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Study on Flue Gas Denitrification Performance and Mechanism Based on Carbon Source of Agricultural Waste

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Abstract: Currently, as environmental pollution becomes increasingly severe, flue gas denitrification has emerged as a significant area of research. With the advancement of modern industry and the improvement of living standards, air pollution has gained growing attention. Sulfur dioxide and nitrogen oxides (NO_x) have become major contributors to air pollution, posing serious harm to the environment. Consequently, flue gas desulfurization and denitrification technologies have become key research focuses in industrial development. This paper explores the selection of agricultural waste carbon sources and their pretreatment methods. It provides an in-depth analysis of the significance of agricultural waste carbon sources in flue gas denitrification, focusing on their performance and mechanisms. The study also discusses the role of agricultural waste carbon sources in flue gas denitrification, aiming to offer new research perspectives for relevant stakeholders.

Keywords: Agricultural waste; Carbon source; Denitrification performance and mechanism of flue gas

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1. Introduction

At the moment, global environmental issues are becoming increasingly prominent, and the prevention and control of various air pollutants have attracted growing attention. Among these pollutants, nitrogen oxides are major contributors, commonly present in the flue gas emissions from industrial production and energy consumption. This widespread presence poses a serious threat to both the ecological environment and human health.

While traditional flue gas denitrification technologies can reduce nitrogen oxide emissions to some extent, they are associated with high costs, operational challenges, and the potential for secondary pollution. As a result, the development of efficient, environmentally friendly, and economically viable denitrification technologies has become a critical focus for researchers and industry professionals.

2. The selection and pretreatment of agricultural waste carbon resources

2.1. Analysis of types and characteristics of agricultural waste

At present, there are many types of agricultural waste, including agricultural product processing waste, crop straw, livestock and poultry manure, etc. These wastes contain very rich carbon elements, which have a good potential as a source of flue gas denitrification carbon. In detail, agricultural waste such as peel, core, and shell generally have good organic materials such as sugar, oil, or starch, which can help decompose and release carbon elements. However, different types of agricultural product processing waste have differences in composition and properties, so it is necessary to conduct comprehensive consideration according to the specific crop situation, to ensure the effect of denitrification and economic benefits. Crop straws such as wheat straw, corn straw, etc., are important components of agricultural waste, with large yields, and wide distribution characteristics, at the same time these crop stalks are rich in cellulose and hemicellulose, where after treatment, can produce a lot of carbon elements that can be used as flue gas denitrification reducing agent. The reducing agent generated by combustion is also sufficient for the amount of flue gas denitrification.

Nonetheless, in the selection of materials, it is also necessary to pay attention to the differences between different kinds of straw in carbon content, ash, calorific value, etc., to ensure the effect of denitrification. Similarly, cattle manure, pig manure, other livestock manure, and other materials are also important sources of carbon sources of agricultural waste [1]. These feces are also rich in carbon, and there are some nutrients such as nitrogen, phosphorus, and potassium, which can be used as organic fertilizers. The same carbon in the manure can also act as a reducing agent to react with the nitrogen oxides in the flue gas to produce harmless nitrogen and water. Even so, it is still necessary to note that the water content of these livestock and poultry feces is still relatively high, and they have certain harmful substances similar to heavy metals, so it is necessary to carry out proper treatment before normal use to minimize the probability of possible environmental pollution.

2.2. Agricultural waste pretreatment technology

The pretreatment technology of agricultural waste is to ensure that the relevant utilization efficiency and denitrification performance can be improved to the maximum extent before the flue gas denitrification. The related pretreatment technology mainly includes crushing, drying, charring, and more. The first step of pre-treatment is to break agricultural waste. Through manual grinding and mechanical crushing methods, agricultural waste can be broken into particles or powders that are easy to handle, and the contact area between the waste and the nitrogen oxides in the flue gas can be expanded, reducing the resistance in the reaction process, to continuously improve the reaction efficiency [2].

Next, the drying treatment is also another important step in the pretreatment. Most of these waste materials will contain more water, which will affect their efficiency as a carbon source in the flue gas denitrification process. Through natural air drying, mechanical drying, and other methods, the water in the waste can be initially removed, to ensure the stability of the reaction with the nitrogen oxides in the flue gas.

Finally, the agricultural waste for pre-treatment also needs to be carbonized. Through carbonization, the organic matter present in the object can be converted into a stable carbon material. In the process of carbonization, the combustible substances and volatile components of agricultural waste will be consumed, and the final solid residue will be very rich in carbon elements. These residues not only have better reduction performance, but also have a very excellent performance in terms of carbon content, and the ash generated in the process of denitrification can also be reduced, thus greatly improving the overall denitrification effect [3].

