Trends and Scope of Utilization of Biochar in Wastewater Treatment

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9.1 Introduction

The presence of contaminants, heavy metals, dyes, and toxic pollutants from industrial and domestic sources in water is a threat to the global ecosystem (Khandegar et al. 2021). Ingestion of heavy metals like Cu, As, Pb, Hg, Au, and Pd by aquatic animals, plants, and humans has severe environmental consequences. The discharge of effluent-containing dyes from textile and fiber processing industries leads to water pollution, and it becomes unfit for human consumption. The problem of water pollution also causes wastage of water and has prompted global researchers to look for eco-friendly, low-cost, effective technology to treat the water for reuse. Some of the most commonly used water treatment processes are membrane separation, composting, landfarming, coagulation, chemical precipitation, advanced oxidation method, ozonation, and adsorption (Chauhan et al. 2020; Kaur et al. 2020a, b; Suri et al. 2020, 2021).

Low cost and ease of availability make adsorption an attractive process for wastewater treatment. Adsorption is a surface phenomenon with the accumulation of atoms, ions, or molecules on a surface from the bulk of fluids or dissolved solids. Molecules that get adsorbed are called adsorbate, and the material used for this purpose is called adsorbent. Two main types of adsorption processes are physisorption and chemisorption. In the first type of adsorption, the attractive force between adsorbate and adsorbent is primarily governed by van der Waals

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forces. The process has low adsorption enthalpy and is reversible. In chemisorption, a chemical reaction occurs between the adsorbate and adsorbent, breaking old bonds and forming new ones. This process is irreversible since the bonds formed in chemisorption are highly ionic or covalent.

Adsorption has an extensive application in industries. It is one of the essential separation processes in which specific components are removed from the fluids and transferred to the surface of the solid adsorbent (Odoemelam et al. 2015). Adsorption is also used to remove hazardous ingredients found in effluents from industries and water treatment plants. It also finds application in drying gases and liquids before loading them into industrial units. Adsorbents are used in gas masks to purify the air from harmful particles getting into our respiratory tracts. Another important application of this process is the removal of foul odor, by using silica gel (Dąbrowski 2001). The biomass sources include waste materials like agricultural or forestry residue and industrial biowaste (Chauhan et al. 2020).

Biochar can be further modified to produce activated charcoal (AC), which has superior properties. The use of AC as an adsorbent is not a new concept. They have been used for many adsorption processes for decades (Dąbrowski 2001). AC is a hydrophobic adsorbent. With the enhanced surface area, AS is successfully used to eliminate pollutants from the air, purify water, remove dyes, and even decolorize cane sugar in sugar industries. The primary advantage of using AC is its high porosity and large specific surface area of 500–2000 m^2/g (Mohammad-Khah and Ansari 2009).

The present chapter focuses on types of biomass used to produce biochar with enhanced surface area. An overview of biochar production processes and characteristics of biochar is provided here. The research on activated charcoal was fabricated from various biomasses to promote the usage of biowaste. The present chapter discusses multiple techniques and optimum conditions to form high-quality activated carbon from biomass, which can be used for industrial purposes, such as removing dyes, heavy metals, and organic and inorganic waste. Further, it can be used for cosmetic and pharmaceutical purposes. The chapter analyzes the scope of biochar for water treatment and provides future directions for research work.

9.2 Types of Biomass Suitable for Biochar Production

Biomass is a biological material obtained from living or recently living organisms. Some of the most common available biomass feedstocks are grains and starch crops which include sugarcane, corn, wheat, sugar beets, industrial sweet potatoes, etc.; agricultural residues like corn stover, wheat straw, rice straw, orchard prunings, etc.; food waste obtained from the food processing industries; forestry materials like logging residues, forest thinnings, etc.; animal by-products like tallow, fish oil, manure, etc.; energy crops like switchgrass, miscanthus, hybrid poplar, willow, algae, etc.; and urban and suburban wastes which include municipal solid wastes (MSW), lawn wastes, wastewater treatment sludge, urban wood wastes, disaster debris, trap grease, yellow grease, waste cooking oil, etc.

