	11±2	n.d.	0.37±0.62	0.0097±0.0168	n.d.	94±8
UPC	95±8	0.066±0.082	2.0±0.9	n.d.								97±8
PCB28 EWP	23±6	0.21±0.10	2.5±2.5	n.d.	58±9	8.9±2.8	9.5±2.3	1.0±0.3	0.0021±0.0022	0.056±0.136	n.d.	103±8
DPC	40±6	0.27±0.17	4.9±2.9	n.d.	28±4	9.8±1.8	11±2	0.047±0.047	0.019±0.018	0.025±0.042	n.d.	94±5
UPC	96±8	0.17±0.11	2.3±0.9	n.d.								98±8
PCB52 EWP	19±4	0.26±0.13	2.7±2.6	n.d.	68±9	6.4±2.4	6.7±2.2	0.97±0.35	0.0025±0.0025	0.033±0.082	n.d.	104±8
DPC	48±8	0.52±0.42	5.0±2.9	n.d.	28±4	9.6±1.4	7.9±1.5	n.d.	0.014±0.015	0.019±0.031	n.d.	99±6
UPC	100±9	0.23±0.17	2.5±1.0	n.d.								103±8
PCB77 EWP	n.d.	0.61±0.4	0.22±0.38	n.d.	67.4±15	16.5±18	8.4±7.1	0.87±1.13	n.d.	0.036±0.089	n.d.	94±15
DPC	17±7	4.9±5.7	0.17±0.16	n.d.	52±17	18.7±2	1.5±0.5	n.d.	n.d.	n.d.	n.d.	94±27
UPC	93±32	5.6±5.8	2.2±1.8	n.d.								100±31

[a]: Results expressed as the percent of PCBs blowing into the reactors. [b]: The summation of different compartment. [c]: Mean value ± standard deviation, for Exposed Whole poplars and Unplanted Controls, n=5, for Dead Poplar Controls, n=3. [d]: non-detectable.