

# Treatment and Prospects of Industrial Wastewater with Biochar

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**Abstract.** As the process of industrialization accelerates, finding effective methods for industrial wastewater treatment has become an important task in the field of environmental protection. However, despite the preparation methods and properties of biochar have been studied, its large-scale application in industrial wastewater treatment has not yet been fully understood and clarified. This paper first analyzes the industrial wastewater to be treated, and combines the mechanism of biochar in treating industrial wastewater, elaborates the cases of biochar applied in real life and the corresponding difficulties. The research results show that biochar is a material with good application potential for industrial wastewater treatment. Its high specific surface area and rich surface functional groups give it good adsorption capacity for various pollutants in industrial wastewater. In addition, the adsorption performance of biochar can be optimized by adjusting its preparation and application conditions. Future research should further explore the long-term stability of biochar in the treatment of industrial wastewater, as well as its application effect in the actual industrial environment. In addition, the development of efficient, economical, and controllable technologies for the preparation and application of biochar, and promoting its large-scale application in industrial wastewater treatment, are also important directions for future research. The research in this paper is of great significance for understanding and utilizing biochar for the treatment of industrial wastewater. The results not only help to improve the efficiency and effectiveness of industrial wastewater treatment, but also provide new ideas and methods for the high-value utilization of waste biomass. Therefore, this research has important theoretical and practical value for promoting the development of industrial wastewater treatment technology and achieving sustainable utilization of environmental protection and resources.

**Keywords:** Biochar; industrial wastewater; wastewater treatment; challenge; application.

## 1. Introduction

Globally, with the continuous development of industrialization and the continuous increase of human activities, industrial environmental crises are becoming increasingly severe, especially the problem of industrial wastewater. Industrial wastewater, including various pollutants such as heavy metals and toxic and harmful substances, poses a huge threat to the environment and biological health. The disorderly discharge of industrial wastewater has destroyed the self-purification ability of water bodies, caused a large number of deaths of aquatic organisms, and the source of water for human consumption has also been severely threatened. Therefore, safe and sustainable treatment of industrial wastewater is becoming increasingly important.

Among the many wastewater treatment technologies, the application of biochar has begun to attract attention. Biochar is a solid product made from various biomasses through methods such as pyrolysis or gasification under low oxygen conditions. It has a high specific surface area and a porous structure, which can adsorb various harmful substances. Biochar can adsorb harmful substances such as heavy metal ions, organic pollutants, and nitrogen and phosphorus in wastewater through its excellent adsorption performance, thereby achieving the purpose of purifying wastewater. In addition, biochar itself has good biological activity, which can provide a good growth environment for microorganisms, which has also played a positive role in biochar in the biological treatment of industrial wastewater.

This paper first focuses on the characteristics of industrial wastewater and the challenges it brings, and then analyzes in detail the methods and principles of biochar for the treatment of industrial

wastewater. This article shows the application potential and effects of biochar in treating industrial wastewater through introducing examples of biochar treatment of wastewater. However, in actual applications, there are still many challenges in how to improve its efficiency and stability in treating industrial wastewater, and how to achieve large-scale production and application of biochar.

## 2. Characteristics and Challenges of Industrial Wastewater

The characteristics and treatment challenges of industrial wastewater are diverse and complex, mainly stemming from the generation and composition of industrial wastewater. The pollutants in industrial wastewater are numerous, including various organic substances, inorganic substances, heavy metals, radioactive materials, etc., some of which have high toxicity and persistence. At the same time, the discharge of industrial wastewater is usually large, and the concentration of pollutants is high, which is extremely destructive to the environment. However, traditional wastewater treatment technologies often fail to meet these requirements. For example, biological treatment technology has a good treatment effect on organic pollutants, but the treatment effect on inorganic pollutants and heavy metals is poor; while physical and chemical treatment technologies have a good treatment effect on inorganic pollutants and heavy metals, the treatment effect on organic pollutants is poor, and the treatment cost is high, the energy consumption is large, and secondary pollution may be produced. Therefore, it is urgent to develop wastewater treatment technologies that can remove various pollutants.

