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Research Article

Evaluation of the Physical Properties of Various Biomass Materials for the Production of Activated Carbon

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Abstract

This study aims to produce activated carbon (AC) from different biomass sources using chemical activation; characterize the AC using Fourier Transform Infrared (FTIR) Spectroscopy, Scanning Electron Microscopy (SEM), proximate and ultimate analysis; and compare the results from the AC produced. The biomass blends of rice husk & groundnut shell (RH-GS), cocoa nut shell & saw dust (CS-SD) and sugar cane bagasse & banana peel (SB-BP) were used for the preparation of AC. The samples were first characterized using proximate and ultimate analysis, SEM, and FTIR spectroscopy. The results of the BG-SD sample characterization showed that the blend produced the best results in terms of adsorptive capacity. It is suggested that surface area difficulties with the ACs be investigated in order to improve their porosity and adsorption capacities.

Keywords: Activated carbon, Carbonization, Biomass sources, Waste characterization, Chemical activation, SEM analysis, FTIR Spectroscopy

1. Introduction

Carbon atoms bound by structural disorder and discontinuity that permit porosity are known as activated carbons (ACs) [1]. Besides, surface functionality as well as porosity might affect how specific an AC is [2]. On a global level, AC usage and prospective applications are constantly growing. Many resources, including coal and lignocellulose biomaterials containing carbon, including industrial waste fractions (such as bark and sawdust), can be used as raw materials to create ACs [3]. The basic materials are transformed through a thermochemical process to produce materials with a lot of carbon. Moreover, by adding activating agents during chemical or physical activation, carbon compounds can be further transformed into ACs [4]. Specific surface area (SSA), porous volume (PV), and porous size distribution (PSD), among other AC features, are dependent on a number of factors, including the raw material, the activation technique, and the process variables applied during the carbonization and activation processes [5].

Biodegradable materials, biologically derived wastes, and residues from agriculture, forestry, and aquaculture are used to create biomass. A variety of raw materials, such as wood, agricultural crops, waste from the processing of wood, manure, and the organic portion of waste products are used to create biomass. When used with variable loads and applications at the location and time of energy need, biomass offers the advantages of being conveniently stored, transported, and used

as a renewable energy source. This distinguishes biomass from other sources of renewable energy even though they can also be nonrenewable. Biomass resources currently available for producing energy can be classified into woody biomass, agricultural sources, and bio wastes [6].

Demand for AC has been steadily rising ever since Raphael von Ostrejko, known as the "father of activated carbon," got it for the first time in 1900 [7]. Market for AC is anticipated to develop at a compound yearly growth rate of 6.31% from 2019 to 2024 [8]. In addition to air and gas filtration, AC is now the method of choice for treating wastewater, aquariums, swimming pools, and potable water [9]. Because of rising environmental contamination, growing health issues, and strict governmental laws, these applications are the most crucial. Besides from that, AC is employed in the pharmaceutical sector to purify vitamins, antibiotics, and other substances as well as the food sector to decolonize and deodorize food and drinks [10]. The monitoring of gas emissions in automobiles, personal safety in the military industry, the recovery of resources like gold and precious metals, and as a catalyst in the removal of mercaptans in oil refineries are some further uses for AC [11]. In electrochemistry, where capacitors and Li-ion batteries are made and used for energy storage, ACs are also growing in popularity [12]. Due to a lack of resources and growing supply chain worries, the AC industry is currently experiencing price problems. Yet, the market is expanding as a result of AC's widespread use in applications for the liquid and gas phases [13].

