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Comparative Analysis of FTIR in Local Activated Carbons for Suitability in the Treatment of Kula Water, Akuku Toru LGA, Rivers State, Nigeria

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Abstract: The study examined the comparative analysis of "Fourier Transform Infrared Spectroscopy" (FTIR) in local activated carbons for suitability in the treatment of Kula Water, Akuku Toru LGA, Rivers State, Nigeria. The locally produced Bamboo, Coconut Shell and Palm Kernel were pyrolysed, activated and sized. FTIR was used to identify the presence of functional groups by detecting the characteristics vibrations of molecular bonds in each of the activated carbons. Descriptive statistics were employed for data analysis. Findings showed that the FTIR spectra of the foreign and bamboo activated carbons; coconut shell activated carbons and palm kernel activated carbons exhibited certain and common functional groups. Findings showed that both FAC and BAC exhibited common functional groups such as hydroxyl, alkanes, and aromatic rings. However, the FAC displays a strong carbonyl peak, indicating the presence of carboxylic acids, ketones, or aldehydes while BAC exhibits unique peaks at 800 cm^{-1} and 500 cm^{-1}, characteristics of C-C stretching in aromatic rings. FAC and CSAC exhibited common functional groups such as hydroxyl (O-H stretching at ~3400 cm^{-1}), alkanes (C-H stretching at ~2900 cm^{-1} and ~2850 cm^{-1}), and aromatic rings. Similarly, both CSAC and FAC exhibit a range of similar functional groups, including a broad and strong peak around 3400 cm^{-1}, indicating the presence of hydroxyl groups. The difference between FAC and CSAC is found in Carbonyl group. FAC displays a strong peak at 1711.61 cm^{-1}, indicating the presence of carbonyl groups (C=O stretching) from functional groups such as carboxylic acids, ketones, or aldehydes, while CSAC showed a medium intensity peak in this region, PKSAC exhibits medium-intensity peaks at C-H bending and C-O stretching, which are consistent with FAC peaks. PKSAC exhibits a similar functional profile to FAC, indicating its suitability for water treatment. However, slight differences in peak intensities may affect their adsorption efficiency and specificity. The study recommended that additional research should be conducted to optimize the production process and explore other locally available biomass materials.

Keywords: *Fourier, Activated Carbons, Suitability, Bamboo, Coconut, Palm Kernel.*

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I. INTRODUCTION

Groundwater represents one of the largest sources of readily available freshwater, accounting for nearly one-third of global freshwater use (Chen et al., 2018). Due to its generally consistent supply and high quality, groundwater serves as a critical resource for domestic, agricultural, industrial, and ecological needs (Kuchampudi et al., 2024). Although it is often naturally protected from contamination, inadequate management has led to several adverse consequences, including declining aquifer levels, deterioration of water quality, ecosystem damage, land subsidence, and seawater intrusion (Chen et al., 2018). Once contaminated, groundwater is difficult and expensive to treat, making pollution detection, particularly in developing regions essential for sustainable management.

Groundwater depletion naturally occurs as water is extracted from aquifers. In many areas, untreated groundwater is consumed directly, posing potential health risks to humans, plants, and animals. Therefore, continuous monitoring of drinking water sources is vital to ensure compliance with World Health Organization (WHO) standards and to detect contaminants that may either survive or hinder treatment processes. Excessive depletion is typically marked by a sustained and significant drop in water levels caused by pumping rates that exceed natural recharge. The magnitude of this issue has been documented on a global scale (Chen et al., 2018).

Adsorption is an effective method for separating substances from gases or liquids by allowing them to adhere to the surface of a solid material known as an adsorbent (Yusuf et al., 2013). In this process, the material being captured is termed the adsorbate. Adsorbents are generally categorized as synthetic, natural, or semi-synthetic. Synthetic adsorbents are favored for their high adsorption capacity, though their production costs are considerable. Natural adsorbents derived from plants, leaves, or flowers are more economical but typically less efficient. Semi-synthetic adsorbents, which combine natural materials with chemical modifications, offer a balance between performance and cost.

Materials with high surface areas such as activated carbon, resins, and zeolites—have been widely employed for wastewater treatment (Hegazi, 2013). To reduce costs while maintaining efficiency, researchers have explored alternative low-cost adsorbents, particularly those derived from agricultural waste and by-products (Hegazi, 2013).

Activated carbon is one of the most widely used adsorbents in water treatment worldwide, valued for its straightforward application and its effectiveness in eliminating a diverse range of contaminants (Okparanma & Ayotamuno, 2008; Ahmad et al., 2007). However, the performance of activated carbon is dependent on the precursor material, its porous structure, and the synthesis techniques used (Otero et al., 2003; Shopova et al., 1997). Utilizing readily available agricultural biomass to produce activated carbon offers a sustainable and cost-effective alternative (Chowdhury et al., 2012; Zuorro & Lavecchia, 2010). Also, there has been strong and growing interest in studies that produce activated carbon (AC) from local and agricultural wastes such as coconut shells, fruit peels, coffee grounds, husks, and seed shell with FTIR spectra. Increasingly reported as a standard part of material characterization; these studies commonly identify the presence and changes in oxygen- and nitrogen-containing surface functional groups (–OH, C=O, C–O, –COOH) after activation (Dittmann et al., 2022). Recent reviews and comparative surveys further emphasize the critical role of material characterization, including FTIR, in understanding and optimizing removal performance for organic micropollutants and natural organic matter (NOM), noting that such performance is heavily influenced by surface chemistry and porosity, even though accurately predicting pollutant-specific removal remains difficult (Dittmann et al., 2022). Numerous comparative adsorption studies, whether between different types of AC or between AC and biochar/modified AC, utilize FTIR to identify changes in functional groups introduced through chemical or physical activation processes such as oxidation or metal impregnation (e.g., with Fe), using FTIR primarily to confirm the presence of functional groups hypothesized to enhance adsorption capacity (Kokuloku et al., 2023). In parallel, a growing number of region-specific studies, including work by Nigerian researchers, explore locally sourced ACs using FTIR alongside other characterization techniques such as scanning electron microscopy (SEM), Brunauer–Emmett–Teller (BET) surface area analysis, and X-ray diffraction (XRD), though these works are typically stand-alone case studies focused on a single feedstock or contaminant (Ajibadem & Maduka, 2024). Across the literature, FTIR is most commonly used as a qualitative tool for confirming the presence of functional groups, typically reporting broad absorption bands near 3400 cm^{-1} for hydroxyl groups, 1700–1740 cm^{-1} for carbonyls, and 1000–1300 cm^{-1} for C–O or C–O–C stretching. Most studies also integrate FTIR data with other analyses such as BET (to determine surface area and porosity), SEM (for morphology), elemental analysis, and adsorption isotherms or kinetics in order to evaluate the performance of the ACs in removing specific contaminants, including dyes, heavy metals, and pesticides.

