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Under the Background of Carbon Peaking and Carbon Neutralization, a New Way to Reduce Emissions of Biomass Waste

Wanghu Sun[1,*], Yuning Sun[2], Li Xu[1], Yuan Zhang[1], Xin Ma[1]

[1]*College of Civil Science and Engineering, Yangzhou University, Yangzhou, China*
[2]*Department of Precision Machinery and Precision Instrumentation, University of Science and Technology of China, Hefei, China*
[*]*Corresponding author*

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Abstract: In view of carbon dioxide and methane with stronger greenhouse effect produced by the incineration, straw returning and landfill of agricultural straw, forestry waste, domestic waste and other biomass, with the literature and findings by our research group, we proposes a novel path to transform organic carbon in biomass into inorganic carbon with stable chemical properties through carbonization, and then reuse carbonization products to produce carbon based materials, and extensively apply carbon based materials in construction projects. In this study, with collection of biomass waste as the premise, by reasonable carbonization process, the extensive application of carbon based materials is the key to achieve pollution and carbon emission reduction. This path is not only conducive to achieving carbon peak and carbon neutralization, but also can save resources, with important economic, ecological and social benefits.

1. Introduction

David T. Allen, academician of the American Academy of Engineering, pointed out that the climate warming effect of each kilogram of methane in the atmosphere is 120 times that of carbon dioxide. Although it will continue to react to produce carbon dioxide in the atmosphere, the warming effect of each kilogram of methane is still 84 times that of carbon dioxide after 20 years, and 28 times that of carbon dioxide 100 years later. Therefore, it requires us to pay great attention this strong greenhouse gas in the short term. The study of Liu Yi's showed that within a 20-year scale, the warming potential of methane is 84 times that of carbon dioxide. The life span of methane is only 8-11 years (about 1/10 of carbon dioxide), and its emission reduction can achieve the goal of curbing global warming in a short time. The data of the US Environmental Protection Agency also indicated that in 100 years, the greenhouse effect caused by a molecule of methane will be 28-36 times that of carbon dioxide. The concentration of methane in the atmosphere has risen from one 177.5 billionth in 2006 to one 185 billionth in 2017". According to the latest data released by the World Meteorological Organization, the concentration of methane in the atmosphere in 2021 was five times that in 1750.

It can be seen that from greenhouse effect and emission acceleration, methane emissions can not be ignored while carbon dioxide emission attached the attention. At the 2021 United Nations Climate Conference, the Sino US Joint Declaration clearly pointed out that the two countries are particularly aware of the significant impact of methane emissions on warming, and believe that taking action to control and reduce methane emissions is a necessary matter in the 21st century. During the conference, the United States and the European Union launched the 'Global Methane Commitment' signed by 102 countries, which planed to reduce global methane emissions by at least 30% on the basis of 2020 by 2030. In order to reduce methane emissions, scholars have carried out a lot of research, where it has become the consensus to reduce methane emissions from three aspects: energy, agriculture and waste.

Known as biogas, biomass fermentation is degraded in anoxic environment to produce methane. Among the total methane emission sources, biological sources account for 80%, and the remaining 20% results from non biological sources. Therefore, methane emissions from biological sources become the top priority[1]. In agriculture, methane and nitrogen dioxide emissions account for 50% and 92% of the country respectively, and improveing feed can reduce methane production of cows and other ruminants when digesting food[2]. But people are releasing more fossil fuel emissions and burning less wood and other biomass, which was also one of the important reasons for the increase of methane emissions, because the combustion produces carbon dioxide, while the anaerobic reaction of biomass will produce methane[3]. The New Zealand scientist Sara Mikaloff Fletcher believed that the most worrying possibilities are those beyond our control, which is rising temperatures may cause wetlands to release more methane, while changes in atmospheric chemical composition may slow down the decomposition of methane. Therefore, the treatment of biomass, especially biomass waste, has become the key technology for methane emission reduction.

