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The Structure and Characteristics of Biochar and Its Application in Pollution Remediation

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Abstract

Biochar is a material with easy access to raw materials, low cost, simple preparation process and broad application prospects. This article introduces the research process of biochar from three aspects of biochar preparation, physical and chemical properties and application. The structure, element composition, functional group types, specific surface area and adsorption properties of biochar are described in detail, and analyzed Its influencing factors. At the same time, the application of biochar in pollution remediation is introduced in detail, and the application prospect of biochar is prospected.

Keywords

Biochar, carbonization, modification, adsorption, pollution.

1. Introduction

Biochar is a carbon rich solid substance formed by oxygen limited pyrolysis (generally lower than 700 ℃) of wood or non lignocellulosic biomass. In the process of pyrolysis and carbonization, the material form transformation from biomass to carbon with porous carbon frame structure and various surface functional groups was completed.

2. Structure of Biochar and Its Main Influencing Factors

The structure of biochar is formed after carbonization processes such as water loss and fracture based on the structure of biomass materials. The biochar is composed of porous carbon frame, stable aromatic compounds and minerals, and the pore structure is constructed by pyrolysis and volatilization of aromatic compounds and other functional groups. The pores of biochar are mainly micropores (< 2 nm), and the proportion of mesopores (2 ~ 50 nm) and macropores (> 50 nm) is relatively small. The structure of biochar is mainly affected by raw materials and pyrolysis temperature. Due to the differences in the structure and material composition of raw materials (i.e. biomass), there are significant differences in the structural characteristics of biochar after pyrolysis and carbonization, such as crystallinity, crosslinking and branching. The macroporous structure of biochar made from raw materials with high lignin content increases, and the biochar made from raw materials with high cellulose content mainly has microporous structure. Pyrolysis temperature is another main factor affecting the structure of biochar. With the increase of pyrolysis temperature, the amorphous carbon structure gradually transformed into graphite microcrystalline structure, the amorphous carbon gradually decreased, and the turbine layered aromatic carbon gradually increased until it tended to graphitization. With the increase of pyrolysis temperature, the volatile substances contained in the raw materials are gradually pyrolysis and volatilized, resulting in a large number of pore structures. However, when the temperature is higher than 700 ℃, the microporous structure of biochar begins to be damaged. When the temperature is higher than 800 ℃, the carbon frame structure begins to be unstable and collapse. The residence time and change rate of pyrolysis temperature also affect the structure of biochar. Studies have shown that when the pyrolysis temperature stays at 500-700 ℃, with 2h as the node, the porosity of biochar increases first and then decreases [1]. Slow temperature rise is more conducive to the formation of microcellular structure of biochar than rapid temperature rise. This is because rapid temperature rise will lead to incomplete pyrolysis of substances (such as tar) and can not volatilize completely, so as to block the pores.

3. Physicochemical Properties of Biochar

3.1. Element Composition

Carbon is the main constituent element of biochar. It mainly exists in the form of aromatic carbon, which is stacked in a ring, forming the main framework of biochar, and a small part exists in the form of organic carbon, such as organic acids, phenols, esters, alcohols, etc. Biochar also contains O, H and N elements, which decrease with the increase of pyrolysis temperature [2,3]. K. Ca, Na and Mg are also constituent elements of biochar. They often exist in ash in the form of carbonate, phosphate or oxide, and their content generally increases with the increase of pyrolysis temperature. After long-term research, it is found that the contents of C and k elements in biochar made of cellulose materials are higher than those made of other materials, and the contents of N, Ca and Mg in biochar made of other materials are higher. In addition, the raw materials for preparing biochar may contain some heavy metals such as Ni, Cr, Cu and Zn. These heavy metals generally become relatively stable with pyrolysis and remain in biochar. These heavy metals content will not change with pyrolysis, their specific weight in biochar will increase with the increase of pyrolysis temperature, but their biological activity will gradually decrease.

