Impact of Biochar on Metal and Hydrophobic Organic Contaminants: A Tool for Environmental Remediation (An Overview)

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Abstract: The importance of biochar in soil through natural processes (bush burning, forest fires) and application to soil (agriculture, waste management, carbon sequestration and pollution remediation) has received significant amount of scientific and regulatory attention. Biochar alters soil properties, encourages microbial growth activity and enhances sorption of metal and hydrophobic organic contaminants though this strongly depends on the feedstock and production process of the Biochar. This paper mainly studied on the impact of biochar on metal and hydrophobic organic contaminants and explores the feasibility of applying Biochar in remediation technology.

Keywords: Biochar, Quantification, Uses, Sorption and Remediation

1. Introduction

Biochar is commonly defined as charred organic matter, produced with the intent to deliberately apply to soils to sequester carbon and improve soil properties [1]. The only difference between biochar and charcoal is in its utilitarian intention; charcoal is produced for other reasons (e.g. heating, barbeque, etc.) than biochar. charcoal (biomass that has been pyrolysed in a zero or low oxygen environment) for which, owing to its inherent properties, scientific consensus exists that application to soil at a specific site is expected to sustainably sequester carbon and concurrently improve soil functions (under current and future management), while avoiding short- and long-term detrimental effects to the wider environment as well as human and animal health. As a material, biochar is defined as: "charcoal for application to soil".

Biochar is a predominantly stable, recalcitrant organic carbon (C) compound created when biomass (feedstock) is heated to temperatures usually between 300 and 1000°C, under low (preferably zero) oxygen concentrations [2]. Biochar is part of a series of materials referred to as black carbons, which are all produced by chemical and/or thermal transformation of the original biomass material [3]. Recent literature reviews have focused on agronomic applications of

biochar [3]. Much less attention has been given to the use of biochar in engineering applications, which may be a more practical use of the material considering the economic forecasts of black carbon production for direct agricultural use have been unfavourable for some time [4]. Therefore, the use of smaller quantities of biochar in targeted applications is encouraged to support a broad-based market for biochar and improve the economics of biochar production [3]. As long as the biochar is not burned for energy generation, the over- all purpose of carbon sequestration is still preserved, despite the fact that biochar may not be directly incorporated into the soil.

As serious interest in climate change mitigation and renewable energy sources has grown, more attention has been focused on the production of the solid products from biomass (biochars) for carbon sequestration purposes [5]. In addition to the studies on the use of biochar for carbon sequestration, a number of reports have focused on alternative applications of biochar for the improvement of soil fertility, plant growth, and decontamination of pollutants such as pesticides, heavy metals, and hydrocarbons [7]. The diverse range of biochar applications depends on its physicochemical properties, which are governed by the pyrolysis conditions (heating temperature and duration) and the original feedstock. Biochar yield, physical and chemical properties depend on the

conditions during pyrolysis as well as the composition of the feedstock biomass [7]. In addition, biochar properties change over time in soil and these changes may also be affected by the initial properties of the biochars [8]. Therefore, the differences between biochar properties have to be well understood as a function of production conditions and feedstock type, inorder to match soil needs with the appropriate biochar type. Thus, detailed information about the complete production process is a key factor in defining the most suitable application of biochars.

Also, the cost of producing biochars have limits their use as adsorbents in wastewater treatment. Thus, deriving biochars from cheap and locally available waste materials is needed to develop a feasible removal technology. Several studies have explored the production of biochars from feedstock such as sewage sludge, industrial wastes, plant residues, and animal manures [8]. Despite the benefits of biochar as a sorbent for contaminant management in soil and water, there is still concern about the environmental impacts of potentially excessive levels of heavy metals in biochars since feedstock can be high in heavy metal contents (such as Cu, Cd and Pb). Therefore the safe use of biochar as soil or water amendments should be ensured by deriving from feedstock less polluted by heavy mental.