All these materials are lignin, cellulose, and hemicellulose with minor constituents like resin, gums, and tannins (Kaur et al. 2016a, b).

The relative proportion of these constituents varies among various species and within the same species grown under different geographical conditions (Kaur 2018). The conversion of biomass to energy depends on relative moisture content and other constituents present in the raw material. The sludges and herbaceous biomass materials with high moisture content undergo biologically meditated fermentation processes using enzymes as the catalyst to produce ethanol-based fuels. Though biological processes have several advantages like low energy consumption, ease of handling, and ability to handle significant feedstock simultaneously, the sensitivity and long treatment times make them challenging to handle. Thus, dry biomass materials like wood chips with lower moisture content can be chosen for thermal treatment processes. Lignin is a further complex polymer that needs a temperature higher than 350 °C to decompose and becomes a less desirable component for biochar production. Thus, biomass species richer in cellulose and lower in lignin content are generally preferred for biochar production.

9.3 Processes for Biochar Production

Char and biochar are similar materials, based on the raw material used for production. The decomposition of any organic materials leads to producing a black, porous compound known as char. When the biomass undergoes thermal decomposition, the material obtained is biochar. Being a waste biomass-based material, biochar is sustainable and helps to add value to a waste product. The general steps for producing biochar include pretreatment, thermal decomposition, char separation, and biochar activation (Fig. 9.1).

9.3.1 Pretreatment

The first step for biochar production includes biomass pretreatment to make it suitable for thermal treatment. Physical pretreatment of biomass can be done using

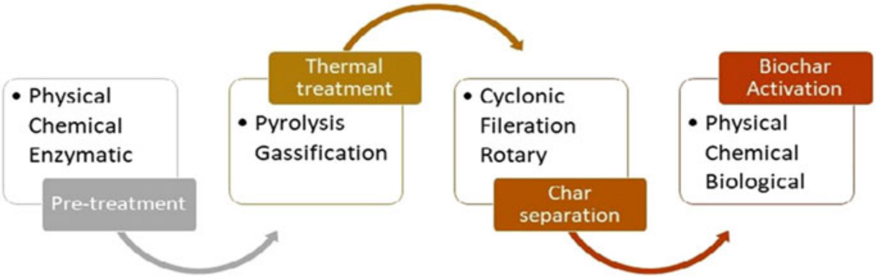


Fig. 9.1 General steps for the production of biochar

chunking, chipping, grinding, and crushing to reduce the particle size, reduce feed variability, and increase the surface area and energy density of feedstock. Various types of chemicals like acid, alkali, and oxidants can change the chemical composition of biomass and help in thermal conversion processes. Treatment with metal-based solutions like $FeCl_3$, $AlCl_3$, and $MgCl_2$ can lead to the generation of engineered biochar with metal hydroxides deposited on its outer surface. Biochar-based nano-composites can be produced by treatment of biomass material with nanoparticles like carbon nano-tubes, graphene oxide, etc. Biomass can also undergo biological treatment to produce biologically active biochar with very high surface area.

Moisture in the raw material leads to high energy consumption and makes biomass susceptible to fungal and microbial decay during storage. Water reduces the shelf-life of biomass species (Kaur et al. 2016a, b). Drying at 105 °C is further required to reduce and stabilize the moisture content. As shown in Table 9.1, there is a significant variation in lignin, cellulose, hemicellulose, fixed carbon, and moisture range of various biomass species. The choice of pretreatment method depends on the chemical composition of raw material, the type of biochar required, and the specific applications it needs to be used.