Despite the growing use of FTIR in activated carbon (AC) research, several limitations persist. Many studies report FTIR data only qualitatively, focusing on basic peak assignments without consistent sample preparation or reporting standard, such as wavenumber labeling, baseline correction, or band deconvolution, making it difficult to directly compare findings across different papers (Dittmann et al., (2022). Additionally, while the literature contains numerous single-feedstock studies, there is a noticeable lack of systematic comparative work that correlates quantified FTIR features, such as peak areas, band ratios, or deconvoluted concentrations of functional groups—with adsorption capacities for a range of contaminants, meaning FTIR remains largely a descriptive rather than predictive tool (Tigrine et al., 2024). Furthermore, the use of advanced statistical techniques, such as chemometrics and multivariate analysis (e.g., principal component analysis, partial least squares regression, and clustering), to analyze FTIR spectra and predict adsorption behavior or classify ACs based on their suitability, is still rare. Although such approaches could transform FTIR from a qualitative method into a predictive modeling tool (Dittmann et al., 2022). Another major limitation is the predominance of adsorption studies conducted using model solutions—typically involving a single dye or metal ion—while far fewer studies evaluate performance in real water matrices such as surface water, groundwater, or industrial effluents, or assess removal of emerging micropollutants like pharmaceuticals and polar pesticides (Tigrine et al., 2024).

Compounding this, FTIR is inherently semi-quantitative and is often presented as standalone evidence of surface chemistry without cross-validation through more quantitative techniques such as X-ray photoelectron spectroscopy (XPS), Boehm titration, or elemental/titrimetric methods; studies that do integrate FTIR with these quantitative measures are still relatively uncommon (Dittmann et al., 2022). Moreover, little attention is given to how FTIR spectral features evolve after adsorption or regeneration cycles and how such changes impact subsequent adsorption behavior, particularly in comparative studies involving multiple feedstocks. Lastly, geographic and regional comparative studies remain limited, as most existing research focuses on single-site or local studies, such as those utilizing Nigerian feedstock, while very few cross-regional investigations assess whether locally produced ACs from different areas exhibit comparable surface chemistry and functional suitability for contaminant removal (Kokuloku et al., 2024). Comparative studies on the FTIR of Bamboo, Coconut shell, and Palm Kernel Shell from this region were not available. The present study examined the comparative analysis of Fourier Transform Infrared Spectroscopy (FTIR) in local activated carbons for suitability in the treatment of Kula Water, Akuku Toru LGA, Rivers State, Nigeria.

II. MATERIALS AND METHODS

A. *Materials*

The materials used in this study include the water sample from Kula Community Borehole in Akuku Toru LGA, Rivers State, Nigeria, The activating agent employed was Nitric acid, chosen due to its previously reported efficacy for metal ion adsorption. Distilled water was utilized as a washing agent during the neutralization process, continuing until the wash water reached a pH of approximately 7 and other specific laboratory equipment.

➢ *Adsorbent Sources*

The study utilized three types of waste biomass as raw materials for adsorbent production: Bamboo, collected at Ozuzu Community, Etche LGA; Coconut Shell, collected in Port Harcourt Local Government; and Palm Kernel Shell, collected in Kula Community, Akuku Toru LGA, all within Rivers State. For reference and comparison, a foreign commercial activated carbon, specifically Calgon Activated Carbon (made in France), was procured from Larison Chemical, Rumuola, Port Harcourt, Rivers State, Nigeria.

➢ *Equipment and Instrumentation*

The laboratory work required several pieces of equipment. A mechanical sieve was used for initial char sizing and for the final grading of the activated carbon product, achieving a particle size range of 250μm−1.18 mm. Drying processes relied on an oven for moisture reduction and sludge drying. The carbonization step required a pyrolysis unit, consisting of a reactor and a condenser for collecting distillates. Chemical activation was carried out using, a muffle furnace was used to heat the material at 500°C−550°C. Finally, characterization was performed using Fourier Transform Infrared Spectroscopy (FTIR), and the adsorption efficiency was tested using a fixed bed reactor apparatus.

B. *Methods*

➢ *Study Area and Climate*

The study was conducted in Kula, Akuku-Toru LGA, Rivers State, Nigeria. The area features a tropical humid climate characterized by heavy rainfall, primarily delivered by the southwest wind, which blows from February through November, with the heaviest precipitation (370 mm average) occurring in September. The short dry season includes December and January, and the region's mean annual temperature is approximately 28°C.

➢ *Biomass Preparation and Sizing*

The raw waste materials (bamboo, coconut shell, and palm kernel shell) were first prepared by thoroughly washing them with water to remove surface impurities and dirt. For sizing, bamboo was cut into 1/2 cm pieces, while coconut and palm kernel shells were broken into smaller, more manageable sizes. All materials were initially sun-dried, which was followed by oven-drying at a temperature of 105^0C for 2 hours to ensure the moisture content was minimized.

➢ *Pyrolysis (Carbonization)*

For char production, the sized and dried materials were measured and introduced into the reactor. Pyrolysis was then conducted in the absence of air for 2 hours at a temperature range of 300^0C–400^0C. Distillates formed during the process were collected via a receiver connected to a condenser to prevent air pollution. The resulting biomass char was cooled to room temperature, weighed, and stored in airtight containers.

➢ *Chemical Activation*

The produced biomass char was chemically activated to enhance its adsorption properties. This process began with milling, where the char was crushed and sieved to obtain smaller particles. A weighed amount of the crushed char was then subjected to acid treatment by mixing it with known volume of 0.1M Nitric acid and stirring until a paste was formed. The resulting paste was heated in an oven to reduce moisture before being transferred to a muffle furnace, where it was heated for 1 hour at 500^0C−550^0C (in the absence of air) to increase the surface area. The activated carbon was cooled and then washed repeatedly with distilled water until the wash solution reached a pH of approximately 7. The final product was dried and sieved to a particle size range of 250μm−1.18 mm before being stored in an airtight container.

➢ *Characterization and Application*

The activated carbons were characterized using Fourier Transform Infrared Spectroscopy (FTIR) to identify the functional groups present on their surface. Subsequently, the best performing adsorbent among the three locally produced carbons was selected for the fixed bed experiment. This setup was utilized to determine necessary design parameters—including column diameter, reactor height, flow rate, adsorbent mass, solution volume, and percentage efficacy all essential for designing the water treatment system for the Kula Borehole Water Sample.

III. RESULTS AND DISCUSSION

A. *FTIR Analysis of Bamboo Activated Carbon (BAC)*

The FTIR results for Bamboo Activated Carbon (BAC) from Fig. 1 and Table 1 highlight the presence of various functional groups, indicating its chemical structure and potential applications in adsorption and catalytic processes. Looking at Table 1, there was the presence of a broad and strong hydroxyl group (O-H stretching) at 3392.96/3400 cm^{-1}, which indicates surface-active sites for hydrogen bonding, enhancing adsorption of polar molecules such as water, alcohols, and acids. Medium intensity peaks for alkanes (C-H stretching) at 2925.62/2900 cm^{-1} and 2852.76/2850 cm^{-1} suggest the presence of alkyl chains, contributing to hydrophobic interactions important for adsorbing non-polar organic pollutants. The absence of carbonyl groups (C=O stretching) at 1711.61 cm^{-1} suggests minimal oxidation during activation, slightly reducing adsorption of polar molecules but also reducing hydrophilicity. Moderate intensity peaks for aromatic rings and alkenes (C=C stretching) at 1624.67/1600 cm^{-1} and 1555.45/1500 cm^{-1} confirm the presence of aromatic structures, improving adsorption by π-π interactions with aromatic or unsaturated molecules. Medium intensity peaks for methane/aliphatic (C-H bending) at 1444.85/1400 cm^{-1} reflect the presence of simple alkyl groups, contributing to non-polar adsorption capacity. The C-O stretching peaks at 1104.43/1100 cm^{-1} indicate the presence of alcohols, ethers, or esters, contributing to adsorption of polar compounds. Weak intensity peaks for alkenes/aliphatic (C-H out-of-plane bending) at 872.98/900 cm^{-1}, bending vibrations (out-of-plane/aromatic C-C) at 599.88/500 cm^{-1}, and aromatic rings (C-C stretching) at 800 cm^{-1} confirm the presence of aromatic structures, though with lower intensity. The absence of metal-oxygen vibrations at 445.72 cm^{-1} indicates minimal inorganic content, enhancing suitability for adsorption applications as excessive inorganic compounds may block active sites. Similar results were observed from the FTIR studies on raw and activated Costus afer with wavelength/Frequency (Cm^{-1}) of between 3852.8- 1028.7 .(King et al , 2024)

