

Production and Characterization of Coconut Shell-Based Activated Carbon for Valorization of Municipal Wastewater

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Abstract— Due to the acute shortage of hygienic water supply in the rural communities and clamour for environmental sustainability, disposable coconut shells were converted to activated carbon by oxygen limited carbonization and acid activation methods. The produced activated carbon was characterized by SEM, BET, and FTIR techniques for its morphology, textural properties and active functional groups, as criteria for water treatment. The characterization has proved that the activated carbon has distributed pores on its surface, possessed functionalized surface with hydroxyl (-OH), carbonyl (C=O) and aromatic group (-C-H), and largely mesoporous in nature (2.421nm) with relatively high specific surface area (363.063 m²/g). In view of the relatively large surface area, porosity and presence of active functional groups on the activated carbon, it can be deduced that it is suitable for valorization of polluted water.

Keywords— Activated Carbon; Adsorption; Contaminants; Sustainability; Valorization; Wastewater.

I. INTRODUCTION

Water is the most abundant natural resources that covers 70% of the Earth's surface, but has insignificant proportion of usage value (only 0.7%) due to quality requirements. Human activities involving agricultural and manufacturing contribute to the emerging contaminants that possess threat to the natural environment and the inhabitants, when wastewater is discharged without remediation [1]. To meet up with the demand of quality and sufficient water, it is imperative to remove the contaminants in the wastewater and reuse [2]. The valorization of wastewater through any possible cost effective and adaptable technology is desirable to address the challenge of wastewater, which is a pivot of achieving Sustainable Development Goal 6 (clean water and sanitation) [3]. In view of limitations of conventional wastewater treatment methods such as biological approach and advanced oxidation, adsorption technology is an option for efficient wastewater remediation, cost effective and adaptable approach [4]. The removal of specific contaminants from the liquid or gas phase by adhesion on solid phase, which leads to reduction in the concentration of the contaminant in aqueous media, is called adsorption process [5]. Among the factors that determine the performance of potent adsorbent include contact time, pH, specific surface area and inertness. Coupled with the forces of attraction (van der Waals), the interaction of these factors determine the effectiveness of an adsorbent for wastewater valorization [6][7]. Conventional activated carbon, as adsorbent, is not economical and eco-friendly due to generation of secondary pollutants after its use. Exploration of various low-value materials for adsorbent development, especially agricultural by-products is welcome due to their

low cost, ease of processing, high tendency of removal of contaminants from the aqueous media, and sustainability [2][6]. Agricultural wastes such as wood, bamboo and coconut shells and husks are commonly used for the production of activated carbon. Coconut shells are particularly suitable, due to their high micropores content, low ash content, high fixed carbon fraction, high water solubility and excellent adsorption characteristic [8][7] [9-10]. Intarapong *et al.* [11] reported that biochar derived from coconut residues exhibit favourable textural properties and surface chemistry for adsorption applications. Activated carbon is primarily produced by carbonization and chemical activation processes to modify the precursor material. The essence of modification is to enhance its surface area and porosity, as well as to introduce functional groups, which aid the removal of targeted contaminants or for chemical reactivity [12-14]. Though, several researches have been conducted on agricultural wastes, but the utilization of these materials to develop activated carbon for purification of water and valorization of wastes is a continuous process in a circular economy framework. Especially, the production of low-cost activated carbon with high surface area, mesoporous in nature, that offers a sustainable alternative for wastewater treatment [15]. In this regard, this study focused on the synthesis and characterization of coconut shell –based activated carbon for municipal wastewater treatment. The expected outcome of the research is to produce activated carbon with relatively high surface area and internal porosity, with oxygenated functional groups for adequate removal of targeted contaminants in municipal wastewater.

II. MATERIALS AND METHODS

Materials

Coconut shells were obtained from coconut vendors in the Nasarawa main market in Nasarawa Local Government Area, Nasarawa State. Tetroxosulphate (VI) acid and distilled water were supplied by Sigma Aldrich Chemicals at analytical grade.

Preparation of Coconut Shell-Based Activated Carbon

Coconut shells were sorted and washed severally with distilled water, dried in an oven at 105°C for 24h and then crushed and sieved using 0.3mm-mesh and stored in an airtight container. It was then carbonized at 600°C for 1h to obtain biochar and cooled down at room temperature. Two hundred grams of the obtained char was impregnated with 100mL tetraoxosulphate (IV) acid (6M) and the mixture was stirred under reflux for 5h. Thereafter, the functionalize adsorbent was washed and filtered severally until a neutral pH was obtained. The sieved powder was stored in a desiccator for subsequent analyses [16].

