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The Research Progress of Bio Char in Environmental Pollution and Treatment

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Abstract

In recent years, various forms of environmental pollution have become increasingly severe, leading to a dangerous state in the atmosphere, water, and soil environments. This poses a threat to people's daily lives and has sparked widespread concern in society. Concurrently, bio char, a novel carbon material known for its large specific surface area, porosity, affordability, and excellent adsorption capabilities, has garnered attention. The incremental development and utilization of bio char have positioned it as a promising contender in sewage treatment, air pollution control, soil pollution treatment and other pollutant adsorption processes. This paper provides a comprehensive review of the preparation of bio char, its current research status, and the factors influencing its adsorption efficiency through an extensive literature survey.

Keywords: Bio char; Adsorption; Bio char preparation; Adsorption influencing factors; Pollutant treatment

1. Introduction

The intensification of human activities and rapid economic development in modern times have had a significant impact on the natural environment. Global challenges such as water pollution and air pollution have arisen as a result. Water pollution, in particular, is a complex issue with numerous sources of contamination. Substances like nitrates are able to be found in both surface and groundwater, disrupting the growth of aquatic organisms and posing a threat to human water resources. It is imperative to address environmental pollution promptly in order to protect various aquatic ecosystems. Carbon is a non-metallic element located in the second cycle of the periodic table IVA group. It is the most abundant element in chemical compounds on Earth and is widely distributed in both the Earth and the universe. Carbon primarily forms compounds like carbonate, carbon dioxide, and others in water and air, as well as in oil, natural gas, and various hydrocarbons. The mining of carbonates, coal, natural graphite, diamonds, and other forms of carbon holds a significant position in the mining industry. Carbon is crucial for the existence of all plants and animals, with a natural abundance of 0.08% and ranking 13th in abundance in the Earth's crust among various elements. Due to its unique electronic orbital characteristics (SP, SP_2, SP_3 hybrids) and the fact that it only consists of the carbon element, carbon exhibits diverse properties depending on its crystal structure. Throughout history, traditional carbon materials such as charcoal, bamboo charcoal, activated carbon, carbon black, natural graphite, coke, graphite electrodes, carbon brushes, carbon rods, and pencils have been commonly used. However, with the advancement of society and the rapid development of modern science and technology, research on carbon elements has led to the development of new carbon materials including diamonds, carbon fibers, graphite sandwich compounds, flexible graphite, nuclear graphite, energy storage carbon materials, glass carbon, and more. Additionally, nanomaterials like carbon nanotubes, fullerenes, nanodiamonds, and graphene have emerged, finding widespread applications in modern life. Bio char is a type of solid substance with a high degree of aromatization and carbon content, formed through anaerobic pyrolysis of waste organic materials. It is characterized by its effective surface area, high porosity, and rich functional groups, making it a cost-effective material with excellent adsorption performance. By enhancing its interaction with substances through physical or chemical adsorption, bio char is widely utilized in the adsorption of organic pollutants, heavy metal ions and other pollutants in sewage treatment and other applications. It has emerged as a novel carbon material due to its ability to not only adsorb pollutants effectively but also support the growth of microorganisms and the formation of microbial biofilms, making it a valuable carrier for immobilized bacteria.

