



## Physicochemical and Characteristic Properties of Activated Carbon Prepared from Mango Seed Shells Via $H_3PO_4$ and $ZnCl_2$ Activation



Idris S.<sup>1\*</sup>, Jamiu W.<sup>2</sup>, Muhammad Boyi Y.<sup>3</sup>, Shehu I. D.<sup>4</sup> & Adeniyi J. O.<sup>5</sup>

<sup>1,5</sup>Department of Chemistry, Federal University of Technology, Minna, Niger State, Nigeria.

<sup>2</sup>Department of Science Laboratory Technology, Chemistry Unit, Kwara State Polytechnic, Ilorin, Nigeria.

<sup>3</sup>Department of Chemistry, Shehu Shagari University of Education Sokoto, Sokoto State, Nigeria

<sup>4</sup>Department of Physical Sciences, Niger State Polytechnic, Zungeru, Niger State, Nigeria.

\*Corresponding Author Email: [suleimanidris@futminna.edu.ng](mailto:suleimanidris@futminna.edu.ng)

### ABSTRACT

Highly porous and surface area activated carbons was prepared from mango seed shells using  $H_3PO_4$  and  $ZnCl_2$  as an activating agent. The activated carbon was prepared firstly by carbonisation followed by activation process. Physicochemical properties of activated carbons namely ash content was found to be  $9.21 \pm 0.03\%$  for AC1 (activated carbon prepared using  $H_3PO_4$  activation) and  $8.12 \pm 0.03\%$  for AC2 (activated carbon prepared using  $ZnCl_2$  activation). ; low moisture content of  $2.03 \pm 0.01\%$  for AC1 and  $2.02 \pm 0.13\%$  for AC2; volatile matter of  $20.11 \pm 0.05\%$  was recorded for AC1 and  $20.02 \pm 0.03\%$  for AC2 while high fixed carbon values was recorded for AC1 as  $68.65 \pm 0.05\%$  and  $69.84 \pm 0.14\%$  for AC2. The findings also revealed BET surface area values of  $227.40 \text{ m}^2/\text{g}$  and  $375.14 \text{ m}^2/\text{g}$  for AC1 and AC2; total pore value of  $0.35 \text{ cm}^3/\text{g}$  and  $0.48 \text{ cm}^3/\text{g}$  for AC1 and AC2 while pore diameter values was found to be  $2.12 \text{ nm}$  for AC1 and  $2.46 \text{ nm}$  for AC2 which indicated that both activated carbons are mesoporous making them crucial in facilitating the access of the adsorbate molecules to the interior of the carbon particles. FTIR analysis in activated carbon revealed stretching vibration C=O bond, C≡C bond, C≡N bond and C-H bond for AC1 and AC2. TGA was used to assess how the material responds to increasing temperatures. The prepared activated carbon has good fixed carbon content, better surface area and good pore diameter for better adsorption application.

### Keywords:

Fixed Carbon,  
Ash Content,  
Functional Group,  
Temperature,  
Porous

### INTRODUCTION

Activated carbon is a carbonaceous material which is predominantly amorphous in nature and in which a high degree of porosity is developed by the process of manufacturing and treatment. Activated carbon can be manufacture from virtually all carbonaceous materials like palm residue, corn cobs, apricot stones, rice husks and date palm seed (Ani *et al.*, 2020; Abdulkarim *et al.*, 2024). However, agricultural wastes offer the most available and cheapest of all the known raw materials. Activated carbon is inexpensive and hence very widely used adsorbent with exceptional adsorption capabilities and versatile applications (Isaac *et al.*, 2025). Activated carbon is a porous carbonaceous material with the highly developed surface area and rich surface groups, are widely used in numerous application. Activated carbons finds applications in treating substances like indigo carmine, removing potentially toxic elements (Hassan *et al.*, 2023) pesticides,

pharmaceutical liquid wastes and also been applied for adsorption, catalyst support, gas separation and storage, solvent recovery and decolorizing. The internal porosity and their related properties such as surface area, pore volume, pore size distribution, and the presence of functional groups on pore surfaces play a significant role in the adsorptive capacities of activated carbons. Activated carbons with abundance of micropores are extensively used for adsorption of small molecule pollutants, and highly developed mesoporous activated carbons are used for the adsorption of larger molecules such as dyes (Leon *et al.*, 2020; Soni *et al.*, 2020; Chuah *et al.*, 2022; Uchebulam *et al.*, 2022; Charles *et al.*, 2023; Tetteh *et al.*, 2024). Activated carbons are widely used as an adsorbent because of their high adsorption capacity, microporous structure, and high surface area. The preparation and effective utilization of activated carbon generated from natural plant materials have attracted worldwide attention in view of the large disposal problem detrimental to the environment.

