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Production and Characterization of Activated Carbon from Coconut Shell for Water Treatment

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ABSTRACT

In this research, activated carbon was produced from coconut shells using a chemical activation method. The material was characterized through Scanning Electron Microscopy (SEM) and Fourier Transform Infrared (FTIR) spectroscopy. Key physiochemical properties were measured, including a pH of 6.80, moisture content of 5.50%, carbon content of 56.80%, ash content of 6.80%, pore volume of 0.45 cm³/g, and porosity of 0.5 cm³/g. Turbidity levels were recorded at 45.00, 31.00, and 22.00 NTU. The activated carbon served as an adsorbent for wastewater treatment, effectively reducing turbidity. This study demonstrated that activated carbon is an effective adsorbent for turbidity removal in wastewater treatment. The morphological structure was examined using SEM, while FTIR analysis revealed significant absorption spectra linked to O-H stretching vibrations of alcohol and phenol functional groups, a higher concentration of conjugated C=C bonds, and C-C bonds within the aromatic ring.

Keywords: Activated Carbon, Characterization, Coconut shells, Application

INTRODUCTION

Activated carbon, often referred to as activated charcoal, is a highly porous form of carbon characterized by a large surface area. It is commonly used for the adsorption of various substances, as noted by several researchers (Yahya et al., 2015). Activated carbon can also be described as a tasteless, solid, microcrystalline, and nongraphitic black carbon material with a highly porous structure (Ravichandran et al., 2018). This material is a class of black carbonaceous porous substances created through the carbonization of materials rich in elemental carbon.

Advancements in activation methods—both chemical (using agents like phosphoric acid or potassium hydroxide) and physical (using steam or CO_2)—have enhanced the porosity and adsorption capacity of activated carbons. This has positioned coconut shell-based activated carbon as a strong competitor to traditional sources (Chen et al., 2017). Known for its high surface area and pore volume, coconut shell-based activated carbon is particularly effective for adsorption processes.

FORMS OF ACTIVATED CARBON

Activated carbon comes in forms of:

a) Powdered activated carbon (PAC) is a finely ground material, with most particles measuring less than 0.18 mm in diameter (80 mesh). In water treatment, PAC can be added directly to the water or passed through a granular activated carbon (GAC) bed. It is utilized in water treatment facilities to manage taste and odor, as well as to remove organic compounds. PAC can be applied either as a dry powder or in slurry form. The dry powder is typically used for low-dose and infrequent applications, while the slurry is delivered using metering pumps for more frequent and higher-dose needs.

b) Granular Activated Carbon (GAC) has an irregular shape and a typical diameter of 0.2 to 1.5 mm. GAC is mainly used as final filtration, after a conventional filtration process or inside a granular media filter, where part of the filter bed is replaced by GAC. In the final filtration configuration, the GAC filter receives high quality water because the water has already passed through the entire purification process.

c) Extruded activated carbons (EAC) are oval granular products with sizes ranging from 1 mm to 5 mm. They are mainly used in gas phase applications due to their low pressure drop, high mechanical strength and low dust content.

Figure 1: Activated carbon powder, granules and pellet

BENEFITS OF ACTIVATED CARBON FOR WATER TREATMENT

Activated carbon is one of the most widely used adsorbents in the world for water treatment. A useful aspect of activated carbon is that it can filter contaminants from water and air, making it an important substance in the filtration system. It is a porous carbon material that has a microcrystalline, non-graphitic form that has been treated to increase its internal porosity. Once activated, the carbon has an internal porosity comparable to a network of tunnels branching into smaller channels. Thus, activated carbons are carbon materials that qualify due to their high surface area and highly developed porous structure. Many developed countries use activated carbon technology for drinking water treatment to improve coagulation, flocculation, decantation, filtration, and disinfection of water to remove organic contaminants, due to its high adsorption capacity. Activated carbon is an effective adsorbent because it is a highly porous material and provides a long surface area for contaminants to adsorb. In fact, activated carbon is a powerful adsorbent commonly used in water purification to remove contaminants and unwanted components. Although activated carbon can be used in a wide range of water treatment applications, it is a critical tool used in all municipal and industrial water treatment plants for the treatment of drinking water, wastewater, and process water.