3.2. Functional Groups

Functional groups such as hydroxyl, carboxyl, carbonyl and ester groups are common in biochar, and most of them are oxygen-containing functional groups or basic functional groups. These functional groups are converted by pyrolysis of protein, cellulose or hemicellulose in the charcoal material. Therefore, the formation of functional groups is determined by the type of charcoal material and the pyrolysis temperature. The protein, cellulose or hemicellulose of the charcoal materials provide the basis for the formation of functional groups. For example, biochar made of cellulose materials has more N and S functional groups than non-cellulose. The pyrolysis temperature further dominates the formation of functional groups. Taking 300℃ as the watershed, the content of carboxyl and carbonyl groups increased first and then decreased. As the temperature gradually increased, aliphatic functional groups gradually decreased first (400-550℃), and then alkyl functional groups gradually disappeared (above 600℃) [4].

3.3. Specific Surface Area

There are a large number of micropores, mesopores and a small amount of macropores in biochar. The pore structure is developed, and various functional groups are widely distributed on the surface and inside, so the specific surface area is relatively large. The specific surface area of biochar generally changes with the pyrolysis temperature. When the pyrolysis temperature is below 400 ℃, some protein, cellulose or hemicellulose, lipids and other substances will be completely pyrolyzed or volatilized, resulting in fewer pores, and therefore a smaller specific surface area. With the increase of temperature, the protein, lipid and other substances contained in the carbon making substrate are gradually pyrolyzed and volatilized, the carbonization is gradually complete, the pores are gradually increased, and the specific surface area is gradually increased. However, it is not that the higher the pyrolysis temperature, the greater the specific surface area of biochar. When the temperature is higher than 800 ℃, the stability of the porous structure of the carbon body will decrease, which will cause partial collapse and block the pores. With the temperature increases, the gradual increase of ash will also block the pores, resulting in a decrease in the specific surface area of biochar.

3.4. Adsorption

Biochar has a strong adsorption capacity, which is related to its specific surface area, functional group composition, pore structure, etc.. And it is also affected by external conditions such as pyrolysis carbonization temperature, acid-base environmental conditions, etc.[5]. Due to its strong adsorption capacity, biochar can be widely used in the field of remediation of heavy metals and organic pollutants. When biochar is used for the remediation of heavy metal pollution, there are basic adsorption processes such as electrostatic attraction, physical adsorption, and surface complexation. The strong adsorption of heavy metals by the oxygen-containing groups on the surface is dominant [6]. At the same time, the mineral components contained in biochar also plays an important role in providing heavy metal binding sites. The porous structure of biochar is also conducive to its adsorption and interception of heavy metal ions, and reduces the migration of heavy metals. The adsorption of organic pollutants by biochar mainly includes electrostatic adsorption, hydrogen bonding, π - π interaction and pore filling. It is a complex combination of a variety of adsorption processes, which is related to the pore structure, surface functional groups, specific surface area and ion exchange performance of biochar.

3.5. Hydrophobicity/Water Holding Capacity

The hydrophobicity of biochar is related to the content of oxygen-containing functional groups on its surface, and its performance is negatively related to the number of oxygen/nitrogen functional groups. Therefore, the hydrophobicity of biochar is affected by the pyrolysis temperature. The higher the pyrolysis temperature, the fewer surface functional groups and the stronger the hydrophobicity. The water holding capacity of biochar is related to the pore structure and connectivity. In general, the higher the pyrolysis temperature, the more microporous structure and the stronger the pore connectivity, the stronger the water holding capacity of biochar [7].