The study focuses on the preparation of activated carbons from mango seed shells using  $H_3PO_4$  and  $ZnCl_2$  chemical activation. Also to characterized the activated carbons using BET analytical instrument which gives information on porosity and surface area; thermogravimetric analysis (TGA) which revealed thermal stability, decomposition characteristic and weight loss behavior of activated carbon with increasing temperature and FTIR to determine the functional group of the activated carbons.

## MATERIALS AND METHODS

### Sample Collection and Preparation

The mango seed shells was collected under the mango trees located at Gidan Mangoro in Bosso Local Government Area of Niger State. The mango seed shells were cleaned of dirt and ground into powder and kept for future used.

### Preparation of Activated Carbon Carbonisation

Exactly 5 g of powdered mango seed shell was weighed into clean crucibles. The crucible was introduced into a muffle furnace at  $800^\circ C$  for 15 minutes after the content of the crucible was poured into a coldwater for instant cooling thereafter washed with water three times then excess water was removed. The sample dried in the oven at  $100^\circ C$  for one h. This process was repeated until a substantial amount of carbonized sample obtained (Reza *et al.*, 2020; Marziyeh *et al.*, 2026).

### Activation Process

Exactly 5 g of already carbonized sample was properly mixed with  $5\text{ cm}^3$  of each 1 M  $H_3PO_4$  and  $ZnCl_2$  activating agent. The sample was allowed to stand for 24 h thereafter washed with tap water and washing with distilled water continue until the pH of 7 for the mixture was achieved then excess water was removed and sample dried in the oven at  $100^\circ C$  for one hour and the activated carbon stored in air tight container for further use (Reza *et al.*, 2020; Marziyeh *et al.*, 2026). Two activated carbons was produced namely AC1 (activated carbon prepared using  $H_3PO_4$  activation) and AC2 (activated carbon prepared using  $ZnCl_2$  activation).

## Determination of Physicochemical Properties of the

### Activated Carbon

#### Volatile matter

Volatile matter content was determined according to standard method (ASTM: D 2974-2014, Boadu *et al.*, 2018 and Ismail *et al.*, 2022). Exactly 1g of activated carbon was measured into a pre-dry crucible and cover with lid, then heat in a Gallenkamp muffle furnace regulated at  $950^\circ C$  for 30 min. After heating, the plate

was cool in desiccators and weigh. The amount weighed was taken as volatile matter.

#### Determination of moisture content

Exactly 2g of the activated carbon was weighed into a crucible. The sample was dried in the oven at a temperature of  $100^\circ C$  for 3 h and cooled in desiccator. The drying and weighing was repeated twice until constant weight obtain and recorded (Boadu *et al.*, 2018 and Ismail *et al.*, 2022).

$$\% \text{ Moisture Content (MC)} = \frac{W_i - W_f}{W_i} \times 100 \quad (1)$$

Where  $W_i$ = Initial weight of activated carbon  $W_f$ = Final weight after drying

#### Determination of Ash Content

A clean and dry crucible was weighed ( $W_0$ ) and 1 g of the powdered sample was added to the crucible, and the combined weight of the crucible and sample recorded ( $W_1$ ). The crucible was placed in a muffle furnace set to  $650^\circ C$  and heated for 3 h until a grayish white ash obtain. After this period, the crucible was removed and allow to cool to room temperature before weighing. The weight of the residue after ashing was recorded as ( $W_2$ ) (Boadu *et al.*, 2018 and Ismail *et al.*, 2022).

$$\% \text{ Ash} = \frac{W_2 - W_0}{W_1 - W_0} \times 100 \quad (2)$$

Where  $W_0$ = Wight of crucible,  $W_1$ = Weight of crucible + activated carbon,  $W_2$ = Weight of crucible + ashed activated carbon

#### Determination of fixed carbon

The fixed carbon (FC) was determined as follows.

$$FC(\%) = 100 - (MC + AC + VM)\% \quad (3)$$

Where MC=Moisture Content AS=Ash Content VM=Volatile Matter

#### Bulk Density of Activated Carbon

A  $25\text{ cm}^3$  cylinder was filled to a given volume with activated carbon. The cylinder was tapped for at least 1 min to compress the carbon to a steady volume. The compressed sample was weighed and the mass (M) divided by the volume occupy in the cylinder (V).