3. The research significance of flue gas denitrification performance and mechanism based on agricultural waste carbon source

3.1. Environmental protection significance

Currently, environmental protection has gradually become a key focus of societal attention, with nitrogen oxides identified as one of the main contributors to air pollution. The harmful effects of nitrogen oxides on the ecological environment threaten the delicate balance of ecosystems. As a result, flue gas denitrification methods utilizing agricultural waste as a carbon source hold significant environmental value for promoting sustainability and environmental development.

Notably, chemical pollutants such as acid rain, fine particulate matter, and photochemical smog are closely linked to nitrogen oxides, highlighting the importance of effective mitigation strategies [4]. The use of agricultural waste carbon sources for flue gas denitrification can effectively reduce the emission of nitrogen oxides, reduce the production of pollutants from the source, ensure air quality, and thus contribute to the ecological balance. On the other hand, if large quantities of agricultural waste are not managed and utilized properly, methods such as open burning—though seemingly convenient—can lead to significant air pollution. This process releases large amounts of pollutants into the atmosphere, including nitrogen oxides, particulate matter, and sulfur dioxide, while also resulting in a considerable waste of resources.

To address this issue, the unified collection and conversion of agricultural waste into a carbon source for denitrification offer a practical solution. This approach not only mitigates uncontrolled waste disposal but also enhances the utilization efficiency of agricultural waste. Furthermore, it supports the sustainable and collaborative development of agriculture and environmental protection.

3.2. The significance of resource utilization

As a widely available and abundant biomass resource, agricultural waste represents an opportunity for sustainable development. During agricultural production, common activities and crop processing generate significant amounts of waste, such as rice husks, fruit husks, and straw. However, due to limited understanding and traditional practices, agricultural waste is often discarded or burned. This not only fails to utilize the inherent value of the waste but also causes environmental pollution, particularly through the release of harmful smoke that pollutes the atmosphere and poses health risks.

By utilizing agricultural waste in flue gas denitrification, its unique properties can be harnessed. Through specific processing technologies, these wastes can be transformed into carbon materials with high adsorption capacities. Such processes enhance their catalytic activity, maximize the added value of these resources, and make them integral to flue gas denitrification reactions. This approach reduces reliance on raw materials used in traditional denitrification methods, diversifies industrial raw materials, and significantly improves the efficiency of flue gas denitrification.

Moreover, this utilization strategy enhances resource efficiency and offers a new economic development pathway for the agricultural industry. Farmers would have greater incentives to actively participate in waste collection and initial processing, fostering rural economic development. Ultimately, this model supports the positive cycle of environmental improvement, resource utilization, and economic growth, contributing to the advancement of both rural economies and ecological sustainability [5].

3.3. The significance of technological innovation

Using agricultural waste as a carbon source for flue gas denitrification is more innovative than the traditional denitrification mode. At the technical level, this research direction can further optimize the denitrification system and process parameters, and efficiently integrate the carbon source of agricultural waste with the existing flue gas treatment process, thus effectively reducing the cost and energy consumption in the process of flue gas denitrification. The research on agricultural waste can also provide more data support and reference materials for the subsequent development of a more accurate and intelligent flue gas denitrification control system so that it can adjust the entire process in real time according to the real situation and continuously improve the efficiency and stability of denitrification. In addition, from the perspective of the preparation of raw materials, researchers can develop a unique pretreatment and carbonization process based on agricultural waste, which can be converted into functional carbon materials with specific functional groups and rich pore structures. Materials with these characteristics can perform excellent functions in the adsorption and catalytic reduction of nitrogen oxides. At the same time, it also lays a more solid foundation for subsequent technological innovation.

4. study on the mechanism of agricultural waste carbon source in flue gas denitrification

4.1. Reaction mechanism of carbon source and NOx

The core of denitrification technology is the reaction mechanism between agricultural waste carbon sources and nitrogen oxides. In the process of flue gas denitrification, the reduction reaction is the main basis of this process, which means that the carbon elements in the carbon source of agricultural waste reduce nitrogen oxides to harmless nitrogen and water. Generally, the main form of carbon in the carbon source of agricultural waste is solid which includes lignin, cellulose, and hemicellulose. When these substances are in contact with the flue gas containing nitrogen oxides, they will adsorb nitrogen oxide molecules, and under the appropriate temperature and catalyst, the carbon elements in the carbon source can also undergo a reduction-oxidation (redox) reaction with nitrogen oxides. In this reaction, the carbon is oxidized to carbon dioxide, and the corresponding nitrogen oxides are reduced to nitrogen and water. For example, NO_x may first be reduced to nitric oxide (NO) and then further react with the carbon in the carbon source to form N_2 and CO_2. Moreover, the process of flue gas denitrification will also be affected by different factors, including the type, nature, and reaction temperature of the carbon source and the type of catalyst, etc., thus in the actual application process, it is necessary to use the basic material and the specific flue gas composition denitrification efficiency as the main reference factors to choose a more suitable agricultural waste carbon source and reaction conditions to achieve the best denitrification effect.

