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An Evaluation of Biochar as an Efficient Adsorbent for Removing Heavy Metals from Aqueous Solutions

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ABSTRACT

Heavy metal pollution is a major environmental concern, as these elements are toxic and can cause significant harm to human health and ecosystems. Industrial activities, mining, and agricultural practices are some of the major sources of heavy metal contamination in water bodies. The conventional methods of heavy metal removal, such as precipitation, coagulation, and ion exchange, have proven to be inefficient and expensive. Therefore, there is a need for alternative, cost-effective, and environmentally friendly methods for removing heavy metals from aqueous solutions. Biochar, a carbon-rich material produced from the pyrolysis of biomass, has emerged as a promising adsorbent for heavy metal removal. This paper aims to evaluate the efficiency of biochar as an adsorbent for removing heavy metals from aqueous solutions.

Keywords: Heavy metal, biochar, adsorbent

INTRODUCTION

Water body contamination caused by a rise in dangerous substances from anthropogenic effluents is one of the contemporary environmental problems. Because they affect aquatic biota and human health even in small amounts, heavy metals like lead and nickel rank among the most harmful contaminants. These metals have been linked to cancer, neurological disorders, genetic abnormalities, hypertension, immunological deterioration, respiratory problems, liver and renal ailments, hypertension, and even mortality [1}. Additionally, improper use of agricultural fertilizers, the discharge of spent batteries, and vehicle exhaust emissions can all seriously contaminate rivers with heavy metals [2,3]

The surface sediments of rivers and lakes are made up of a complex mixture of different mineral bodies, clay, silt, and organic stuff. The primary source of heavy metals in sediment is contaminated water bodies, and between the sediment and the water body, a number of transformation and movement processes take place, including ion exchange, redox, complexation-decomplexation, precipitation-dissolution, and adsorption-desorption.[4,5]

Owing to their poor mobility and long residence times, heavy metals present in sediment are challenging for microbes to degrade. [6]In addition to killing aquatic plants and animals and providing a further risk to human health and life through transmission through the food chain, these metals have the potential to constitute a "new source of pollution," contaminating the water body twice. The problem of heavy metal pollution in river sediments and waterways is getting more and more urgent. [7] In this paper, we will review the current research on heavy metal adsorption by biochar and its mechanism. We will also discuss the factors that influence the adsorption efficiency of biochar and potential future research directions in this field.

HEAVY METAL POLLUTION

Heavy metal pollution is a global environmental issue that has become a major concern in recent years. Heavy metals such as cadmium, lead, mercury, and chromium can enter the environment through various industrial activities, agricultural practices, and natural processes. These metals are highly toxic and can accumulate in living organisms, causing adverse effects on human health and the environment. Therefore, effective methods for the removal of heavy metals from contaminated environments are urgently needed.

Heavy metal removal from industrial waterways has been accomplished by the use of conventional techniques such as membrane separation, electrochemical treatment, coagulation, evaporation, and precipitation. However, they are inefficient and unfavorable due to high costs, significant sludge output, and partial removal.[8]. Unfortunately, the majority of these methods are pricey, hence more economical technologies utilizing inexpensive adsorbents must be developed.[9]. The most important aspect of adsorption technology is the identification of suitable adsorbents. It is preferable for an adsorbent to have characteristics such a large specific surface area, fast adsorption rate, and brief equilibrium time [10]. From this perspective, due to its low cost, plentiful availability, and no ecological impact, biochar stands out from many other innovative functional materials used for environmental applications as a highly effective adsorbent. Advantageous features of biochar include its enormous specific surface area, complex surface-active functional groups, stable chemical properties, and distinct pore structure[11].Furthermore, it possesses a significant capacity for the adsorption and elimination of heavy metal contaminants, immobilization and passivation, and enhancement of environmental quality. As a result, research on the adsorption of heavy metal contaminants in various valence states found in contaminated water bodies has made extensive use of biochar[12]. One promising approach for the removal of heavy metals from contaminated environments is the use of biochar. Biochar is a carbon-rich material produced through the pyrolysis of biomass. It has a highly porous structure and a large surface area, making it an ideal adsorbent for heavy metals. Biochar has been extensively studied for its potential as a low-cost and sustainable solution for heavy metal pollution. Because different types of biochar have different adsorption qualities depending on the raw materials and manufacturing circumstances used, different types of biochar cannot remove all the heavy metals from polluted water bodies. Additionally, the kind and quantity of heavy metals present have an impact on how well biochar adsorbs them. This leads to a tendency for biochar's adsorption effectiveness on certain heavy metals to vary. For the purpose of eliminating heavy metals from contaminated water, there are numerous adsorbents based on biochar; however, the initial biochar has a low adsorption capacity and poor adsorption selectivity for some heavy metal contaminants[13].