Thus, the AC industry eventually had to look for less expensive alternative precursors that would still meet environmental regulations due to escalating costs for traditional feedstock and severe penalties for environmental damage. Lignocellulose-derived biomass has proven to be a desirable solution to these problems from an economic and ecological perspective [14]. There are various forms of AC available with various physical characteristics, including pore size distributions, surface features, and morphologies (e.g., pelletized, granular, powdered, spherical, or beads, etc.) [15]. Porosity architectures and surface functional groups of AC vary depending on the precursor material, activation technique and conditions (such as temperature and oxygen), and post-treatment reactions. For example, the powdered and granular versions of AC are the most widely used kind [16]. Consequently, the objectives of this study are to produce AC from different biomass sources using chemical activation, characterize the AC using FTIR, SEM, proximate and ultimate analysis and compare the results from the AC produced.

2. Materials and Methods

2.1 Materials

Carbonaceous precursors use for the preparation of AC were biomass blends of rice husk & groundnut shell (RH-GS), cocoa nut shell & saw dust (CS-SD) and sugar cane bagasse & banana peel (SB-BP). They were collected separately from Maiduguri Monday Market, Borno State-Nigeria. Samples were washed greatly with deionize water to remove mud and other impurities present on the surface and then sun-dried for a week. An activating agent was used, in this case. Materials which include the samples, equipment, glass wares and reagents used in this work are listed in Tables 1 and Table 2.

Table 1: List of Reagents Used.

S/No	Reagents	Manufacturer	Description	Source
1.	Deionized Water	Kaduna Polytechnic Lab	Analytical Grade	Spectral Laboratory
2.	Samples	Food wastes	Biodegradable biomass	Maiduguri Monday Market

Table 2: List of Equipment and Glassware Used.

S/No	Glass ware	Manufacturer	Description	Source
1.	Conical flask	Pyrex, England	Borosilicate	Spectral Laboratory
2.	Beaker	Approxboro, England	Borosilicate	Spectral Laboratory
3.	Measuring Cylinder	Bomex, Germany	Borosilicate	Spectral Laboratory
4.	Crucibles	LSP Industrial Ceramics	Ceramic	Spectral Laboratory
5.	Laboratory Spatula	Bürkle Nigeria	Stainless	Spectral Laboratory
6.	Weigh Balance	Apex Scientific	0 - 200 mg	Spectral Laboratory
7.	Desiccator	Normax-Fabrica de Vidro Cientifico	10 liters	Spectral Laboratory
8.	Drying Oven	The Grieve Corporation	150 liters	Spectral Laboratory
9.	Muffle Furnace	Bionics Scientific	4 liters	Spectral Laboratory
10.	Crucible with Cover	Shanghai Gongtao Ceramics Co., Ltd.	15 mL and 30 mL	Spectral Laboratory
11.	Laboratory Test Sieve	ENDECOTTS	425 μm	-

Combustible parts of the samples were separated from non-combustible ones before they were used for the experiment. The three experiments carried out were described.

2.2. Experimental Section

2.2.1 Preparation of Sample

Sugarcane bagasse, rice husks, peanut shells, coconut shells, banana peels and sawdust pose a lot of challenges in handling and disposal. Bagasse and co. could serve as an additive in the manufacture of sludge-based adsorbents to increase their adsorption capacity. After crushing and pressing sugarcane to get juice, bagasse was collected and dried. To create different particle sizes, it was ground and sieved. The chars were then activated.

2.2.2 Synthesis of Activated Carbon from Biomass Blend

After collecting the biomass from Maiduguri Monday Market, Borno State, Nigeria, various blends were formed (i.e., RH-BS, CS-SD and SB-OP). A typical process that involves initial cleaning to remove dust, dirt and other impurities was carried out. The cleaned waste biomass was then dried under sunlight for 1 week. The dried waste biomasses were pre-carbonized in a muffle oven at 700 ℃ for 3h under nitrogen atmosphere to obtain carbon black before grinding and its subsequent activation. The carbonized waste biomass particles were then blended and mixed in the ratio of 1:1 (RH**:**GS, CS**:**SD and SB**:**OP). Then separate blends were activated using chemical activation method. Finally, the prepared ACs were washed with distilled water, dried and kept in a closed container until further use. The ACs were named RG-ACs, CS-ACs and OS-ACs using initial alphabets in the 3 blends.