A number of types of agricultural crop residues or agricultural by-products (wastes) have been used for biochar production, including various types of waste wood [4] corn cob and corn stalk, wheat residues, rice straw and sugar beet tailing e.t.c. The composition and proportions of different constituents including cellulose, hemicellulose, lignin, and small amounts of extractives vary with the type of biomass. These constituents also pyrolyze at different temperatures, with thermal degradation of hemicelluloses and celluloses occurring first (at temperatures of 470–530 K and 510–620 K, respectively) and lignin last (between 550 and 770 K). Due to variations in lignin and recalcitrant carbon content among biochar source materials, the amount of biochar produced from a given amount of biomass varies greatly, with the highest yields typically from lingo-cellulosic (wood-derived) biomass. Thus, poor production efficiencies and/or low or seasonal availability of certain feedstock's (i.e., low-lignin biomass) may limit their widespread use. For example, the seasonal availability and geographical distribution of agricultural residues present challenges to operate biomass-only power plants. Therefore, it may be preferable to utilize a combination agricultural residues, manures, urban organic food wastes, and wood chips to offset decreased availability of these products over the winter month [9].

This paper reviews the literature available for the production of biochar from different category of biomasses, quantification and characterization of the resultant biochar, adsorptive capacity, and the progresses made on experimental work that can serve as a promising adsorbent for the treatment of waste/groundwater or contaminated sites, which can in turn convert one environmental problem to a new cleaning Technology.

2. Production of Biochar

2.1. Category of Biomasses

A wide variety of waste biomass materials (wood, manure, rice husk, sewage sludge, municipal waste etc.) can be used to produce biochar. However, Wu et al. [10] critically discussed the potential types of feedstock and the production procedures (pyrolysis). The pyrolysis of biomass can be carried out in a reactor via gasification or carbonisation at varying temperatures and times depending on the intended use of the end product. During heating, there are mass losses, chemical transformations and structural changes, which largely depend on the duration of heating, initial moisture, wood species and temperature of treatment [11]. The final thermal conversion of biomass yields three basic products; liquid (liquid hydrocarbon and water), solid (biochar) and gas [12]. Table 1 highlights the fate of feedstock in a thermal treatment reactor.

Table 1. Important parameters and product (in% wt) of different carbonisation processes.

Parameters	Processes				
	Fast pyrolysis	Slow pyrolysis	Microwave pyrolysis	Hydrothermal conversion	Gasification
Temperature	~450-500°C	400-500°C	Frequencies of 915 MHz (λ=~33cm) and 2.45GHz (λ=~12cm)	~180-250°C	~800°C
Vapour Residence Time	~1-2s	h-week	No vapour residence time	No vapour residence time,~1-12h processing time	~10-20%
Biochar production	~12%	~35%	~7%	~50-80%	~10%
Bio-oil Production	~75%	~30%	~85%	~5-20%	~5%
Syngas Production	~13%	~35%	~8%	~2-5%	~85%
References	Fierro 2011 Bridgewater and Peacocke 2000	Sensos 2003	Soshi et.al 2009; Shiung Lam, 2012	Brown 2009, Libra et.al. 2011	Ballat 2009, Catherine 2011

2.2. Current Uses of Biochar

Lehmann and Joseph [13] defined biochar as a carbon-rich product obtained when biomass, such as wood, manure, or plant residues are heated in a closed system with little or no air. During exploration in the Amazonia, European explorers in the 19th Century discovered dark soils that have been referred to as the "Terra Preta" soils, which are known to

contain large amounts of char-derived carbon and exhibit higher levels of microbial activity and improved nutrient availability and crop yield compared to soils with little or no biochar addition. It has been suggested that the indigenous population in the Amazon adopted the process of mulching, burning, charring and application of charcoal and ash to increase soil quality [14].

Biochar has often been produced under controlled temperatures in the absence of oxygen and applied to soils and, in recent times, it has been favoured as a soil management tool due to its long-term stability and recalcitrant nature with soil sequestration capabilities for economic and environmental benefits [14]. Biochar is produced with the intent of improving soil productivity, carbon storage, mitigation of climate change or filtration of percolating soil water [13]. The increased research and development on strategies to improve and produce bioenergy from renewable energy sources to contribute to the energy needs of developing and developed societies will contribute to the deposition of biochar-like products into the environment. Additionally, it may be produced as a result of uncontrolled bush burning or wild fires and then deposited onto soil and it has been reported that biochar-amended soils have the ability to retain moisture, increase cation exchange capacity (CEC), increase adsorptive capacity and increase pH [15]. The biochar within such soils is thought to be highly stable for thousands of years; being resistant to biochemical decomposition, but the extent of this recalcitrance may well be dependent on the production process. Therefore, there could be growing applications of biochar to soils for agriculture, waste management, carbon capture and contaminated land remediation.