METHODS

Coconuts were obtained from Otefe-Oghara market, Delta State, Nigeria and cracked to separate the shells from the seeds. Coconut shells (CS) were washed with distilled water to remove dirt and impurities. The washed CS was dried in an oven to remove traces of water. Chemical activation was applied. Before carbonization, the raw material was impregnated with $CaCl_2$ and H_3PO_4 acids as activating agents to improve the pore size of the activated carbon, which would translate into increased adsorption capacity. After impregnation, CS was transferred to a Muffler oven at a temperature (450-9000C) for about 2-3 hours, which resulted in the formation of coconut shell charcoal. The charcoal was left to stand for 1 hour at room temperature. After washing, the samples were crushed into pieces of different sizes using a mortar and pestle. The materials were mechanically sieved to produce three sizes of activated carbon: powdered (0.7 mm), granular, and pelleted (0.51 mm). A solution was prepared by dissolving 100 grams of CaCl2 in 300 milliliters of distilled water. Charcoal was then added to this solution and kept in the dark for 24 hours to allow for the separation of carbon from impurities. After the impurities were removed, the carbon was dried in an oven for 7 to 8 hours and subsequently crushed to create Crystalline Activated Carbon (CA). The samples underwent chemical activation and were dried at 150°C for approximately 1 hour before being placed in a 40 cm by 3.6 cm adsorption column. The activated carbon was layered in the column, with each of the three sizes filling 15 cm and 100 ml of volume.

Turbidity Determination

The adsorption process was carried out using an adsorption column of length 40cm and diameter 3.6cm. The volume of the column was 500ml. The activated carbon was made into three sizes (powdered, granular, and pelleted), and was poured into the adsorption column to form three layers, each occupying 15.0cm length of the column and 100ml volume of the column. The activated carbon was poured in such a way that the powdered layer forms the top, followed by the larger sized carbon (granular size), while the largest size (pelleted size) forms the base of the column. Three fish pond water samples were made available for adsorption process, the influent (initial turbidity of the sample) was measured using the turbidity meter, after which the sample was poured into the adsorption column using a perforated plastic plate to ensure an even distribution of the sample in the column. Adsorption took place and the emerging sample coming out of the base of the column, which is now the effluent, was collected and tested for its turbidity.

Characterization of Physicochemical properties of prepared activated carbon (Coconut shell)

The pH was measured with a pH meter. To determine moisture content, samples were weighed and then dried in an oven at 110°C for three hours until they reached a constant weight. The percentage of moisture content was subsequently calculated.

The volatile matter percentage of the activated carbon (AC) sample was assessed using the standard method (ASTM D5832-98, 2004), while the ash content was measured following the ASTM D2866-11, 2004 method.

The bulk density of the AC was determined using a measuring cylinder. The iodine number was measured according to the ASTM D4607-94, 2006 method.

Porosity, defined as the ratio of total void spaces within a solid porous material to its bulk volume (Hassan et al., 2015), was evaluated in this study.

The surface functional groups and morphology of the carbonized and activated coconut shell (CS) were analyzed using Fourier Transform Infrared Spectroscopy (FT-IR) and Scanning Electron Microscopy (SEM).

RESULTS AND DISCUSSION

Table1: Physicochemical Properties of Coconut Shell Activated Carbon (CS/AC)

Properties	
PH	6.80
Pore Volume	0.45
Porosity (cm^3/g)	0.75
Moisture content (%)	5.50
Ash content (%)	6.80
Carbon content (%)	56.80

pH value obtained in this research work is 6.5 which is slightly acidic ad this can influence adsorption capacity and performance of the CS-AC.

The pore volume measured was 0.75 cm^3/g, closely aligning with the findings of Nyamfulet et al. (2020). Pore volume indicates the total volume of pores within the material, which is essential for high adsorption capacity. Porosity, defined as the presence of pores and voids in the material, was found to be 0.45 cm^3/g, further influencing adsorption capacity.

The moisture content was recorded at 5.5%, which is consistent with the work of Nyamfulet et al. (2020). These results suggest that CS-CA is a more effective adsorbent.

Ash content, which represents the inorganic residue left after combustion, affects both adsorption capacity and performance. The ash content for CS-AC was noted to be 6.8%, in agreement with the findings of Sanni et al. (2017).