### 2.1. Characteristics

Industrial wastewater is wastewater generated during the industrial production process, and its sources are very wide, with the specific source largely depending on the type and process of industrial production. Heavy industrial factories such as steel mills, chemical plants, and oil refineries generate a large amount of wastewater during their production processes; light industrial factories such as food processing plants, textile mills, and paper mills also generate various types of wastewater during their production processes; during the mining process, a large amount of water is used to wash ore, resulting in mine wastewater; a large amount of wastewater is also generated during coal mining and oil drilling processes.

The main components of industrial wastewater are closely related to the type and process of the source industry. These include various compounds such as sugars, proteins, fats, phenols, and benzene as organic substances; inorganic substances such as sulfates, chlorides, nitrogen compounds, phosphates, and heavy metal ions; various particles such as sand, clay, and biological fragments as suspended solids; and microbes such as bacteria, viruses, and algae [1]. Table 1 shows the components and sources of some main types of industrial wastewater.

**Table 1.** Main Components of Industrial Wastewater

Category	Pollutants	Source
Heavy Metal Ions	Pb	Tin, lead, and zinc smelting industry, electroplating and battery manufacturing.
	Cd	Zinc smelting, electroplating, phosphate fertilizer production, and battery manufacturing.
	Cr	Steel smelting, leather tanning, and electroplating.
	Cu	Copper smelting, electroplating, and the production of certain pesticides.
	Zn	Zinc smelting, rubber manufacturing, and electroplating.
Heavy Metal Ions	Benzene	Petrochemical and chemical industries.
	Phthalates	Plastic products production, paints, adhesives, and detergents.
	PCBs	Manufacture and use of transformers and capacitors, certain lubricants, paints, adhesives, and plastics.
	PAHs	Petroleum refining and waste incineration.

Firstly, a major characteristic of industrial wastewater is the variety of pollutant types. Various industrial production activities may generate different types of pollutants, including organic substances, inorganic substances, heavy metals, sediments, thermal pollutants, radioactive materials, etc. For instance, the wastewater generated by the chemical industry may contain a large amount of organic compounds and heavy metals, while the wastewater generated by the coal industry may contain a large amount of minerals and suspended matter. At the same time, some industrial wastewater may contain special pollutants, such as petroleum substances in the wastewater from the oil and petrochemical industries. As shown in Table 2, the composition of pollutants contained in a Bisphenol A production factory in Guangdong Province, China.

**Table 2.** Water Quality of Incoming Wastewater from Bisphenol A Production Process

Facility name	Maximum drainage volume	Temperature	Pressure	Water quality
Phenol-Stripped water	10.03 t/h	40 °C	0.2 Kpa	COD 6500 mg/L, BOD 3300 mg/L, Acetone 2746 mg/L, Phenol <10 mg/L, Methanol 118 mg/L, Sodium sulfate 29820 mg/L PH 3.5~4.5,
Catalyst sorting wastewater	88.4 t/h (Discharged once every 8-9 months, duration 12 hours)	40° C	0.2 Kpa	CODcr 20 mg/L, Trace amounts of catalyst particles PH 3.5~4.5,
Catalyst adjustment wastewater	44 t/h (Discharged once every 8-9 months, duration 30 hours)	40 °C	0.2 Kpa	CODcr 20 mg/L, Trace amounts of catalyst particles

Secondly, industrial wastewater typically contains high concentrations of pollutants, which results in high chemical oxygen demand (COD) and biological oxygen demand (BOD). Industrial production processes often generate large quantities of waste, which, before entering industrial wastewater treatment systems, tend to mix together, forming wastewater with high pollutant concentrations. For example, wastewater from the electroplating industry typically contains extremely high concentrations of heavy metal ions like chromium, nickel, copper, and zinc, which far exceed those in domestic wastewater.