2.2.3 Characterization of Activated Carbon

In general, the selection of a characterization methodology must be based on the type of information that is important for the specific use of the materials in question. As already mentioned, the characterization of adsorbents from biomass materials should be performed not only on the final product but also on the precursor of the AC. Analysis of the raw material is required to determine moisture, percentage of main polymer structure, as well as density and the presence of other compounds [17].

Proximate analysis was conducted prior to carbonization phase and ultimate analysis after that, to provide important

information about the properties of the final product [18]. Techniques applied for the characterization of the samples are Fourier Transform Infrared Spectroscopy (FTIR), Scanning Electron Microscopy (SEM) and ultimate analysis.

3. Results and Discussion

3.1. Physiochemical Properties of Activated Carbon Produced

3.1.1. Bulk Density

Bulk densities measured, ranged from 0.5417 to 0.7183 mg/L, with BG-SD having the lowest bulk density and OS-CS the highest. There was no remarkable difference in the mean bulk densities of the powdered blends varieties as shown in Table 3. The bulk density of a material affects how easily it may be transported, notably in terms of container space. However, more advanced correlations have shown bulk density as a key predictive indicator in determining the suitability of a material for absorption purposes in water treatment systems, with materials of lower bulk densities reported to have a higher adsorptive capacity. Compared with bulk densities reported by other researchers, the bulk densities of blends varieties can be harnessed for synthesis of adsorbents.

3.1.2. Moisture Content

Dry basis moisture content of the biomass blend varieties ranges from 4.12-7.15%. Values obtained are in the acceptable range that has been reported in the literature. However, other scholars have reported values out of this range. This could be attributed to the difference in the drying conditions such as higher temperature and longer drying times whereas, the average particle size difference could also have led to differing moisture content.

3.2. Proximate and Ultimate Analysis of the AC

3.2.1 Proximate Analysis

Proximate analysis of the selected biomass-sourced ACs provided various fixed carbon content depending on the moisture content, ash content and volatile matter content present. While ultimate analysis gave sulphur, hydrogen, oxygen, nitrogen and carbon (C) contents present in each precursor raw material. Results from the proximate analysis and ultimate values are reported for these selected materials, even though the values obtained for other samples with different carbonization time was not significantly different for the selected samples. CS-OP, BG-SD and RH-GS had a fixed carbon content of ~27.24, ~32.33 and ~32.82 wt% respectively. This is comparable to earlier studies reported on AC from similar biomass raw materials. A detailed summary of the entire proximate results for the selected samples are shown in Table 3.

Table 3: Proximate Analysis.

S/N	Parameter	Unit	RH-GS	OP-CS	BG-SD
	Feedstock	g	5	5	5
1.	Moisture content	%	4.12	4.74	7.15
2.	Ash content	%	61.33	0.72	1.79
3.	Volatile matter	%	5.86	71.54	65.88
4.	Fixed carbon	%	32.82	27.24	32.33
5.	Bulk density	mg/L	0.6322	0.7183	0.5417

3.2.2 Ultimate Analysis

The carbon, hydrogen, nitrogen, oxygen and sulphur contents in the 3 biomass blends are shown in Table 4.

Table 4: Ultimate Analysis Results.

S/No	Parameter	Unit	RH-GS	OP-CS	BG-SD
	Feed stock	%	100	100	100
1	Carbon	%	51.76	56.48	68.13
2	Hydrogen	%	11.01	11.97	9.49
3	Oxygen	%	36.69	31.21	21.90
4	Sulphur	%	0.21	0.05	0.17
5	Nitrogen	%	0.33	0.29	0.31

This ultimate composition is close to those of other biomasses summarized and reported by Pathak et al. (2016) and in the same range with other biomass blends varieties. Carbon content in all the peels renders them viable for AC production. Normally, the higher the C content, the more viable a material is for AC precursor. Moreover, there are relatively higher C in some blend's varieties. Based on the composition, the suitability for AC production for the biomass blends varieties is in the order: BG-SD > OP-CS > RH-GS.