2. Progress of Bio Char Research

2.1 Preparation Method of Biological

Activated carbon is currently classified into two types: pyrolysis and hydrothermal synthesis. The method of preparation has a significant impact on the physical and chemical properties of the activated carbon, including yield, ash content, specific surface area, pore structure, species and quantity of functional groups, and cation exchange capacity. Pyrolysis typically involves two methods: chemical activation, and physical activation method. The physical activation method typically involves the reaction of carbon materials with water vapor, carbon dioxide, or air oxidation gas at high temperatures to generate carbon monoxide, carbon dioxide, and hydrogen hydrocarbon gas. This reaction process requires high temperature of 200 to 800 degrees Celsius to oxidize the carbon, creating etching and pores within the material to form a developed microporous structure. Unlike water vapor activation, which has a molecular diameter smaller than water molecules, activated carbon prepared by CO_2 activation results in a much higher proportion of microporous volume.The chemical activation method involves mixing chemical agents with materials, carrying out a pyrolysis reaction under an inert atmosphere, removing the chemical agents from the activated material, and then drying them with deionized water and alkaline and acidic solvents to obtain activated carbon. Activated carbon prepared through chemical activation offers advantages such as richer pores, a larger specific surface area, and a shorter preparation period compared to activated carbon prepared through physical activation methods. This results in activated carbon with superior pore performance. Commonly used chemical reagents include acids (phosphoric acid (H_3PO_4), sulphuric acid (H_2SO_4), hydrochloric acid (HCl)), alkalis (Potassium hydroxide (KOH), sodium hydroxide (NaOH), potassium carbonate (K_2CO_3), sodium carbonate (Na_2CO_3)), and metal compounds (zinc chloride ($ZnCl_2$), magnesium oxide (MgO), iron oxide (Fe_2O_3)) (Yin, 2019). The chemical activation reaction typically occurs at medium to low temperatures, with different chemical reagents acting on raw materials in distinct ways. The physical and chemical activation method combines physical activation and chemical techniques in the production of activated carbon. This method utilizes activators like water vapor and carbon dioxide (CO_2) in a coactivation process, treating raw materials with chemical reagents first.Another method of hydrothermal synthesis of biological carbons mainly refers to the hydrothermal carbonization method of biomass. This method uses water as a medium to degrade biomass into bio char at a specific temperature (typically 100 to 250 degrees Celsius) and pressure (0.5 to 16.5MPa). This method is not only simple to operate, low in energy consumption, but also mild in reaction conditions. In the process of hydrothermal synthesis, bio char does not need to be pretreated with raw material dehydration and strict drying, which is capable to greatly reduce the cost. In addition, the researchers also found that the bio char obtained by this method has more active sites than the bio char obtained by other methods, which greatly improves its adsorption activity (Zhao et al.,2023).
In addition to the above solutions, other methods of biomass conversion include flash carbonization and baking techniques. However, the adoption of new pyrolysis technology is hindered by cost and high energy consumption issues.

2.2 Research Status

Through a review of the literature, it is evident that bio char has gained prominence in the realm of environmental pollution control due to its unique characteristics. It has become a widely adopted treatment method, leveraging its biological carbon properties to employ adsorption for pollution remediation. The adsorption method is valued for its cost-effectiveness, ease of operation, efficient separation effect, and potential for reusability, thus establishing itself as a crucial approach in pollution control. Bio char plays a significant role in air pollution control by adsorbing CO_2 molecules from the atmosphere, thereby helping to mitigate the greenhouse effect. bio char is characterized by highly developed narrow micropores, which continuously adsorb

CO_2 molecules until saturated. Moreover, the abundant mesopores within activated carbon materials reduce mass transfer resistance of CO_2, enhancing the utilization efficiency of micropores and strengthening the interaction between the material and CO_2 molecules (Ren et al., 2022).

Heavy metals in sewage are also one of the serious problems that plague people nowadays. Copper excess causes metabolic disorders (Liu, 2023), and even endangers life. The urgency of removing heavy metals from sewage is paramount. The physical and chemical properties of bio char play a significant role in enhancing the efficiency of heavy metal removal in aqueous solutions. Functional groups' interaction with heavy metals can directly or indirectly impact adsorption mechanisms, including electrostatic interaction, surface complexation, ion exchange, and mineral components that greatly influence the precipitation effect. Surface modification of carbon adsorbents is essential for advancing new technologies and optimizing their physicochemical and adsorption properties. Specific functional groups introduced on the carbon surface can selectively adsorb target heavy metals. Among various biological carbonization modification methods, three common chemical modification methods effectively introduce oxygen, nitrogen, and sulfur energy groups on the biological carbon surface, enhancing heavy metal adsorption: oxidation, nitride, and sulfide (Ji, 2023). Bio char usually contains soluble phosphate and carbonate, which have the capacity to precipitate $PO_4^{3-}$and CO_3^{2-} with heavy metal elements such as Cd^{2+} and Pb^{2+} in water, forming relatively stable minerals ($CdCO_3$、$PbCO_3$, et al.) (Xiong et al., 2003).The study investigated the impact and processes involved in the removal of Pb^{2+}, Cu^{2+}, Zn^{2+}, and Cd^{2+} by cattle dung bio char (Xu et al., 2013). It was observed that the primary mechanism of heavy metal removal included the binding and sedimentation of Pb^{2+}, Cu^{2+}, Cd^{2+}, and Zn^{2+} with phosphate or carbonate.