In general, BAC contains a mix of oxygen-containing functional groups (hydroxyl, alcohols, and ethers) and aromatic structures, providing active sites for adsorption. The presence of both hydroxyl and alkyl groups makes BAC amphiphilic, allowing it to adsorb both polar and non-polar molecules, making it versatile for water and air treatment applications. Adsorption mechanisms include polar interactions governed by hydroxyl, alcohol, and ether groups, and non-polar interactions driven by alkyl chains and aromatic π-π interactions. Possible applications of BAC include water treatment for adsorbing dyes, heavy metals, and organic pollutants; air purification for volatile organic compounds (VOCs); and catalysis as a good catalyst support material due to its aromatic structure and functional groups.

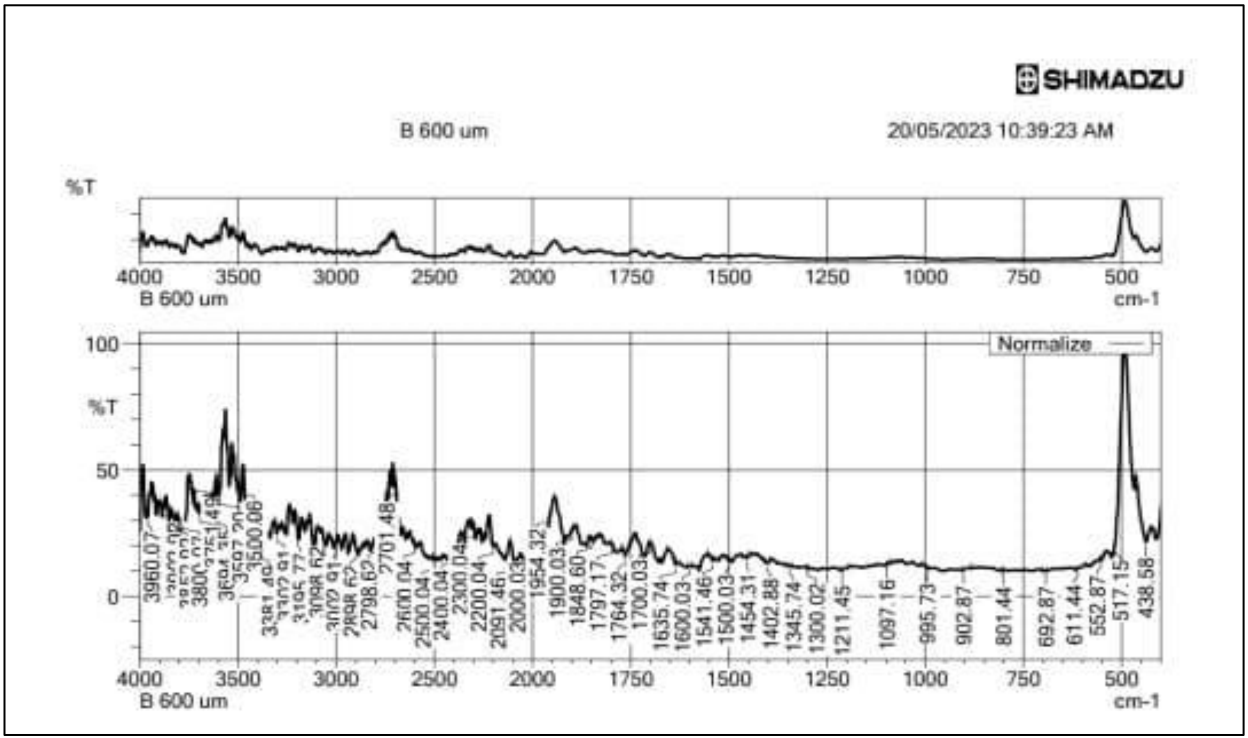

Fig. 1 FTIR Spectra of Bamboo Activated Carbon (BAC)

Table 1: FTIR Results for Bamboo Activated Carbon Samples

Wavenumber (cm⁻¹)	Functional Group	Peak Assignment	BAC
3392.96 / 3400	Hydroxyl	O-H stretching	Broad and strong
2925.62 / 2900	Alkanes	C-H stretching	Medium
2852.76 / 2850	Alkanes	C-H stretching (symmetric)	Medium
1711.61	Carbonyl	C=O stretching	Not observed
1624.67 / 1600	Alkenes/Aromatic Rings	C=C stretching	Moderate
1555.45 / 1500	Aromatic Rings	C=C stretching	Moderate
1444.85 / 1400	Methane/Aliphatic	C-H bending	Medium
1104.43 / 1100	Alcohols/Ethers	C-O stretching	Medium
872.98 / 900	Alkenes/Aliphatic	C-H out-of-plane bending	Weak
599.88 / 500	Bending Vibrations	Out-of-plane/Aromatic C-C	Weak
445.72	Inorganic Compound	Metal-Oxygen vibration	Not observed
800	Aromatic Rings	C-C stretching	Weak

B. FTIR Analysis of Coconut Shell Activated Carbon (CSAC)

The FTIR analysis of Coconut Shell Activated Carbon (CSAC) from Fig.2 and Table 2 provide valuable insights into its chemical composition and the functional groups present on its surface, which influence the material's properties, especially its adsorption capacity and reactivity. A broad and strong peak at 3400-3600 cm⁻¹ indicates the presence of hydroxyl groups (-OH) from surface-bound water molecules or phenolic groups, enhancing the material's hydrophilicity and adsorption capacity for polar molecules. Medium intensity peaks at 2900-2850 cm⁻¹ suggest the presence of aliphatic hydrocarbons due to incomplete carbonization of the coconut shell precursor material. A medium intensity peak at 1750-1650 cm⁻¹ indicates carbonyl groups like ketones, aldehydes, or carboxylic acids, which enhance adsorption of polar compounds. Moderate intensity peaks at 1600 and 1500 cm⁻¹ reflect the aromatic nature of the activated carbon, with conjugated double bonds characteristic of graphitic layers formed during carbonization. A medium intensity peak at 1400-1300 cm⁻¹ indicates the presence of aliphatic C-H bonds, further confirming incomplete carbonization and retention of hydrocarbon chains. Medium intensity peaks at 1300-1200 cm⁻¹ and 1200-1000 cm⁻¹ correspond to oxygenated functional groups like alcohols, ethers, and esters, enhancing the adsorption of polar organic compounds. Weak intensity peaks at 900-800 cm⁻¹ and 700-600 cm⁻¹ confirm the presence of aromatic structures, characteristic of substituted or unsubstituted aromatic rings contributing to the adsorption of aromatic pollutants. A weak peak at 445.72 cm⁻¹ indicates traces of inorganic impurities or residual activating agents, which could influence the surface properties and catalytic activity of the carbon.