Moreover, the flow rate of industrial wastewater can fluctuate significantly. This is because the intensity and pace of industrial production activities can vary due to changes in production plans, equipment maintenance, changes in raw materials, among other factors. For instance, some industries with strong seasonal patterns (such as the food and beverage industry) may produce large quantities of industrial wastewater during peak production seasons, while barely producing any in the off-season.

Furthermore, the difficulty in treating industrial wastewater is also one of its significant characteristics. Given the diverse types, high concentrations, and complex nature of the pollutants present in industrial wastewater, which may also contain substances that are hard to degrade, like certain organic substances and heavy metals, treating industrial wastewater often requires complex techniques, such as a combination of physical, chemical, and biological treatment methods.

The impact of industrial wastewater on the environment and human health is also a key characteristic. If industrial wastewater is discharged into the environment without adequate treatment, it can cause severe pollution to water bodies, soil, and air, disrupt ecological balance, and affect human health through pathways like the food chain. For example, organic substances in industrial wastewater could reduce the dissolved oxygen in water bodies, impacting the health of aquatic

ecosystems, while heavy metals in industrial wastewater could enter the human body through the food chain, posing threats to human health.

## 2.2. Harm of Industrial Wastewater to Humans

Firstly, let's discuss the detrimental effects of industrial wastewater on human health. Industrial wastewater contains various harmful substances, including heavy metals, organic pollutants, radioactive substances, and pathogens. Once these substances enter the human body, they can have severe implications for health. For example, heavy metals can affect normal physiological functions and lead to various diseases. Organic pollutants can accumulate in body tissues, leading to the decline of organ functions, such as the liver and kidneys. Pathogens can enter the human body through polluted water sources, possibly causing various diseases such as cholera and typhoid. The effects of these substances on the human body can be chronic; long-term exposure may lead to a variety of chronic diseases such as cancer and neurological disorders. Certain pollutants, like endocrine disruptors, can interfere with the normal functioning of the body's endocrine system, leading to fertility issues, early puberty, and other problems. This not only impacts current human health but also poses a threat to the reproductive health of future generations.

Secondly, the harm that industrial wastewater causes to the environment also directly affects human lives. Pollutants enter the soil and groundwater through the water cycle, affecting the growth and quality of crops and, consequently, the safety of human food. Simultaneously, polluted water bodies disrupt aquatic ecosystems, reduce biodiversity, and impact many ecosystem services that humans depend on, such as food supply and recreational activities.

Furthermore, the discharge of industrial wastewater also has socio-economic implications. Wastewater treatment requires substantial financial investment, which poses a burden on economic development. Additionally, water source pollution leads to a reduction in water resources, affecting both human life and industrial production. Industrial pollution also causes public dissatisfaction, leading to social tension and conflict.

## 2.3. Difficulties in Governance

Firstly, the complexity of industrial wastewater presents a major challenge in its management. Industrial wastewater typically contains a variety of pollutants, including organic substances, heavy metal ions, inorganic ions, and various microbes, among others. The types and concentrations of these pollutants often vary depending on the type and stage of industrial production, and pollutants in industrial wastewater are generally found at high concentrations [2]. This necessitates that wastewater treatment technologies be highly adaptable and flexible, capable of tackling a wide array of pollutants and maintaining effective treatment performance under different environments and conditions.

Secondly, the efficiency and cost of industrial wastewater treatment present another significant challenge. Given the typically large volumes of industrial wastewater discharged, the efficiency of wastewater treatment directly impacts the scale and operational costs of wastewater treatment facilities. While many existing wastewater treatment technologies can achieve good results under laboratory conditions, their application often encounters limitations in actual industrial production due to factors such as high treatment volumes, long processing times, and high costs.