9.3.2 Thermal Treatment Processes

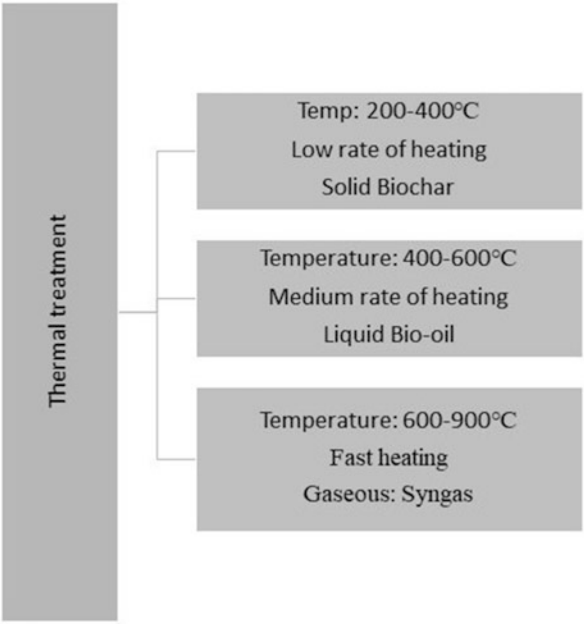
The heating of various biomass species under controlled conditions in specially designed equipment leads to biomass conversion to biochar. Pyrolyzers are the reactors used to heat materials without air in temperatures between 200 and 900 °C. While the temperature is less than 400 °C, solid products, i.e., biochar, can be obtained as the main product (Kaur et al. 2021). As shown in Fig. 9.2, a lower range of temperatures (200–400 °C) is required to produce solid biochar as the primary product. Biomass is a complex mixture of compounds richer in carbon, hydrogen, and oxygen, breaking down into smaller molecules during pyrolysis. While heating biomass material between 200 and 250 °C, water evaporation takes place. Rapid loss of biomass with the decomposition of cellulose, hemicellulose, devolatilization, and production of condensable and non-condensable gases occurs between temperatures 200 and 350 °C. In the intermediate range of temperature (400–600 °C), liquid bio-oil is obtained and collected. The heating of biomass to a temperature of more than 600 °C is required to produce gaseous products like syngas.

Biochar can be produced by slow pyrolysis of biomass (temperature less than 400 °C). The separation of biochar is required as soon as it is formed during the process, as char acts as a catalyst for developing polyaromatic hydrocarbons (PAH). Cyclone separators, in-bed vapor filtration, and rotary particle separator can be used to separate char.

Table 9.1 Chemical composition of various types of biomass

Type of biomass	Lignin (%)	Cellulose (%)	Hemicellulose (%)	Moisture (%)	Fixed carbon (%)	Reference
Sunflower residue	20.94	–	35.18	–	–	Çepelioğullar and Pütün (2013)
Triticum aestivum (wheat straw)	16.3	39.1	24.1	13.2	20.3	Nanda et al. (2013)
Cotton stalk	20.51	40.17	27.98	6.92	14.75	Khan et al. (2020)
Sugarcane bagasse	4.01	38.01	33.27	8.79		Hua and Li (2016)
Walnut waste	36.89	32.19	26.20	6.98	15.99	Özsin and Pütün (2018)
Peach stone	39.26	29.50	25.10	6.88	19.84	Özsin and Pütün (2018), Demirbas (2005)
Hazelnut seed coat	53	29.6	15.7			
Phleum pratense (timothy grass)	18.1	34.2	30.1	9.3	12.6	Nanda et al. (2013)
D. strictus bamboo	25	53.6 (lignocellulose)	–	6.8	–	Kaur et al. (2016a, b)
Eucalyptus globulus	26.7	–	23.8	–	–	Pinto et al. (2018)
Beechwood	21.9	45.8	31.8	7.4	24.6	Demirbas (2005)

Fig. 9.2 Thermal treatment processes for the conversion of biomass to biochar



9.3.3 Posttreatment of Biochar

Once biochar is formed, selective posttreatment of biochar is required to make it appropriate for specific applications. Both physical and chemical posttreatments can produce biochar of necessary surface area, pore volume, and active functional groups. Inducing iron oxides in biochar can further help increase the surface area and pore volume. Another significant advantage of using activated charcoal as an adsorbent is that it can be regenerated by washing with organic solvents, mineral acids, caustic soda, or steam. Hence, the adsorbent can be reused (Mohammad-Khah and Ansari 2009).

