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Review article

Interaction of arsenic with biochar in soil and water: A critical review

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A B S T R A C T

Biochar exhibits a great potential to act as a universally applicable material for water and soil remediation due to extensive availability of feedstocks and favorable physio-chemical surface characteristics; nevertheless, studies related to its application on the remediation of toxic metalloids are relatively rare. Hence, this review highlights biochar production technologies, biochar properties, and recent advances in the removal and immobilization of a major metalloid contaminant, As in water and soil. It also covers surface modification of biochars to enhance As removal and microbial properties in biochar amended soil. Experimental studies related to the adsorption behaviors of biochar and the underlying mechanisms proposed to explain them have been comprehensively reviewed. Compared to the number of research publications in SCOPUS database on "Biochar+Water" (≈1290 – Scopus), the attention drawn to examine the behavior of biochar on the remediation of As is limited (≈85 - Scopus). Because of the toxicity of As, the subject urgently needs more consideration. In addition to covering the topics listed above, this review identifies research gaps in the use of biochar as an adsorbent for As, and proposes potential areas for future application of biochars.

Contents

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1. Introduction

Arsenic (As) is the 20th most abundant element in the geosphere, and the 14th in seawater. However it has been recognized as an extremely toxic metalloid for humans as well as for fauna and flora [1–3]. The mean amount of As in the earth's crust is known to be approximately 1.8 mg/kg [4], but this number is increased due to anthropogenic pollution. Inorganic anionic As species, arsenite [As(III)] and arsenate [As(V)], as well as organic species, particularly mono-, di- and, tri-methyl arsenates, have been recognized as major toxic species of As in natural water systems. Furthermore, more noxious organic and inorganic thio-As species can be found widely in geothermal and marine environments [5,6]. Elevated concentrations of As in groundwater have been reported in many parts of the world [7]. Interestingly every year, some new locations are found with high background arsenic concentrations. As noted, As can be found in soils due to both geogenic and anthropogenic activities, and it may occur at a wide range of concentrations, ranging from μg/kg levels to extremely high concentrations such as 250,000 mg/kg [8,9]. The levels of As is extremely minute to be a causative factor for health issues and hence, the safe permissible value has kept very low compared to other toxic metals (10 μg/L) by the World Health Organization (WHO).

A variety of technologies such as chemical oxidation, precipitation, adsorption, ion exchange, reverse osmosis, and membrane separation has been adopted for the removal of As in water and wastewater. Adsorption is considered as an effective remediation strategy due to its low cost and relatively simple design [10–12]. However, the removal of As from aqueous solutions is a serious challenge for researchers, engineers, and technologists due to varying As speciation depending on pH of the media. Few studies have confirmed the application of some materials that are efficient in remediating both As(III) and As(V) species irrespective of the pH [13,14]. Interactions of microorganisms with different As species also are important in remediating As contaminated environmental systems [15]. Up to date, many materials, such as titanium carbonitride-derived adsorbents, agricultural wastes (rice husks), and iron oxide granules, which have been tested for As remediation, are either speciation specific or pollutant-specific, and, hence, they are not applicable for the simultaneous removal from a mixture of contaminants in aqueous solutions. Therefore, explore materials that can be used for the simultaneous remediation of many different pollutants and their species may receive strong attention. Activated carbon covers a wide spectrum of applications in drinking water treatment due to its high performance, high surface area, mechanically strong properties and avoids chemical waste products that need to be added in other applications. However; it is hardly applicable for soil remediation due to the cost involved in the production [16]. Hence, current focus has been drawn to biochar, because it is a cost effective and environmentally feasible carbonaceous product derived by the pyrolysis of certain feedstocks that has applications in a variety of contaminated environments [17,18]. However, yet biochar has not achieved high surface area as in the case of Activated carbon and poor in mechanical properties hence, it limits the application into water treatment.

In the past decade, biochar has been experimented extensively in various agricultural and environmental problems, due to its strong influence on immobilization of contaminants, improvement in soil health, and carbon sequestration in relation to climate change [19,20]. In addition, research has revealed that biochar also has an affinity for, and can retain, both heavy metals and organic compounds that contaminate wastewaters [17,21]. Moreover, biochar can be produced from residues that are often burnt in fields or buried in landfill, thus having a triple line benefit namely economic, reduction in polluted soil and water and production of renewable energy [22]. Many studies have reported an excellent ability of biochars to remove heavy metals, organic pollutants, and other pollutants from aqueous solutions [17,18,21–23]. Due to the above-revealed factors, research on biochar have been increasing at an exponential rate over the past few years.

1.1. Research on arsenic and biochar

The use of charcoal in agriculture or, biochar, as it is now referred to is a millennium old practice in all continents but specifically in Japan and China, Brazil, India, Australia and parts of Africa [24,25] [30]. Studies of its use has shown that soils where charcoal has been incorporated for centuries have resulted much more fertile than the surrounding soils. Publications related to As adsorptive remediation both in soil and water environment during the years from 1980 to 2014 (according to ISI Web of Science™) have been growing steadily [Fig. 1]. The figure shows the growing interest of the scientific community on As remediation research, and the trend on the As remediation in soil and water has extended from the phase of scientific research to engineering applications. There has been a significant increase of field scale and pot experiments during the last decade that have been conducted to investigate the effectiveness of biochar as a soil amendment to immobilize As [26,27]. However, there is still a gap between research focused on soil remediation and research on As remediation in aqueous media [Fig. 1(a)]. Only a few studies are focused on As immobilization in soil than the water research. At the same time, there has not been a centre of attention to understand the As mobilization/release mechanisms due to the application of different biochar produced from various production technologies.

Existing publications on biochar mainly deal with its application in technical, economical, climate-related aspects; soil quality and remediation; and remediation of water and wastewater [17,20,21,28–31]. With the increasing interest in scientific research on biochar and its surface modifications, an integrated understanding of the mechanisms of biochar to remediate As in