

# Application of Biochar for Organic Pollution Control and Energy Storage

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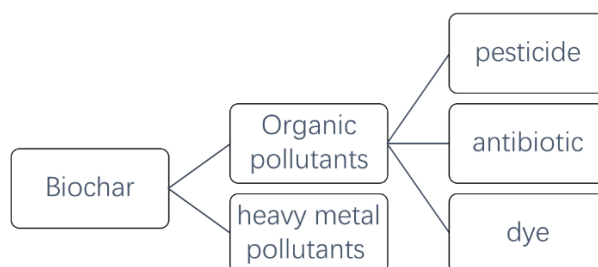
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**Abstract.** Against the backdrop of a growing global climate problem, Against the background of a growing global climate problem, the research on biochar resource utilization is of great importance and urgency. This paper investigates the physical and chemical properties of biochar and its preparation method, and analyzes its principle, application and development prospect in organic pollution control and energy storage. Biochar, due to its large specific surface area and high specific electric capacity, has higher capacitance and charging/discharging stability and lower production cost as graphite electrodes for graphite batteries compared to traditional materials. Biochar is ideally utilized in the field of energy storage. The research and application of biochar is not only helpful for the utilization and transformation of traditional fossil fuel to renewable and clean energy, but also an ideal development area for the rational improvement of soil pollution and the rational disposal of bio-organic wastes.

**Keywords:** Biochar; organic pollution control; energy storage; carbon neutrality.

## 1. Introduction

Global warming caused by excessive greenhouse gas emissions and frequent extreme climate events in recent years have affected human social production and consumption, lifestyle and Lebensraum. The discharge of industrial waste also causes damage to the current living environment of humanity. Hard-to-degrade organic pollutants and heavy metals which contained in industrial waste have an adverse effect on soil. The porous structure of biochar can play a role in the adsorption of organic matter, and heteroatomic functional groups can be combined with heavy metal ions in the soil to produce precipitation. It has an extremely positive effect to the improvement of soil properties. And it is a reasonable reuse of biomass, the preparation of Biochar is a good means of carbon resourcing and carbon storage. As the anode of graphite battery, Biochar has many outstanding advantages, such as large specific capacitance, stable reaction performance, various and adjustable properties of modified carbon. It has great research significance in the field of energy storage. As a new low-carbon resource, Biochar has important application value in the field of ecological environment. Its application status in the field of soil pollutant control is shown in Fig. 1.



**Fig 1.** Application of biochar in environment. (Photo/Picture credit: Original)

For pesticide removal, KOH-modified and Na<sub>2</sub>S-modified corn stover biochar developed by Tan et al. showed better adsorption of atrazine than primitive corn biochar [1]. For Antibiotic removal, primitive Biochar has good adsorption effect on antibiotics, but most of the current research focuses

on the adsorption of modified Biochar on antibiotics and the investigation of the principle of action. Song et al. [2] found that nitric acid modified corn stover biochar showed greater saturated adsorption capacity and adsorption rate constants compared to control corn stover biochar in the adsorption of antibiotics sulfachloropyridazine (SCP), sulfamethoxazole (SMZ), and sulfamonomethylpyrimidine (SMA). For Removal of dyes, both primitive biochar and modified biochar have been extensively studied in this field.

For removal of heavy metals, utilizes the property of the functional groups of Biochar to generate precipitation with metal ions in the soil. Biochar reduces the mobility of heavy metal ions, resulting in lower bioactive state extractable heavy metals in the soil, thus reducing crop uptake of heavy metal ions.

In the field of energy storage, biochar as a capacitor material possesses high specific capacity, good mechanical flexibility and electrochemical stability. It is an ideal material for making supercapacitors. In this study, exploring the reaction principles of these methods and the physical and chemical properties of the prepared biochar. By analyzing the application principles of biochar in the direction of organic matter pollution control and energy storage, exploring its application areas and future development prospects.