The FTIR analysis includes the presence of hydroxyl, carbonyl, and ether groups, highlighting the oxygen-rich functionalization of the CSAC surface, beneficial for the adsorption of polar and ionic species. The significant aromatic content, indicated by C=C stretching and out-of-plane bending peaks, enhances the adsorption of nonpolar molecules. The presence of aliphatic C-H bonds suggests some hydrocarbon chains remain due to incomplete pyrolysis. The weak metal-oxygen vibration peak suggests minor inorganic impurities that may or may not affect adsorption performance depending on their concentration and type.

In terms of applications, the combination of polar and nonpolar functional groups makes CSAC versatile for adsorbing a broad variety of contaminants, such as heavy metals, colorants, and organic substances. The hydroxyl and carbonyl groups enhance the material's ability to adsorb water and other polar solvents, making it suitable for aqueous applications like water purification. The presence of residual hydrocarbons and weak inorganic peaks suggests that additional thermal or chemical treatment could further purify and enhance the material's properties.

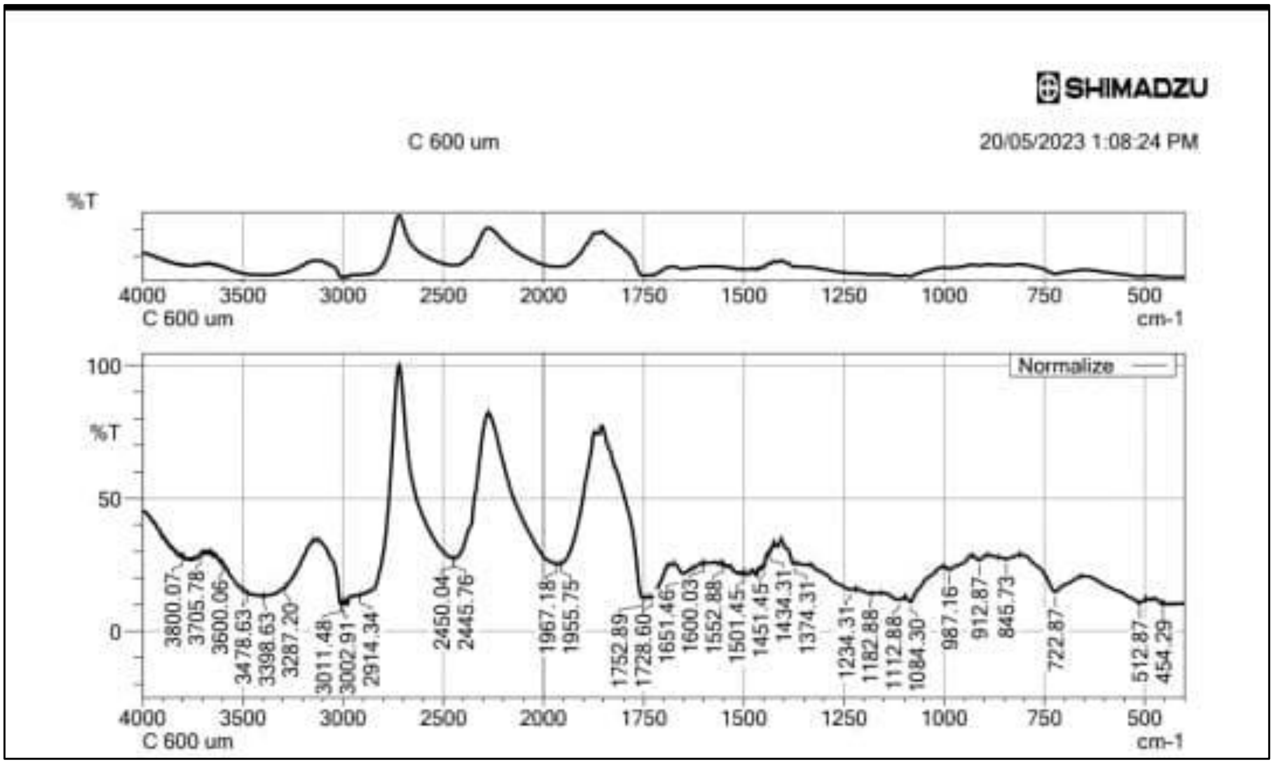

Fig. 2 FTIR Spectra of Coconut Shell Activated Carbon (CSAC)

Table 2: FTIR of Coconut Shell Activated Carbon (CSAC)

Wavenumber (cm⁻¹)	Functional Group	Peak Assignment	CSAC
3400-3600	Hydroxyl	O-H stretching	Broad and strong
2900-2850	Alkanes	C-H stretching	Medium (C-H asymmetric and symmetric stretching)
1750-1650	Carbonyl (C=O)	C=O stretching	Medium intensity
1600	Aromatic Compounds	C=C stretching	Moderate
1500	Aromatic Compounds	C=C stretching	Moderate
1400-1300	Alkanes/Methane	C-H bending	Medium
1300-1200	Alcohols/Ethers/Esters	C-O stretching	Medium intensity
1200-1000	Alcohols/Ethers/Esters	C-O stretching	Medium intensity
900-800	Aromatic Compounds	C-H out-of-plane bending	Weak intensity
700-600	Aromatic Compounds	C-H out-of-plane bending	Weak intensity
445.72	Inorganic Compound	Metal-Oxygen vibration	Weak

C. FTIR Analysis of Palm Kernel Shell Activated Carbon (PKSAC)

The FTIR spectrum of Palm Kernel Shell Activated Carbon (PKSAC) from Fig. 3 and Table 3 provide information about the functional groups on its surface, which affects its chemical properties and adsorption capabilities. The broad and strong O-H stretching at 3905.78 cm⁻¹ indicates hydroxyl groups, likely from surface-bound water molecules or phenolic groups, enhancing hydrophilicity and adsorption of polar molecules. The observed medium peaks for asymmetric and symmetric C-H stretching at 2926.68 cm⁻¹ and 2858.62 cm⁻¹ indicate the presence of aliphatic hydrocarbons, with the absence of peaks at 2900 and 2850 cm⁻¹ suggesting partial decomposition during activation. The medium peak at 1794.32 cm⁻¹ represents carbonyl functional groups like ketones or esters, while the absence of peaks in the typical 1750-1700 cm⁻¹ range indicates variations in oxidation state or functionalization. The moderate peak at 1605.17 cm⁻¹ confirms the presence of aromatic rings or unsaturated bonds, characteristic of activated carbon's graphitic regions, while the absence of peaks at 1600 and 1500 cm⁻¹ suggests some aromatic structures may have been altered or removed. The medium-intensity peak at 1441.45 cm⁻¹ indicates the presence of aliphatic chains, with the absence of the 1400 cm⁻¹ peak suggesting less prominent aliphatic content due to high-temperature activation. Medium peaks at 1306.74 cm⁻¹ and 1102.88 cm⁻¹ indicate the presence of alcohols or ethers, enhancing adsorption of polar organic molecules, while the absence of peaks in adjacent regions suggests limited functional diversity. A weak peak at 994.53 cm⁻¹ indicates the presence of alkenes or aromatic compounds, with the absence of peaks in the 900-800 cm⁻¹ range suggesting a lower concentration of these functional groups. The weak peak at 585.72 cm⁻¹ indicates out-of-plane bending vibrations from aromatic compounds, with the absence of peaks in adjacent regions suggesting limited variety of bending modes. The weak metal-oxygen vibration peak at 440.01 cm⁻¹ indicates trace amounts of inorganic impurities, potentially from the activation process. The peaks also present hydroxyl, carbonyl, and aromatic groups that enhance ability to adsorb a broad spectrum of contaminants, hydrophilicity due to strong hydroxyl and medium C-O peaks making PKSAC suitable for aqueous applications like water purification, a partially aromatic structure reflected in the moderate C=C stretching peak, and minimal inorganic content beneficial for adsorption. Compared to CSAC, PKSAC shows a hydroxyl peak at a higher wavenumber, suggesting different types or densities of hydroxyl groups, slightly less aliphatic content, weaker aromatic peaks indicating CSAC may have a more developed graphitic structure, and a weak metal-oxygen vibration peak at a slightly lower wavenumber, suggesting different inorganic impurities. PKSAC's functional groups make it suitable for removing both organic and inorganic pollutants from water and air, with potential for further modification to enhance specific functional groups and improve selectivity for certain pollutants. However, PKSAC may be slightly less effective for adsorption of nonpolar aromatic compounds due to its weaker aromatic peaks. In essence, the FTIR analysis demonstrates that PKSAC was a versatile material with promising adsorption capabilities, particularly for polar and ionic compounds, with further optimization enhancing its performance for specific applications.