Oxygen composition in all the blends suits them for better reactivity during AC production. Presence of oxygen influences the reactivity of biomass during pyrolysis, which consequently affects the final products yield and quality. Studies have suggested that the more the presence of oxygen in the biomass, the more will be the reactivity. The oxygen and hydrogen compositions for all the varieties suit them for chemical activation. Oxygen and hydrogen compositions (Table 4) above 25% and 5% respectively, predictably imply better activation chemically.

3.3 Activated Carbon Characterization

After activation, the ACs were characterized using FTIR and SEM, where the results obtained were vividly explained.

3.3.1 FTIR Analysis

To study the surface functional groups present in ACs, FTIR analysis was performed. From the chart of Figure 1, the FTIR spectroscopy of AC shows the peaks for OP-CS, RH-GS, and BG-SD, which are 3850.04, 3850.04 and 3842 cm^{-1} respectively. They are ascribed to –OH stretching of hydroxyl group which decreased considerably in AC. It shows a reduced intensities in AC FTIR spectroscopy due to decomposition during the carbonization process. The band for OP-CS, RH-GS, and BG-SD are 2353.23, 2438.1 and 2337.8 cm^{-1} corresponding with C–H symmetric and asymmetric vibrations of the methoxyl groups. Sharp peak at 1543.1,1519.96 and 1527.67 cm^{-1}, which are attributed to C-O vibrations in the ACs; OP-CS, RH-GS, and BG-SD respectively are shown in Figures 1-3.