## 2. Biochar

### 2.1. Definition of Biochar

Biochar is a carbon-rich solid product obtained from biomass, which is heated and decomposed under anoxic conditions, and is a kind of carbon material with high carbon content, porous, strong adsorption capacity and multipurpose use, which has long been widely used in the world as a hygroscopic agent, deodorizing agent, soil conditioner, heavy metal adsorption stabilizer, and carbon sequestering agent, etc. [3]. In terms of physical properties, Biochar tends to consist of connected large pore channels and small, fine micropores with large pore sizes and large specific surface areas. The physical properties, chemical properties, and adsorption capacities of biochar which produced by different raw materials and thermodynamic circumstances differed. As the pyrolysis temperature increased, the specific surface area of the biochar increased and aromatization deepened. The adsorption capacity of biochar with a pyrolysis temperature of 500 °C is higher than that of biochar with a pyrolysis temperature of 300 °C in the preparation process, and the difference of raw materials selected in the preparation of biochar can also cause the difference of chemical properties; biochar prepared from livestock manure usually has a high pH, while biochar prepared from plant straw has a lower pH [4].

### 2.2. Biochar Preparation

At present, there are a lot of researches on biochar around the world, and there are many methods available for the preparation of biochar. After comprehensively researching a variety of methods for the preparation of biochar, this study classifies the current methods for the preparation of biochar into the following three types according to the principles of preparation.

#### 2.2.1 Biomass pyrolysis carbonization

The biomass raw material needs to be pretreated (neutralized the acid and alkali then washed it by water to neutral before drying). Weigh the pretreated biomass quantitatively and add them to the reactor. At a certain pressure, after the reactor is programmed to heat up to a predetermined temperature (200 °C-900 °C), the raw materials are beginning thermally decomposed. After the reaction was complete, remove the product after cooling to room temperature under the protection of an inert gas, and the target product biochar was prepared by washing to neutrality and drying in distilled water [5]. Pyrolysis methods can be categorized into slow decomposition and fast decomposition based on the different parameters such as pyrolysis heating rate, time of biomass.

During pyrolysis at slow heating rates (0.1-0.8 °C/s), biomass undergoes degradation, decomposition and transformation, formation of carbon-rich solids and condensable and non-condensable volatile products [6]. Under slow pyrolysis reaction, the yield of biochar product is higher and the mass percentage of biochar solids in the product can be up to 60% [7]. However, due to the long residence time of the reaction, some kinetically inferior tandem side reactions take place, which result in the production of many by-products and reduce the selectivity of the reaction for generating the target product biochar. Rapid pyrolysis is the process of heating low-temperature biomass feedstocks to higher reaction temperatures (450 °C-550 °C) in a very short period of time and under anaerobic conditions. The short residence time of the reaction and the fast rate of heating and cracking result in very high bio-oil yields, and the maximum yield of one complete liquefaction process can reach 85%, so the fast high temperature cracking process is also known as the fast biomass liquefaction process [6]. The yield of Solid biochar produced by rapid pyrolysis are very low, and usually a single cracking process only produces coke with a content of less than 12% [8]. Rapid cracking produces biochar with low calorific value and high oxygen content.

### 2.2.2 Biomass hydrothermal carbonization.

Hydrothermal carbonization is based on water as the reaction medium, at a certain temperature (180 °C-250 °C) and high pressure, the reaction is carried out in hours. The process of converting biomass raw materials into carbon materials dominated by biochar [9]. The hydrothermal carbonization reaction takes place in water, so the reaction is not affected by the water content of the feedstock, and is mostly applied to biomass feedstocks with high water content [10]. Hydrothermal carbonization has mild reaction conditions and a controlled process, making it easy to achieve a more uniform carbonization process.

### 2.2.3 Biomass pyrolysis gasification

Biomass gasification is a process of pyrolysis, oxidation, and reductive reforming of biomass polymers under certain thermodynamic conditions using oxygenates as gasification agents, which ultimately converts them into combustible gases with carbon monoxide, hydrogen, and methane as the main components.

Biochar is mainly produced in the stage of pyrolysis reaction: biomass feedstock into the reactor is first heated, most of the water is released at 105 °C; when the reactor temperature reaches 150 °C or more [11], the irreversible pyrolysis reaction of polymer organic matter begins, and the higher the temperature, the more intense the decomposition; The remaining char and ash were obtained after the volatile components in the biomass were continuously precipitated under heating conditions. However, the yield of biochar is very low, the conversion rate of tobacco stalk biochar which prepared by gasification by Fu et al. [12] is only 20%.