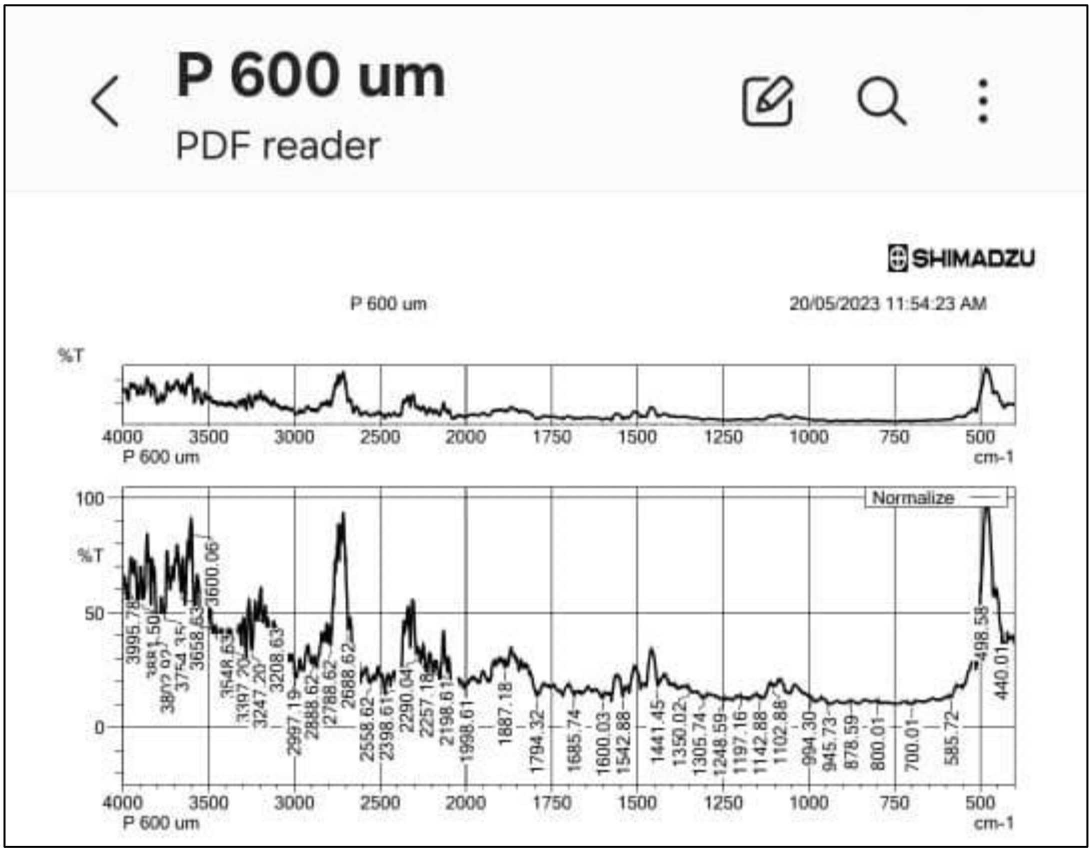

Fig. 3 FTIR Spectra of Palm Kernel Shell Activated Carbon (PKSAC)

Table 3: FTIR Peaks for Palm Kernel Shell Activated Carbon (PKSAC)

Wavenumber (cm^{-1})	Functional Group	Peak Assignment	PKSAC
3905.78	Hydroxyl	"O-H stretching"	Broad and strong
3400	Hydroxyl	ˇˇ	Not observed
2926.68	Alkanes	"C-H stretching"	Medium
2900	Alkanes	ˇˇ	Not observed
2858.62	Alkanes	"C-H stretching (symmetric)"	Medium
2850	Alkanes	ˇˇ	Not observed
1794.32	Carbonyl	"C=O stretching"	Medium
1750-1700	Carbonyl	ˇˇ	Not observed
1605.17	Aromatic Rings/Alkenes	"C=C stretching"	Moderate
1600	Aromatic Rings/Alkenes	ˇˇ	Not observed
1500	Aromatic Rings	ˇˇ	Not observed
1441.45	Methane/Aliphatic	"C-H bending"	Medium
1400	Methane/Aliphatic	ˇˇ	Not observed
1306.74	Alcohols/Ethers	"C-O stretching"	Medium
1300-1200	Alcohols/Ethers	ˇˇ	Not observed
1102.88	Alcohols/Ethers	ˇˇ	Medium
1100-1000	Alcohols/Ethers	ˇˇ	Not observed
994.53	Alkenes	C-H out-of-plane bending	Weak
900-800	Alkenes	ˇˇ	Not observed
585.72	Bending Vibrations	Out-of-plane bending vibration	Weak
700-600	Bending Vibrations	ˇˇ	Not observed
445.72	Inorganic Compound	Metal-Oxygen vibration	Not observed
440.01	Inorganic Compound	ˇˇ	Weak

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D. FTIR Analysis of Foreign Activated Carbon (FAC) Sample

The analysis of the activated carbon from Fig. 4 and Table 4 reveal a variety of surface functionalities and compounds. A broad and strong peak at 3392.96 cm^{-1} indicates the presence of surface hydroxyl groups (-OH) or adsorbed water molecules, common in activated carbon due to its porous nature and surface oxidation. Medium intensity peaks at 2925.62 cm^{-1} and 2852.76 cm^{-1} relate to the symmetric and asymmetric vibrations of aliphatic C–H bonds suggesting the presence of aliphatic hydrocarbons, possibly from precursor material or incomplete carbonization. A strong peak at 1711.61 cm^{-1} signifies the presence of carbonyl groups (C=O), indicating carboxylic acids, esters, aldehydes, or ketones formed during activation or surface oxidation. Moderate peaks at 1624.67 cm^{-1} and 1555.45 cm^{-1} correspond to C=C stretching vibrations, indicating aromatic rings or conjugated double bonds consistent with the graphitic nature of activated carbon. Medium intensity at 1444.85 cm^{-1} corresponds to aliphatic C-H bending, further confirming aliphatic hydrocarbons. A medium peak at 1104.43 cm^{-1} suggests the presence of alcohol or ether groups on the carbon surface, possibly from chemical activation or residual surface oxygen functionalities. A weak peak at 872.98 cm^{-1} indicates aliphatic or alkenic C-H bending, characteristic of unsaturated hydrocarbons or surface alkenes. Another weak peak at 599.88 cm^{-1} represents out-of-plane aromatic C-C bending vibrations, common in carbon materials with aromatic structures. A weak peak at 445.72 cm^{-1} suggests metal-oxygen bonds, likely from metal impurities or inorganic additives used during activation, while the absence of a peak at 800 cm^{-1} suggests that aromatic rings may not be as prominent.