HEAVY METAL ADSORPTION BY BIOCHAR

Biochar has been shown to have a high affinity for heavy metals due to its surface functional groups, such as carboxyl, hydroxyl, and phenolic groups, which can form strong electrostatic interactions with metal ions [14]. Additionally, the porous structure of biochar provides a large adsorption surface for heavy metals to bind to.

Several studies have demonstrated the effectiveness of biochar in removing heavy metals from contaminated environments. For example, Liu et al. investigated the adsorption of cadmium (Cd) and lead (Pb) by wheat straw biochar and found that it had a high adsorption capacity for both metals [15]. Similarly, other studies have shown the potential of biochar in removing other heavy metals such as copper (Cu), zinc (Zn), and nickel (Ni)[16,17].

MECHANISM OF HEAVY METAL ADSORPTION BY BIOCHAR

The adsorption mechanism of heavy metals by biochar is a complex process that involves physical, chemical, and biological interactions. The physical adsorption of heavy metals occurs through Van der Waals forces, which are primarily responsible for the high adsorption capacity of biochar (Liu et al., 2018). Chemical adsorption occurs through ion exchange and surface complexation, where metal ions bind to the functional groups on the surface of biochar. Biological interactions, such as microbial activity, can also play a role in the adsorption of heavy metals by biochar [18].

BIOCHAR AS AN ADSORBENT FOR HEAVY METAL REMOVAL

Biochar has a high surface area, porous structure, and functional groups, making it an effective adsorbent for heavy metal removal. The surface area of biochar can range from 100 to 1000 m2/g, providing a large area for adsorption [19]. Additionally, the porous structure of biochar allows for the formation of micro and mesopores, which increase the adsorption capacity [20]. The functional groups present on the surface of biochar, such as carboxyl, hydroxyl, and phenolic groups, facilitate the binding of heavy metal ions through complexation and ion exchange [19].

Several studies have demonstrated the efficiency of biochar in removing various heavy metals from aqueous solutions. For instance, Zhang et al. (2015) investigated the adsorption of cadmium (Cd) and lead (Pb) ions by different types of biochar. They found that the biochar produced from rice straw had the highest adsorption capacity for both Cd and Pb, with removal efficiencies of 94.1% and 92.2%, respectively. Similarly, a study by Li et al. (2017) showed that biochar produced from pig manure was highly effective in removing copper (Cu) and zinc (Zn) ions from aqueous solutions, with removal efficiencies of 98.7% and 96.5%, respectively [21].

The efficiency of biochar as an adsorbent for heavy metal removal is influenced by various factors, such as biochar properties (e.g., surface area, pore structure, and functional groups), solution properties (e.g., pH, metal concentration, and contact time), and environmental conditions (e.g., temperature and presence of other contaminants). For instance, a study by Ma et al. (2019) showed that the adsorption capacity of biochar for Pb and Cu ions increased with an increase in biochar dosage, solution pH, and contact time [22].However, the presence of other cations, such as calcium (Ca) and magnesium (Mg), decreased the adsorption capacity of biochar due to competition for the available binding sites [23].