Several materials with high carbon content are converted to AC by either gas/physical or chemical activation and carbonization. In the gas activation method, raw material is pyrolyzed to high temperatures to eliminate volatile matter after sun- or oven-drying. The next step is to oxidize, usually with carbon dioxide, or supply steam at yet higher temperatures for selective oxidation. As incomplete combustion takes place, the by-products leave the surface of carbon, creating voids and increasing the surface area of the adsorbent. The charcoal formed by this process is usually granular, which can be broken down to convert into powder form (Mohammad-Khah and Ansari 2009). Binding agents can be used further to form pellets of AC. Subjecting the biochar to a ball mill can also produce biochar nano-scale particle size of high surface area.

Chemical treatment is a simple method that alters the surface chemistry to enhance the surface area, porosity, negative zeta potential, and oxygen-containing functional groups of biochar particles. Various chemicals like HCl, HNO_3, KOH, NaOH, $KMnO_4$, and H_2O_2 have been used by researchers to alter the characteristics of chemical modified biochar. In the chemical activation process, chemicals like potassium hydroxide, zinc chloride, phosphoric acid, or other alkaline metal hydroxides are used to activate charcoal and carbonization at higher temperatures. The raw material is impregnated in proper ratios of the activating agent to achieve effective results. After activated charcoal is formed, the sample is washed to neutralize or remove excess chemicals.

9.4 Specific Characteristics of Biochar

AC has a structure of hexagonal graphite plates. Each carbon atom forms a covalent bond with three neighboring carbon atoms. The addition of some heteroatoms, like oxygen, hydrogen, sulfur, nitrogen, etc., in the carbon matrix can help improve the adsorption capacity of biochar. These heteroatoms act selectively toward specific adsorbates. AC has a large number of pores which are divided into three categories: micropores, macropores, and mesopores. The adsorbent is used with micro- and macropores for gas adsorption, whereas, in liquid adsorption, more mesopores are used. All these pores contribute to a significant surface area of AC which in turn enhances the adsorption (Chowdhury et al. 2013).

The principal property of AC is its high specific surface area and variable pore size distribution. Brunauer-Emmett-Teller (BET) isotherms are used to find the particular surface area of AC which gives five types of profiles. Generally, as mentioned earlier, the specific surface area of AC ranges from 500 to 2000 m^2/g. The factors that affect the porosity of AC are (1) activating agent, (2) activation temperature and time, (3) gases used in carbonization and activation, (4) mixing procedure, and (5) heating rate. Fourier transform infrared (FTIR), X-ray diffraction (XRD), X-ray fluorescence (XRF), and scanning electron microscope (SEM) techniques are used for the characterization of AC to see the overview of specific surface area, porosity, composition, and other characteristics of adsorbent.

Factors affecting the properties of AC as reported by Banerjee et al. (2020) are as follows:

- Raw materials: Organic materials with high carbon content are used to synthesize high-quality activated charcoal. Generally, the biomass used as a precursor should have high carbon content, low ash content, high density, high volatile content, and cost-effectiveness.
- Pyrolysis temperature: High temperatures are preferred for carbonizing the biomass to decompose the sample. The temperature is one of the factors that decide the properties of the prepared AC.
- Activating agent: Use of activating agent in proper ratio improves adsorption at the surface of the carbon.
- Activation time: Activation time affects the carbonization and hence the final properties of AC. If the time increases, the surface area of the adsorbent increases

as well, whereas the percentage yield decreases. Therefore, the sample has to be kept for the optimum time.

- Activation temperature: With the increase in temperature, new pores form, and existing pores broaden, increasing carbon adsorption. But the further increase in temperature decreases the yield due to the release of a high volume of volatile matters.

9.5 Classification of Activated Carbon

Activated carbon can be classified into diverse types depending on the production method, appearance, function, and pore size. AC can be divided into granular and powdered from the shape, and granular activated carbon includes amorphous and shaped forms. Depending on the raw materials, activated carbon can be divided into wood-based, coal-based, nut shell-based, petroleum, and regenerated activated carbon. According to the different functions of the application, it can be divided into liquid adsorption, catalytic performance, and gas adsorption of activated carbon. It can be physically activated carbon, chemically activated carbon, and physically and chemically activated carbon based on production methods.