Biomass waste mainly includes waste from agricultural and forestry production, as well as domestic garbage. In a broad sense, it should also include plant roots, fallen leaves and other biomass remaining in the soil. These substances are rich in organic carbon, and in the long and complex changing process, the proportion of decomposition into chemical stable simple carbon is minor, and most of them still generate carbon compounds such as carbon dioxide and methane. Studies have shown that landfill is far more harmful than incineration and the main measures for implementing conservation tillage in double cropping rice areas, that is rotary tillage straw returning to the field, has the largest contribution to the greenhouse effect. Both no straw returning and no tillage methods are conducive to reducing the greenhouse effect, because most of the straw in the no tillage methods is in an aerobic environment, which greatly reduces the generation of methane[4]. From the perspective of greenhouse effect, it is better to convert into carbon dioxide than to generate methane.

On December 23th, 2022, Nature published the latest achievements of the energy microorganism innovation team of the Biogas Research Institute of the Ministry of Agriculture and Rural Affairs of China, where this study found that a new methanogenic archaea from oil reservoir can directly oxidize long-chain alkyl hydrocarbons in crude oil to produce methane under anaerobic environment, becoming the fifth way to produce methane and breaking through the traditional recognition that methanogenic archaea can only grow by using simple compounds, that is methanogenic archaea can only grow by acetic acid fermentation, carbon dioxide reduction, methyl cracking and oxymethyl conversion. This achievement has expanded the understanding of the carbon metabolism function of methanogenic archaea, and also questioned the safety of soil carbon sequestration.

In view of the above, if incinerated, wastes from agricultural and forestry production, as well as domestic garbage and organic wastes, will directly generate pollutants such as carbon dioxide and dust. If landfilled, it will not only generate carbon dioxide, but also generate methane with stronger greenhouse effect. Therefore, this study proposes a novel way to reduce pollution and carbon emission and save resources by converting organic carbon in biomass into inorganic carbon through carbonization, and then using carbonization products to produce building materials.

2. Carbonation Mechanism of Biomass

Carbonization refers to the pyrolysis reaction under absolute oxygen and high temperature condition, where the polymers that make up biomass and organic matter break into small molecules of volatile matter and precipitate, leading to the remaining carbon and the formation of simple carbon. Carbonization technique has a long history, and massive researches are being carried out, which has practical significance of saving resources and reducing pollution. At present, the research of carbonization technology mainly focuses on wood treatment and functional materials.

In terms of wood treatment, there are many research achievements on wood's moisture absorption characteristics[5], mechanical properties[6], anti-corrosion capacity, fire resistance limit, etc. The research purposes involve improving wood properties[7], strengthening the protection of ancient buildings (because many ancient buildings in China are wood structures)[8], etc. Now, the technical specifications of carbonization are mature, and the application of carbonized wood is also extensive.

In terms of functional materials, research on activated carbon, machine-made charcoal, wood ceramics, wood carbonization electrodes (CW electrodes) and other functional materials has become a hotspot in carbonization technique. For example, The researches of Chen Yangyang[9] et al. was preparation and performance of different kinds of wood carbonization electrodes, and Tao Yubo et al.'s research on wood ceramics reached 11.79 MPa in bending strength[10]. The carbonization temperature of functional materials is much higher than that of wood treatment carbonization. In the carbonization process, there are not only decomposition and cracking, but also complex changes in microstructure, where functional materials rely on their specific structures to achieve their functions.

According to the previous research of our team[11], carbonization is divided into six stages: pre-treatment, primary carbonization, moderate carbonization, deep carbonization, high temperature carbonization and modified carbonization. Among them, pre-treatment is used to sort, crush, screen, modify and shape raw materials, which is the key to ensure the smooth progress of carbonization and ensure that the shape, size and quality of carbonized products meet the technical requirements, the main characteristics of other stages are as follows:

(1) Primary carbonization. With the temperature between room temperature and 200℃, the raw materials are degassed and dried, and then pyrolysis starts. The generated gas is mainly water vapor and volatile. Because the loss of water in the amorphous area of the wood leads to the formation of new hydrogen bonds between adjacent cellulose, which makes the fiber arrangement closer. At this time, the thermal degradation reaction does not occupy the dominant position, so the bending strength and elastic modulus of the heat treated wood have increased, and the carbonization products are in an absolutely dry state. The strength, corrosion resistance, deformation resistance and other properties of bamboo and wood materials are enhanced, and the original texture is maintained. It is suitable for manufacturing bamboo and wood decorative materials.