3. Quantification and Characterization of Biochar

3.1. Quantification of Biochar

Quantification of biochar is the act of measuring observations with the aim to distinguish Biochar from soil organic matter and from other forms of black carbons produced from varieties of biomasses. The techniques employed depend on spectroscopic characteristics rather than physical separation or isolation. Some of the techniques that most effectively distinguish different types of Biochar can also be used to characterize individual Biochar wastes (or collection of fragments) recovered from both soil and solution systems. Classification of Biochar has been an issue based on its chemical complexity and diversity. Due to its recalcitrance nature, Biochar cannot be easily extracted from soil using chemical methods, though potential biomarkers maybe. The results from studies using the physical location of Biochar within a soil matrix [16] suggest that usefulness of physical separations using density or means other than hand sampling approach (which is restricted to very small samples) is susceptible to site factors. Until recently, the most practical methods have sought to remove non-black

components (i.e., oil, organic matter and mineral carbonates) with subsequent evaluation of the residue. However, for quantifying Biochar, particularly this type of quantification may be affected by the presence of the more frequent recalcitrant black carbon forms, as well as by the presence of highly resistant organic carbon compounds, such as those stabilized on the biomass not incompletely removed, which in some cases are estimated alone. Different technical methods differentiate components of increasing minimum stability incompletely charred biomass, Biochar, charcoal, activated carbon, soot, and graphitic black carbon [17]. D. Obemah and Z. Baowei [18] have analysed the possible ways biochar can be quantified. According to them, Leaching method in this grouping includes removal of nonblack carbon by chemical oxidation (e.g., sodium chlorite and potassium dichromate), using ultraviolet radiation, or by a thermal approach [11]. Hydrolysis, pyrolysis (HyPy) is an alternative way to the removal of non-black carbon which evolved gas analysis from the character of the varied gaseous products of thermal decomposition. A combined chemo thermal oxidation method, with a temperature of threshold forms the foundation of a benchmark procedure for the determination of fixed carbon, which is composed of the most stable fraction of black carbon and has the more stable component of Biochar. Virtual separations have conventionally been based on spectroscopic techniques in combination with pre-treatment (or other allowance) for numeral interference, for example, using hydrofluoric acid pyrolysis, gas chromatography, mass spectroscopy (Py CG/MS), and solid state 13C nuclear magnetic resonance (13CNMR) spectroscopy with cross- polarization, block deterioration, and combined with magic angle spinning (MAS) [19] or chemically extracted and purified biomass products, particularly benzene polycarboxylic acid (BPCA) and laevoglucose [20]. The utilization of these methods depends on the purpose of the analysis and the specific nature of the target fraction, so even though all have been evaluated for a set of environmental and black carbon samples in aringtrial there remains comparatively little agreement as to a widespread paradigm. On the other hand, UV or chemical oxidation with elemental and 13CNMR analysis of residues, thermal analysis [21], and Py Hy [22] were identified as the most promising techniques. A partial new development in the quantification of Biochars has been the use of correlative techniques based on mid-infrared (MIR) spectroscopy. Initially, evaluated for the estimation of organic carbon content of bulk soil and solution samples, among their key properties, algorithm shave been utilized for relating MIR response spectrum to Biochar, using a calibration set assessed using UV-oxidation method.