FACTORS AFFECTING HEAVY METAL ADSORPTION BY BIOCHAR

The adsorption efficiency of biochar is influenced by various factors such as pH, contact time, initial metal concentration, and biochar properties [24]. The pH of the solution is a crucial factor as it affects the surface charge of biochar and the speciation of metal ions. Generally, biochar has a higher adsorption capacity at lower pH levels due to the increased positive charge on its surface. The contact time between biochar and metal ions also plays a crucial role, as a longer contact time allows for more adsorption to occur. The initial metal concentration in the solution is another significant factor, as a higher concentration can saturate the adsorption sites on the biochar surface, leading to a lower adsorption capacity. Lastly, the properties of biochar, such as surface area, pore size distribution, and surface functional groups, can greatly influence its adsorption efficiency.

BIOCHAR MODIFICATION FOR ENHANCED ADSORPTION

To improve the adsorption efficiency of biochar, various modification techniques have been employed, such as physical, chemical, and biological modifications. Physical modifications, such as ball milling and acid treatment, can increase the surface area and porosity of biochar, resulting in improved adsorption capacity[25]. Chemical modifications, such as impregnation with iron (Fe) and manganese (Mn) oxides, can enhance the functional groups on the surface of biochar, leading to increased adsorption of heavy metals [26]. Biological modifications, such as using fungi and bacteria, can also enhance the adsorption capacity of biochar through the production of extracellular enzymes and metabolites that can bind heavy metals [27]

COMPARISON WITH OTHER ADSORBENTS

Biochar has been compared with other adsorbents, such as activated carbon, zeolites, and clay minerals, for its efficiency in removing heavy metals from aqueous solutions. In general, biochar has shown comparable or higher adsorption capacities than these conventional adsorbents. For instance, a study by Huang et al. (2015) showed that the adsorption capacity of biochar for Pb was higher than that of activated carbon[28] Similarly, a study by Bolan demonstrated that biochar had a higher adsorption capacity for Cd than zeolites [18].

ADVANTAGES AND LIMITATIONS OF BIOCHAR AS AN ADSORBENT

The use of biochar as an adsorbent for heavy metal removal has several advantages, such as low cost, availability, and sustainability. Biochar can be produced from a variety of biomass feedstocks, including agricultural residues, forestry wastes, and animal manure, making it a readily available and cost-effective adsorbent[19]. Furthermore, biochar production can also contribute to the reduction of greenhouse gas emissions and the sequestration of carbon, making it a sustainable solution for heavy metal pollution.

However, there are also some limitations to the use of biochar as an adsorbent. One of the major limitations is the lack of standardization in biochar production, which can result in variations in its properties and adsorption efficiency[29]. Additionally, the large-scale production of biochar for industrial applications may require significant amounts of biomass, which could potentially compete with food production and have adverse effects on land use and biodiversity.

FUTURE RESEARCH DIRECTIONS

Despite the potential of biochar in heavy metal adsorption, there is still a need for further research to optimize its use. One area of future research could focus on the modification of biochar properties to enhance its adsorption efficiency for specific heavy metals. Additionally, studying the long-term effects of biochar application on soil health and plant growth is essential for its practical application in contaminated environments. Further research is also needed to investigate the fate of heavy metals adsorbed by biochar and their release potential under different environmental conditions.

CONCLUSION

Biochar has shown great potential as an efficient adsorbent for removing heavy metals from aqueous solutions. Its high surface area, porous structure, and functional groups make it an effective and environmentally friendly alternative to conventional adsorbents. However, further research is needed to standardize biochar production and optimize its properties for specific heavy metal removal applications. Additionally, the potential impacts of large-scale biochar production on the environment and food security should also be carefully considered. Overall, biochar holds promise as a sustainable solution for mitigating heavy metal pollution in water bodies. With the growing concern over heavy metal pollution, the use of biochar as an adsorbent can provide a sustainable solution for the remediation of contaminated environments.

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