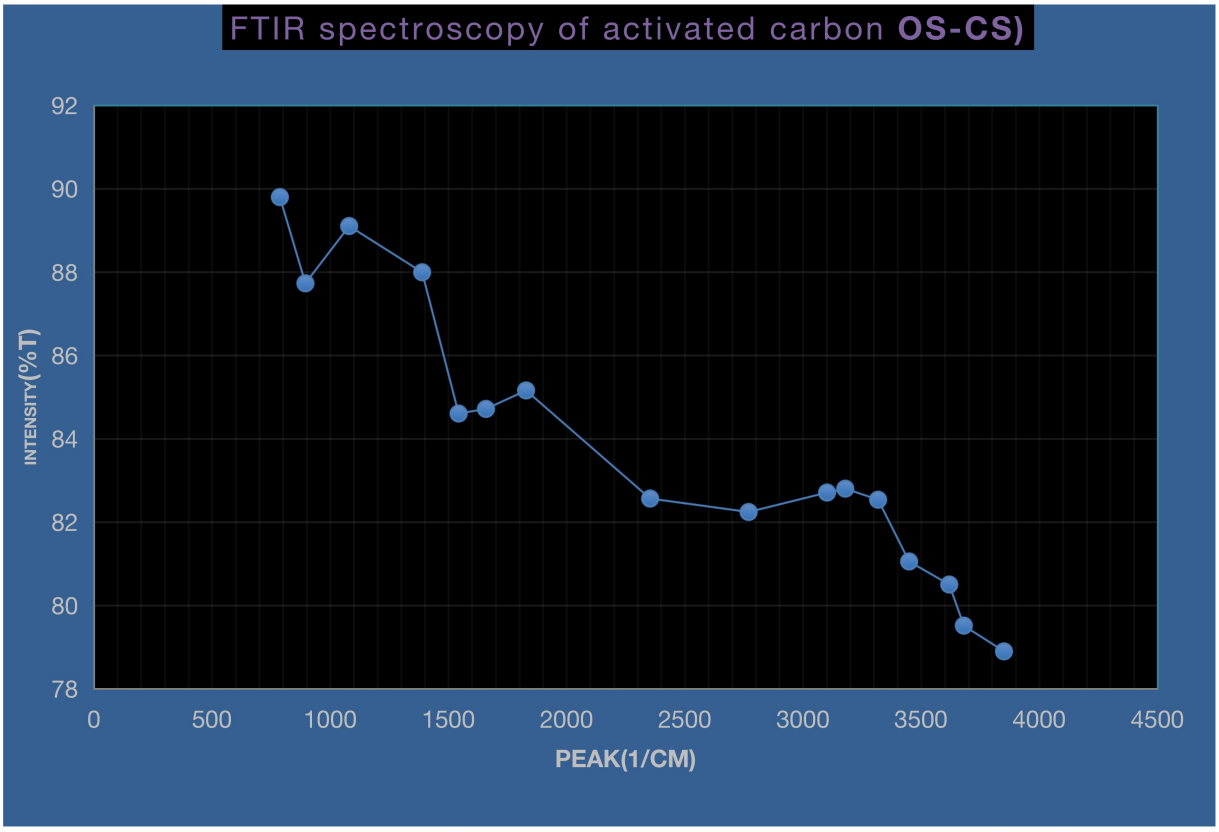

Figure 1: FTIR Spectroscopy of Activated Carbon: OP-CS.

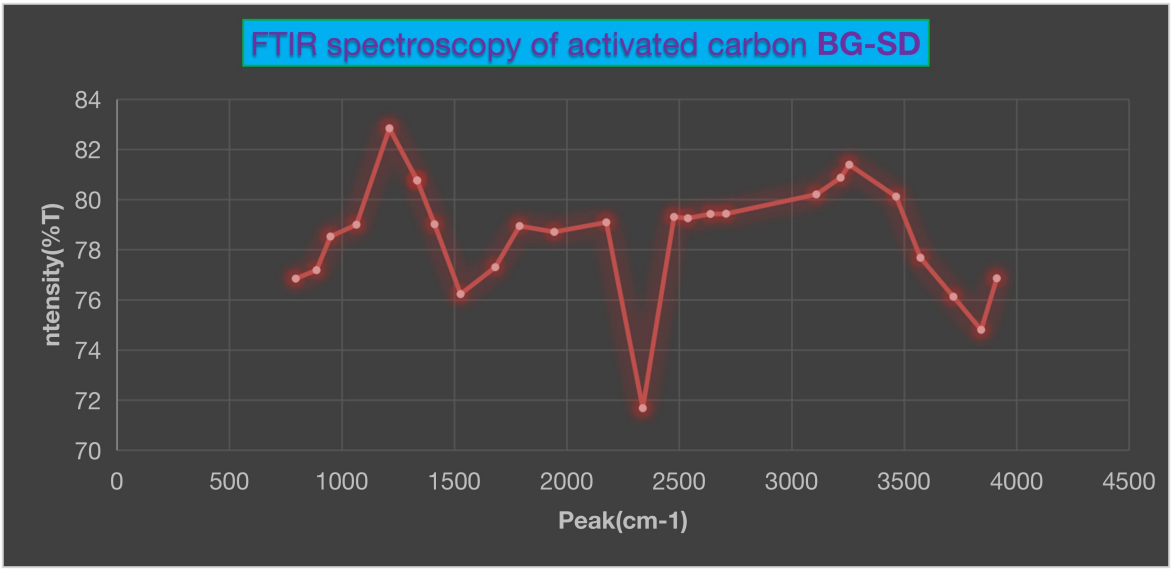

Figure 2: FTIR Spectroscopy of Activated Carbon: BG-SD.

