Renewable and Sustainable Energy Reviews 87 (2018) 1–21

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

A review on utilization of wood biomass as a sustainable precursor for activated carbon production and application

Mohammed Danish[a,*], Tanweer Ahmad[b]

[a] Universiti Kuala Lumpur Malaysian Institute of Chemical and Bio-Engineering and Technology, Lot 1988, Taboh Naning, Alor Gajah 78000, Melaka, Malayasia
[b] Department of Chemistry, School of Natural Science, Madda Walabu University, Bale, Robe, Ethiopia

A R T I C L E I N F O

Keywords:
Activated carbon
Wood biomass
Adsorbent
Adsorption
Pollutant

A B S T R A C T

Activated carbon has been an ideal material for the separation of a variety of chemical pollutants. Its extensive use is limited due to the cost of production, which has triggered the researches on the viable option for the non-conventional and cost-effective production. The application of biomass waste has been widely explored as an alternative to expensive methods of activated carbon production from coal. In this study, detailed list of production methods of activated carbon from wood biomass is presented systematically. The attempt has also been made to review the physical properties, such as ultimate and proximate analyses of wood biomass material. Further, the chemical compositions of wood, such as hemicelluloses, cellulose, and lignin are also dealt with. Finally, this review incorporates the existing research papers on wood-derived activated carbons to understand the influence of pyrolysis temperature, activation temperature, and effect of various physical and chemical activation conditions on the production, surface characteristics and adsorption behavior of activated carbons. The outcome of this study revealed that the activated carbons from wood biomass exhibit promising characteristics in terms of surface area, pore size and pore volume, surface functional groups, and surface entrapment behavior against various water soluble chemical toxicants.

1. Introduction

Water is an essential constituent of the planet earth, which plays a very important role in the proper performance of the earth's ecosystem. Getting potable and pristine water is now a challenging task in different parts of the world. The geometrical growth of world population, house hold and agricultural activities, burgeoning industrialization, modern technocratic civilization, and other geological, environmental and global changes, causes a gradual increase in water pollution. Recently, various toxic chemicals such as micro-pollutants, endocrine disrupting phthalates compounds, personal care products, pesticides, and inorganic anions have been found at dangerous levels in drinking waters throughout the world. Therefore, various types of health issues in human beings are reported owing to water pollution [1]. Contaminated water is one of the most challenging issues because it is a huge threat to both human health and the existence of symbiotic relationship between human and environment [2]. Keeping in view the seriousness of the water contamination caused by the high concentration of noxious compounds. There is an urgent need for developing a robust, economically viable and environmentally friendly treatment to eliminate them from water. To safeguard the human health and restore the environmental symbiosis.

It is necessary to purify water and keep our environment clean, which requires an innovative new technique for the creation of highly effective adsorbents and efficient filtration media [3,4]. On an industrial scale, water and wastewater treatment technologies have been evolved in the past years for the removal of diverse aquatic pollutants. The water purification concepts discovered thus far, include filtration, ultra-filtration and dialysis [5], reverse osmosis, solvent extraction [6], advance oxidation [7], evaporation, coagulation, flocculation [8], aerobic and anaerobic treatment, activated sludge, microbial reduction [9], adsorption [10], ion exchange, and magnetic separation [11]. Adsorption is a familiar separation technique known since the earlier history of science and considers as an efficient and user-friendly method

Abbreviations: BET, Brunner Emmet and Teller; AC, Activated Carbon; IUPAC, International Unions of Pure and Applied Chemistry; FTIR, Fourier Transform Infrared Spectroscopy; XPS, X-ray Photoelectron Spectroscopy; pHzpc, pH at zero point charge; FESEM, Field Emission Electron Microscopy; EDX/EDS, Energy dispersive x-ray spectroscopy; CHNS, Carbon hydrogen nitrogen and sulfur analysis; PET, Polyethylene Terephthalate; SAC, Steam Activated Carbon; CSAC, Chemical followed by Steam Activated Carbon; CC, Commercial activated Carbon; CAC, Chemically Activated Carbon; EDTA, Ethylene diamine tetraacetica acid; SDAC, Saw Dust Activated Carbon; COD, Chemical Oxygen Demand; SMX, Sulfamethoxazole; D-R, Dubinin-Raduskevich

* Correspondence to: Malaysian Institute of Chemical and Bioengineering Technology (MICET), Universiti Kuala Lumpur, Lot 1988, Alor Gajah 78000, Melaka, Malaysia.
E-mail addresses: mdanish@unikl.edu.my, mdanishchem@gmail.com (M. Danish).

https://doi.org/10.1016/j.rser.2018.02.003
Received 4 April 2017; Received in revised form 28 October 2017; Accepted 6 February 2018
1364-0321/

for the elimination of a wide range of toxic pollutants from wastewater [12–14]. It has been found to be a better method than others for wastewater treatment in terms of simplicity of design, initial cost, ease of operation, and sensitivity towards noxious pollutants.

Activated carbon is a term used to express carbon-rich materials which contain well-built internal pore structure. The high surface area, well-organized macro, meso, and micro-pores, and a wide range of chemical functional groups present on the surface of activated carbon make it a versatile material which has numerous applications. Activated carbons have been globally recognized as the oldest, widely used and most popular adsorbent in water and wastewater treatment industries [15]. It has been used as a versatile adsorbent against a wide range of water-soluble and gaseous pollutants. Their extensive use as an adsorbent encompasses removal of undesirable taste, odor, color, and other inorganic and organic impurities from industrial and municipal wastewater, solvent recovery, and air pollution control from inhabited places. They are increasingly used in the field of the pharmaceutical industry for the removal of color from syrups; for the removal of ingested toxins from the human body; for the bacterial infections in certain ailments; for the recovery of gold, silver, and other metals in hydrometallurgy industries; and as catalysts and catalyst supports. They are also renowned for their applications in the gas mask filter manufacturing industry, food processing industries, chemical industries, and automobile pollution control devices [16].