$$\text{Bulk Density (g/cm}^3\text{)} = \frac{\text{Mass}}{\text{Volume}} \quad (4)$$

#### pH and Conductivity Measurement

Exactly 1.0 g of activated carbon was weighed into beaker, and  $20\text{ cm}^3$  of was added to the sample. The sample was macerated with a long glass rod to ensure uniform wetting. The water volume was increased to  $100\text{ cm}^3$ . The sample was then stirred for 30 s and left to stand for 1 h. Throughout the experiment, the beaker was covered with clean, washed glass covers. After the standing period,  $10\text{ cm}^3$  of the extract was decanted into a clean, dry beaker. The pH and conductivity of the

extract was measured immediately using a pH meter and a conductivity meter at room temperature.

#### Yield of Activated Carbon

The yield of activated carbon is defined as the ratio of the weight of the resultant activated carbon to the weight of the original precursor, measured on a dry basis (Ismail *et al.*, 2022).

$$\text{Yield (\%)} = \frac{\text{Weight of Activated Carbon}}{\text{Weight of Precursor}} \times 100 \quad (5)$$

#### Characterisation of Activated Carbon

##### Brunauer-Emmett-Teller (BET)

The Brunauer-Emmett-Teller (BET) Surface was determined by nitrogen adsorption at 77 K. The nitrogen gas adsorption measurements were done after the carbon was degassed at 300 °C in an inert condition for 24 h. The BET surface area, mesopore volume, micropore surface area and pore diameter of the activated carbon was determined by the application of the Brunauer- Emmett-Teller (BET), Dubinin-Asthakov (DA) and BJH (Barrett–Joyner–Halenda) analysis software respectively (Boadu *et al.*, 2018).

##### Frourer Transform Infrared Spectrometer

(Themo Nicolet, model magna 760) was used to determine the functional groups of the activated carbon using the pellet press disk technique. The adsorbent/KBr mass ratio was 100:1. The spectral scanned at the rate of 10 nms<sup>-1</sup> ranged from 4000 to 400 cm<sup>-1</sup>.

##### Thermogravimetric Analysis (TGA)

It is used to investigate the thermal stability, decomposition characteristics and weight loss behaviour of activated carbon with increase in temperature.

## RESULTS AND DISCUSSION

### Physicochemical Properties of the Activated Carbon

The findings showed the ash content of AC1 and AC2 were found to be in the range of 9.21±0.03%-8.12±0.03% and moisture content was in the range of 2.03±0.01% -2.02±0.13% for AC1 and AC2 respectively indicating good and well dried activated carbons. The findings indicated volatile matter of 20.11±0.05% and 20.02±0.03% for AC1 and AC2 were as fixed carbon content were 68.65±0.05% and 69.84±0.14% for AC1 and AC2. The results of the carbon content agreed well with a previous finding which reported a fixed carbon content of equal to or greater than 65% (Boadu *et al.*, 2018).

**Table 1: Physicochemical properties of activated carbons**

Parameters	AC1	AC2
Ash Content(%)	9.21±0.03	8.12±0.03
Moisture Content(%)	2.03±0.01	2.02±0.13
Volatile Matter(%)	20.11±0.05	20.02±0.03
Fixed Carbon(%)	68.65±0.05	69.84±0.14
pH	7.08±0.01	7.01±0.14
Conductivity(μS/cm)	0.13±0.12	0.18±0.03
Bulk Density(g/cm <sup>3</sup> )	0.30±0.15	0.29±0.03
% Yield	36.5±0.04	40.5±0.13

AC1 (Activated carbon prepared using H<sub>3</sub>PO<sub>4</sub> activation) and AC2 (Activated carbon prepared using ZnCl<sub>2</sub> activation).

The outcome of the research revealed pH range of 7.08±0.01 and 7.01±0.14 for AC1 and AC2 respectively. The pH of activated carbon is important to the adsorption of pollutant in solution and for most applications activated carbon pH of 6.5-7.5 is accepted. Activated carbon with adequate bulk density helps to improve the filtration rate by forming an even cake on the filter surface. The activated carbons bulk density was found to be 0.30±0.15 and 0.29±0.03 g/cm<sup>3</sup> respectively. The

activated carbons indicated percentage yield of 36.5±0.04 for AC1 and 40.5±0.13for AC2 respectively.