According to Ikelle and Ivoms (2014), carbon content reflects the removal of volatile matter. The measured carbon content was 56.80%, indicating a high level of carbon that enhances effective adsorption and influences surface area, pore structure, and reactivity.

Table 2: Results of Turbidity Determination

Sites	Parameters Turbidity (NTU)	Parameters Turbidity (NTU)
	IT	AAC
FPW 1	95.00	45.00
FPW 2	88.00	31.00
FPW 3	62.00	22.00

FPW= Fish Pond Water, IT=Initial Turbidity AAC=After Activated Carbon

SEM Analysis

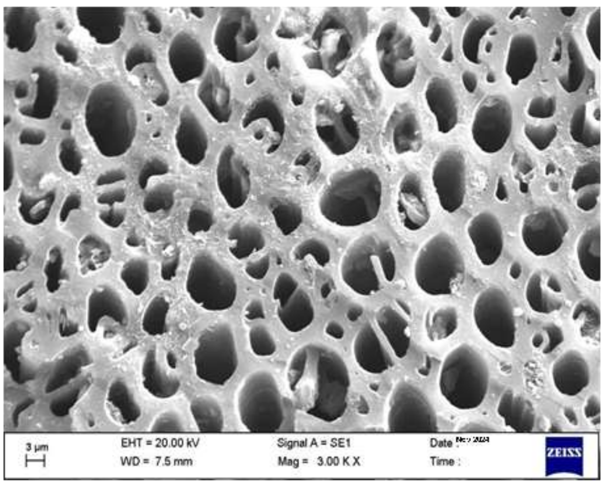

Fig 2: SEM micrograph Activated carbon

FT-IR Analysis

In this study, Field Emission Scanning Electron Microscopy (SEM) was employed to examine the surface morphology of activated carbon samples. Figure 2 illustrates the detailed surface features, revealing numerous large pores on the activated carbon's surface. A closer inspection of Figure 2 indicates that these pores are particularly prominent, a result of the higher ratios of calcium chloride used during the activation process.

The SEM images show that the presence of these pores is linked to the calcium chloride, which was burned with the raw material during carbonization. The unburned residue was subsequently removed during washing. Calcium chloride serves as a dehydrating agent, facilitating the formation of larger pores by promoting the removal of volatile compounds and the breakdown of carbonaceous material, ultimately leading to a well-developed porous network.

However, the images also reveal significant material debris within these pores, suggesting that some unreacted residues or by-products from the activation process remain. This debris may stem from incomplete combustion or residual precursor material that was not fully converted during activation.

The SEM analysis not only highlights the surface porosity but also offers insights into the activation process's effectiveness. By examining the surface morphology and pore structure, as well as identifying any residues or non-activated areas through SEM imaging, we can assess the activation process's efficiency and the thoroughness of material removal. This information is vital for optimizing the activation process, ensuring that the activated carbon performs optimally in various applications such as adsorption, catalysis, water treatment, and filtration. Calcium chloride enhances the chemical reactions that open pores in the carbon structure, thereby increasing the volume of fine pores and, consequently, the surface area of the activated carbon.

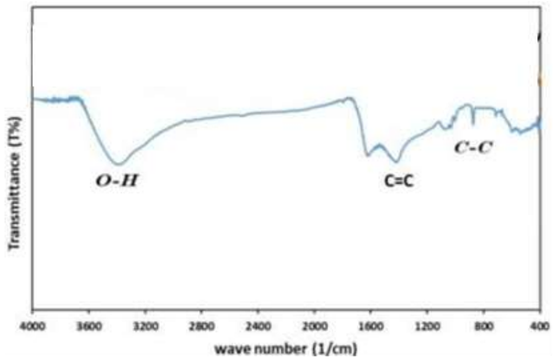

Figure 5: FT-IR spectra of activated carbon from CS/ AC

CONCLUSIONS

The research findings indicate that waste coconut shells can be effectively transformed into pure activated carbon for wastewater treatment. Scanning Electron Microscopy (SEM) results revealed significant changes in the pore structure and surface area of the produced activated carbon. Additionally, Fourier Transform Infrared Spectroscopy (FT-IR) results demonstrated an increase in conjugated carbon-carbon double bonds (C=C), suggesting an expansion in surface area and the formation of pores. The activated carbon generated through this process exhibited impressive properties, including water purification and adsorption capabilities.

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