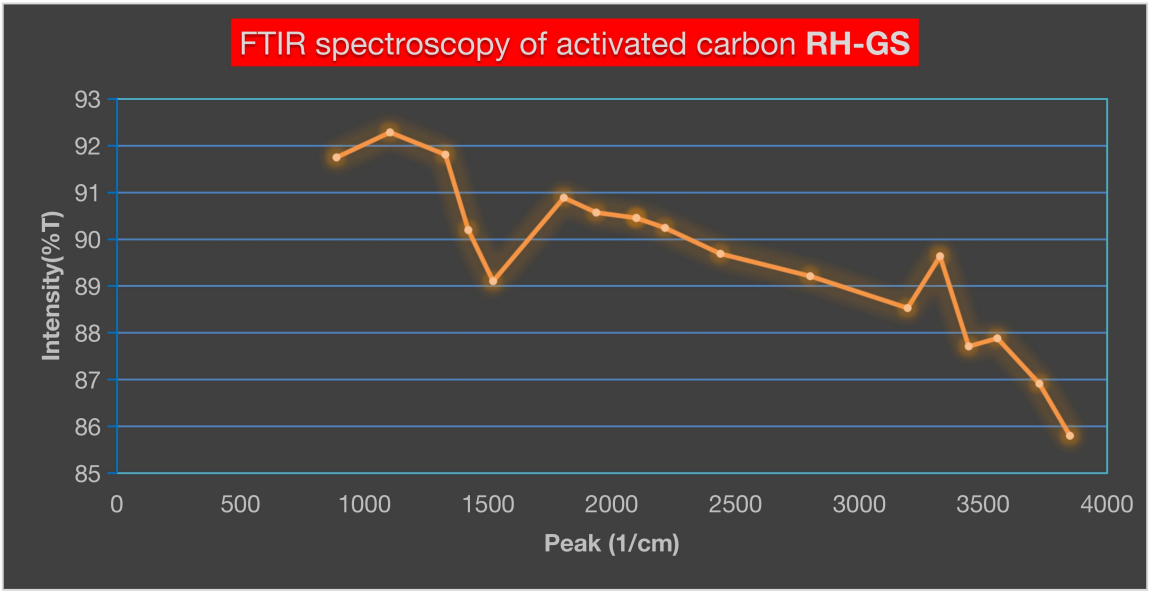

Figure 3: FTIR Spectroscopy of Activated Carbon: RH-GS.

3.3.2 SEM Analysis

Surface roughness of AC made from biomass, comprising CS-OP, BG-SD, and RH-GS, is depicted in Figures 4, 5, and 6. The dehydrating agent will be the activating agent; sodium hydroxide (NaOH), which was combined with the precursor before being subjected to activation. During chemical activation, the activating agent penetrates the biomass blend's surface texture to aid in the development of a porous structure. It is evident that AC has a porous microstructure with numerous irregular pores and broken edges. Similar morphology was observed in the AC made from empty banana fruit [20]. The evaporation and gasification of the activating agent (in this case, NaOH) during the activation process by leaving the area it occupies during the impregnation step causes the formation of holes and cavities.