9.5.1 Granular Activated Carbon (GAC)

Granular activated carbon uses coal-based carbon as raw material, which has a black amorphous appearance, a developed pore structure, good adsorption performance, high mechanical strength, easily repeated regeneration, and low cost. GAC can be used for various applications like decolorization, gas purification, and wastewater treatment. The majority of activated carbon particles with an apparent size larger than 0.18 nm (about 80 mesh) can be fragmented, spherical, and hollow microspheres in shape.

9.5.2 Powdered Activated Carbon (PAC)

Powdered activated carbon has the advantages of fast filtration speed, good adsorption performance, strong decolorization and odor removal ability, economic durability, etc. The products are widely used in food, beverage, medicine, tap water, sugar, oil, and other industries. However, two significant factors are restricting the application of powdered activated carbon in water treatment:

1. It is a complicated process to separate, recover, and regenerate separately after use.
2. Compared with granular activated carbon, the cost is higher.

In addition to powdered activated carbon produced from wood chips, it includes powdered products from granular activated carbon.

9.5.3 Activated Carbon Rods (CTO)

Activated carbon rods are processed and compressed based on granular activated carbon to form carbon rods, which can strengthen the removal of residual odors in the water. The adsorption capacity is faster and more robust. CTO is used in water treatment equipment to remove residual chlorine, chemical pesticides, different colors, and odors and to filter fine impurities in water.

9.5.4 Activated Carbon Fiber (ACF)

Traditional activated carbon has been activated and processed as porous carbon in powder or granular form. In contrast, activated carbon is fibrous, with micropores on the thread. Its ability to adsorb organic gases is higher than granular activated carbon in the air, 5–6 times higher in an aqueous solution, with a 100–1000 times faster absorption rate. ACF is the third generation of new adsorption materials following the widely used powdered activated carbon and granular activated carbon (compressed activated carbon).

9.5.5 Activated Carbon According to the Different Activators

Different activators such as zinc chloride, phosphoric acid, potassium hydroxide, sodium hydroxide, potassium hydroxide, sodium hydroxide, carbon dioxide, air, and steam are used to prepare activated carbon. While steam activation method is economically viable, chemical activation produces AC of high porosity and greater surface area (Hamad and Idrus 2022).

9.6 Biochar-Based Green Adsorbent

Studies have been performed to optimize the reaction conditions to produce activated charcoal from various biomasses. Waste materials like coconut shells were investigated to develop an activated charcoal adsorbent. Researchers have studied the effects of temperature, time, and impregnation ratio of activating reagent and found the ideal conditions.

Coconut shell: Coconut shell was collected, dried in the sun, and reduced to 2–3.5 mm in size. The raw material was carbonized in a Herbold pyrolyzer at an optimum temperature of 600 °C. Pyrolyzed coconut shell was activated using 40% $ZnCl_2$ solution for 50 min. The AC was washed with 0.1 N HCl and water and dried at 120 °C (Mozammel et al. 2002). Banana peel, a waste material used to prepare activated charcoal, showed a high surface area. Mopoung (2008) described the effects of pyrolysis temperature and mass ratio of KOH.

Banana peel: Banana peel was collected, washed, and dried at 110 °C for 3 h. The sample was carbonized at 500–700 °C for 1 h. Further, charcoal was impregnated with KOH in the ratio of C:KOH ranging between 1:2 and 1:4. AC was washed with HCl. pH was neutralized, and excess KOH was removed using hot water. The sample was dried at 110 °C. Cobb et al. (2012) produced a simple, inexpensive, and effective activated charcoal from an agricultural waste by-product, i.e., coconut shell, using pyrolysis and chemical activation techniques. They tested three different chemically activated charcoal adsorption capacities and found the one activated with sodium chloride to be most effective and feasible. The raw material was carbonized at 500–800 °C and activated by soaking in 50% NaCl solution for 24 h.

