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POTENTIAL USE OF BIOCHAR IN WASTEWATER TREATMENT OPERATIONS AND SOIL IMPROVEMENT

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Abstract
Biochar is produced through thermochemical decomposition, so called as pyrolysis, of different biomass groups in the presence of little or no oxygen. Resultant material is highly stable material with excellent surface characteristics and pore structure and is also rich in functional groups. Such properties of the material are largely influenced by pre- and post-treatments and thermal decomposition conditions. Various methods have been used for thermal decomposition of biomass, such as pyrolysis thermal carbonization, torrefaction and microwave heating at different temperatures and for different durations. Biochar has recently started to be used for wastewater treatment and water pollution control purposes. It is also used to improve soil properties including aggregate stability, water holding capacity and organic matter content. It is a new, economic and environment friendly material to be used in wastewater treatments technology and soil improvement. In this study, biochar production technologies and properties of resultant materials were summarized and potential use of biochar in wastewater treatments operations and for soil improvement were assessed in detail.

Keywords: Biochar, pyrolysis, soil properties, treatment, wastewater.

1. INTRODUCTION

Biomass feedstock is subjected to thermal decomposition either in the presence of little oxygen or lack of oxygen to produce biochar, in other words, to turn biomass feedstock into a carbon-rich porous material (Figure 1). Several types of biomass feedstock are used in biochar production. Such materials are mostly organic materials, manures, wood chips, algae, treatment sludge (Xiong et al., 2017). There is an increasing interest in biochar since biochar production can offset greenhouse gas emissions (Creamer and Gao, 2016) and offers an efficient, low-cost and environment-friendly absorbent especially for wastewater treatment purposes (Cha et al., 2016).

For biochar production, biomass feedstock passes through different thermal decomposition processes. These processes (pyrolysis, microwave-assisted pyrolysis, hydrothermal carbonization, gasification) are realized under different temperatures and for varying durations (Fang et al., 2018). The thermal decomposition process to be selected is largely dependent on purpose of use, available biomass feedstock and technological conditions. Before and after thermal decomposition process,

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biomass feedstocks pass through different pre- and post-treatments to improve or enrich the physical and chemical characteristics of the final product.

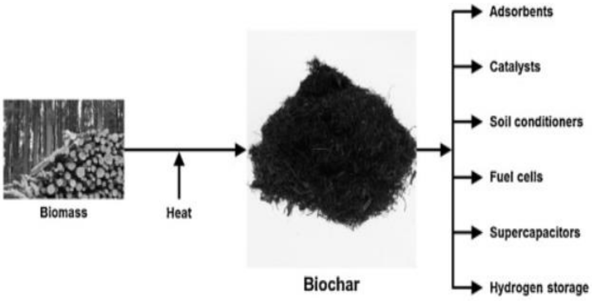

Figure 1. Biochar (Cha et al., 2016)

Just because of current climate change and global warming, water resources are continuously depleted. It will be impossible to meet food and water demands of ever-increasing populations in near future. Irrigation is the primary input in agricultural production activities to increase yield levels. Excessive water use in irrigation also contributes to rapid depletion of water resources. Modern irrigation techniques or water-saving technologies should be employed in irrigations. Treated wastewater effluents could also be used in irrigations. Water resources are polluted by untreated wastewaters containing organic and inorganic contaminants such as dyes, heavy metals, surfactants, pharmaceuticals and pesticides discharged into receiving water bodies (Zulfiqar et al., 2019). Biochar has recently been used in wastewater treatment operations, especially to adsorb metals and various other pollutants (Palansooriya et al., 2019).
Besides water resources, agricultural soils are also contaminated with different pollutants. Soil contamination is a global issue especially in developing countries. Heavy metals pose serious risks of pollution in soils. Heavy metals usually come from anthropogenic activities, such as metal mining, smelting and industrial operations, fertilizers, composts, sewage sludge, pesticides and organic manures. Pollutants coming from different sources result in soil degradation. In this paper, initially biochar production was assessed in detail, then potential use of biochar in wastewater treatment operations and soil remediation were evaluated.