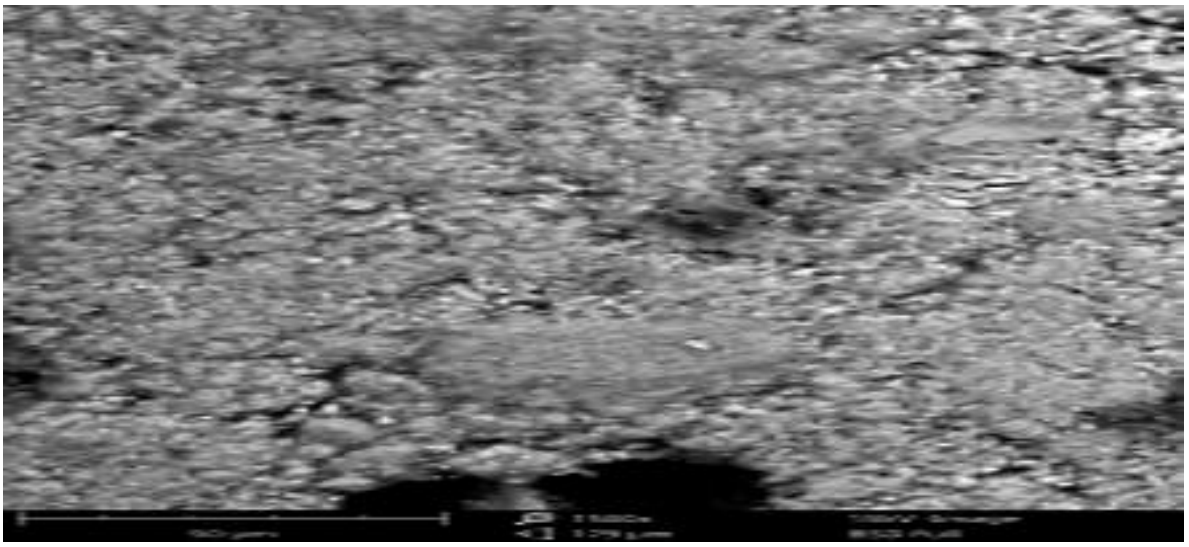

Figure 4: SEM Microstructures of the Activated Carbons: (a) BG-SD.

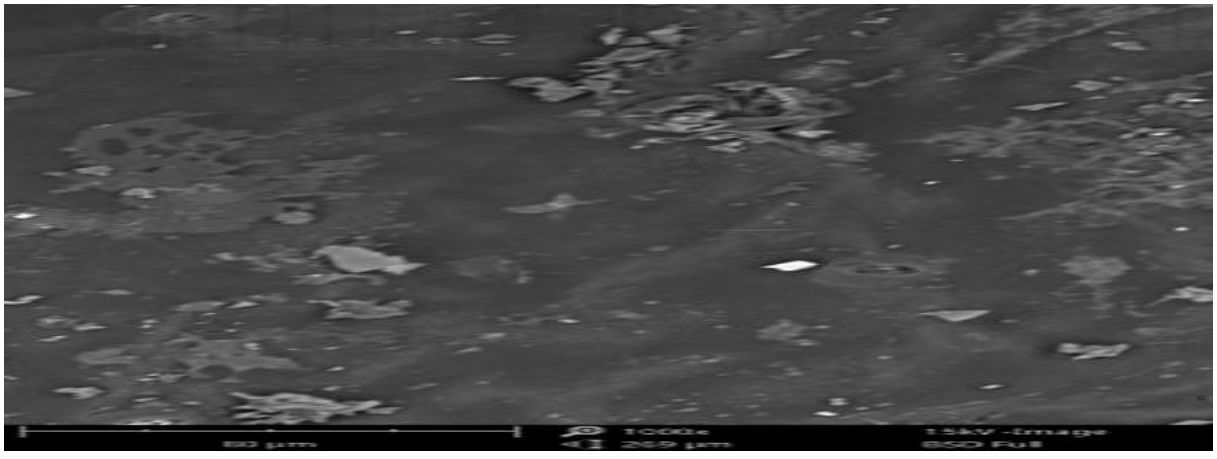

Figure 5: SEM Microstructures of the Activated Carbons: (b) OS-CS.

