Remediation of Soils and Sediments Contaminated with Organic Compounds using Biochar

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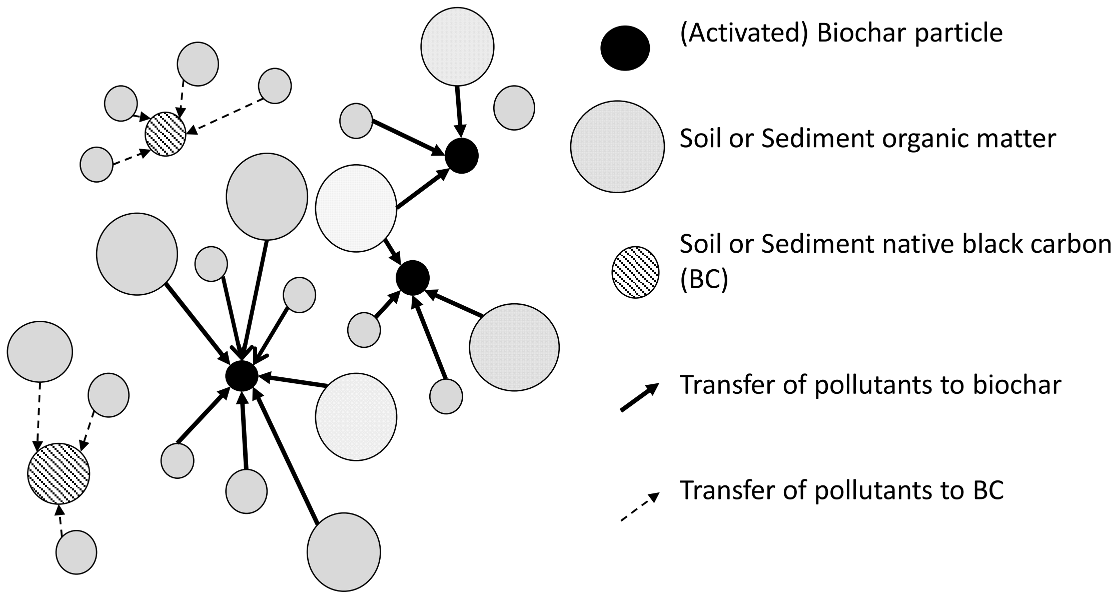
The principle of sorbent amendment

Traditional "dig-and-dump" or dredging practices to remove contaminated soils and sediments are costly, and there is a need to develop cost-effective in-situ remediation strategies. One option is the addition of a sorbing agent to the contaminated soil or sediment. For this, activated carbon (AC) – defined as a carbonaceous material that has undergone activation (e.g., steam, chemical treatment) to increase its sorption properties – is often used as a sorbing agent for in-situ remediation[1]. AC can be made from both biomass and anthracite or lignite coal, by pyrolysis followed by activation through steam or strong base. When AC is made from biomass it is also referred to as activated biochar, which is produced from a more sustainable material than coal-based AC[2]. Also non-activated biochar can be used for contaminant immobilization. Most statements in this paper are true for biochar, activated biochar and activated carbon from coal. As an umbrella term we will write "biochar/AC".

When biochar/AC is added to the contaminated soil or sediment, contaminants undergo a mass transfer from soil/sediment particles to much more strongly sorbing biochar/AC particles. Thus porewater concentrations are reduced and the risk of the contaminants decreases[3]. Biochar and AC are effective sorbents for a large array of compounds[4], such as many pesticides, polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), dioxins/furans (PCDD/Fs), polybrominated compounds (PBDEs) and even perfluorinated compounds such as PFOS[5]. The binding strength of AC and biochar can vary enormously, from being less strong than soil organic matter to a million times stronger than it[6]. Biochar typically sorbs around a factor of 10 less strongly than AC[6].



Transfer of organic pollutants from a contaminated soil or sediment to biochar or AC (from "Biochar for Environmental Management", second edition, chapter 22).