3.2. Chemical Characterization

The original biomass feedstock and its Biochar can be subjected to a range of analyses in order to provide the basic physicochemical characteristics of each raw and pyrolysed material. The chemical characteristics of individual feedstock species and therefore of Biochar derived from the feedstock

have always been shown to vary significantly both spatially and temporarily. Biochar production is often assessed through changes that might occur in the elemental concentrations of C, H, O, S, and N and associated ratios [17]. Yu et al. on their recent work [23], where they used Biochar-based catalyst in the transesterification of canola oil, found out that the elemental analysis showed a decrease in the H/C and O/C ratios with increasing temperature of pyrolysis. Elemental ratios of O/C, O/H, and C/H have been found to provide a reliable measure of both the extent of pyrolysis and level of oxidative adjustment of Biochar in the soil and solution systems and are relatively straightforward to be determined [24]. BET (Brunauer, Emmett, and Teller) areas increased with an increase of carbon burn-off, irrespective of the pyrolytic temperature. This indicates that the burn-off of the carbon has the most significant consequence on the increase of the surface area. In general, the surface area, pore volume, and average pore size increased with residence time and pyrolytic temperature. Cheng et al. [25] worked extensively on the magnetic Biochar for the sorption of organic pollutants and phosphates determined that the surface areas (internal and external surface areas) of Biochars were fewer than other Biochars, whereas the average pore radius use of the former was larger than the latter. This might be due to the magnetic Biochars containing substantial amount of the iron oxide, which have smaller surface areas and plentiful temporary pores. Operational determination of acidic and basic functional groups on Biochar can be performed by Boehm titration in which the Biochar is equilibrated in the presence of consecutively strong bases (HCO^{3-}, CO_3^{2-}, OH^-, and ethoxides) or strong acids (H_2SO_4, HCl, and HNO_3) followed by titration of the extract with strong acid or base to estimate the fraction that reacted. Differences in the number of the acids or bases needed are used to estimate their relative amounts of carboxylic, lactonic, phenolic, and carboxylic functional groups (base equilibration) or basic functionalities (acidic equilibration) [16]. Characterization of Biochar used as soil amendment and, the ethoxides equilibration is commonly omitted as it measures functional groups that are dissociated only at a very high pH, while immobilization of pollutants occurs at moderately low pH [25]. The Boehm titration operates well for hydrophobic Biochar but a major shortfall appears when a significant number of bio-oils or mineral surfaces are present [17]. In carbonization of biomass feedstock for the preparation of Biochar four regions of changes are normally observed at non-hydrothermal conditions. They include dehydration, pyrolysis, grapheme nucleation, and finally carbonization. These changes can be observed when Biochar is subjected to Fourier transform infrared spectroscopy (FTIS/FTIR). Again FTIS/FTIR can also be used to identify the chemical functional groups present on the original Biochar [26]. As enumerated by Lee et al., their recent work [27] showed that samples used in preparing gasification BC (700°C) and fast pyrolysis Biochar (450°C) showed characteristics bonds similar to those of cellulose. It is clear between the baseline corrected FTIR spectra of the sample that with increase in temperature, there is a remarkable decrease in features associated with O–H (3600–100cm^{-1}), C=C and C=O stretching (1740–1600cm^{-1}) and aromatic C=C and C–H deformation modes of alkenes (1500–1100cm^{-1}), and the C–O–C symmetric stretching (1097cm^{-1}) characteristics of cellulose and hemi- celluloses. In the combined sorption of Pb^{2+} and its mechanism case study by Qiu et al. [26], Biochar was found to contain an abundant amount of carboxyl and hydroxyl groups through FTIR spectra analysis of their sludge-derived Biochar (SDBC). Cationic exchange capacity (CEC) as widely known in agronomical sector is the measure of the surface charge in soil or Biochar, which increases as the Biochar ages [16] and has been ascribed to an increase in some oxygenated functional groups on the surface of the Biochar [25]. The most distinct change in any absolute CEC values was observed for the Biochar as a result of time where it increased from 278 to 518 mmolc kg^{-1}, most likely because oxidation process created hydroxyl and carboxylic acid functional groups [277]. Biomass feed stock is a major fact or governing the status of such physicochemical l properties; pyrolytic temperature is the most significant process parameter.