Getachew et al. (2015) dealt with defluoridation of water by activation of carbon fabricated from banana peel and coffee husk. Firstly, collected banana peels were washed, dried, and crushed. After the size reduction, the sample was kept in the furnace at 400 °C for 1 h for carbonization. For chemical activation, 40 mL of concentrated sulfuric acid was added to the carbonized banana peel and stirred continuously. The mixture was kept at 100 °C for 5 h. Prepared AC was cooled, washed, and dried at 110 °C for 5 h and saved for further use. Secondly, the coffee husk was collected and washed with hot distilled water at 100 °C. The sample was treated with 50 mL of concentrated sulfuric acid and pyrolyzed at 150 °C for 12 h. AC was dried and reduced to 0.6 mm in size.

Budhiary and Sumantri (2021) desired to fabricate AC from plantain peel to reduce the liquid waste produced by tofu-making industries. The banana peel was cut into 1–2 cm pieces and dehydrated in the oven at 60 °C for 6 days. Delignification of raw material was done by soaking it in NaOH solution for 12 h. Peels were filtered and washed with distilled water. The sample was then carbonized at 700 ° C for 2 h. The prepared AC was used for further adsorption studies.

Sugar beet bagasse: Samadi et al. (2009) investigate sugar beet bagasse-based AC to adsorb carcinogenic chromium (IV) from an aqueous solution. Bagasse was collected, cut into 2 cm pieces, washed with deionized water, and dried. The sample was mixed with 5 M $ZnCl_2$ for 24 h at room temperature and then carbonized at 160–180 °C for 8 h. The produced charcoal was thermally activated in a furnace at 650–750 °C for 2 h, using carbon dioxide as the purge gas. The prepared AC was washed with HCl acid solution and kept for further use (Table 9.2).

Olive stones: Olive stone is a lignocellulosic material, with hemicellulose, cellulose, and lignin as the main components. Olive stones could be an adequate feedstock to obtain active carbons with good adsorptive properties and hardness, which could be of interest in future environmental protection programs. Yakout and Sharaf El-Deen (2016) studied the effects of activating agent concentration on the pore structure and surface interaction of AC derived from olive stone using phosphoric acid as the activating agent. Olive stones were used as a precursor

Table 9.2 Various types of biomass used for biochar preparation

Biomass	Method	Reagent for activation	Optimum parameters	Reference
Coconut shell	Pyrolysis + Chemical activation	$CaCl_2$ or $ZnCl_2$	• Carbonization at 500–800 °C • Soaking in 25% activating reagent for 24 h	Cobb et al. (2012)
Coconut shell	Carbonization + Chemical activation	$ZnCl_2$	• 2–3.5 mm coconut shell • Carbonization at 400–600 °C • 1.8 g/cm^3 corresponding to 1100 g of $ZnCl_2$ • Activation time: 2 h	Mozammel et al. (2002)
Banana peel	Pyrolysis + Chemical activation	KOH	• Carbonization at the temperature of 500–700 °C for 1 h • Impregnating ratio of C: KOH from 1:2 to 1:4	Mopoung (2008)
Banana peel	Delignification + Carbonization	NaOH	• Cut to 1–2 cm and then dried at 60 °C for 6 days • Soaked in 1 M NaOH for 12 h • Carbonization at 700 °C for 2 h	Budhiary and Sumantri (2021)
Neem leaves	Chemical activation + Carbonization	H_3PO_4	• Leaves crushed to 400 ASM mesh • Impregnation with H_3PO_4 in a 2:1 ratio • Heating at 260 °C for 30 min	Marichelvam and Azhagurajan (2018)
Banana peel	Carbonization + Chemical activation	H_2SO_4	• Carbonized at 400 °C for 1 h • 40 mL of conc. H_2SO_4 was added to 1000 mL of charcoal for activation	Getachew et al. (2015)
Coffee husk	Chemical activation + Carbonization	H_2SO_4	• 100 g of husk activated with 50 mL of conc. H_2SO_4 • Carbonized at 150 °C for 12 h	Getachew et al. (2015)
Bamboo dust	Carbonization + Chemical activation	HNO_3	• Carbonization at 200 °C for 2 h • Activated using 0.5 M HNO_3 for 2 h at 350 °C	Odoemelam et al. (2015)
Bamboo	Carbonization + Oxidation	Air	• Carbonization from 400 to 1000 °C for 1 h • Air oxidation at 270 °C for 2 h	Odoemelam et al. (2015)
Wood apple fruit	Carbonization + Chemical activation	$ZnCl_2$	• Carbonization at 300 °C for 1 h • Activated using 1 N $ZnCl_2$ in a 1:5 ratio for 12 h	Ashtaputrey and Ashtaputrey (2020)