The spectrum indicates a variety of oxygen-containing functional groups (hydroxyl, carbonyl, and ether), enhancing the adsorption capacity of the activated carbon for polar molecules. The FTIR analysis of the Functionalized Activated Carbon (FAC) reveals a chemically active surface with various functional groups, highlighting its potential for adsorption processes and industrial applications. The spectrum indicates a variety of oxygen-containing functional groups such as hydroxyl, carbonyl, and ether, which enhance the adsorption capacity for polar molecules.

The diverse functional groups enhance the FAC's ability to adsorb both polar and non-polar contaminants. The spectrum highlights the material's surface chemistry, providing insights into its suitability for applications like water treatment or gas adsorption. The functional groups suggest areas where the material can be further modified (e.g., oxidation or reduction) to enhance performance. This analysis underscores the FAC's versatility and promise for various industrial applications, as a result of its active surface chemistry.

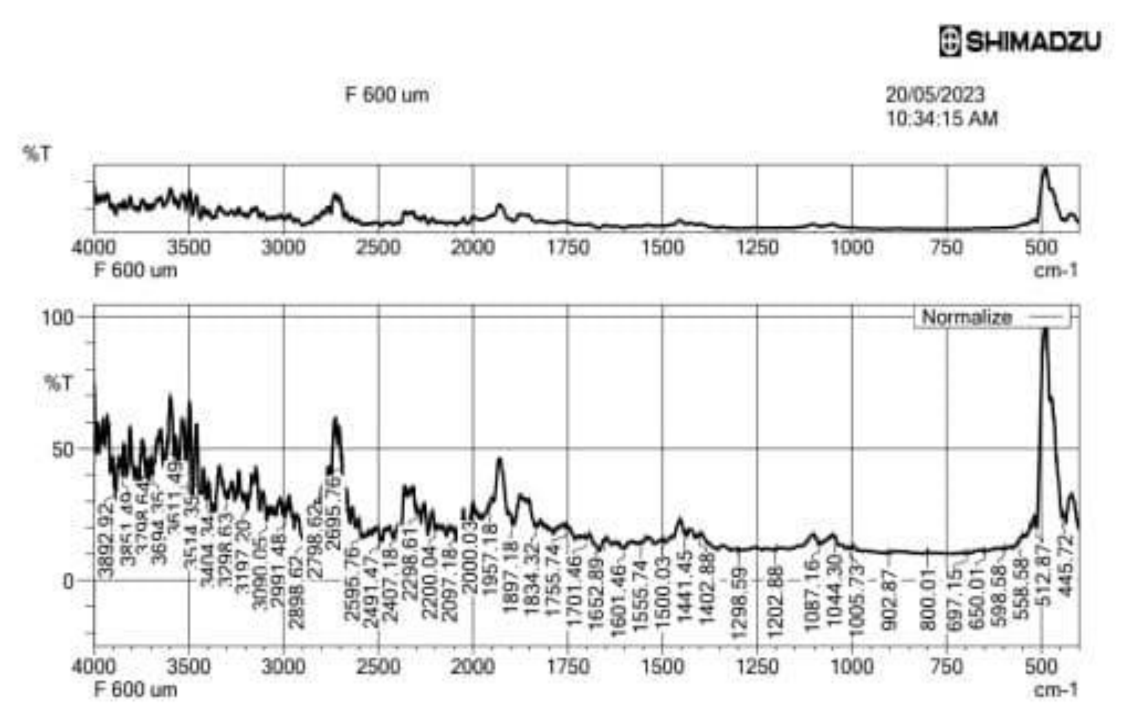

Fig. 4 FTIR Spectra of Foreign Activated Carbon (FAC)

Table 4: FTIR Results for Foreign Activated Carbon (FAC)

Wavenumber (cm⁻¹)	Functional Group	Peak Assignment	FAC
3392.96 / 3400	Hydroxyl	"O-H stretching"	Broad and strong
2925.62 / 2900	Alkanes	"C-H stretching"	Medium
2852.76 / 2850	Alkanes	"C-H-stretching (symmetric)"	Medium
1711.61	Carbonyl	"C=O stretching"	Strong
1624.67 / 1600	Alkenes/Aromatic Rings	"C=C stretching"	Moderate
1555.45 / 1500	Aromatic Rings	"C=C stretching"	Moderate
1444.85 / 1400	Methane/Aliphatic	"C-H bending"	Medium
1104.43 / 1100	Alcohols/Ethers	"C-O stretching"	Medium
872.98 / 900	Alkenes/Aliphatic	"C-H out-of-plane bending	Weak
599.88 / 500	Bending Vibrations	Out-of-plane/Aromatic C-C"	Weak
445.72	Inorganic Compound	Metal-Oxygen vibration	Weak
800	Aromatic Rings	C-C stretching	Not observed

E. Comparison of FTIR Analysis for Foreign Activated Carbon (FAC) and Bamboo Activated Carbon (BAC)

The FTIR analysis in Table 5 highlights similarities and differences in "the functional groups present in Bamboo Activated Carbon (BAC) and Foreign Activated Carbon (FAC)". The identified peaks provide insights into the chemical composition and potential adsorption capabilities of both activated carbons, which are critical for water treatment applications.

Table 5: Comparison of FTIR Results for Foreign and Bamboo Activated Carbon Samples

Wavenumber (cm⁻¹)	**Functional Group**	**Peak Assignment**	**FAC**	**BAC**
3392.96 / 3400	Hydroxyl	O-H stretching	Broad and strong	Broad and strong
2925.62 / 2900	Alkanes	C-H stretching	Medium	Medium
2852.76 / 2850	Alkanes	C-H stretching (symmetric)	Medium	Medium
1711.61	Carbonyl	C=O stretching	Strong	Not observed
1624.67 / 1600	Alkenes/Aromatic Rings	C=C stretching	Moderate	Moderate
1555.45 / 1500	Aromatic Rings	C=C stretching	Moderate	Moderate
1444.85 / 1400	Methane/Aliphatic	C-H bending	Medium	Medium
1104.43 / 1100	Alcohols/Ethers	C-O stretching	Medium	Medium
872.98 / 900	Alkenes/Aliphatic	C-H out-of-plane bending	Weak	Weak
599.88 / 500	Bending Vibrations	Out-of-plane/Aromatic C-C	Weak	Weak
445.72	Inorganic Compound	Metal-Oxygen vibration	Weak	Not observed
800	Aromatic Rings	C-C stretching	Not observed	Weak

* Foreign Activated Carbon (FAC) * Bamboo Activated Carbon (BAC)