Not only are heavy metals a concern in water, but excessive antibio tics and nitrogen are also significant environmental pollution issues. The increasing use of antibiotics and poor management practices have led to a significant rise in antibiotic pollution, resulting in many microorganisms in the environment developing resistance to antibiotics. This imbalance between the removal and entry rates of antibiotics into the environment underscores the urgent need for efficient removal methods to mitigate the harmful impacts on human health and the environment. From basic activated carbon to advanced modified bio char, and even new nano carbon materials with promising development potential, carbon materials play a crucial role in the adsorption process of antibiotics (Cai et al., 2019). The adsorption interaction between carbon materials and antibiotics can be described by physical adsorption, chemisorption and electrostatic interaction (Ersan et al., 2017). Currently, traditional carbon materials like activated carbon are commonly used for antibiotic adsorption. However, recent studies have shown that newer carbon materials such as carbon fiber, porous carbon, and nanocarbon materials also exhibit effective adsorption of antibiotics. These innovative materials are increasingly being utilized in the removal of antibiotics through adsorption processes (Jiang et al., 2021). At present, many researchers have shown that bio char has a good adsorption effect on antibiotics in water, but there are also many problems, such as bio char modification methods waiting to be studied (Zhang, 2024).

Bio char has the ability to host and stimulate the growth of microorganisms, enhancing their metabolic activities and enabling them to thrive in challenging environments. By facilitating the biodegradation of microorganisms, bio char addresses the limitations of saturated adsorption, preventing the release of pollutants and ultimately improving its reusability (Huang & Ma, 2021).The rise in heavy metal and organic pollutant contamination in soil has emerged as a pressing global environmental concern. Research on the use of bio char for mitigating heavy metal pollution in agricultural land has garnered significant attention. Through processes like adsorption, bio char is able to decrease the bioavailability and leaching of heavy metals and organic pollutants in soil. Acting as an alkaline agent, bio char can also enhance soil pH and stabilize the composition of heavy metals in the soil. A review of current literature indicates a growing interest in utilizing bio char as a soil amendment. For example, Cui et al. (2011)found that the use of bio char could significantly reduce the absorption of Cd in rice; Park et al. (2011) study showed that application of bio char significantly reduced the NH_4NO_3 extraction concentration and accumulation of Cd, Cu and Pb in Indian mustard; according to study by Karami et al. (2011), biological carbon can effectively reduce the Cu concentration in ryegrass; According to the research by Wang et al. (2017) Application of bio char significantly reduced the Cd content with a strong exchange state, Make the rape absorption amount significantly reduced. According to the study by Zhou et al. (2008). Cotton straw carbon has a remediation effect on soil cadmium pollution, to reduce the cadmium content in vegetables. To improve the quality of vegetables. In the studies of Lin et al. (2007), Man (2016) and Liu (2016), the bioavailability of bio char against heavy metals in contaminated soil, including Pb, Cu, Cd, Zn, and their effectiveness against phytotoxicity. It is an effective remediation agent of soil contaminated by heavy metals.

2.3 Factors Affecting Bio Char Adsorption Capacity

Four mechanisms for the biological adsorption of metals are proposed: firstly, the interaction of metal ions with the charged surface of biological carbon through electrostatic forces; secondly, the ionization of protons on the bio char surface leading to complexation with metal ions or ion exchange; thirdly, the interaction and adsorption of electrons in the delocalization of biological carbon; and finally, the beneficial impact of adsorbed metals on the pores of bio char. Ultimately, the effectiveness of bio char in remediating soils contaminated with heavy metals hinges on the affinity of the biological carbon and its metal absorption capacity.