## 3. Application of Biochar in Organic Pollution Control

### 3.1. Application Principle

Biochar has a loose and porous structure with a very high surface area. In addition, in terms of chemical composition, biochar contains many functional groups. Complexation, electrostatic interactions, and hydrogen bonding between the functional groups of biochar and the adsorbed substances can be generated. Therefore, the adsorption capacity of biochar can be increased. Pollutants in water and soil can be removed through physical or chemical interaction between biochar and the pollutants. Substances such as heavy metals, pesticides, antibiotics, and dyes can be immobilized efficiently.

### 3.2. Application Examples

Metal oxide composite modified biochar composites shows a good adsorption of methyl orange and methylene blue dyes in aqueous solution. The development of this aspect in the chemical industry

is reflected in the photocatalytic technology. Wei [10] et al. found that although the raw materials for the preparation of pristine biochar are widely available, their adsorption of dyes varies greatly. The adsorption performance of biochar needs to be improved by physical, chemical and biological modification methods. Biochar and its composites have been developed as novel adsorbents and catalysts for pollutant degradation. However, research on biochar-based catalysts is still at the laboratory scale level. Tests to evaluate their application to real industrial wastewater are still relatively limited.

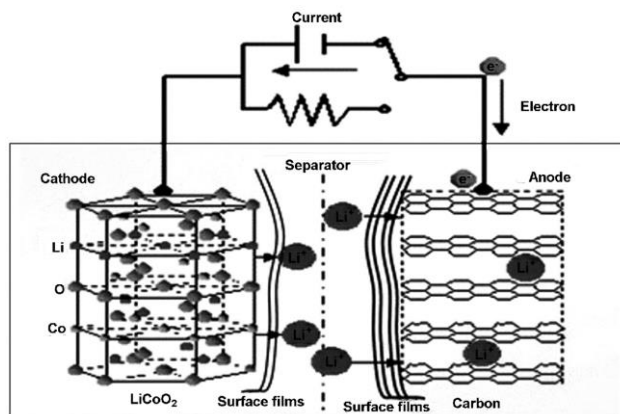
### 3.3. Application Prospects

As a new type of low-carbon resource, biochar has an important application value in the field of ecology and environment. It can be used as an adsorbent to efficiently remove heavy metals, pesticides, antibiotics and dyes from polluted environments. Besides, it can be used as a soil conditioner to improve soil nutrient effectiveness, microbial activity, soil organic matter, water retention and soil crop yield. In addition, it can be used as a carbon sequestering agent to reduce CO<sub>2</sub> and other greenhouse gas emissions.

## 4. Application of Biochar for Energy Storage

### 4.1. Application Principle

Reversible battery due to the ability to convert electrical energy into chemical energy, which in turn is converted into electrical energy through a chemical reaction at the desired time. It is very good to meet the demand of energy storage. So batteries are widely used in the field of energy storage. A new generation of energy systems, lithium-ion batteries are made of lithium storage compounds as positive and negative materials. They feature high multiplicity, cheap cost, high thermal stability, extended cycle, and/or high capacity. An operational schematic of a lithium-ion battery having a graphite anode and a lithium-cobaltate cathode is illustrated in Fig. 2 [13]. The positive reaction is shown in Eq. (1), the negative reaction is shown in Eq. (2) and the total reaction is shown in Eq. (3).



**Fig 2.** The schematic presentation of the most commonly used li-ion battery based on graphite nodes and Li-CoO<sub>2</sub> cathode. <https://pubs.rsc.org/en/content/articlelanding/2011/ee/c1ee01598b#!>



Instead of graphite as a cationic material, biochar has a high specific surface area and a relatively stable structure, with the help of which different biochars can provide different and high specific capacities, also there are differences in the properties of biochar made from different biomass raw materials and these differences between the properties can be utilized and make lithium-ion batteries with different properties.