3.3. Physical Characterization

Scanning electron microscopy (SEM) is a microscopic technique in determining the image macroporosity and physical morphology of solid substances [15]. The macroporous structure (pores of approximately 1 μm diameter) of Biochar produced from cellulose plant material depends upon the intrinsic architecture of the feed- stock, and it is potentially important to water-holding and adsorptive capacity of pollutant in soil and solution systems [15]. SEM micrographs of BCCS (cotton (Gossypium herbaceum) straw) and BCPS (potato (Solanum tuberosum) straw) obtained in other previous study are shown in Figure 1. The Biochars produced at different pyrolytic temperature had a distinguishable honey-comb-like structure due to the presence of tubular structures originally emanating from plant cells. As a result of these well-developed pores, the Biochars possessed a high BET surface area. The significance of pyrolytic temperature leads to the suggestion that Biochar produced at low pyrolytic temperature may be appropriate for regulating release of fertilizer nutrients [28], while high temperatures would lead to a material analogous to AC in environmental remediation [29]. It can also be detected that the surfaces of low temperatures Biochar can be hydrophobic, and this may reduce its capacity to store water in soil as well as adsorb pollutants. The form, type, preliminary preparation steps and size of the biomass feedstock, and type of pyrolysis product may affect the characteristics, nature, quality, and potential use of Biochar [28]. Initially, the ratio of exposed to total surface area of Biochar will be affected by its size. Additionally, although low pyrolytic temperature Biochar is stronger than high temperature products, it is brittle and pores are abraded into fine fractions once incorporated into the soil. In explaining

the relationship between the mechanism of heavy metal sorption and SEM, Qiu et al. proposed a vivid explanation [26]. They observed bright zones on the pores surface of Pb-loaded BC at pH = 5 in the SEM photography. Its EDX spectrum represents the red surface and additionally established the occurrence of silicon and phosphorus, which might exist in the form of $5PbO \cdot P_2O_5 \cdot SiO_2$ (lead phosphate silicate) precipitates which was again identified by XRD spectra. They concluded that the precipitates should be an important means of modelling the mechanism for Pb^{2+} removal from oil system and again can be related to solution system.
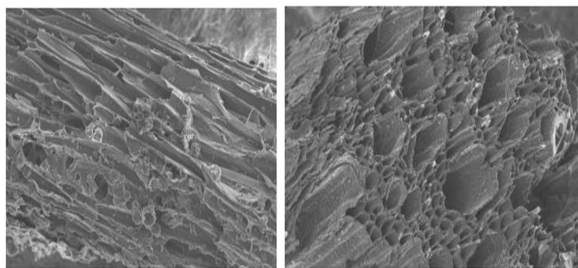

Figure 1. Photomicrograph from SEM.

4. Sorptive Properties of Biochar

Unlike any other carbonaceous fuel, Biochar is generally used as a soil amendment and in water treatment. The physicochemical properties of Biochar such as surface area, charged surface, and functional group vary appreciably based on the biomass source and pyrolysis condition, which affect the adsorptive capacity of Biochar to heavy metals and organic compounds.

4.1. Sorption of Metals

From previous studies, the most appropriate and effective method for heavy metal or trace metals removal has been proven to be adsorption using Biochar [25-26]. The adsorption mechanisms mainly include electrostatic interaction, ionic exchange, chemical precipitation, and complexion with functional groups on Biochar surface [26]. Mechanisms of heavy metal sorption amendment and, the ethoxides equilibration are commonly omitted as it measures functional groups that are dissociated only at a very high pH, while immobilization of pollutants occurs at moderately low pH [25]. The Boehm titration operates well for hydrophobic Biochar but a major shortfall appears when a significant number of bio-oils or mineral surfaces are present [17].

Soil is well known for its adsorption and CEC properties. The adsorption of heavy metals by soils and Biochar effect on the mobility and fate of the heavy metals have been extensively studied in recent times [47, 69–72]. The results showed that the addition of wood Biochar to soil did not have any significant effect on the dry matter yield of maize plants, even at the highest rate of application, but Biochar application decreased the concentration of As, Cd, and Cu in maize shoots, which depended upon amount of Biochar