A large number of studies (Wang et al., 2016; Jane et al.,2016; Liu et al. ,2012) have shown that the adsorption capacity of bio char with different properties is also very different due to the large differences in pore structure, ash content, cation exchange capacity, pH value and elemental composition of bio char. According to the study by Chang et al. (2016). Corn cob charcoal and dragon locust carbon at the same pyrolysis temperature, the removal rate of Cu^{2+} gradually increased with the extension of the pyrolysis time. By Tong et al. (2011), the adsorption amount of Cu^{2+} from large to small is rapeseed straw carbon, peanut straw carbon and soybean straw carbon. Ding et al. (2011)and Zhu (2011) prepared bio char with different temperatures of pine strips. From high to low, the remediation effect of lead and cadmium in soil is as follows: P-700, P-500 and P-300. Li et al. (2012) found that the specific surface area of 700℃ was large. The pore structure is more fully developed, BC700 The adsorption capacity of Cd is greater than BC350, and 350℃. According to Jian et al. (2016), pyrolysis of chicken manure into 700 degrees Celsius is able to achieve better. But there are also studies where showed that, application of wood chip bio char and chicken manure bio char is able to increase the biological efficacy of Cu^{2+} and Zn^{2+} (Hou et al., 2011). Li Mingyao prepared bio char from 300~600℃ of rice straw (Li et al., 2013). It was found that the Cd content of the effective state in the soil from large to small was reduced by W_4, W_5, W_6 and W_3.

The carbonization temperature of bio char and the types of organic pollutants are also two major factors affecting its adsorption capacity. The carbonization temperature determines the properties of bio char, which in turn affects its adsorption performance. The adsorption of straw bio char by different types of pollutants with different characteristics also showed significant differences. The bio char obtained by cracking at different temperatures will have great differences in its own composition and structural characteristics, among which the polar (Uchimiya et al., 2010), hydrophilic (Wang et al., 2012), aromatic (Chen & Chen, 2009), specific surface area (Liu et al., 2010), pore structure (Uchimiya et al., 2011) and so on, will affect the adsorption effect. Bio char for different organic pollutants adsorption strength and adsorption lag, not only depends on the properties of bio char itself, also with organic hydrophobic (Bornemann et al., 2007), polar (Yang & Sheng, 2003), molecular size and structure (Ahmad et al., 2012) of have certain relationship, therefore, biological carbon adsorption strength of different organic pollutants and the degree of hysteresis also has certain relationship with the hydrophobicity of organic matter.

2.4 Potential Hazards Of The Bio Char

While bio char shows promising results in heavy metal treatment, soil remediation, and air pollution control in short-term experiments, its long-term environmental impact remains uncertain. Research indicates that while bio char enhances soil quality and crop yields, it is capable of reducing the effectiveness of herbicides, posing challenges in weed control. Moreover, bio char, derived from agricultural waste may contain heavy metals such as copper aluminum, and other pollutants. If not properly managed, bio char could introduce new sources of pollution to soil and water, potentially causing harm to the environment. Furthermore, the production of bio char generates various pollutants, including organic compounds like polycyclic aromatic hydrocarbons and environmentally persistent free radicals.

3. Conclusion

Biochar is a new type of environmentally friendly adsorbent, which has the characteristics of low cost, abundant sources and great market potential. It is an ideal environmental adsorbent with huge growth opportunities in the remediation of organic pollution, the regulation of heavy metal contaminants, and the management of antibiotic contaminants. This study provides a comprehensive overview of the use of biomass-derived biochar to solve various environmental pollution problems, especially in the adsorption of various pollutants in water bodies and atmosphere. In addition, the effectiveness of biochar in the adsorption of environmental organic pollutants, new pollutants and heavy metal ions, as well as its application in soil remediation, were highlighted. In this paper, various preparation techniques of biochar are studied, and the methods of biochar pyrolysis and hydrothermal synthesis are introduced in detail. In addition, it emphasizes that the adsorption capacity of biochar materials with different properties is different under different conditions, indicating that their basis and adsorption properties are different. Different stomatal structures, ash element composition, affinity and other factors will affect the adsorption capacity of biocarbon to pollutants. Therefore, this study delved into the factors affecting biochar adsorption under various scenarios. The use of biochar to remediate contaminants in soil and water is a promising new technology. As an environmental functional material that has attracted much attention, biochar needs to further study the theoretical system and application technology of pollution control in the real environment. Moreover, whether the pollutants invested in biocarbon treatment will cause secondary pollution to the environment is also a question worthy of deep thought, which needs to be considered in follow-up research.

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Declaration of Conflicting Interests

All authors declare that they have no conflicts of interest.

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