The conductivity test is important because it shows the presence of leachable ash which is considered impurity and undesirable (Isaac *et al.*, 2025). The conductivity of 0.13±0.12 and 0.18±0.03 μS/cm demonstrated the prepared activated carbons contain less leachable ash.

### Characterisation Properties of Activated Carbon

#### Brunauer-Emmett-Teller (BET)

The BET surface area value is an indication of the presence of many adsorption sites and thus showing desirable characteristics for potential use as pollutant

adsorbent (Boadu *et al.*, 2018). The carbonization temperature accelerates thermal degradation and the volatilization process of the impregnated sample. This process leads to increases in the surface area and pore development. The findings indicated surface area of 227.40 m<sup>2</sup>/g and 375.14 m<sup>2</sup>/g for AC1 and AC2 respectively. Total pore volume of 0.35cm<sup>3</sup>/g and 0.48cm<sup>3</sup>/g was recorded for AC1 and AC2 (Table 2) respectively. The prepared adsorbents are both mesoporous making the crucial materials for facilitating the access of the adsorbate molecules to the interior of the carbon particles (Isaac *et al.*, 2025).

**Table 2: Surface area and pore size characterization of the activated carbons**

Parameters	AC1	AC2
BET Surface Area(m <sup>2</sup> /g)	227.40	375.14
Micropore volume(cm <sup>3</sup> /g)	0.21	0.32
Mesopore volume(cm <sup>3</sup> /g)	0.14	0.16
Total pore volume (cm <sup>3</sup> /g)	0.35	0.48
Pore diameter (nm)	2.12	2.46

#### Fourier Transform Infrared (FTIR) Analysis

FTIR identifies the functional groups present on the carbon surface which also helps in understanding the

surface chemistry and potential interaction with target molecules in adsorption applications. FTIR spectroscopy structure gives the chemical structures of activated carbon, providing insights into its reactivity and adsorption capabilities for various industrial application. The FTIR analysis of both AC1 (Figure 1) and AC2 (Figure 2) reveals the presence of important functional groups that contribute to the adsorption capacity of the activated carbon produced. Some prominent peaks for AC1 around 1802 cm<sup>-1</sup> indicates stretching vibration C=O and another peak at 2105 cm<sup>-1</sup> which indicates C≡C stretching vibration in alkyne aliphatic hydrocarbon. Another peak at 2327 cm<sup>-1</sup> which indicates C≡N bond in nitrogen functional group and last peak at 2879 cm<sup>-1</sup> indicates C-H stretching vibration in aliphatic hydrocarbon. Also AC2 shows peak at 1015 cm<sup>-1</sup> which indicates C≡N stretching and another peak 1408 cm<sup>-1</sup> which indicates C-C bond in aromatic hydrocarbon. Peaks at 1606 cm<sup>-1</sup> indicates unsaturated bond in aromatic hydrocarbon and another peaks 2078 cm<sup>-1</sup> which indicates C≡C stretching vibration in alkyne aliphatic hydrocarbon. FTIR analysis in activated carbon identify surface functional groups, analyze the molecular structure, chemical composition and properties. It also provides valuable insight into surface properties and chemistry of activated carbon, helping to optimize its performance in various applications.

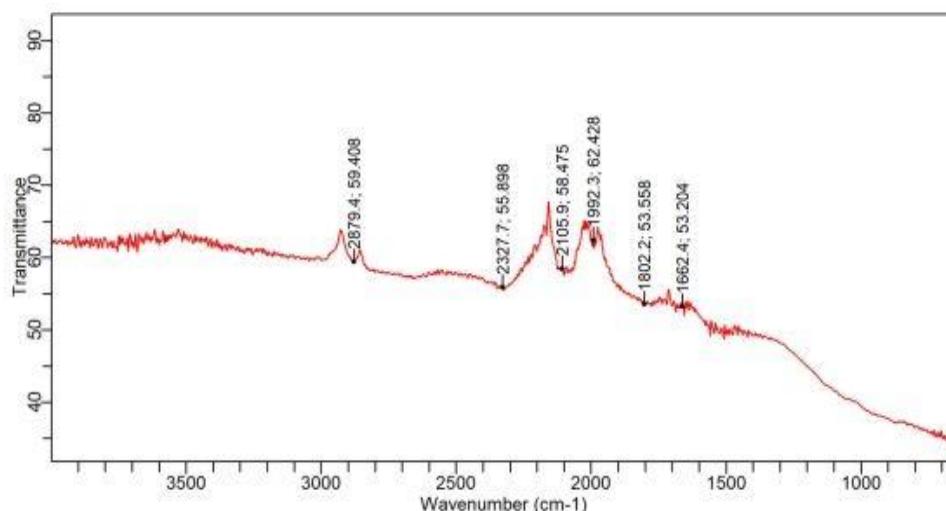


Fig.1: Fourier transform infrared spectroscopy of activated Carbon (AC1)