2. BIOCHAR PRODUCTION

Different biomass feedstocks and production technologies are used in biochar production. Raw feedstocks are subjected to pre-treatments, primary thermal decomposition process and post-treatments to get a final product with desired physico-chemical properties.

2.1. Biomass Feedstock

Several types of raw material can be used in biochar production. The primary issue herein is to select suitable thermal decomposition technology for each raw material and to apply relevant pre- and post-treatments to get desired quality traits. Biochar feedstocks could be gathered under three broad categories as of: Plant raw materials (forestry residues, agricultural residues), municipal and livestock waste raw materials (sewage sludge, manure) and algal raw materials (algal biomass) (Table 1).

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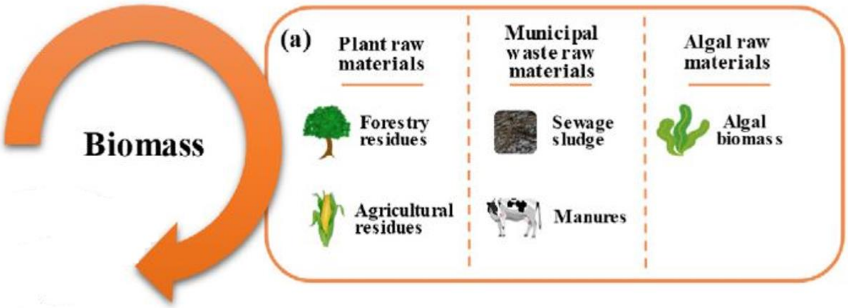

Figure 2. Biomass feedstocks for biochar production (Xiang et al., 2020)

Table 1. Biomass feedstock for biochar production

Bamboo wood	Peanut shell	Bagasse
Pomela peal	Marine macro algal	Sawdust
Pine wood	Banana peels	Reed
Paper mill sludge	Cauliflower leaves	Crab shell
Sewage sludge	Peanut hull	Wheat straw
Rice husk	Maple wood	Wood waste
Green waste	Switch grass	Corn stalks

2.2. Pre-treatments

Pre-treatments applied to biomass feedstock are classified as physical, chemical and biological pre-treatments. In physical pre-treatments, biomass feedstocks are dried at different temperatures to reduce initial moisture content, dried samples are crushed into small pieces mechanically, then these particles sieved through sieves with different opening sizes. The physical pre-treatment method to be applied is totally dependent on the nature of feedstock. For instance, lignocellulosic or plant raw materials are generally dried in an oven at 105 ºC for 24 hours, then crushed and sieved (Essandoh et al., 2017). Dewatered treatment sludge is usually dried overnight, then crushed and sieved. Paper-originated raw materials (newspapers, cardboard, scarp paper) are initially shredded, then converted into pulp (Randolph et al., 2017). Algal raw materials are washed and rinsed through, then turned into granular forms (Roberts and de Nys, 2016).

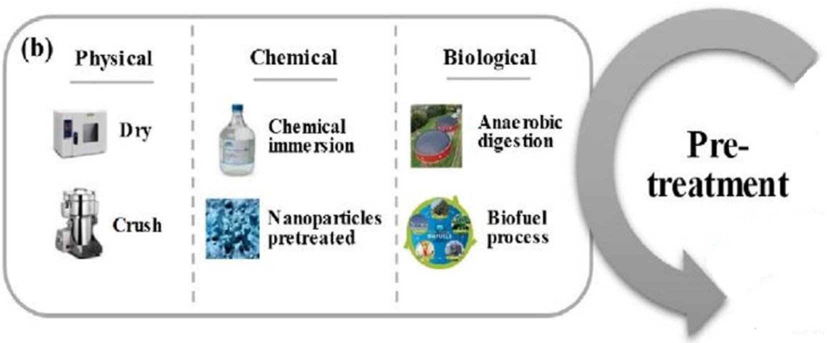

Figure 3. Pre-treatments applied to biomass feedstocks (Xiang et al., 2020)

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In chemical pre-treatments, biochar feedstocks are subjected to chemicals or functional materials. Biomass feedstocks are dipped into chemical solutions and dried, then utilized for biochar production (Tan et al., 2016). Nanoparticles or natural colloids are also used as chemical pre-treatment to produce biochar-based nanocomposites (Inyang et al., 2015). Acids and oxidants-like corrosive chemicals are used as potential chemical pre-treatments. Such treatments significantly improve specific surface area, pore structure, surface-active functional groups (Zhao et al., 2018). In biological pre-treatments, biological processes are employed to improve biomass feedstock before thermal decomposition process. Bacterial treatments and anaerobic digestion are used to produce biologically activated biochar with enhanced characteristics (Yao et al., 2015).

