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Production Technology of Biochar

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Organic waste, as the main constituent of solid biomass, has a high potential for biochar generation. Biomass waste materials appropriate for biochar production include crop residues from agriculture, forestry, municipal solid waste, food and animal manures, etc. The biochar derived from biomass is a highly rich source of carbon produced from biomass using thermal combustion in an oxygen-limited environment. The unique properties of biochar such as large surface area, high porosity, functional groups, high cation exchange capacity, stability make it suitable for various applications. The fast and ease of preparation, eco-friendly nature, reusability, and cost-effective are few advantages of biochar. The process parameters are mainly responsible for determining the yield of biomass. The parameters include temperature, types of biomass, residence time, heating rate, pressure, etc. Temperature is the main parameter affecting the characteristic of biochar. The common thermochemical techniques used for biochar production include pyrolysis, hydrothermal carbonization, gasification, flash carbonization and torrefaction. Of all these methods, pyrolysis is the most commonly used to produce biochar. The organic compounds present in the biomass decompose at a specific temperature in an oxygen-limited environment. Many agricultural residues have been utilized for producing biochar such as rice straw, wheat straw, waste wood, sugar beet tailings, corn cob, etc. These biomasses are composed of mostly cellulose, hemicellulose and lignin components.

Methods of Biochar Production

1. Pyrolysis

The process of thermal decomposition of organic materials in an oxygen-free environment under the temperature range of 250−900 °C is called pyrolysis. This process is an alternate strategy for converting the waste biomass into value-added products like biochar, syngas and bio-oil. During the process, the lignocellulosic components like cellulose, hemicellulose and lignin undergo reaction processes like depolymerization, fragmentation and cross-linking at specific temperatures resulting in a different state of products like solid, liquid and gas. The solid and liquid products comprise of the char and bio-oil whereas the gaseous products are carbon dioxide, carbon monoxide and hydrogen

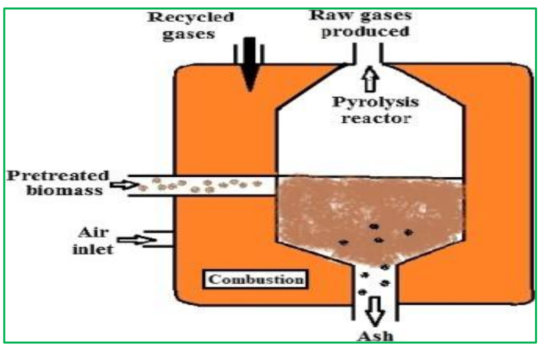

Fig. 1 Mechanism of pyrolysis

and also syngas (C_1-C_2 hydrocarbons). Various types of reactors such as paddle kiln, bubbling fluidized bed, wagon reactors and agitated sand rotating kilns are used for biochar production. The biochar yield during the pyrolysis process depends on the type and nature of biomass used. Temperature is the main operating process condition that decides the product efficiency. Generally, the yield of biochar decreases and production of syngas increases when the temperature is increased during the pyrolysis process.

Fast pyrolysis: Fast pyrolysis is deliberated as a direct thermochemical procedure that can liquefy solid biomass into liquid bio-oil with a high potential for energy application. Fast pyrolysis conditions are described by: (i) fast warming paces of biomass particles (>100 °C/min), (ii) joined with short times of the biomass particles and pyrolysis fumes (0.5–2 s) at high temperatures and (iii) moderate pyrolysis treatment temperatures (400−600 °C). A key distinctive component of fast pyrolysis innovation is the need to keep the fume residence time in hot zone to the base, to accomplish great bio-oil quality. This can be accomplished by guaranteeing fast extinguishing or cooling of the fumes.

Slow pyrolysis: In slow pyrolysis, the rate of heating is very less around 5−7 °C/min and possesses a longer residence time of more than 1 h. The slow pyrolysis innovation has a better yield of char contrasted different pyrolysis and carbonization strategies. The biochar could be utilized as a dirt enhancer to improve soil quality.

The mechanism of the pyrolysis process is shown in Fig. 1.

2. Hydrothermal Carbonization

Hydrothermal carbonization is considered to be a cost-effective method for biochar production as the process can be performed at a low temperature around 180−250 °C. The product using the hydrothermal process is referred to as the hydrochar to differentiate the product produced from dry processes such as pyrolysis and gasification. During the process, the biomass is blended using water and is placed in a closed reactor. The temperature is slowly increased for maintaining stability. At different temperatures, the products are produced as follows: biochar at a temperature below 250 °C referred to as hydrothermal carbonization, bio-oil between 250−400 °C known as hydrothermal liquefaction and gaseous products syngas such as CO, CO2, H_2 and CH_4 produced at a temperature above 400 °C referred as hydrothermal gasification. Fig. 2 represents hydrothermal carbonization procedure. The hydrolysed product proceeds through series of reactions such as dehydration, fragmentation and isomerization to form intermediate product 5-hydroxymethylfurfural and their derivatives. Furthermore, the reaction proceeds through condensation, polymerization and intramolecular dehydration to produce the hydrochar. The high molecular weight and complex nature of lignin make the mechanism complicate. The lignin decomposition starts through dealkylation and hydrolysis reaction producing phenolic products like phenols, catechols, syringols, etc. Finally, the char is produced through repolymerization and cross-linking of intermediates. The lignin components that are not dissolved in liquid phase are transformed into hydrochar similar to pyrolysis reaction.