and were ground to 1 and 2 mm in size and dried. The sample was chemically activated with 80% by 200 mL of phosphoric acid solution. The mixture was stirred at 85 °C for 4 h. After activation, the carbonization of the sample was done at 500 °C for 2 h. Produced AC was washed with distilled water and dried.

Potato peel: Moreno-Piraján and Giraldo (2011) used potato peel to obtain AC to remove copper (II) from an aqueous solution. Colombian potato peel was collected from cultivations, washed, and dried before beginning the process. The sample was impregnated with an aqueous solution of $ZnCl_2$ in the concentration of 160 wt%. The sample was then pyrolyzed in an argon atmosphere for 4 h. Kyzas and Deliyanni (2015) synthesized AC from potato peel to adsorb pharmaceutical effluents. The first method used was hydrothermal treatment. Another method for synthesizing AC was through chemical activation. The potato peel sample was treated with 2 M KOH solution and stirred overnight. After drying at 100 °C for 24 h, the mixture was carbonized at 600 °C under nitrogen for 2 h. Prepared AC was washed, dried, and ground. Bernardo et al. (2016) studied the effectiveness of waste potato peel AC for removing diclofenac. Chemical activation technique was used to obtain the charcoal. The potato peel waste was immersed in a saturated aqueous solution of K_2CO_3 in 1:1 and stirred for 2 h at room temperature. The activated sample was then dried at 100 °C for 24 h. The impregnated sample was then carbonized in an electric furnace at 700 °C for 1 h in a nitrogen atmosphere. Obtained AC was washed with distilled water and dried at 100 °C overnight.

Corncob: El-Sayed et al. (2014) assessed AC prepared from corncob using a chemical activation technique. Corncob was collected, washed with distilled water, and dried. After size reduction to 0.05 mm, the raw material was impregnated with phosphoric acid in a ratio of 1:2 (w/w) for 24 h and neutralized by washing with distilled water. The sample was then subjected to pyrolysis in the absence of air at 400 °C for 2 h. The prepared AC was washed and dried at 100 °C.

Bamboo waste: Odoemelam et al. (2015) fabricated bamboo dust and bamboo-based AC for the removal of lead (II) and cadmium (II) ions from aqueous solutions, discarded as industrial wastewater that gets accumulated in living tissues throughout the food chain. The waste bamboo sample was collected from bamboo tree, washed, cut into pieces, and sun-dried. One-half of the selection was ground and converted into AC through chemical activation. Bamboo dust was soaked in 0.5 M HNO_3 solution and stirred for 30 min at a temperature of 30 °C. Hayakawa et al. (2018) tested the adsorption ability of bamboo AC for adsorbing cesium and strontium. The sample was crushed and dried up to 3–6 months. Bamboo was carbonized in an alumina crucible at temperatures ranging from 400 to 1000 °C for 1 h. Charcoal was converted into activated charcoal using the gas activation technique. Air oxidation was carried out for 2 h at 270 °C in a kiln.