2.3. Thermal Decomposition Processes

Biochar feedstocks pass through different carbonization methods to produce engineered biochar (Table 2) (Figure 4) (Xiang et al., 2020; Mohan et al., 2014). Pyrolysis is a thermochemical decomposition process conducted under anoxic conditions. Operational temperature, heating rate and duration significantly influence composition and physico-chemical characteristics of final product. Through pyrolysis, feedstocks are decomposed, saline and alkaline substances are separated and carbonization is realized (Irfan et al., 2016). Pyrolysis temperature designates process speed and duration. Generally, prolonged pyrolysis durations are desired for complete decomposition of feedstock (Mohamed et al., 2016).

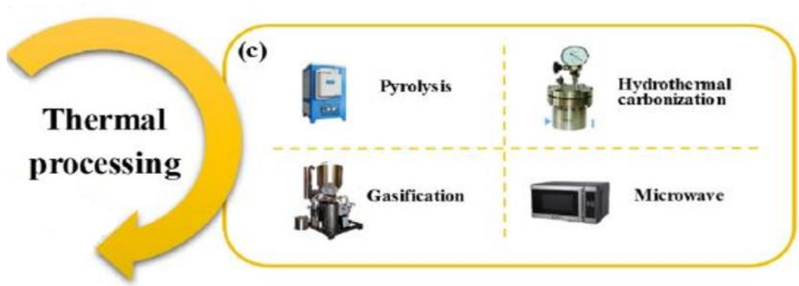

Figure 4. Thermal decomposition processes (Xiang et al., 2020)

Table 2. Thermal decomposition of biomass feedstocks

Thermal decomposition process	**Key Parameters**	**Temperature Power**	**Duration**
Pyrolysis	Temperature, heating rate, duration	300 – 850 ºC	1 – 3 h
Microwave-assisted pyrolysis	Power, irradiation duration	400 – 500 W	1 – 10 min
Hydrothermal carbonization	Temperature, duration, pressure	120 – 260 ºC	1 – 16 h
Gasification	Temperature, duration, pressure, gasification agent	> 800 ºC	10 – 20 s

Thermal decomposition of biomass feedstock to produce biochar under microwave power is so called as microwave-assisted pyrolysis (Mutsengerere et al., 2019). It shortens process duration, reduces energy consumption and offers efficient heat transfer (Duran-Jimenez et al., 2018). Microwave power and irradiation time designate process duration and final product quality traits. Excessive microwave powers alter pore structure of biomass, thus reduce specific surface area of the final product (Jimenez et al., 2017).

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In hydrothermal carbonization, biomass feedstock is not pre-dried and directly converted into biochar under temperatures of between 120 – 260 ºC (Fang et al., 2018), pressures of between 2 -10 MPa and for durations of between 5 - 240 minutes (Kambo and Dutta, 2015). Resultant product is called as hydrochar. Another process to produce biochar is gasification in which biomass feedstock is converted into gas fuel using gasification agents under temperatures of greater than 800 ºC (You et al., 2017). Resultant product contains alkali salts and alkaline earth minerals at high levels (Kambo and Dutta, 2015) and generally used in soil improvement (Yu et al., 2019).

2.4. Post-treatments

Following the thermal decomposition process, resultant product is subjected to physical or chemical post-treatments to further improve quality traits of final product including specific surface area, pore volume, surface chemistry and surface-active functional groups (Figure 5) (Van Vinh et al., 2015).