Furthermore, the reuse and resource recovery of industrial wastewater represent important goals of modern wastewater management. As water resources become increasingly scarce, how to recover useful components from wastewater and transform wastewater into usable resources has become a significant direction in wastewater management. However, challenges remain in how to effectively separate and transform various pollutants, and ensure the safety and economy of reuse.

Additionally, the environmental risks and societal impacts of industrial wastewater cannot be overlooked. The discharge and treatment of industrial wastewater may not only cause environmental pollution and impact the stability of ecosystems but could also pose threats to human health, causing widespread societal concern. Thus, the treatment of industrial wastewater requires strict supervision to ensure businesses comply with relevant environmental protection regulations. However, practical

supervisory work may face limitations in terms of manpower, material resources, and technology. Therefore, achieving effective wastewater management while meeting environmental standards and societal expectations represents a complex and crucial task.

### 3. Treatment of Industrial Wastewater Using Biochar

Biocarbon management industrial sewage can mainly be reflected in several aspects of physical, chemical, ion exchange, improvement of biological activity.

#### 3.1. Physical Mechanism

The physical mechanisms of biochar in industrial wastewater treatment primarily derive from its unique physical properties and distinctive microstructure. Its high specific surface area can effectively adsorb suspended particles and large molecular organic substances in wastewater, and its microporous structure can physically retain and filter these pollutants to prevent their further dispersion. Together with its microporous structure that helps to block the spread of biological contaminants such as microbes and viruses, it serves to adsorb, filter, and concentrate organic substances and inorganic pollutants in industrial wastewater [3]. Its pore-channel structure retains and filters suspended particles and large molecular organic substances in the wastewater, effectively preventing the further migration and spread of these pollutants. Moreover, the surface functional groups of biochar can remove heavy metal ions and other harmful ions from wastewater through ion exchange and adsorption actions. In this process, the microporous structure of biochar can also prevent the spread of biological pollutants such as microbes and viruses, thereby protecting the cleanliness of water resources on a larger scale.

#### 3.2. Chemical Mechanism

Biochar can also treat industrial wastewater through chemical methods.

##### 3.2.1 Catalytic oxidation

Biochar possesses abundant surface functional groups, such as carboxyl, hydroxyl, and phenolic groups, which enable its involvement in chemical oxidation reactions. For instance, organic pollutants or heavy metal ions in wastewater can undergo oxidative reactions with the functional groups on the surface of biochar, transforming into more stable and less toxic substances, thereby achieving wastewater purification. Furthermore, in certain advanced oxidation processes, biochar can serve as a catalyst or carrier to facilitate the oxidative degradation of pollutants in wastewater.

##### 3.2.2 Catalytic reduction

Biochar can serve not only as an oxidant but also as a reductant. On the one hand, biochar itself can participate in the reduction of pollutants in wastewater through electron transfer reactions. On the other hand, the surface functional groups of biochar can act as electron donors, engaging in chemical reduction of pollutants in wastewater. This reduction reaction can convert certain harmful substances in wastewater, such as nitrates, dyes, and other pollutants, into less toxic or non-toxic compounds, thereby achieving the purification of wastewater.

##### 3.2.3 Ion exchange

The ion exchange mechanism of biochar in industrial wastewater treatment mainly involves the action of its surface functional groups. Biochar's surface contains numerous negatively charged functional groups, such as carboxyl (-COOH) and hydroxyl (-OH). These functional groups can adsorb cations from wastewater, such as heavy metal ions, while simultaneously releasing an equal amount of protons or other cations. This represents a typical ion exchange process.

For example, copper ions ( $\text{Cu}^{2+}$ ) in wastewater can be adsorbed by the carboxyl groups on the surface of biochar, as shown in the reaction formula (1). In this process, biochar's carboxyl groups first capture the copper ions from the wastewater and then release a proton, completing the ion

exchange process and effectively removing copper ions [4]. This ion exchange mechanism enables biochar to efficiently remove heavy metal ions and other harmful ions from wastewater, making it an important component in the treatment of industrial wastewater.