Rice straw: Ramangkoon et al. (2016) optimized the production of activated charcoal from rice straw for medical and pharmaceutical applications using a chemical activation process. Collected rice straw was cut into small pieces, dried, and sieved to 60-mesh particle size, carbonized at 400 °C for 2 h, and further impregnated using 85% phosphoric acid for 24 h. Recarbonization was done at 700 °C for 1 h, and then it was neutralized with distilled water and dried at 110 °C for 24 h. Babar et al. (2019) aimed to generate a low-cost and efficient substitute method of production of activated carbon from biomaterials. Their process started with washing the raw material, i.e., rice straw, and dehumidifying it at 105 °C for 24 h. The dried mass was impregnated with magnesium chloride in 1:1 proportion, kept for 2 h at room temperature, and dried for 48 h for activation. After that, the treated material was carbonized by pyrolysis at 550 °C for 2 h. Pattananandecha et al. (2019) fabricated high-performance activated charcoal for cosmetics and pharmaceutical applications using chemical techniques. Rice straw with the highest lignin content was selected, washed, cut into 60-mesh size particles, and dried at 110 °C for 24 h. The raw material was carbonized at 400 °C in a furnace for 2 h and cooled to room temperature. Activation was performed using 85% potassium hydroxide in a reflux ratio of 1:10 w/v at 70–80 °C for 2 h. Obtained activated carbon was washed with hot water to neutralize and dried at 110 °C for 24 h.

Apple fruit shell: Ashtaputrey and Ashtaputrey (2020) prepared activated charcoal from wood apple fruit shell to lower the concentration of dissolved pollutants in effluents. The sample was purchased from the local market, washed, cut into pieces, and oven-dried at 110 °C for an hour. Carbonization was done without oxygen at 300 °C for 1 h. Prepared charcoal was dried at 110 °C and ground to 100–200 mesh size. The sample was chemically activated using a 1 N aqueous solution of $ZnCl_2$ in the ratio of 1:5 ($ZnCl_2$:C) for 12 h. Prepared AC was turned into a paste and again carbonized at 300 °C.

Castor seeds: Ferreira et al. (2020) produced and characterized the adsorption performance of AC made from castor seeds. A laboratory press was used to convert grains into the cake. The dried cake sample was impregnated with 40% phosphoric acid in the ratio of 2:1 in favor of castor seed cake. The obtained cake was dried at 105 °C after resting for some time. The dried material was carbonized at 800 °C for 1 h. Kim (2004) used waste peach stones to produce granular activated carbon. The sample was crushed to 1.41–0.25 mm size. AC was formed by impregnating H_3PO_4 at 500 °C for 1.5 h.

Miscellaneous: Marichelvam and Azhagurajan (2018) attempted to adsorb one of the most hazardous materials, mercury, using AC made from the banana corm and neem leaves. Banana corm was cut dried at room temperature for a week and then under 106 °C for 16 h in a hot air oven. On the other hand, neem leaves were dried at 90 °C for 3 h. The sample was activated using phosphoric acid in the ratio of 2:1 and heated at 260 °C for 30 min. AC was then washed with distilled water and dried.

9.7 Conclusion

Like any other adsorbent, biomass AC finds various applications in the food processing, petroleum, pharmaceutical, and automobile industry. It is also used to remove pollutants and dyes from wastewater treatment plants. One of the significant advantages of AC derived from biomass is using waste material to synthesize something beneficial. Since biomass has low inorganic ash content, the production of AC is relatively environment friendly over AC from other raw materials. Conventionally, AC has been synthesized from coconut shells, coal, lignite wood, and animal bone. Still, due to the unavailability of these raw materials in some places, other biomass is used, which has shown remarkable results in quality and sustainability. Nowadays, agricultural wastes like rice straw, shells of almonds, hazelnut, olive pits, pistachio hull, corncob, banana corn, and many other by-products are used to produce AC.

It can be concluded that the use of biomass for the preparation of activated carbons is a cheap and straightforward way and that can be employed for adsorption of active industrial compounds such as organic, inorganic, and heavy metal. Further, activated carbon can be a good candidate as an electrode material for energy storage technologies. A detailed cost estimation (production, operation, and maintenance) would be beneficial to highlight the cost-effectiveness of the AC prepared from biomass.

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