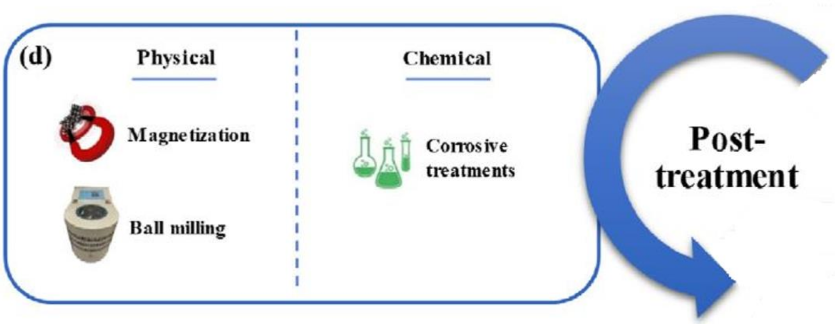

Figure 5. Post-treatments applied after thermal decomposition (Xiang et al., 2020)

Magnetization is used to convert final product into a magnetic material through loading material surface especially with iron particles (Tan et al., 2016; Shengsen Wang et al., 2019). Ball milling is applied to break up chemical bonds, alter particle size and have nanoscale biochar particles (Lyu et al., 2017). With ball milling, final product is enriched with specific surface area, pore volume and adsorption capacity (Xiang et al., 2020). In corrosive treatments, final product is immersed into acid, alkali and oxidant solutions to modify surface chemistry of the product.

3. BIOCHAR USE IN WASTEWATER TREATMENT

Biochar with a large specific surface area and rich surface-active functional groups is utilized as an efficient adsorbent for removal of several contaminants (heavy metals, pesticides, organic contaminants, nitrogen and phosphorus) from wastewaters. Different biochars are used for treatment of municipal, industrial and agricultural wastewaters and stormwaters (Figure 6) (Xiang et al., 2020). Biochar has recently been used in treatment of industrial wastewaters coming from different sources to adsorb various pollutants. Pollutant adsorption of biochar is largely designated by biochar dose, ambient pH and duration of contact (Poonam and Kumar, 2018).
Biochars are utilized alone or in combination with biofilters for treatment of municipal wastewaters. Significant quantities of nitrogen and phosphorus are recovered through this technology (Cole et al., 2017). Aluminum oxyhydroxide-loaded biochar is generally used for either recycle or re-use of phosphorus of wastewaters. In municipal wastewater treatment processes, biochars perform well for organic carbon, COD, TSS, TKN and TP (Manyuchi et al., 2018).

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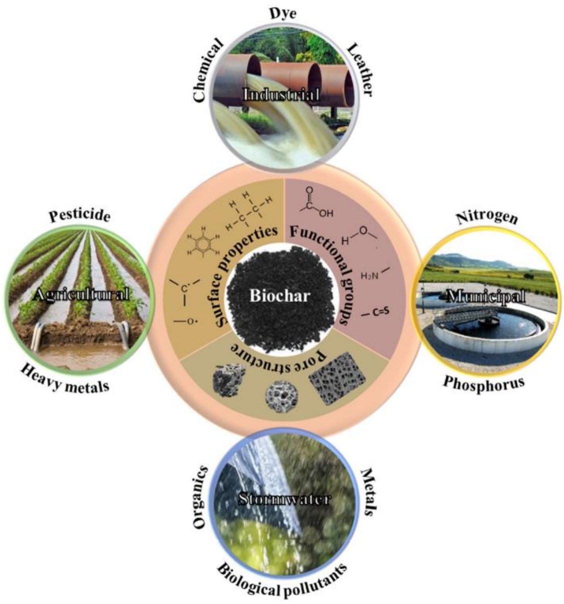

Figure 6. Biochar for treatment of different wastewaters (Xiang et al., 2020)

Biochar and various other modified forms are used for treatment of agricultural wastewaters (Wei et al., 2018). Biochars are especially used to remove common pesticides from agricultural drainage effluents. Mandal and Singh (2017) reported quite a high adsorption of common pesticides with biochars produced through pyrolysis of rice husks with acid pre-treatments. Adsorption capacity of biochar is primarily dependent on volume of pores and biochar pH (Liu et al., 2015).
Biochar-enriched filtration mediums are used for efficient removal of copper and zinc in stormwaters. However, attention should be paid in design and testing of biochar media to have expected performance in treatment of stormwaters (Gray, 2016). Biofilters enriched with biochars could improve total organic carbon, total nitrogen and phosphorus removal performance of the system. Removal capacities of contaminants in stormwaters are designated by biochar characteristics, pollutants and chemical composition of stormwaters (Mohanty et al., 2018).