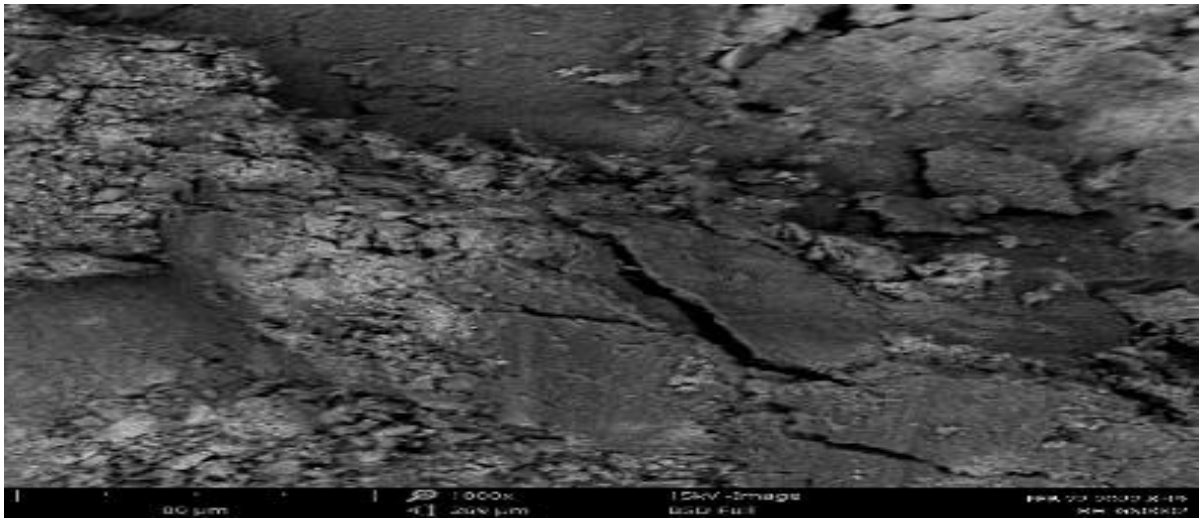

Figure 6: SEM Microstructures of the Activated Carbons: (c) RG-GS.

4. Conclusion

This work examines FTIR, Proximate, Ultimate and SEM of biomass mixtures namely, CS-OP, BG-SD and RH-GS to evaluate their applicability for AC production. Almost all varieties have AC yield potential, specifically due to their ash content, which is below 5% (except in the case of RH/GS). The increase in volatile matter upon treatment with NaOH implies a larger surface area for the AC, but could also be suitable for synthesis gas production.

The conclusion that biomass blend use can serve as an affordable raw material for the manufacturing of AC in the near future can be drawn from the findings of experimental examination of the ACs generated in the current study, thereby minimizing their presence in the environment as waste material. The synthesis of AC from biomass blend works best when utilizing a chemical activation process with NAOH as the activating agent. According to the results of the SEM study, AC has an amorphous crystalline structure and a microporous surface structure, respectively. A good adsorbent must have a porous surface and an amorphous crystalline structure.

Thus, adsorption and filtration applications can make use of AC in powder form. Using FTIR spectroscopy research, it can be seen that water and hydroxyl groups in the AC powder vanished after the precursor and AC were both activated. After activation, the C material also exhibits an increase in aromaticity and the creation of new surface groups. All of the blend types' elemental compositions make them suitable for the generation of AC, with C contents high enough to produce chars and oxygen and hydrogen contents predictable enough to be reactive during torrefaction operations. Based on the results of the BG-SD sample characterization, it can be concluded that the blend produced the best results in terms of absorptive capacity. Therefore, it is advised that issues with the ACs' surface area be looked upon in order to enhance their porosity and adsorption capabilities.

Authors Contribution

Based on CRediT standards, authors description can be described as follows: Mr. Saka is credited with the project conceptualization and funds acquisition; Mrs. San-Pedro does the formal analysis, data curation and edit the review; Mr. A. M. Abubakar provides the resources as well as the needed administration and supervision of the work; Dr. T. Sylvain conducts data validation and software use; Mr. Budianto visualize, investigates and wrote the methodology; and Dégninou Houndedjihou wrote the original draft and also participates in the editing of the review by anonymous reviewers.

Conflicts of Interest

There are no conflicts of interest reported by the writers.

Acknowledgment

All participants to this work played an uncompromising role right from the conceptualization to the completion and publication of this work. Further gratitude goes to Engr. Hamza Umar at the Department of Chemical Engineering, University of Maiduguri, Nigeria for his technical assistance.

Data Availability Statement

Data presented in this study are available on request from Mr. Tahiru Saka (send mail to tahirusaka23@gmail.com).

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