The FTIR spectra of the foreign and bamboo activated carbons on Table 5 reveal distinct chemical profiles. Both exhibit common functional groups such as hydroxyl (O-H stretching at ~3400 cm⁻¹), alkanes (C-H stretching at ~2900 cm⁻¹ and ~2850 cm⁻¹), and aromatic rings (C=C stretching at ~1600 cm⁻¹ and ~1500 cm⁻¹). However, significant differences are observed. The foreign activated carbon displays a strong carbonyl peak (C=O stretching at 1711.61 cm⁻¹), indicating the presence of carboxylic acids, ketones, or aldehydes. Additionally, a weak peak at 445.72 cm⁻¹ suggests the presence of inorganic compounds, potentially metal-oxygen bonds. In contrast, bamboo activated carbon exhibits unique peaks at 800 cm⁻¹ and 500 cm⁻¹, characteristic of C-C stretching in aromatic rings, suggesting a different aromatic structure compared to the foreign sample. These variations in peak intensities and the presence of specific functional groups, such as carbonyl groups in the foreign activated carbon and the distinct aromatic ring structure in the bamboo activated carbon, likely arise from differences in raw materials, activation methods, or processing conditions. In reality, both show characteristic peaks for hydroxyl groups (O-H stretching), alkanes (C-H stretching), and aromatic rings (C=C stretching), indicating the presence of these functional groups in both materials; and both exhibit medium-intensity peaks for C-H bending in aliphatic hydrocarbons and C-O stretching in alcohols or ethers, suggesting the presence of similar functionalities in both. To show the differences, FAC displays a strong carbonyl peak (C=O stretching at 1711.61 cm⁻¹) while BAC does not show this peak, suggesting the presence of carbonyl groups (, ketones, carboxylic acids or aldehydes) in FAC. In addition, FAC exhibits a weak peak at 445.72 cm⁻¹, indicating the presence of inorganic compounds, possibly metal-oxygen bonds, which are absent in BAC; and BAC shows unique peaks at 800 cm⁻¹ and 500 cm⁻¹, characteristic of C-C stretching in aromatic rings, suggesting a different aromatic structure compared to FAC.

F. Comparison of FTIR of Foreign Activated Carbon (FAC) and Coconut Shell Activated Carbon (CSAC)

The FTIR analysis in Table 6 highlights similarities and differences in the functional groups present in Coconut Shell Activated Carbon (CSAC) and Foreign Activated Carbon (FAC). The identified peaks provide insights into the chemical composition and potential adsorption capabilities of both activated carbons, which are critical for water treatment applications. Both CSAC and FAC show broad and strong peaks at 3400 cm^{-1}, indicating the presence of hydroxyl groups. These groups enhance hydrophilicity and facilitate hydrogen bonding, making both activated carbons effective for adsorbing polar contaminants, such as phenols, dyes, and heavy metals, from water. Medium-intensity peaks in both samples at 2900 cm^{-1} and 2850 cm^{-1} reflect the presence of saturated hydrocarbons. While alkanes contribute minimally to adsorption, their presence indicates residual organic components from the carbon precursors, potentially impacting the surface properties of the activated carbons. Medium-intensity peaks (1750–1700 cm^{-1}) for both CSAC and FAC indicate the presence of carbonyl groups, such as carboxylic acids, ketones, or aldehydes. These groups play a crucial role in chemisorption by forming ionic or covalent bonds with contaminants like heavy metals (e.g., lead, mercury) and organics.

Aromatic Rings (C=C Stretching) was observed at 1600 cm^{-1} and 1500 cm^{-1} with both CSAC and FAC showing moderate peaks at these wavenumbers, reflecting the presence of aromatic structures. Aromatic rings enhance π-π interactions with aromatic contaminants, such as benzene, toluene, and xylene, making both carbons suitable for removing organic pollutants. Medium-intensity peaks at 1400 cm^{-1} suggest the presence of aliphatic hydrocarbons (C-H Bending) in both samples. Although these groups are not directly involved in adsorption, they may slightly influence the hydrophobicity of the activated carbons. The peaks at 1300–1200 cm^{-1} and 1100–1000 cm^{-1} with medium-intensity peaks in both samples confirm the presence of alcohol and ether groups, which contribute to polar interactions. These groups have the ability of enhancing the adsorption of polar contaminants, including alcohols, phenols, and certain pesticides. The peaks at 900–800 cm^{-1} and 700–600 cm^{-1} displayed weak-intensity peaks for both samples which indicate out-of-plane bending vibrations, likely from unsaturated hydrocarbons (Alkenes/Aliphatic Hydrocarbons). These peaks further validate the presence of structural hydrocarbons in both activated carbons, which might assist in capturing smaller hydrophobic organic molecules. This weak peak at 445.72 cm^{-1} was observed only in FAC, suggesting the presence of inorganic compounds, potentially metal oxides. These compounds can enhance the adsorption of heavy metals by providing specific binding sites, giving FAC a slight edge in heavy metal removal over CSAC. Both CSAC and FAC exhibit functional groups suitable for water treatment applications. However, FAC's unique metal-oxygen vibration peak suggests it may be slightly better suited for removing heavy metals, while CSAC was comparable for general adsorption of organic and polar contaminants. To show similarities, both CSAC and FAC exhibit a range of similar functional groups, including:

- Hydroxyl Groups: Both show a broad and strong peak around 3400 cm^{-1}, indicating the existence of hydroxyl groups, likely from water molecules or surface-bound -OH groups.
- Alkanes: Both exhibit medium-intensity peaks at around 2900 cm^{-1} and 2850 cm^{-1}, characteristic of C-H stretching vibrations in alkanes, suggesting the occurrence of aliphatic hydrocarbon moieties.
- Aromatic Rings: Both show moderate peaks in the region of 1600-1500 cm^{-1}, indicating the presence of C=C stretching vibrations in aromatic rings.
- Aliphatic Hydrocarbons: Both exhibit medium-intensity peaks around 1400 cm^{-1}, indicating C-H bending vibrations in aliphatic hydrocarbons.
- Alcohols/Ethers: Both exhibit medium-intensity peaks in the region of 1300-1200 cm^{-1} and 1100-1000 cm^{-1}, characteristic of C-O stretching vibrations, suggesting the presence of alcohol or ether functional groups.
- vi)Aromatic Rings: Both show weak peaks in the region of 900-800 cm^{-1} and 700-600 cm^{-1}, characteristic of C-H out-of-plane winding vibrations in aromatic rings.

The differences include:

- Carbonyl Groups: FAC displays a strong peak at 1711.61 cm^{-1}, indicating the presence of carbonyl groups ("C=O stretching") from functional groups such as carboxylic acids, ketones, or aldehydes. In contrast, CSAC shows a medium intensity peak in this region, suggesting a lower abundance of carbonyl groups.
- Inorganic Compounds: FAC exhibits a weak peak at 445.72 cm^{-1}, suggesting the presence of inorganic compounds, potentially metal-oxygen bonds. This peak was absent in CSAC, indicating the absence of such inorganic components.

