Mitigating Airborne PCB Emissions from Sediments with Black Carbon Materials and PCB-Degrading Biofilms

Project 5’s long-term goal is to provide environmental science and engineering solutions to decrease the flux of airborne PCBs at Superfund sites. Our objective is to develop novel synergistic coupled sorptive and reactive black carbon materials (e.g., biochars) containing aerobic PCB-degrading biofilms and evaluate the efficacy of these materials to remove LC-PCBs from sediments under variable salinity, temperature, and dissolved oxygen concentrations. We will do this by:

1) Optimizing tailored black carbon materials with sorptive and reactive properties toward LC-PCBs and the ability to host aerobic PCB-degrading biofilms.

We hypothesize that black carbon materials can be tailored as delivery vehicles for aerobic PCB-degrading microorganisms. Experiments are underway to determine the efficiency with which Paraburkholderia xenovorans strain LB400 cells form biofilms on the surfaces of a variety of black carbon materials such as granulated activated carbon and biochar. Results are expected in the coming weeks and will be described in a future progress report.

2) Evaluating the performance of black carbon materials containing aerobic PCB-degrading biofilms to lower LC-PCB concentrations in water and air under relevant environmental conditions.

Project 5 Trainees have developed and conducted aerobic, time-series PCB biodegradation assays in lab-scale bioreactors using Paraburkholderia xenovorans LB400 as a candidate PCB-degrading bioaugmentation strain. The biodegradation assays screened for all 209 PCB congeners using GC-MS/MS Triple Quadrupole technology in collaboration with the ISRP Analytical Core. Quality assurance and quality control (QA/QC) criteria were developed to ensure rigor and transparency of the experimental results. These criteria included use of surrogate and internal standards, evaluation of NIST-certified standard reference material, and development of a method-specific limit of quantification (LOQ) by analyzing method blanks with every batch of samples.

The biodegradation assays developed by Project 5 Trainees were conducted both in the...
absence and presence of sediment gathered from a PCB-contaminated wastewater overflow lagoon in Altavista Virginia. In absence of sediment, strain LB400 degraded 76% of total PCBs in 1 week and biodegraded congeners spanning all homolog groups contained in commercial PCB mixture Aroclor 1248, up to and including hexachlorobiphenyls. In presence of PCB-contaminated sediment, LB400 biodegraded just 7% of total PCBs in 1 month and acted upon only mono- and di-chlorinated PCB congeners. Although these experiments clearly illustrate how aerobic microbial PCB biodegradation is limited in sediments by a lack of bioavailability / bioaccessibility to PCB molecules, the mono- and di-chlorinated PCBs degraded are among the most volatile of the PCB congeners. These findings reinforce the hypothesis that LC-PCBs are primary targets of aerobic PCB-degrading microorganisms and support the hypothesis that the activity of aerobic PCB-degrading bacteria can potentially decrease PCB volatilization from sediments. These findings also underscore the need for PCB bioremediation techniques that address the “bioavailability bottleneck”.

Another set of PCB biodegradation assays were conducted in the presence of Altavista sediment amended with saponin, a plant-derived biosurfactant, and poplar tree root extract. The goal of including these amendments was to test whether they could increase the bioavailability / bioaccessibility of PCB molecules to the LB400 cells by increasing the aqueous concentration of total PCBs via desorption from the sediment particles. Previous studies have shown that saponin enhanced PCB biodegradation in PCB contaminated sediment. Root exudates contained in root extract have also been shown to exhibit a biosurfactant effect. Project 5 Trainees also tested whether the amendments helped to maintain viable cell concentrations over the month-long incubation period by acting as an auxiliary or diauxic substrate. During the biodegradation assays, saponin significantly (p < 0.05) enhanced aerobic biodegradation of di- and tri-chlorinated congeners whereas poplar tree root extract did not have a significant effect on aerobic PCB biodegradation. Both saponin and plant root extract helped boost cell viability over the course of the incubation period but neither effect was significant (p > 0.05), relative to the unamended live cell treatment. Another biodegradation assay is being conducted to determine the concentration of saponin which most efficiently enhances PCB biodegradation by LB400.