4.2. The mechanism of microbial action

The mechanism of microbial action plays a key role in the flue gas denitrification process using agricultural waste as a carbon source. Agricultural waste contains a variety of organic components, providing an abundant substrate for microbial survival. When these wastes are used as the base material for flue gas denitrification, specific microbial communities can thrive on their surfaces and within their internal spaces. These microorganisms decompose complex organic substances in the agricultural waste through metabolic activities, converting them into intermediates such as small organic acid molecules. These intermediates enhance the adsorption capacity for nitrogen oxides and alter the chemical properties of the waste’s surface, thereby actively participating in the denitrification reaction.

Additionally, the metabolic activities of microorganisms can significantly influence their environment by altering local pH, redox potential, and other physicochemical conditions. These environmental changes positively impact the efficiency of the flue gas denitrification process. Furthermore, microorganisms secrete extracellular polymers during growth, which form biofilms on the surface of the agricultural waste carbon source. These biofilms improve the stability and resistance of the materials to erosion, providing specialized reaction sites for the adsorption and transformation of nitrogen oxides, ultimately enhancing the efficiency and sustainability of the denitrification process.

Certain specialized microbial strains can also directly participate in the reduction of nitrogen oxides. For example, denitrifying bacteria can convert nitrogen oxides into nitrogen gas, ensuring the smooth progression of the reduction process—a critical step in flue gas denitrification. These microorganisms possess unique enzyme systems, such as nitrate reductase and nitrite reductase, which catalyze the stepwise reduction of nitrogen oxides. This enzymatic action effectively removes nitrogen elements and minimizes the NO_x content in flue gas.

4.3. Carbon energy regeneration and recycling

In the denitrification process using agricultural waste carbon sources for flue gas treatment, the regeneration and recycling of the carbon source is a valuable and practical mechanism. After the adsorption and catalytic reduction of nitrogen oxides, the surface active sites and internal structure of the carbon source may change, leading to a gradual decline in overall denitrification performance. However, specific regeneration processes can restore the properties of the carbon source and enable its reuse.

Thermal regeneration is an effective method for restoring the activity of agricultural waste carbon sources. Under appropriate high-temperature conditions, the carbon source can be heated to desorb nitrogen oxides adsorbed on its surface. Additionally, the pore structure and surface functional groups damaged during the reaction can be repaired, restoring the carbon source's adsorption and catalytic activity. This process allows the carbon source to regain its efficient denitrification capacity.

From a carbon cycle perspective, regenerating agricultural waste carbon sources enhances raw material utilization efficiency and reduces costs. This approach decreases the demand for fresh carbon source materials while optimizing resource use in reduction reactions, aligning with the principles of sustainable development.

Furthermore, during continuous recycling, researchers can refine the regeneration process through systematic experimentation on operating conditions. Such efforts can improve the recycling efficiency and extend the number of recycling cycles, unlocking additional value from the carbon source. This iterative optimization supports advancements in recycling technologies and contributes to environmental sustainability.

5. Conclusion

With the development of the economy and continuous advancements in scientific research, the performance and mechanisms of flue gas denitrification are constantly being optimized and refined. Agricultural waste carbon sources, when used as the primary material in flue gas denitrification, promote the regeneration and recycling of carbon sources, offering significant value for environmental protection and sustainable development.

This new research direction not only contributes to technological advancement but also fosters economic growth in related industries. Furthermore, in terms of denitrification performance and mechanisms, agricultural waste carbon sources have demonstrated effective denitrification capabilities.

The reaction mechanism between carbon sources and nitrogen oxides is relatively complex. However, the involvement of microorganisms greatly enhances denitrification efficiency, presenting a novel approach to flue gas denitrification technology. Additionally, the regeneration and recycling mechanism of the carbon source further enhances the economic feasibility and sustainability of using agricultural waste in flue gas denitrification.

Disclosure statement

The author declares no conflict of interest.

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