addition, pH values of soils, and ability of metal to adsorb on Biochar [30]. When Biochars made from sludge and lignite were applied to soil, not only are the properties of the soil improved but also the mobility of the Heavy Metals in the mixtures, which is connected with the characteristics of the matrix, maybe affected. Other notable researches have also indicated that increase in soil pH will subsequently lead to an increase of Cd in solution by adsorption [31]. The sorption of anthropogenic hydrophobic organic compounds (HOCs) (e.g., PAHs, polychlorinated biphenyls, PCBs, pesticides, and herbicides) in soil and sediments is generally described based on two coexisting and simultaneous processes, absorbing into natural (amorphous) organic matter (NOM) and adsorption into naturally occurring Biochar material. It has been estimated that Biochar can account for as much as 80–90% of total uptake of trace HOC in soils and sediments [31]. Biochar application is therefore expected and accepted to improve the overall sorption capacity of soil [32] and, consequently, influence toxicity, transport, and fate of trace contaminants, which may be already or are to be added to soils. Despite the fact that little is still known on the microscale process controlling sorption to Biochar [74] in soils and sediments, it has been suggested that it is mechanistically different from the conventional sorption model for NOM and that it is also a less reversible process. While adsorption onto Biochar has little or no concentration dependence, adsorption to Biochar has been shown to be strongly concentration dependent [33], with affinity decreasing for increasing solute concentration. Biochar is applied to soil for the conditioning and fertilization purposes; application can also be favourable in reduction of toxic components. Recent studies have shown that Biochar is also capable of adsorbing heavy metals such as lead, cadmium, nickel, and some notable organic contaminants that contaminated soils which can cause harm to human, plants, and animals [33]. For that reason, Biochar as an additive to a soil can be expected to improve its overall adsorption capacity impacting toxicity because there is a decrease in transportability and depletion of the presence of metal or organic compounds. Due to its low cost and limited environmental impact, Biochar would be a promising strategy for remediation of polluted environment [34]. Recent studies have shown that Biochar in collaboration with activation have comparable adsorption and absorption abilities, which plays a great role in removal of contaminants such as lead (Pb) [34].

Considering recent experimental methods, results have shown that metal ions are strongly adsorbed onto specific active sites containing phenolic and carboxyl functionalities of the surface of Biochar [35]. Reviewing of Biochar application to wastewater treatment, contaminants such as heavy metal (lead) intake by Biochar, involves replacing already existing ions that might be present on the Biochar with the metal ion in solution system, suggesting a potential correlation between content of the Biochar and its remediation potential for metals [30]. From previous research, monitoring, reviewing, and basic understanding of

Biochar, proper or accurate application to benefit environment concerns will be in the near future the simplicity of production methods to the capability for integration into less developed countries.

4.2. Sorption of Anthropogenic Hydrophobic Organic Compounds

The sorption of anthropogenic hydrophobic organic compounds (HOC) (e.g. PAHs, polychlorinated biphenyl - PCBs, pesticides and herbicides) in soils and sediments is generally described based on two coexisting and simultaneous processes: absorption into natural (amorphous) organic matter (NOM) and adsorption onto occurring charcoal materials [36]. Comparatively to that of NOM, charcoals (including soot) generally hold up to 10-1000 times higher sorption affinities towards such compounds [90]. It has been estimated that Biochar can account for as much as 80- 90% of total uptake of trace HOC in soils and sediments and that it applies to a much broader range of chemical species than previously thought. Biochar application has been highlighted to improve the overall sorption capacity of soils, and consequently, influence toxicity, transport and fate of trace contaminants, which may be already present or are to be added to soils. While absorption to NOM has little or no concentration dependence, adsorption to biochars has been shown to be strongly concentration dependent [37], with affinity decreasing for increasing solute concentrations [37-38]. Several equations have been employed to describe such behaviour, including that of Freundlich [36] and Langmuir [39], although more recent equations based on pore-filling models have shown better fits [40].

Previous studies have also convincingly demonstrated that adsorption to charcoals is mainly influenced by the structural and chemical properties of the contaminant (i.e. molecular weight, hydrophobicity, planarity) [36], as well as pore size distribution, surface area and functionality of the charcoal [38]. Among most classes of common organic compounds, biochar has been shown to adsorb PAHs particularly strongly, with desorption having been regarded as 'very slow' (rate constants for desorption in water of 10-7-10-1 h-1, and even lower in sediments) [38]. Large body of evidence is available on the way the characteristics of HOC influence sorption to biochars, the contribution of the char's properties to that process has been far less evaluated. The presence of organic compounds with higher hydrophobicity and/or molecular sizes has shown to reduce adsorption of lower molecular weight compounds to biochars [37]. In the same way, some metallic ions (e.g. Cu^{2+}, Ag^+) present at environmental relevant concentrations (50 mg L^{-1}) may significantly alter surface chemistry and/or pore network structure of the char through complexation [38].