### 3.3. Biological Activity

Biochar itself serves as an excellent microbial carrier, providing a suitable environment for the survival and proliferation of microorganisms due to its porous structure. The microenvironments within the pores are conducive to the survival and growth of microorganisms. These microorganisms form biofilms in the pores, enhancing the stability of biochar and its ability to remove pollutants [5]. Some of these microorganisms can decompose organic compounds, degrade or transform heavy metal ions, thereby improving the efficiency of wastewater treatment.

Furthermore, the surface functional groups of biochar can adsorb and enrich nutrients in wastewater, such as nitrogen and phosphorus, providing a source of nutrients for microbial growth and activity, further promoting microbial growth and activity. These microorganisms can decompose and absorb these nutrients, effectively removing nutrients from wastewater [6].

Moreover, the biological activity of biochar also extends to improving water quality and promoting ecological restoration. Biochar can improve the physicochemical properties of water, such as adjusting pH levels and increasing dissolved oxygen content in wastewater, which in turn facilitates the growth of beneficial microorganisms, thus enhancing the ecological environment of water bodies and enabling the resource utilization of wastewater.

## 4. Application

At present, there are already a considerable number of cases in China where biochar is utilized for the treatment of industrial wastewater. This article aims to elucidate the practical applications of biochar in industrial wastewater treatment, drawing from the achievements made by domestic scholars and a real case that has been successfully implemented in production.