4. BIOCHAR USE IN SOIL REMEDIATION

Biochars produced through different thermal decomposition processes of various biomass feedstocks are utilized for soil remediation in other words, to overcome soil pollution (Sun et al., 2018). Various soil improvement methods and processes were developed for efficient remediation of polluted soils and to minimize potential harmful impacts of such technologies. Biochars with diverse physicochemical characteristics offer an efficient remediation strategy in prevention of soil pollution (Figure 7) (Ji et al., 2022).
Impact of biochars on soil pollution are largely dependent on biomass feedstocks and physicochemical properties of the biochar. Biochar organic pollutant removal efficiency also depends on biochar physico-chemical properties and pollutants. Biochars catalyze decomposition of organic pollutants. Biochar with quite a high specific surface area could efficiently adsorb heavy metals from the soils (Dhaliwal et al., 2020).

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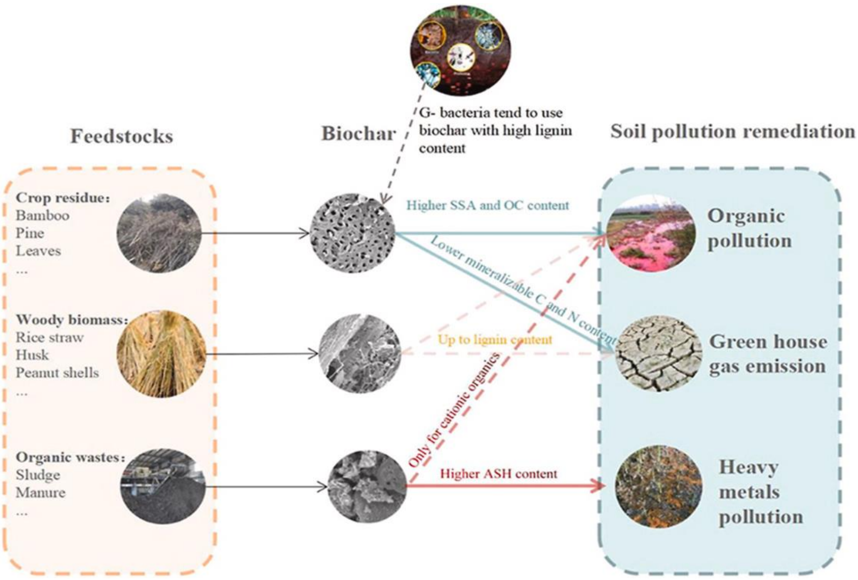

Figure 7. Biochar use in soil remediation (Ji et al., 2022)

Biochar treatments to soils may regulate greenhouse gas emissions through regulation of nitrification and denitrification processes and soil microbial activity (Ji et al., 2022). Biochar treatments also affect soil microorganisms, then improve soil pH, pore structure, water holding capacity and soil nutrients (Cayuela et al., 2014). Accordingly, these improved parameters influence soil enzymes and enzyme activity. Biochar treatments were proven to increase soil enzyme activity. Biochar, rich in phosphorus, potassium and magnesium promotes microbial activity of the soils (Lehmann et al., 2011).

5. CONCLUSION

Soil and water pollution pose serious threats on essential resources globally. Impacts of climate change and global warming further exacerbate such threats. Biochar, produced from various biomass feedstocks through different thermal decomposition technologies, has recently been used for soil remediation and wastewater treatment purposes. Biochars with quite a high specific surface area, abundant surface-active functional groups, have efficiently been used to remove heavy metals, organic pollutants, pesticides and various other pollutants from industrial wastewaters, municipal wastewaters, agricultural wastewaters and stormwater runoffs. Biochar is also used for soil remediation through improved soil microbial activity, enzyme activity, reduced greenhouse gas emissions and removal of toxic and hazardous pollutants. Biochar research is mostly conducted under laboratory conditions. Thus, further large-scale research is recommended to be conducted under field conditions.

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