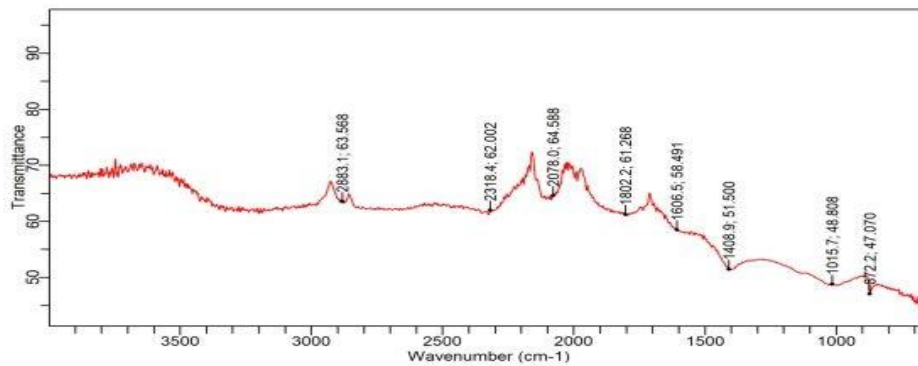


Fig. 2: Fourier transform infrared spectroscopy of activated Carbon (AC)

**Thermogravimetric Analysis (TGA) Analysis**

TGA analysis provides information on the moisture content, volatile matter, thermal stability, decomposition temperature, oxidation and combustion as well as ash content. It is commonly used to characterize materials and optimize processes (González-García, 2018). In this study, TGA was used to assess how the material responds to increasing temperatures (Figure 3 and 4). The gradual weight loss observed during heating is primarily attributed to the removal of moisture and volatile organic compounds from the activated carbon. The outcome of the results revealed that as the temperature increases, the activated carbon percentage weight decreases for both

AC1 and AC2. As for AC1 the weight loss decreases drastically after the temperature of 500°C while AC2 is more drastic at temperature of 500 °C as the weight percentage continue to decreases which signifying the breakdown of the organic structure and the release of non-carbon elements like hydrogen and oxygen. This stage is crucial for the formation of the porous structure, as it leaves behind a carbon-rich framework with high adsorptive capacity. The material’s thermal stability beyond this temperature range demonstrates its suitability for high-temperature applications such as gas adsorption and catalytic processes (Isaac *et al.*, 2025).