## 4.2. Application Examples

Biochar has a high specific capacity, and with the help of the high specific area of charcoal to form a static double electric layer on the surface of the electrode to complete the energy storage, the capacitance of the capacitor can be significantly improved by increasing the specific surface area of the electrode. This property can be utilized for the fabrication of supercapacitors, also biochar has good mechanical flexibility and electrochemical stability [14].

## 4.3. Application Prospects

Biochar is generally a char material obtained by cracking carbonization using organic matter from green plants (e.g., rice husk, straw, bagasse) as raw material. Most biological resources are renewable and very economical to obtain. Most of biological resources will cause large environmental pollution because they have not been fully utilized before discarded (such as the burning of waste straw), thus the development of the use of biochar can improve the utilization of biomass raw materials, reduce the environmental problems brought about by the waste biomass, and at the same time, charcoal is also an important structural and functional material, the market demand is very large, the use of biomass to prepare a variety of excellent performance of charcoal materials (such as charcoal fibers, synthetic graphite and so on), not only to reduce the cost of these materials, but also can achieve the sustainable development of these materials.

Nowadays, the energy storage materials and devices on the market mainly use graphitized carbon. However, with the development of high-power portable devices and new energy vehicles, the market has put forward higher requirements for energy storage materials and devices, such as high reversible capacity, high-current discharge capability, and fast charging and discharging capability, and it is obvious that the graphitized carbon material (theoretical capacity of 372 mAh/g, actual capacity of 300-350 mAh/g) cannot satisfy these requirements, so the researchers have set their sights on other materials, such as graphene, graphene-like, nanotubes, and biochar, etc. [15]. However, compared to biochar, graphene, graphene-like, nanotubes materials, etc. are more expensive and the majority of the raw ingredients come from fossil resources, which might lead to higher environmental degradation and are not yet sustainable. As a result, it became imperative to research and develop biochar energy storage materials and devices.

## 5. Conclusion

Biochar, as a renewable resource, has great research value in organic pollutant adsorption as well as energy storage, and is also important for reducing carbon emissions. Currently, there are three methods of preparing biochar, which are pyrolytic carbonization, hydrothermal carbonization, and pyrolytic gasification. Slow pyrolysis is a pyrolysis process in which the biomass material is subjected to a slow temperature increase (0.1-0.8 °C/s) in the absence of oxygen and at high temperatures. During this process, biomass forms carbon-rich solids and volatile products. The method prepared biochar with a high content of solid products, but with a high content of side reaction products, and the reaction selectivity for generating biochar products is low. Fast pyrolysis is a reaction in which the biomass raw materials is heated to a higher reaction temperature in a short period of time. The product of fast pyrolysis is highly oxygenated and has an extremely high bio-oil content. Hydrothermal carbonization is the process of converting biomass feedstock into biochar-based carbon materials using water as the reaction medium under certain thermodynamic conditions. Pyrolysis gasification is the process of converting biochar into combustible gases with CO, H<sub>2</sub> and CH<sub>4</sub> as the main components under certain thermodynamic conditions, using oxygenates as gasification agents. In the field of organic pollutant control, biochar can be incorporated into the soil to adsorb organic pollutants from the soil. In terms of energy storage, this paper focuses on the participation of biochar material in the battery reaction as a graphite electrode replacing conventional graphite lithium batteries. Biochar has large specific electric capacity, complex pore structure and diverse doping modification. By utilizing these characteristics, lithium batteries with good performance can be

produced by using biochar as anode. It is expected to replace graphene, which is expensive to produce, as the research direction of energy storage materials for new energy batteries in the short term. At present, the preparation technology of biochar has been able to reach a specific surface area of  $4000\text{m}^2/\text{g}$  in the laboratory. Also, the doping and modification technology of biochar materials has become more and more advanced and diversified. However, these advanced technologies are not yet industrialized due to environmental concerns and cost constraints. Currently, the surface area of industrially prepared biochar is around  $2000\text{m}^2/\text{g}$ . Future research in this area will be directed towards the engineering application of these well-established biochar preparation methods in the laboratory. The research direction of biochar utilization is an ideal, efficient and effective way to sequester carbon from waste biomass. It is one of the popular research directions in the field of carbon neutralization.

## Authors Contribution

All the authors contributed equally and their names were listed in alphabetical order.

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