Despite its enormous industrial applications, the biggest hurdle in the frequent use of activated carbons in the industries is the cost of production and vague methods associated with production and regeneration processes [17]. At the beginning of the development of activated carbons, coal was believed to be an affluent source of carbon; therefore, it was considered as the best precursor material for the conversion of activated carbon with large surface area. Coal mines are limited and non-renewable. Therefore, the paradigm shifted towards renewable resources, such as biomass or any carbon-rich waste for activated carbon production. All natural resources that can be grown through the agricultural activities in short rotation of cultivation period considered as the renewable resources. And most of the agricultural waste biomasses contain chemical constituents that have a high carbon content, which make them suitable precursor for activated carbon production.

Utilization of biomass to produce activated carbon is a wise approach in pollution control strategy in two ways. First, it can fix the carbon of biomass that prevents the production of CO_2 or CH_4; and second, it produces activated carbon which is industrially useful and environmentally benign materials that can go into the soil and enter natural carbon cycle process. Conversion of wood wastes into valuable carbon material can also resolve environmental issues like an accumulation of agricultural waste, which causes air and water pollution during natural degradation process [18]. Availability of low-cost by-products from biomass production and processing industry has proven to be a potential raw material for the synthesis of activated carbons [19]. Some attempts have been made to identify cost-effective methods and precursors to produce activated carbon. The list of precursor materials from agricultural biomass sources to produce low-cost activated carbon is presented in Table 1.

This review presents the discussion on the utility of different wood species biomass as a precursor to produce activated carbon. The specific objectives of this review article is as follows: (1) identify the chemical and elemental composition of wood species, (2) discuss the preparation methods for wood-derived activated carbons, (3) address the effects of activating agents, concentration, time and temperature on different wood species-derived activated carbons, (4) discuss the changes observed in physical and chemical properties of the wood-derived activated carbons as a result of different activation conditions, (5) summarize the contemporary research development in potential applications of the wood-derived activated carbons as an adsorbent for the removal of various organic and inorganic pollutants.

Table 1
List of precursor materials from different agricultural source for the production of low-cost activated carbon.

Adsorbents	References
Cassava peel	[20]
Jatropha curcas fruit shell	[21]
Spent coffee ground	[22]
Olive seeds	[23–25]
Rice husk	[26]
Corn cob	[27]
Coconut shell	[28,29]
Pecan shell	[30,31]
Rice straw	[32,33]
Macadamia nutshell	[34]
Fruit stones & nutshell (hazelnut shells, peanut hulls)	[35]
Apricot stones	[36]
Almond shell	[37,38]
Grain of sorgum	[39]
Cedar wood	[40,41]
Date stone	[12,13,42]
Acacia mangium wood	[43]
Pomegranate seeds	[44]
Neem leaves	[45]
Palm oil shell waste	[46,47]
Wheat straw	[48]
Rice husk ash	[49]
Coconut coir dust	[50]
Natural condensed tannin	[51]
Vetiver roots	[52]

1.1. Wood as a sustainable biomass and its chemical composition

Wood biomass can be produced in short rotation, and it can be utilized as a sustainable precursor for the production of activates carbon. Conversion of wood biomass into activated carbon not only makes it a more versatile material for industrial application but also curb the formation of CO_2 and methane (form due to aerobic and anaerobic digestions), which are a major greenhouse gas. Lignocellulosic chemicals are the primary constituents of the wood biomass. The well-structured fibrous constituents of wood have a significant contribution in the preparation of granular activated carbons. Cellulose contains partially crystalline linear polysaccharide units that have around 3000 glucose units in a chain. Cellulose and hemicellulose units are quite similar to each other, but the only difference is in the quantity of saccharide units. Hemicellulose consists of a smaller number of saccharide units compared to cellulose. The average elemental percentage in hemicellulose are as follows: carbon, 44.4 wt%, oxygen, 49.4 wt%, and hydrogen, 6.2 wt%. The lignin part of wood biomass has very complex molecular arrangements. The 3-D polymeric arrangement of phenylpropane units in lignin are linked together by C–O–C or C–C bonds. These kinds of chemical bonding in lignin gives higher carbon percent (62 wt%) and lower oxygen percent (32 wt%) in the molecules. The C–O–C and C–C bonds not only connect to the phenylpropane units but also associate with the hemicellulose and cellulose units. Thus, lignin unit of the wood serves as a binding material for the lignocellulosic structure [53]. The major chemical constituents of wood biomass are hemicellulose, cellulose, and lignin; and minor chemical components are protein and oil. On an average, the quantitative proportion of hemicellulose, cellulose, and lignin in wood biomass are observed in the range of 20–35, 40–50, and 15–35%, respectively. During pyrolysis of lignocellulosic biomass, the decomposition of hemicelluloses is reported in the temperature range of 200–260 °C, followed by the decomposition of cellulose in the temperature range of 240–350 °C, and lignin degraded in the temperature range of 280–500 °C. The loss of mass in the temperature range of 240–400 °C is primarily owing to chain scission and mineralization of lignin and cellulosic units by breaking C-C and C-O bonds within glycopyranose ring with the evaporation of water, CO, and CO_2 molecules [54]. The