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Review

Engineered/designer biochar for contaminant removal/immobilization from soil and water: Potential and implication of biochar modification

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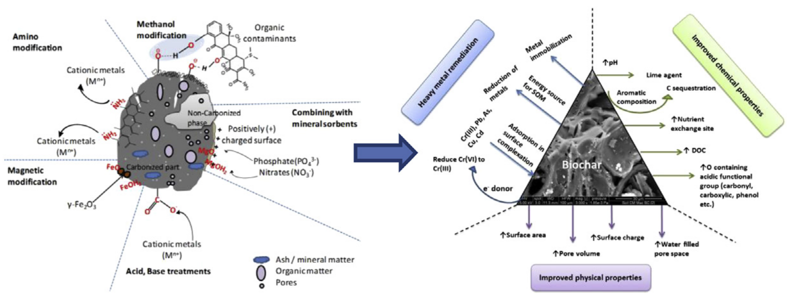
HIGHLIGHTS

- Recent developments of engineered biochar for contaminant removal are reviewed.
- Chemical, physical, impregnation, and magnetic approaches improve applicability.
- Immobilization mechanisms of organic/inorganic contaminants are evaluated.
- Outcome-based biochar modifications can enhance environmental remediation.

GRAPHICAL ABSTRACT



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ABSTRACT

The use of biochar has been suggested as a means of remediating contaminated soil and water. The practical applications of conventional biochar for contaminant immobilization and removal however need further improvements. Hence, recent attention has focused on modification of biochar with novel structures and surface properties in order to improve its remediation efficacy and environmental benefits. Engineered/designer biochars are commonly used terms to indicate application-oriented, outcome-based biochar modification or synthesis. In recent years, biochar modifications involving various methods such as, acid treatment, base treatment, amination, surfactant modification, impregnation of mineral sorbents, steam activation and magnetic modification have been widely studied. This review summarizes and evaluates biochar modification methods, corresponding mechanisms, and their benefits for contaminant management in soil and water. Applicability and performance of modification methods depend on the type of contaminants (i.e., inorganic/organic, anionic/cationic, hydrophilic/hydrophobic, polar/non-polar), environmental conditions, remediation goals, and land use purpose. In general,

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Sorption
Surface chemistry

modification to produce engineered/designer biochar is likely to enhance the sorption capacity of biochar and its potential applications for environmental remediation.

Contents

1. Introduction

Biochar, a stable carbon (C)-rich by-product synthesized through carbonization of biomass in an oxygen-limited environment (Lehmann and Joseph, 2009) has been recognized as a multifunctional material for energy and environmental applications. Variety of applications include C sequestration (Kuzyakov et al., 2009; Woolf et al., 2010), greenhouse gas emission reduction (Singh et al., 2010), land remediation, contaminant's immobilization (Ahmad et al., 2014; Mohan et al., 2014b) and soil fertilization (Chan et al., 2007, 2008).

The chemical and physical properties of biochar mainly depend on feedstock types and pyrolysis conditions i.e., residence time, temperature, heating rate, and reactor type. Conventional carbonization (i.e. slow pyrolysis), fast pyrolysis, flash carbonization, and gasification are the main thermochemical processes that are widely employed for biochar production (Manyà, 2012). In general, biochar produced at high temperatures (600–700 °C) shows highly aromatic nature with well-organized C layers, but has fewer H and O functional groups due to dehydration and deoxygenation of the biomass (Ahmad et al., 2014; Uchimiya et al., 2011), potentially with lower ion exchange capacities (Novak et al., 2009). On the other hand, biochar produced at lower temperatures (300–400 °C) has more diversified organic characters, including aliphatic and cellulose type structures and contain more C=O and C–H functional groups (Glaser et al., 2002; Novak et al., 2009). The complex and heterogeneous chemical and physical composition of biochar provides an excellent platform for contaminants removal through sorption (Park et al., 2015a; Vithanage et al., 2015a). In spite of considerable scientific work on the uses of biochar for environmental uses, extensive attention has recently been focused on the modification of biochar with novel structures and surface properties in order to enhance its remediation efficacy and environmental benefits (Ok et al., 2015). It is timely and essential to review the scientific literature on novel modifications and their effects. For the sake of facilitating future design and improving performance and widespread use of -engineered char materials like biochar for environmental applications and remediation, this review paper provides a timely comprehensive summary and critical evaluation of the principles and applications of various surface modifications on biochar in view of up-to-date available peer-reviewed research work.

2. Modification methods for engineered/designer biochar preparation

Available modification methods that have been investigated in previous literature are summarized in Table 1, which can be divided into four main categories, i.e., chemical modifications, physical modifications, impregnation with mineral sorbents, and magnetic modifications (Fig. 1).

2.1. Chemical modification

Chemical modification process involves both one step modification and two-step modification process. The carbonization and activation steps are achieved simultaneously during one-step chemical activation in the presence of an activating chemical agent. Two-step chemical activation involves carbonization of raw feedstock followed by activation of the carbonized product by mixing with a chemical agent or pretreatment of precursors before the carbonization process (Azargohar and Dalai, 2008; Qian et al., 2015).

2.1.1. Acid/base treatment and chemical oxidation process of biochar

Treatments to the carbon precursors or resulted biochar after pyrolysis during chemical modification have been reported to effect profoundly on biochar performance as an amendment or sorbent (Kasparbauer, 2009). All treatments create additional costs but are beneficial in the end due to enhanced properties. Treatment by chemical modification is generally carried out by addition of acids