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Review

Current state of in situ subsurface remediation by activated carbon-based amendments

Dimin Fan [a, *], Edward J. Gilbert [b], Tom Fox [c]

[a] Oak Ridge Institute for Science and Education (ORISE) Fellow at the U.S. Environmental Protection Agency, Office of Superfund Remediation and Technology Innovation, Arlington, VA, 22201, USA
[b] Office of Superfund Remediation and Technology Innovation, U.S Environmental Protection Agency, Arlington, VA 22202, USA
[c] Colorado Department of Labor and Employment, Division of Oil and Public Safety (OPS), Denver, CO 80202, USA

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A B S T R A C T

The last decade has seen a growing interest in applying activated carbon (AC)-based amendments for in situ subsurface remediation of organic contaminants such as chlorinated solvents and petroleum hydrocarbons. This remedial technology has been promoted by several major AC-based product vendors on the market. These products involve impregnation or co-application of chemical or biological additives to facilitate various contaminant degradation processes in conjunction with contaminant adsorption. During field applications, rapid contaminant removal and limited rebound after emplacement have often been reported and considered as two major advantages for this remedial technology. Nevertheless, questions remain to be answered regarding its true effectiveness and longevity given the lack of subsequent field characterizations and evidence of the degradation process, especially biodegradation. Additional uncertainties reside in how subsurface heterogeneity may affect the design, implementation and performance monitoring of this technology. In light of these uncertainties, this review presents an independent analysis that focuses on both the scientific and practical aspects of AC-based remedial technology for in situ subsurface remediation by gathering and synthesizing the scientific knowledge and practical lessons from a broad range of contaminant removal processes involving adsorption and/or degradation. The analysis showed that the scientific soundness of combining adsorption and degradation proposed for all the AC-based products is well supported by the literature on ex situ treatment. However, the in situ effectiveness might be affected by additional factors, such as geological heterogeneity, amendment transport and distribution, and total contaminant mass, which require more thorough and quantitative evaluation. Overall, the technology may provide a viable tool in addressing major remediation challenges encountered in current practice, such as mitigation of back diffusion from residual sources in low permeability zones and treatment of low concentration plumes.

Contents

* Corresponding author. Postal address: USEPA (5203P), 1200 Pennsylvania Ave NW, Washington, DC 20460, USA.
E-mail address: fan.dimin@epa.gov (D. Fan).

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1. Introduction

Over the last decade, in situ application of AC-based amendments has emerged as a promising remedial technology for the cleanup of subsurface organic contaminants such as chlorinated solvents and petroleum hydrocarbons (Simon, 2015). The technology involves the combination of adsorption, the process widely used in ex situ water treatment (Bansal and Goyal, 2005; Cloirec and Faur, 2006; Perrich, 1981), and degradation, which has been extensively applied for in situ remediation over the last twenty years (Siegrist et al., 2014; Stroo and Ward, 2010; Stroo et al., 2014; Tratnyek et al., 2014). The combination of these two processes is proposed to be more effective than the conventional in situ remedial technologies that solely rely on degradation, because adsorption provides a secondary mechanism that retards contaminant migration, which, at the same time, also enhances degradation by allowing extended contact time between contaminants and reactive additives.

In the current remediation market, five AC-based products have been applied in the field and are available through three commercial vendors and one noncommercial research laboratory. The products are mainly composed of AC particles varying from colloidal to granular size, and specific chemical or biological additives to promote degradation. Detailed information on these products, including physical properties, chemical/biological additives, target contaminants, and the corresponding degradation pathways, is summarized in Table 1. BOS-100® and BOS-200® were the first two commercial AC-based products, developed in the early 2000's, whereas COGAC® and PlumeStop® are more recent commercial products. The estimated number of sites that used BOS-100® and BOS-200® has exceeded 100 and 1000, respectively (Simon, 2015). COGAC® and PlumeStop® have also seen a rising number of field applications.

Despite the rapidly increasing number of field-scale applications, there is a lack of both independent scientific investigations of the commercial products and well-documented detailed case studies reported by the vendors. Questions have been raised regarding whether the success of AC-based remedial technologies claimed at a number of sites is fully justified by the field evidence. The main uncertainty resides in the effectiveness and persistence of contaminant degradation. Additional concern has also been raised on the impacts of the specific amendment delivery approaches on the assessment of treatment performance. As a result, in situ application of AC-based amendments is still considered an emerging technology to the remediation community, which underscores the need for a comprehensive assessment of the technology.

As the first independent analysis of the AC-based remedial technology, this review evaluates the state of practice of this technology for in situ remediation from both scientific and practical perspectives. Due to the lack of peer reviewed information for the commercial AC-based products, our assessment is partly based on reviewing a broad range of relevant scientific topics. These topics include adsorption by AC in wastewater treatment (Çeçen and Aktas, 2011) and sediment cleanup (Ghosh et al., 2011; Patmont et al., 2015), and various degradation-based remedial technologies as degradation is an essential component claimed for all the AC-based products used for in situ remediation. These prior works provide the scientific foundations and practical lessons that help improve the assessment of the AC-based remedial technology. The overall goals are to improve the current understanding of the AC-based remedial technology in the remediation industry, identify the key technical aspects that need to be considered during remedial design, implementation, and performance monitoring; and provide recommendations to improve and advance the research and applications of the technology for future site cleanup.

Table 1
Comparison of five AC-based products (four commercial and one non-commercial) that have been used for in situ applications.

Product	Physical Property	Additive	Target CoCs	Degradation Pathway
BOS-100®	Granular manufactured by Calgon	Impregnation of zerovalent iron	Chlorinated solvents	Abiotic reductive dechlorination
BOS-200®	Powdered manufactured by Calgon	Electron acceptors, phosphorus, nitrogen nutrients, $CaSO_4$, Facultative bacteria mix	Petroleum hydrocarbons	Short-term aerobic and long-term anaerobic bioaugmentation
COGAC®	Granular or powdered	Calcium peroxide, sodium persulfate, Nitrate occasionally	Petroleum hydrocarbons *and* chlorinated solvents	Chemical oxidation, aerobic and anaerobic biostimulation
PlumeStop®	Colloidal sized AC suspension	Proprietary organic polymer, hydrogen or oxygen release compounds, bacterial strains	Chlorinated solvents *or* petroleum hydrocarbons	Anaerobic biodegradation for chlorinated solvents *or* aerobic biodegradation for petroleum hydrocarbons (augmetation or stimulation)
Carbon-Iron	Colloidal sized AC suspension	Carboxymethyl cellulose as the colloidal stabilizer, impregnation of nano zerovalent iron	Chlorinated solvents	Abiotic reductive dechlorination

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