Characterization of the Coconut-based Activated Carbon

The Fourier transition infrared spectroscopy (FTIR) analysis was conducted using Spectrum 65 FT-IR (Perkin Elmer) in the wave number range of 4000 - 400 cm⁻¹ using KBr pellets, with a resolution of 4 cm⁻¹ at 20 scans. The synthesized activated carbon was coated with a thin layer of carbon and the surface morphology was analysed using scanning electron microscope (SEM) and irradiated with a beam of electrons of 20kV. Analysis of specific surface area and pore size for the activated carbon was performed by determining the volume of N₂ adsorbed at various relative pressures at 77K, in the BET analyser.

III. RESULTS AND DISCUSSION

The morphology, surface functional groups, specific surface area and pore volume of coconut-based activated carbon was determined using SEM, FTIR and BET/BJH, respectively.

Nitrogen-Adsorption-Desorption Analysis

With the influence of specific surface area on the mechanism of adsorption, N₂ adsorption-desorption data were used to assess the textural properties of the coconut –based activated carbon. The results of textural properties for the coconut-based activated carbon are summarized in Table 1.

The BET specific area and specific volume of the prepared coconut-based activated carbon was 363.063 m²/g and 0.217cc/g, respectively. Ejimadu *et al.* [17] reported values of specific surface area and pore volume for coconut-based activated carbon as 320.70 m²/g and 0.10cc/g, respectively.

Prawiranti and Mandasari [18] also reported specific surface area of 345.57 m²/g for coconut-based activated carbon for gas purification. The variation in values could be attributed to the fixed carbon content and possibly collapse of pore structure at higher pyrolysis temperature as a result of volatilization of organic material and intense carbonization [17][19]. The results show that coconut-based activated carbon is mesoporous (2.421nm). Mesoporous structure avails optimum pore size that can facilitate the adsorption of organic species on the adsorbent's surface. The range for mesoporous adsorbents is between 2 and 50nm [20-21]. These tiny low-volume pores are what give the activated carbon its larger surface area. The larger the surface area, the more sites and more contaminants in the water attach to the sites [22][19].

TABLE 1: N₂- adsorption-desorption isotherm data of the coconut-based activated carbon

Parameter	Value
^a BET Specific Surface Area(m ² /g)	363.063
^b BJH Pore Volume(cc/g)	0.217
^b Pore Diameter(nm)	2.421
^c Micropore Volume(cc/g)	0.165
^c Micropore Specific Area	463.576

a-Determined by BET method, b- Determined by BJH method, c-Determined by DR

Fourier Transition Infrared Spectroscopy (FTIR) Analysis

The FTIR spectrum of the coconut-based activated carbon and its main identified absorption bands are presented Fig. 1 and Table 2, respectively.

The range of absorption bands detected in the spectrum of the activated carbon starts from 530.24 to 3689.97 cm⁻¹, which reveal the bond characteristics inherent in it. The surface functional groups present in the sample that drive adsorption of organic and inorganic contaminants include hydroxyl, carbonyl and aliphatic C-H groups. The oxygen-linked functional groups serve as depositional locations for adsorption of contaminants in aqueous media [28][24]. Hydroxyl and carbonyl groups are significant for adsorption due to their ability to form hydrogen bonds and interact with polar molecules. Aromatic group equally enhance the surface area and provide additional sites for adsorption [23][26]. The hydroxyl groups(-OH) in alcohol, phenol and carboxylic acid are responsible for the adsorption peaks at 3689.97 cm⁻¹-3619.6 cm⁻¹. The bands detected at 800-700 cm⁻¹ correspond to C-H out-of-plane bending of aromatic compound, those between 1200 cm⁻¹-1000 cm⁻¹ are due to C-O stretching vibrations on the ester, alcohol, ether and carboxylic acid. The bands detected at 400-700 cm⁻¹ are assigned to the aromatic C-H group of the hydrocarbon [25][29][30][24][27].

TABLE 2. Main bands identified in FTIR spectra of the investigated coconut-based activated carbon and its possible assignments

Band wave number (cm ⁻¹)	Assignment	Literature	References
3689.97, 3619.61	OH group stretching	3751.60-3396.91	Rahimi <i>et al.</i> [23]
1028.30, 1004.06	C-O bending of alcohol, ether and caboxylic acid	1200-1000	Daudi <i>et al.</i> [24] Rampe <i>et al.</i> [25]
910.80	Aliphatic C-H out-of- plane bending	900-800	Harriet <i>et al.</i> [26]
788.41, 749.74	C-H out-of-plane bending of aromatic compound	800-700	Hashem <i>et al.</i> [28]
680.86, 530.24	C-H group of hydrocarbon	700-400	Harriet <i>et al.</i> [26] Rampe <i>et al.</i> [25]