(2) Moderately carbonization. At the temperature of 200℃~300℃ (basically consistent with the carbonization boundary of 300 ℃ in Eurocode 5 and 288 ℃ in North America standard), biomass and other organic substances will undergo thermal decomposition reaction, especially unstable components such as hemicellulose (200℃~260℃), cellulose (260 ℃~310℃) begin to decompose, and its internal structure begins to disappear and change to aromatic structure, generating a small amount of liquid such as acetic acid, and the ignited mixture gases consisted of carbon dioxide,

carbon monoxide, methane, etc. Because cellulose macromolecule chain breaks to form small molecules, which destroys the skeleton structure of wood, the physical structure starts to be wrecked, thus reducing the mechanical strength of wood.

(3) Deep carbonization. At the temperature of 300℃~450℃, most organic substances will undergo intense thermal decomposition reaction, such as lignin pyrolysis (310℃~450℃), which generates methane, carbon dioxide, carbon monoxide, acetic acid, tar, etc, releasing a certain amount of reaction heat energy. Due to the fracture of a large number of C-O and C-C bonds, the hydrocarbon structure and carbonization layer begin to form, resulting in massive mass loss and structural changes, such as the disappearance of the polyphenol structure (400℃~410℃). Aromatic structure turns to polycyclic aromatization, and the content of elemental carbon increases gradually.

(4) High temperature carbonization. At the temperature of 450℃~600℃, cracking and aromatization is mainly reacted, producing carbon monoxide, carbon dioxide, methane and other small molecular substances, leaving a large number of pores and the carbon network shrinks. With the increase of temperature, the gasification composition gradually decreases, and the formation of volatile matter has been completed. The impact of temperature on carbon content begins to weaken, and the weight loss tends to stabilize, where the carbon content accounts for more than 90%.

(5) Modified carbonization. With a temperature of more than 600℃, secondary carbonization plays a major role, which is to screen and shape the above carbonized products, and carbonize them under certain pressure, modification, wrapping and other conditions to change the microstructure of carbon based raw materials and improve their performance, mainly including:

Sintering and carbonization. High temperature sintering under certain conditions can significantly improve the mechanical properties of carbon based materials. For example, when the sintering temperature increases from 650℃ to 800℃[12], the compressive strength of wood ceramics increases from 0.21kN/cm2 to 0.88kN/cm2. The sintering carbonization temperature is more than 800℃, and the compressive strength of carbonized products is high.

Pore enlarging carbonization. When the temperature is below 400℃, since the gas in biomass has not completely overflowed and the porous structure of carbon has not yet formed, the specific surface area of charcoal carbonization can hardly be measured in the test at this occasion. Therefore, the production of activated carbon requires pore enlarging carbonization, and the temperature is controlled at about 950 ℃ to improve the specific surface area of carbon.

Closed pore carbonization. Due to the precipitation of gas in the carbonization process, many pores are connected with each other, which is not conducive to heat preservation, so it is necessary to wrap the raw materials to seal the pores[13].

Crystallization carbonization. The products of high-temperature carbonization are mostly amorphous carbon, which is the molecular fragments of graphite layered structure roughly parallel to each other and piled together irregularly, with poor mechanical properties. Therefore, it is necessary to realize the crystallization or microcrystalline of its molecules through crystallization carbonization, which is the focus of subsequent research.

In the above carbonization stages, primary carbonization and moderate carbonization are suitable for wood heat treatment, while moderate carbonization and deep carbonization are used for local recycling of solid waste, and deep carbonization and modified carbonization are mostly applied in the manufacture of functional materials. The carbonization process is various due to different raw materials and different quality requirements of carbonization products, and the carbonization products are also different due to different carbonization processes, which includes both aggregates and powders, and need to make full use and save resources. In addition, in the carbonization process, some are endothermic reactions, and some release reaction heat, so it is vital to use the waste heat to achieve the goal of energy conservation. Moreover, both harmful gas and combustible gas are emitted, so it is necessary to use the combustion of combustible gas, the purification of waste gas and the recovery of waste liquid to achieve energy conservation and environmental protection.