Reduced sorption in the presence soil and sediment

Binding to biochar/AC occurs through "adsorption", which is a surface attachment process of a chemical to a material (absorption to non-thermally altered organic materials involves distribution throughout a material). This "adsorption" mainly takes place in very narrow (nanometer-sized) pores, and the capacity of these pores is limited[4]. This means that biochar/AC is less effective as a sorbent at high concentrations (where adsorption sites get saturated). Moreover, pores in biochar/AC are prone to clogging by non-thermally altered organic matter in the presence of soil and sediment ("sorption attenuation"). This attenuation has been shown to be a factor 10 to 100, i.e. in the presence of soil or sediment, biochar/AC sorbs 10 to 100 times weaker than in water[7,8]. However, this attenuation effect has been shown to disappear over time, showing that slow diffusion through pore-clogging lipids or organic matter can still take place[9].

Strongly native sorption in soils and sediments

Biochar/AC is most effective for soil or sediment remediation purposes when the soil or sediment is low in native pyrogenic organic material[10] as this will strongly compete with biochar/AC for contaminants. In other words, if the soil already sorbs strongly—and often this is the case, especially in sediments[4]—it will be more difficult to increase its sorption potential by adding a strong sorbent.

Slow soil to sorbent mass transfer

Another issue is the speed at which mass transfer from the soil or sediment to the sorbent material occurs. In the absence of mixing, modeling has shown that soil/sediment-to-sorbent mass transfer times can be as long as a decade for hydrophobic compounds such as PCBs and dioxins[11]. For smaller PCBs, and thus also PAHs and most pesticides, the process is usually faster (months to a year), as has been shown in the field[12].

The optimal biochar for sorbent amendment: one produced at high temperature

Optimal biochar/ACs need to be selected for purposes of remediation, and higher temperature activated biochars perform the best for remediation uses[6]. It has been shown that AC is more effective than biochar in some specific remediation instances—such as reducing PAH risk in sewage sludge[13] and this is to be expected based on the higher AC-water than biochar-water partitioning coefficients for many organic compounds.

Deleterious side effects of sorbent amendments

Activated carbon has been shown to exert some negative eco-toxicological effects on sediment-living organisms[14, 15, 16]. For soil, much less work has been done on such effects. One study indicates that biochar is more benign than AC for soil biota such as earthworms and springtails; in fact, avoidance tests showed that earthworms preferred biochar-amended soil over non-amended soil, but not AC-amended soil[17].

Effect on biodegradation potential

Upon sorbent amendment the contaminants themselves also become less available for uptake by microorganisms and thus biodegradation, which may be considered a disadvantage if the goal of remediation is to decrease total contaminant concentrations to benchmark values. However, this may not necessarily be a problem, as it is the same biochar/AC-bound contaminant fractions that are then unavailable for uptake by organisms as those that are not available for degradation. In other words, the degradation-resistant fractions are not dangerous. A study has shown that PAHs that were newly added several years after in situ AC-amendment were still degradable, but at lower rates than in non-amended soils[18].

Life-cycle assessment

Complete life-cycle assessments comparing the different potential sorbent (e.g., AC from anthracite vs. activated biochar vs. non-activated biochar), such as one comparing coal AC to biomass AC for sediment contamination[2] are needed.

Summary

In this scheme the most important processes influencing biochar/AC sorption effectiveness in remediation are summarized.

Summary of sorption strength of biochar/AC, and its possible effectiveness in soil/sediment remediation, as well as possible confounding factors and their approximate magnitude

Process	Quantitative effect
Sorption strength of biochar/AC	1-1,000,000 x stronger than non-thermally altered organic matter
Slow soil-to-sorbent mass transfer rates	1-100 times weaker sorption
Weakening of sorption in soil/sediment by pore clogging	1-100 times weaker sorption
Strong sorption to soil/sediment itself	Factor 1-30 stronger than non-thermally altered organic matter

Literature

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