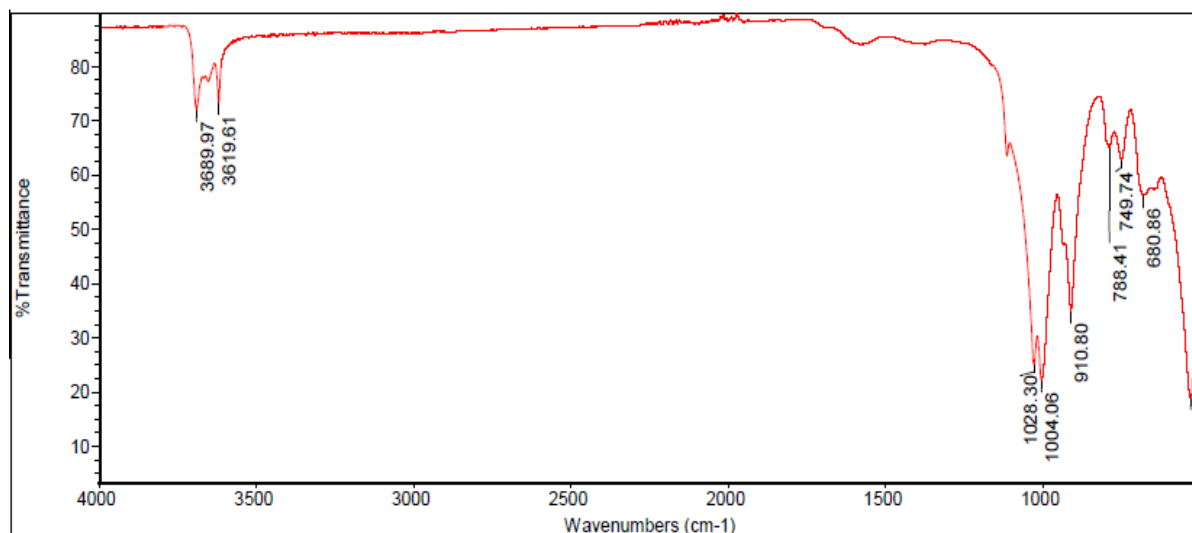


Fig. 1. FTIR spectra of the coconut-based activated carbon

Scanning Electron Microscopy (SEM) Analysis

The microstructure and surface morphology of the coconut-based activated carbon were visualized by SEM technique, as shown in Fig. 2. The SEM image revealed a well-organized hierarchical pore structure, at 1500 times magnification. The emergence of mesopores was observed, and micropores, with uneven distribution. The mesopores serve as transitional diffusion pathways, while the micropores provide a high surface area that facilitates the efficient remediation of organically polluted water [31-32][18]. These pores provide ample active sites for contaminants to adsorb onto the adsorbent, thereby influencing the adsorption process [33-34]. Generally, the surface appears rough, irregular, fractured and angular, which creates a massive contact area for trapping impurities. The aforesaid surface appearance of the sample would exposed its active sites for adsorption to take place perfectly [28][35].

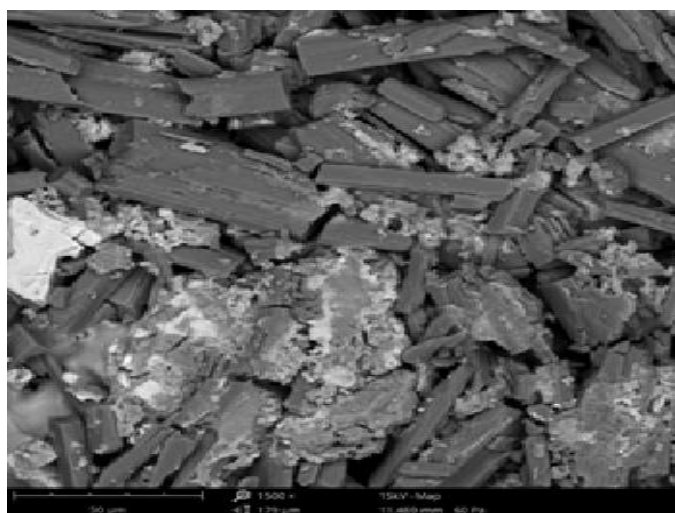


Fig. 2. SEM micrographs for coconut-based activated carbon

IV. CONCLUSION

Coconut shell-based activated carbon was produced by carbonization at 600°C and chemical activation using 6M tetraoxosulphate (VI) acid. The produced activated carbon was characterized for its morphology, surface functional groups and textural properties using SEM, FTIR and BET/BJH, respectively. The results of the characterization proved that the activated carbon has distributed pores (micro- and mesopore) on its surface, and possessed functionalized surface with hydroxyl, carbonyl and aromatic groups. Based on the relative high specific surface areas and surface chemistry of the activated carbon, it could be used in the treatment of wastewater. However, performance test is recommended for sorption of contaminants in domestic wastewater, to prove the potency of the produced activated carbon.

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