3. Application of Carbon Based Materials

Carbon based materials are materials with carbon as the main chemical component. In a broad sense, carbon based materials include not only wood materials with organic carbon as the main component, such as wood, bamboo plywood, etc., but also various carbon simple materials with different crystal structures, such as graphite, carbon fiber, etc. Carbon based materials are divided into plates, rods, blocks, coiled materials, coatings, and powders according to their shapes. Among them, rods, such as wood gratings, carbonized wood, and coiled materials, such as peeled wood bark. This topic focuses on the research of carbon based plates, blocks and powders.

Carbon based plates are divided into integrated panels, rough panels and decorative panels according to structure and finishing conditions. Integrated panels and decorative panels can be further subdivided according to finishing materials and colors, such as stone paint exterior wall panels, latex paint interior wall panels, plastic surface stair panels, paint cabinet door panels, etc. It can be seen from these subdivision types that the mechanical properties of plates are required to be high.

In construction projects, carbon based plates are suitable for making components such as wallboards. Structural members can be divided into flexural members, compression members, tension members, torsional members, etc. The internal force (such as axial force, bending moment, shear force, torque, etc.) and deformation will occur when the component is subjected to direct (load) and indirect actions, and the main strength indicators are tension and pressure. Reinforced concrete is a composite material composed of steel bars in tension and concrete in compression. Therefore, the stress factors of carbon based materials can also be divided into tension factors and compression factors. Carbon based materials, such as plates and rods, are composite materials composed of fibers with large tensile strength, strong corrosion resistance and high heat resistance temperature as the tensile factor, such as carbon fiber, glass fiber, basalt fiber, steel wire, etc., and carbon based aggregate as the compressive factor, and cementitious materials to cement the tensile factor and compressive factor together, which have outstanding technical advantages in light weight, high strength, energy conservation and environmental protection[14].

Carbon based block is a kind of material which is made of carbon based aggregate bonded together with cementitious materials to form a block shape, such as carbon base block, carbon base water seepage floor tile, etc. Carbon based block materials have low performance requirements for aggregates and are widely used, which can consume a large amount of biomass wastes, domestic garbage and other wastes, thus reducing environmental pollution.

Carbon based powder is mostly the tailings after screening of carbonization products, with small particle size and many impurities, which can be used for soil improvement in construction and garden projects. The research of Fu Weijun et.al shows that agricultural wastes are mainly made of biochar (mainly inorganic carbon) and directly utilization can increase the soil carbon pool, and reduce the emission of methane and nitric oxide and add SOC by changing the physical and chemical properties of soil and microbial community structure, bringing considerable emission reduction and sink increase. Biochar can also play a role in increasing production by increasing soil fertility, and will not cause diseases and pests. Compared with direct returning to the field, aerobic composting, anaerobic fermentation and incineration for power generation, it gives full play to the resource attribute of waste, with less negative effects[15].

4. Conclusions

(1) From the above carbonization mechanism study, it can be seen that adopting appropriate

carbonization process to treat biomass waste can scientifically realize the inorganic transformation of organic carbon, which can not only greatly reduce greenhouse gas emissions, but also avoid the generation of methane.

(2) The carbonization products used to produce building materials are technically reliable, and can realize the resource utilization of biomass waste, and can reduce the use of high pollution and energy consumption materials such as cement and steel.

(3) The benefits of using carbonized products to produce building materials need to calculate the traditional economic cost, and the benefits of carbon trading, as well as the social benefits of saving resources and reducing pollution.

In short, in order to achieve the goal of carbon peaking and carbon neutralization, the scientific treatment of biomass waste is significant and highly urgent.

5. Patents

(1) A window screen based on electrostatic adsorption and photocatalyst, Chinese invention patent, ZL201510769642.2;

(2) A Mercerized photocatalyst emulsion paint and its production process, Chinese invention patent, ZL201510766822.5;

(3) A kind of Water purification process and water purification equipment, Chinese invention patent, ZL201410376716.1;

(4) An intelligent multi-purpose anti-theft window, Chinese invention patent, ZL201310229192.9;

(5) A composite foam glass exterior wall panel with self-thermal insulation and non- decoration features, Chinese invention patent, ZL201310325951.1.

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