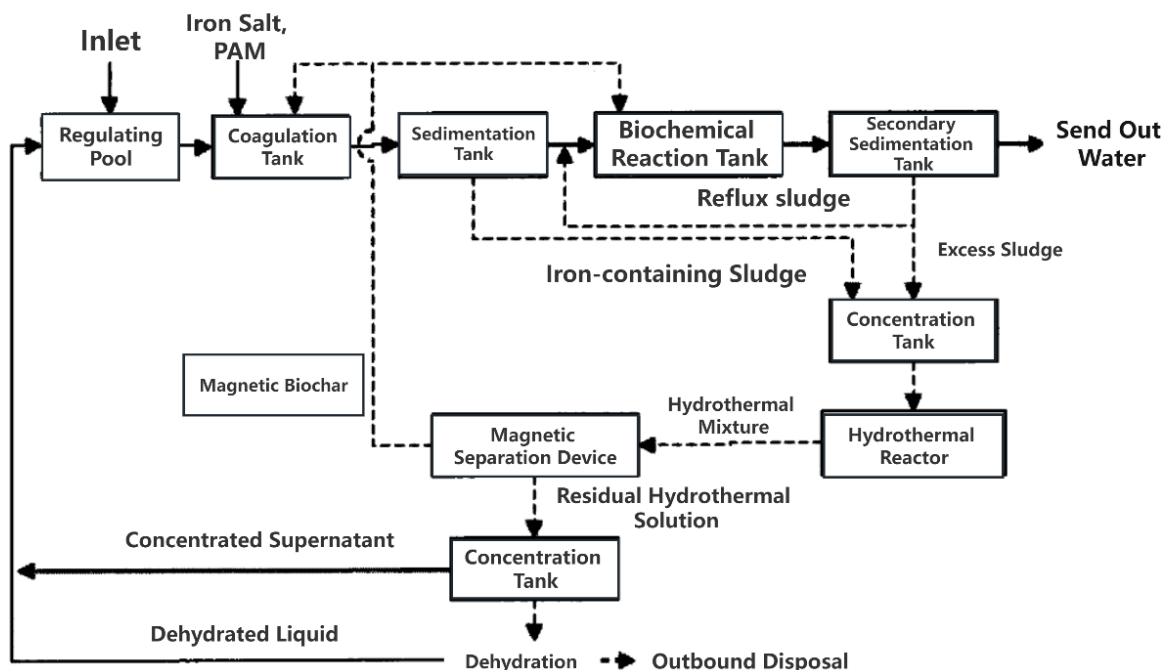
### 4.1. Achievement

The main application of biomass char in the field of wastewater purification is to use it for the removal of pesticides, other organic solvents, and heavy metal ions from wastewater. Cheney al. compared the adsorption performance of biomass char adsorbents produced at different carbonization temperatures on organic pollutants. The study found that biomass char adsorbents exhibited strong adsorption capacity for 4-nitrotoluene in water, and as the carbonization temperature increased, the adsorption performance of biomass char adsorbents gradually improved, with the optimum performance observed below 400 °C. Chen also discovered that biomass char derived from pine branches effectively removes environmental pollutants such as naphthalene, nitrobenzene, and dinitrobenzene from contaminated water bodies. Moreover, the research indicated that biomass char showed higher adsorption capacity for mercury ions compared to commercial coal-based activated carbon.

Chen conducted a study on the adsorption of  $\text{Cd}^{2+}$ ,  $\text{Cu}^{2+}$ ,  $\text{Ni}^{2+}$ , and  $\text{Pb}^{2+}$  in water and soil using biomass char produced at different temperatures. It was found that as the pH of the biomass char increased, its adsorption and immobilization of heavy metal ions were strengthened. Additionally, when investigating the adsorption of  $\text{Pb}^{2+}$  in water, Chen used biomass char produced from pine and rice bran, and found that the presence of abundant oxygen-containing functional groups on the surface of biomass char resulted in strong adsorption effects for  $\text{Pb}^{2+}$ . Chen research revealed that rice straw-derived biomass char prepared at 350 °C, 500 °C, and 700 °C exhibited maximum adsorption capacities for  $\text{Pb}^{2+}$  at 65.3 mg/g, 85.7 mg/g, and 76.3 mg/g, respectively. These values were 5 to 6 times higher than the original straw biomass and 2 to 3 times higher than activated carbon.

## 4.2. Comprehensive Application Cases

In practical applications, various methods for treating industrial wastewater using biomass char have been employed in China. This article takes an example of enhancing the treatment efficiency of printing and dyeing wastewater using magnetic biomass char. The process flowchart is shown in Fig. 1. Printing and dyeing wastewater undergoes coagulation and sedimentation using iron salts, followed by biochemical treatment. The resulting slurry is allowed to settle in a secondary sedimentation tank. Some of the sludge is returned to the biochemical treatment system, while the remaining sludge is combined with the iron sludge generated during coagulation and sedimentation. The mixture is then sent to a sludge thickener for concentration. The concentrated sludge is subjected to a hydrothermal reaction, producing a hydrothermal mixture. The hydrothermal mixture is passed through a magnetic separation device to isolate and collect magnetic biomass char. Part of the collected magnetic biomass char is returned to the coagulation stage to enhance flocculation and sedimentation effects. Another portion is sent back to the wastewater biochemical treatment stage to improve the efficiency of wastewater treatment. The remaining hydrothermal fluid, which has not been separated by the magnetic separation device, is transported off-site after concentration and dewatering. The supernatant from the concentration process and the dewatering liquid are both returned to the biochemical treatment system. This process enhances the treatment efficiency of wastewater and achieves functional modification of sludge. It is characterized by simplicity of operation, improved performance in wastewater biochemical treatment, and resource utilization of sludge [7-10].



**Fig 1.** Flow chart of magnetic Biochar method to strengthen printing and dyeing wastewater treatment. <https://www.dowater.com/tech/2019-04-06/938625.html>

## 5. Current Challenges and Prospects

Despite the significant progress made by scholars in the field of using biomass char for treating organic wastewater, there are still some unresolved issues.