3) Scaling up production of biofilm-coated black carbon materials and demonstrate the feasibility of decreasing airborne PCB flux from contaminated sediments at the mesocosm-scale.

We hypothesize that production of novel black carbon materials containing PCB-degrading biofilms can be scaled up and effectively applied in laboratory-based mesocosms. Project 5 Trainees have isolated an additional bioaugmentation candidate that is native to the Altavista sediment. A Rhodococcus sp. was isolated from a “simulated lagoon” using isolation chip (iChip) technology. The Rhodococcus sp. can grow on biphenyl crystal as the sole carbon and energy source in the same growth pattern as LB400. The PCB-biodegradation capability of this bioaugmentation candidate is currently being evaluated in an ongoing biodegradation assay. Results of this experiment are also expected in the coming weeks and will be described in a future progress report.

Recent Publications:

Ewald JM, Humes SV, Martinez A, Schnoor JL, Mattes TE. Growth of Dehalococcoides spp. and increased abundance of
reductive dehalogenase genes in anaerobic PCB-contaminated sediment microcosms, (link is external) [3] Environmental Science and Pollution Research International, 2020 March; 27(9); 846-8858, PMCID: 3651356-019-05571-7, [Project 5]

Metabolic flexibility of SUP05 under low DO growth conditions(link is external) [4]. Environmental Microbiology, Epub. DOI: doi.org/10.1111/1462-2920.15226 PMID: 32893469 [Project 5]

Datasets:
Bako, C.M.; Mattes, T.E.; Marek, R.F.; Horneck K.C.; Schnoor J.L. - Biodegradation of PCB Congeners in Wastewater Lagoon Sediment(link is external) [5] (Dataset), [Project 5, Analytical Core]

Project Leader: Tim Mattes, PhD
Dr. Mattes is a Professor in Civil and Environmental Engineering at the University of Iowa. He is an expert in environmental microbiology and biotechnology, and molecular microbial ecology, will be responsible for the overall direction and management of Project 5. He will be principally responsible for the work described in Aims 2 and 3, where the black carbon materials with biofilms will be tested under different environmental conditions.

Jerald L. Schnoor, PhD, PE, Co-Investigator
Dr. Schnoor has considerable experience as the Editor-in-Chief of Environmental Science and Technology, and serves as the Chair of the EPA-ORD Board of Scientific Counselors. Dr. Schnoor is an international leader in the field of phytoremediation and has expertise in developing super-sorbent biochar materials for use in remediation. Schnoor will actively participate in the design of laboratory experiments for Aim 1, where he will develop biochar materials from different feed stocks and under different pyrolysis conditions. In 2019 Schnoor received the American Chemical Society Award for Creative Advances in Environmental Science and Technology for pioneering the science and practice of phytoremediation.

Andres Martinez, PhD, Co-Investigator
Dr. Martinez has expertise in analytical chemistry and passive sampling approaches for detection of PCB in air, pore water and sediments. Andres will develop the materials and methods for the Aim 2 passive sampler experiments as well as the PCB passive samplers in the Aim 3 mesocosm experiments. In addition to supervising and participating in activities relevant to this ISRP project, he will work closely with ISRP researchers to coordinate the overall project, design experiments, analyze data, and disseminate experimental findings.

Greg Lefevre, PhD, Co-Investigator
Dr. LeFevre has expertise in fungal biotransformation processes and development of synergized biological-aboricotic surface mediated redox reactions. He will contribute this expertise in the Aim 1 experiments with developing fungal and bacterial biofilms on biochar surfaces and investigating the synergistic combinations between reactive black carbon surfaces and microorganisms in the context of PCB biodegradation.

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Webmaster: david-purdy@uiowa.edu
Supported by the NIEHS Superfund Research Program