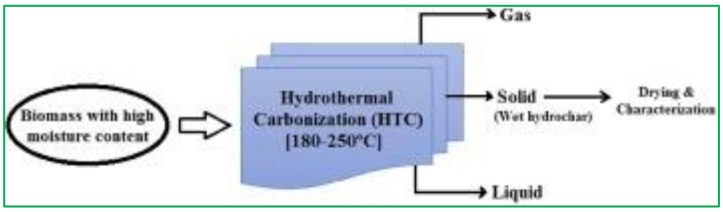

Fig. 2 Hydrothermal carbonization procedure

3. Gasification

Gasification is a thermochemical method of decomposition of the carbonaceous material into gaseous products i.e., the syngas comprising CO, CO_2, CH_4, H_2 and traces of hydrocarbons in presence of gasification agents such as oxygen, air, steam, etc and high temperature. It is noted that the reaction temperature is the most significant factor in determining the production of syngas. It was found that as temperature increased carbon monoxide, hydrogen production increased while other contents such as methane, carbon dioxide and hydrocarbons were decreased. The major product of this process is syngas and the char are referred to as the by-product with less yield. The gasification process was shown in. The gasification mechanism can be sub-divided into many steps as follows:

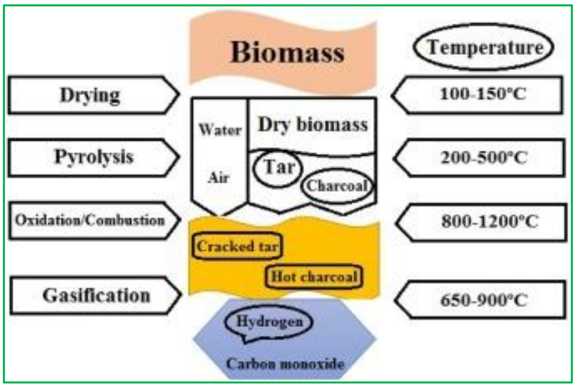

Fig. 3 Process of gasification

3.1. Drying

During this process, the moisture content in the biomass is completely evaporated without energy recovery. The moisture content varies from different biomass material. Drying is employed as a separate process during the gasification process when the biomass contains high moisture content.

3.2. Oxidation/Combustion

The oxidation and combustion reactions of gasification agents are the main energy sources for gasification process. These gasification agents react with the combustible species present in the gasifier to produce CO_2, CO and water.

4. Torrefaction and flash carbonization

Torrefaction is a newly emerging technique for biochar production. It employs a low heating rate thus referred to as mild pyrolysis. The oxygen, moisture and carbon dioxide present in the biomass removed using inert atmospheric air in absence of oxygen at temperature of 300 °C using various decomposition processes.The torrefaction process modifies the biomass properties such as particle size, moisture content, surface area, heating rate, energy density, etc. The steps involved in torrefaction process are represented in Fig. 4. The process of torrefaction can be performed (a) Steam torrefaction: The biomass is treated using steam in this process with temperature not more than 260 °C and residence time of around 10 min. (b) Wet torrefaction: It is also called hydrothermal carbonization proceeds with the contact of biomass with water at temperature 180−260 °C and residence time of 5−240 min. (c) Oxidative torrefaction: This process is carried out by treating biomass with oxidizing agents like gases that are utilized for combustion process for generating heat energy. This heat energy is used to produce required temperature.

The mechanism of torrefaction process is an incomplete pyrolysis process and the process proceeds as following reaction conditions: temperature – 200−300 °C, residence time – less than 30 min, heating rate – less than 50 °C/min and in absence of oxygen. The process of dry torrefaction process can be classified into various phases such as heating, drying, torrefaction and cooling.

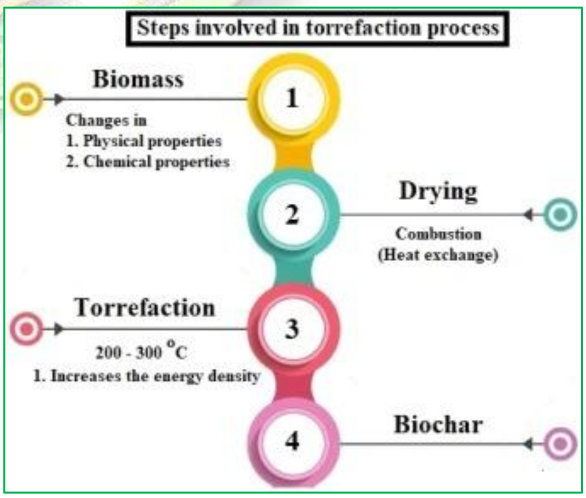

Fig. 4 Steps involved in torrefaction process