### 5.1. Challenge

Firstly, an important issue is the cost of preparing biomass char. The production of biomass char mainly relies on the pyrolysis process, which requires a significant amount of energy input, leading

to higher production costs. Additionally, acquiring and processing the biomass feedstock also incurs expenses. These factors combined contribute to the relatively high preparation and application costs of biomass char, affecting its widespread implementation in industrial wastewater treatment.

Secondly, post-adsorption treatment of biomass char is a crucial concern. After adsorbing pollutants from wastewater, biomass char requires appropriate treatment to remove the adsorbed contaminants if it is to be reused [11]. This treatment process often involves the use of acids or alkalis and may generate by-products, adding complexity and costs to the treatment. Moreover, how to safely and effectively dispose of these adsorbed pollutants is also an issue that needs to be addressed.

Next, biomass char needs to selectively adsorb target pollutants in complex wastewater, which places high demands on the surface properties of the material. Proper modification of biomass char to enhance its affinity for specific pollutants is a challenging task that requires more research and experimentation.

Additionally, since biomass char is derived from various biomass sources through pyrolysis, its quality may vary due to differences in biomass types and pyrolysis conditions. This instability in quality may affect the adsorption performance and treatment efficacy of biomass char, making it important to control and ensure the quality of the material [12].

Lastly, although biomass char is considered an environmentally friendly material, its long-term environmental impacts are not fully understood. For example, biomass char may influence the structure and function of soil microbial communities and may also impact soil physical properties, such as structural stability and permeability. These potential environmental effects require further research and assessment to ensure the environmental safety of biomass char [13].

## 5.2. Future Trends and Prospects

With the increasing popularity of green and sustainable development concepts, biomass char is considered an environmentally friendly and sustainable material due to its biomass origin and carbon-neutral characteristics. It is expected that in the future, as more research reveals the adsorption capabilities of biomass char for various pollutants, especially heavy metal ions and organic contaminants, its application in wastewater treatment will be further promoted and developed.

On the other hand, the preparation and modification technologies of biomass char will also be improved and optimized. Currently, some research is exploring more energy-efficient and higher-efficiency methods for preparing biomass char, as well as modification techniques that enhance its adsorption performance for specific pollutants. These technological advancements will help reduce the production cost of biomass char and improve its performance in wastewater treatment, thus driving its application in industrial wastewater treatment.

Lastly, since the environmental impacts of biomass char are not yet fully understood, future research will focus more on its behavior and effects in the environment. This will contribute to a better understanding of the long-term effects of biomass char in the environment and effective management and disposal of adsorbed biomass char, ensuring its environmental friendliness and sustainability.

In summary, despite facing certain challenges in wastewater treatment, biomass char's green, sustainable, and efficient characteristics make it hold enormous development potential in future wastewater treatment. With further progress in research and technology, the application of biomass char in this field is expected to become increasingly widespread.

## 6. Conclusion

Industrial wastewater treatment is a critical topic in the field of environmental protection. As a novel environmental material, biomass char has brought new possibilities to industrial wastewater treatment due to its excellent adsorption performance and environmental-friendly properties. This article expounds on the different applications of biomass char in various industries, such as petrochemical, heavy metal, and pharmaceutical industries. In these domains, biomass char not only

effectively removes organic substances and heavy metal ions from wastewater but also enhances wastewater's biodegradability, thus improving the overall wastewater treatment effectiveness. However, the application of biomass char in wastewater treatment also faces several challenges. Firstly, the high production cost of biomass char somewhat limits its use in industrial wastewater treatment. Secondly, effective regeneration and disposal methods for biomass char after adsorbing pollutants from wastewater need to be addressed. Additionally, the quality stability and selective adsorption capabilities of biomass char require further improvements. Nevertheless, the prospects for biomass char in industrial wastewater treatment remain optimistic. With advancements in biomass char preparation and modification technologies and further research on its environmental impacts, the application of biomass char in industrial wastewater treatment is expected to gain more momentum. This article, combined with practical case studies, provides a research direction for the application of biomass char in the field of industrial wastewater treatment.

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