Frequently, contaminated soils contain a mix of organic solvents, PAHs, heavy metals and pesticides, adding to the naturally occurring mineral and organic matter. Nevertheless, most studies on organic sorption to charred materials have relied on single-solute experiments, whereas those using multiple solutes hold more practical relevance [37].

Competitive sorption can be a significant environmental process in enhancing the mobility as well as leaching potential of HOC in biochar-enriched soil. Most of the evidence of increased sorption to HOC by biochar incorporation into soil is indirect (i.e., bulk and biochar or soot sorption is determined separately and bio char's contribution is then proved comparatively to a treatment without biochar) and earlier attempts for its direct assessment overestimated it [36]. Yet, the potential of biochar amendment of soils for enhancing soil sorption capacity and, therefore mitigating the toxicity and transport of relevant environmental contaminants in soils and sediments appears undeniable.

4.3. Remediation of Both Metal and Hydrophobic Organic Contaminants

Applying biochar amendments to mixed contaminated soils indicated that fractions of mobile Zn and Cd significantly decreased with biochar amendment, and the concentrations of PAHs were also reduced in response to biochar amendment, with removal rates >50% for the heavier, more toxicologically relevant PAHs [6]. Similarly, biochar was effective in immobilizing both Pb and atrazine in the soils [34]. In another study, no significantly competitive effect between organic pollutant including naphthalene and p-nitrotoluene and phosphate was observed [41]. Given these promising results, biochar may have a great potential as a unique amendment for immobilization of both heavy metal and organic contaminants in co-contaminated soils and wastewater [42]. The simultaneous immobilization and sorption of metal and organic contaminants is attributed to different mechanisms: metals are immobilized via sorption or reaction with certain elements on the biochar surface, whereas organics contaminants are primarily removed via sorption. The metal removal generally involved in the immobilization on biochar surface and reaction with certain elements, while organic contaminants were sorbed by biochar. For example, for Pb and atrazine removal by biochar, Pb reacted with P originally contained in biochar to form insoluble hydroxypyromorphite [$Pb_5(PO_4)_3(OH)$], as determined by X-ray diffraction, which was presumably responsible for soil Pb immobilization, whereas atrazine stabilization may result from its direct sorption by biochar [34]. Heavy metal ions might also have different effects on organic contaminants removal, which derive from the interaction mechanisms of heavy metal ions with organic matter and biochar surface functional groups. In a study by Jia et al. [43], Cu^{2+} greatly enhanced the sorption of oxytetracycline (OTC) to biochar at different pH values (i.e., by 16.4%, 66%, and 53.7% at pH 3.5, 5.5, and 7.5, respectively). In another study, it was found that redox-active metals, such as Fe, Cu, and Mn, on surface of biochar, could have been involved in the enhanced reduction of nitro herbicides [44]. However, contradictory effects on the mobility, bioavailability, and toxicity of specific elements also existed in mixed contaminated soils. Cu and As concentrations in soil pore water increased more than 30-fold

after adding biochar amendments, associated with significant decreases in Pb, Cr, and PAHs [6]. Similarly, biochar treatments were more effective at reducing organic contaminant bioavailability, and benefits of biochar in terms of reducing inorganic contaminant bioavailability were limited due to the low cation exchange capacity of the applied biochar [103].

5. Conclusion

Biochar can be derived from a wide range of sewage sludge, forest residue, organic and agricultural wastes biomass feedstock, at different pyrolysis conditions and at a range of balances. The characteristics of Biochars identified by physical and chemical methods reveal the basic structure and property of Biochar. This study provides details from previous studies on the effectiveness of biochar in the sorption of metal and organic compounds. Addition of Biochar should decrease the toxicity and mobility of metal and hydrophobic organic pollutants. This work stresses the importance of biochar for immobilization of contaminants with high concentrations.

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