4. Application of Biochar in Pollution Remediation

Due to its strong adsorption performance, biochar is widely used in the field of pollution remediation. Biochar is a high cost-effective polluted water treatment material, which can adsorb heavy metals such as arsenic, mercury, chromium and lead, inorganic pollutants such as nitrogen and phosphorus and organic pollutants such as pesticides and benzene [8]. The results show that 1g biochar can adsorb 1 mmol of cadmium and 1.9 g biochar is required to adsorb 1 mmol of zinc in waste water. The biochar prepared from sawdust can completely remove sulfathiazole (20.3 mg·L^{-1}). The adsorption capacity of biochar made of different materials is different. The adsorption capacity of biochar made of straw (SC)for arsenic (10 mg·L^{-1}) in water is 42mg·kg^{-1}, that of biochar made of pine needle (PC) is only 57% of SC, and that of biochar made of cow dung is 49% of SC. After the biochar was modified with hydrofluoric acid and potassium acetate, the adsorption capacity of lead in water increased from 7.56 mg·g^{-1} to 16.70 mg·g^{-1}. After the biochar made of wheat straw was modified with potassium hydroxide and ferric nitrate. The adsorption capacity of As^{3+} increased from 1.05 mg·g^{-1} to 65.20 mg·g^{-1} [9]. After the biochar made of rape straw was modified by phosphate co pyrolysis, the number of carboxyl groups on its surface was significantly increased and the complexation with heavy metals was significantly enhanced. After being added to the soil, it could significantly reduce the contents of Pb^{2+}, Cu^{2+} and Cd^{2+} in the soil, prevent the migration of heavy metals from the soil to crop roots, and effectively reduce the accumulation of heavy metals in the crop. Lu et al. [10] found that biochar made of rice straw had the highest adsorption rate of Zn^{2+}, while water hyacinth biochar could adsorb about 90% of As^{5+} in soil. The aromatic structure of biochar made of corn stover can make pesticides accumulate in the smaller pores on the surface of the biochar to achieve the removal effect. Biochar loaded with nano-iron sulfide reduces the exchangeability of Cr^{6+} and the ability to combine with carbonate in contaminated soil.

5. Future Study

Some progress has been made in the preparation, physical and chemical properties and application of biochar, which can be used to repair soil pollution and water pollution and enhance the carbon fixation capacity of soil. Using biochar as composting additive can enrich the diversity of microbial community, accelerate the degradation of organic matter, transform organic nutrients into soluble nutrients and improve soil quality. However, the research is mostly limited to small batch and small-scale laboratory stage, and there is still a big gap from mass production and large-scale application. At present, the development and utilization of biochar should focus on environmental protection, low cost and high efficiency in preparation, breaking through the bottleneck of the existing carbon production process, and making the biochar industry a truly "low-carbon, ecological and high-efficiency" development.

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References

[1] Zhang J, Liu J, Liu R. Effects of pyrolysis temperature and heating time on biochar obtained from the pyrolysis of straw and lignosulfonate. Bioresour Technol, Vol.176 (2015),p.288–291.

[2] Tan X.F, Liu Y.G, Zeng G.M, et al. Application of biochar for the removal of pollutants from aqueous solutions[J]. Chemosphere, 2015, 125: 70–85.

[3] Zhang J, Wang Q. Sustainable mechanisms of biochar derived from brewers' spent grain and sewage sludge for ammonianitrogen capture. J Clean Prod, Vol. 112, (2016) , p. 3927–3934.

[4] Li H, Dong X, da Silva E.B, et al. Mechanisms of metal sorption by biochars: biochar characteris-tics and modifications. Chemosphere, Vol. 178 (2017), p. 466–478.

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[5] Li L.C, Zou D.S, Xiao Z.H, et al. Biochar as a sorbent for emerging contaminants enables improvements in waste man-agement and sustainable resource use. J Clean Prod, Vol. 210 (2019), p. 1324–1342.

[6] Zhang J, You C. Water holding capacity and absorption properties of wood chars. Energ Fuel, Vol. 27 (2013), p.2643–2648.

[7] Tan X F, Liu Y G, Zeng G M, et al. Application of biochar for the removal of pollutants from aqueous solutions. Chemosphere, Vol. 125 (2015), p. 70–85.

[8] Zhang J.J, Shao J.G, Jin Q.Z, et al. Effect of deashing on activation process and lead adsorption capacities of sludge-based biochar. Science of the Total Environment, Vol. 716 (2020), p.137016.

[9] Zhu S.H, Zhao J.G, Yin Y.J, et al. Appilcation of goethite modified biochar for arsenic removal from aqueous solution. Environmental Science, Vol. 40 (2019), No.6, p. 2773-2782.

[10] Lu K.P, Yang X, Gerty G.L, et al. Effect of bamboo and rice straw biochars on the mobility and redistribution of heavy metals (Cd, Cu, Pb and Zn) in contaminated soil. Journal of Environmental Management, Vol.186, (2017) No.2, p. 285-292.