Table 6: Comparison of FTIR of Activated Carbon for Foreign and Coconut Shell Activated Carbon (CSAC)

Wavenumber (cm^{-1})	**Functional Group**	**Peak Assignment**	**FAC**	**CSAC**
3400-3600	Hydroxyl	O-H stretching	Broad peak, indicating hydroxyl groups (e.g., water, surface -OH)	Broad and strong
2900-2850	Alkanes	C-H stretching	Peaks associated with aliphatic hydrocarbons	Medium (C-H asymmetric and symmetric stretching)
1750-1650	Carbonyl (C=O)	C=O stretching	Possible peak suggesting ketones, aldehydes, or carboxylic acids	Medium intensity
1600	Aromatic Compounds	C=C stretching	Peak could indicate aromatic structures or unsaturated bonds	Moderate
1500	Aromatic Compounds	C=C stretching	Not reported	Moderate
1400-1300	Alkanes/Methane	C-H bending	Peaks related to C-H bending vibrations in hydrocarbons	Medium
1300-1200	Alcohols/Ethers/Esters	C-O stretching	Possible C-O stretching vibrations	Medium intensity
1200-1000	Alcohols/Ethers/Esters	C-O stretching	Possible C-O stretching vibrations	Medium intensity
900-800	Aromatic Compounds	C-H out-of-plane bending	Peaks characteristic of aromatic rings with substitutions	Weak intensity
700-600	Aromatic Compounds	C-H out-of-plane bending	Peaks characteristic of aromatic rings with substitutions	Weak intensity
445.72	Inorganic Compound	Metal-Oxygen vibration	Possible peak indicating metal oxide impurities	Weak

* FAC = Foreign Activated Carbon * CSAC = Coconut Shell Activated Carbon

G. *Comparison of FTIR Peaks for "Palm Kernel Shell Activated Carbon (PKSAC) and Foreign Activated Carbon (FAC)"*

Table 7 shows the comparison of FTIR peaks for PKSAC and FAC. It is therefore shown that PKSAC was 3905.78 cm^{-1} and FAC was 3392.96 cm^{-1} which exhibited broad and strong peaks for O-H stretching, suggesting the presence of hydroxyl functional groups. These groups are hydrophilic and contribute significantly to the adsorption of polar contaminants in water. The peaks identified in PKSAC at 2926.68 cm^{-1} and 2858.62 cm^{-1} and in FAC at 2925.62 cm^{-1}, 2852.76 cm^{-1} display medium-intensity peaks corresponding to saturated hydrocarbons (Alkanes with C-H Stretching). These peaks indicate the presence of organic residues from carbon precursors but contribute minimally to water treatment efficiency. The PKSAC peak at 1794.32 cm^{-1} was similar to the FAC peak at 1711.61 cm^{-1}, showing the existence of carbonyl groups ("C=O Stretching"). These groups enhance adsorption capacity for organic contaminants and dyes due to their polar nature.

Both PKSAC (1605.17 cm^{-1}) and FAC (1624.67 cm^{-1}) show moderate peaks for aromatic C=C stretching. Aromatic structures increase the affinity for adsorbing aromatic pollutants, such as phenols and polycyclic aromatic hydrocarbons. PKSAC exhibits medium-intensity peaks at 1441.45 cm^{-1} (C-H bending) and 1102.88 cm^{-1} (C-O stretching), which are consistent with FAC peaks (1444.85 cm^{-1} and 1104.43 cm^{-1}). These peaks confirm the presence of functional groups that enhance the interaction with organic pollutants. The weak peak at 440.01 cm^{-1} in PKSAC was similar to the weak peak at 445.72 cm^{-1} in FAC, indicating metal-oxygen bonds, which might be associated with the presence of minerals in the activated carbon. PKSAC exhibits a similar functional profile to FAC, indicating its suitability for water treatment. Both samples demonstrate the presence of functional groups essential for the adsorption of a broad spectrum of contaminants, including polar and non-polar substances, aromatic compounds, and heavy metals. However, slight differences in peak intensities may affect their adsorption efficiency and specificity.

Table 7. Comparison of FTIR Peaks for "Palm Kernel Shell Activated Carbon" (PKSAC) and Foreign Activated Carbon (FAC)

Wavenumber (cm^{-1})	Functional Group	Peak Assignment	PKSAC	FAC
3905.78	Hydroxyl	O-H stretching	Broad and strong	Not observed
3400	Hydroxyl	O-H stretching	Not observed	Broad and strong
2926.68	Alkanes	C-H stretching	Medium	Medium
2900	Alkanes	C-H stretching	Not observed	Medium
2858.62	Alkanes	C-H stretching (symmetric)	Medium	Not observed
2850	Alkanes	C-H stretching (symmetric)	Not observed	Medium
1794.32	Carbonyl	C=O stretching	Medium	Not observed

1750-1700	Carbonyl	C=O stretching	Not observed	Medium intensity
1605.17	Aromatic Rings/Alkenes	C=C stretching	Moderate	Not observed
1600	Aromatic Rings/Alkenes	C=C stretching	Not observed	Moderate
1500	Aromatic Rings	C=C stretching	Not observed	Moderate
1441.45	Methane/Aliphatic	C-H bending	Medium	Not observed
1400	Methane/Aliphatic	C-H bending	Not observed	Medium
1306.74	Alcohols/Ethers	C-O stretching	Medium	Not observed
1300-1200	Alcohols/Ethers	C-O stretching	Not observed	Medium intensity
1102.88	Alcohols/Ethers	C-O stretching	Medium	Not observed
1100-1000	Alcohols/Ethers	C-O stretching	Not observed	Medium intensity
994.53	Alkenes	C-H out-of-plane bending	Weak	Not observed
900-800	Alkenes	C-H out-of-plane bending	Not observed	Weak intensity
585.72	Bending Vibrations	Out-of-plane bending vibration	Weak	Not observed
700-600	Bending Vibrations	Out-of-plane bending vibration	Not observed	Weak intensity
445.72	Inorganic Compound	Metal-Oxygen vibration	Not observed	Weak
440.01	Inorganic Compound	Metal-Oxygen vibration	Weak	Not observed

***** FAC = Foreign Activated Carbon * PKSAC = Palm Kernel Shell Activated Carbon

IV. CONCLUSION AND RECOMMENDATIONS

A comparative of analysis of Fourier Transform Infrared Spectroscopy (FTIR) in local activated carbons for suitability in the treatment of Kula Water, Akuku Toru LGA, Rivers State, was carried out in this study. The study therefore concluded that the FTIR spectra of the foreign and bamboo activated carbons, coconut shell activated carbons and palm kernel activated carbons exhibited certain and common functional groups. Firstly, both FAC and BAC exhibited common functional groups such as hydroxyl, alkanes, and aromatic rings. However, the FAC displays a strong carbonyl peak, indicating the existence of functional groups like aldehydes, carboxylic acids, or ketones, while in contrast, BAC exhibits unique peaks at 800 cm^{-1} and 500 cm^{-1}, characteristics of C-C stretching in aromatic rings. FTIR spectra showed that both FAC and CSAC exhibited common functional groups such as hydroxyl (O-H stretching at ~3400 cm^{-1}), alkanes (C-H stretching at ~2900 cm^{-1} and ~2850 cm^{-1}), and aromatic rings (C=C stretching at ~1600 cm^{-1} and ~1500 cm^{-1}). The foreign activated carbon displays a strong carbonyl peak (C=O stretching at 1711.61 cm^{-1}), indicating the existence of functional groups like aldehydes, carboxylic acids, or ketones. The difference between FAC and CSAC is found in Carbonyl group whereby FAC displays a strong peak at 1711.61 cm^{-1} while CSAC shows a medium intensity peak in this region, suggesting a lower abundance of carbonyl groups and, also FAC exhibits a weak peak at 445.72 cm^{-1}. Furthermore, the peaks identified in PKSAC at displayed medium-intensity peaks corresponding to saturated hydrocarbons, which indicate the presence of organic residues from carbon precursors but contribute minimally to water treatment efficiency. Both PKSAC and FAC showed moderate peaks for aromatic C=C stretching. PKSAC exhibits medium-intensity peaks at C-H bending and C-O stretching, which are consistent with FAC peaks. PKSAC exhibits a similar functional profile to FAC, indicating its suitability for water treatment. However, slight differences in peak intensities may affect their adsorption efficiency and specificity.

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