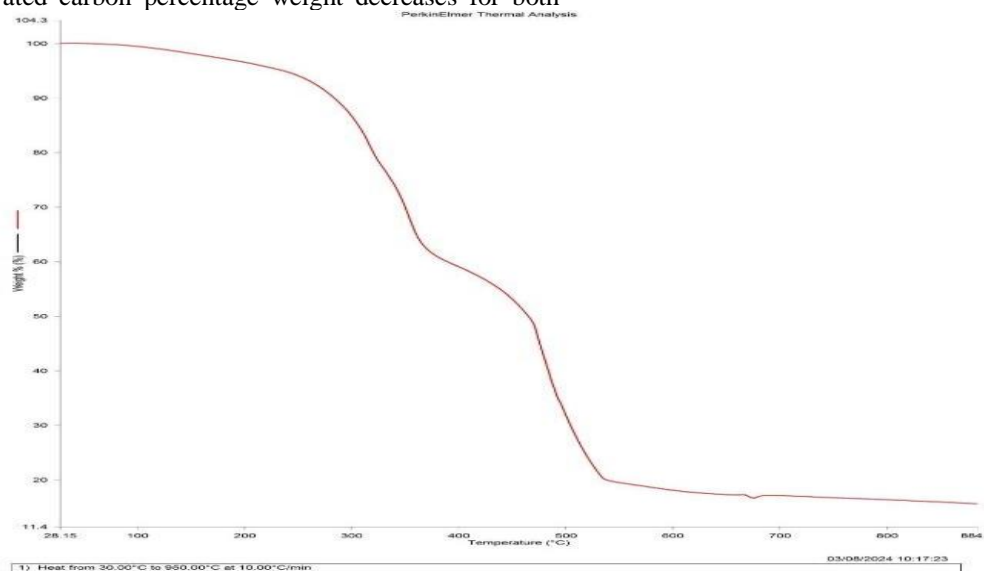


Fig. 3 Thermogravimetric analysis of AC1

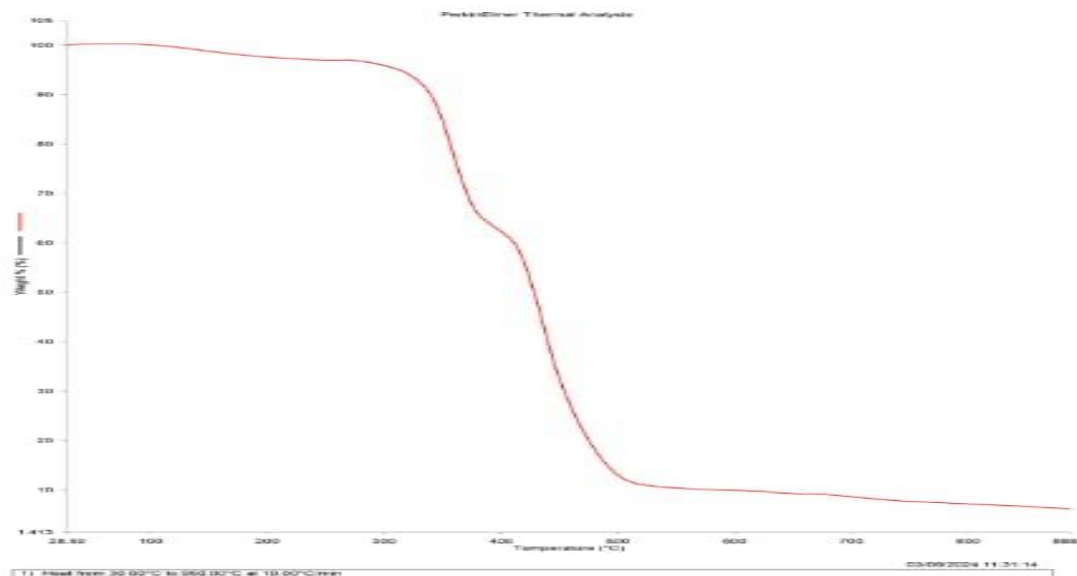


Fig. 4: Thermogravimetric analysis of AC2

## CONCLUSION

The activated carbons prepared from mango seed shells have good BET surface area indicating better adsorption sites for the activated carbons and both are also mesoporous that are needed in facilitating the access of the adsorbate molecules to the interior of the carbon particles. The FTIR analysis of both AC1 and AC2 reveals the presence of important functional groups that contribute to the adsorption capacity of the activated carbon produced. In both samples C≡N, C≡C, C-H and C-C bonds were all available. These groups play a vital role in enhancing the hydrophilicity and chemical reactivity of the activated carbon, which is beneficial for adsorption of polar compounds.

## ACKNOWLEDGEMENTS

The authors are grateful to all the laboratory technologists, Department of Chemistry, Federal University of Technology Minna, Niger State Nigeria, for their support during the research period.

## REFERENCES

Abdulkarim, M., Ibrahim, I. L., Mohammed, M. and Musah, M. (2024). Preparation and characterization of activated carbon from date palm (*Phoenix dactylifera*) seeds. *FUDMA Journal of Science*, 8(3):409-415

Ani, J. U., Akpomie, K. G., Okoro, U. C., Aneke, L. E., Onukwuli, O. D., & Ujam, O.T. (2020). Potentials of activated carbon produced from biomass materials for sequestration of dyes, heavy metals, and crude oil components from aqueous environment. *Applied Water Science*, 10(2):69.

Boadu, K. O., Joel, O. F., Essumang, D. K. And Egbuomwan, B. (2018). Comparative Studies of the Physicochemical Properties and Heavy Metals adsorption Capacity of Chemical Activated Carbon from Palm Kernel, Coconut and Groundnut Shells. *Journal of Applied Science Environmental Management*. 22 (1).1833–1839.

Charles, M., Joseph, A. and Benson, E. (2023). The use of locally formulated green de-oiler in oil field effluent water treatment, *Glob. J. Eng. Technol. Adv.* 15 (3):124–134.

Chuah, C.Y. and Laziz, A.M. (2022). Recent progress in synthesis and application of activated carbon for CO<sub>2</sub>, *Capture*, C 8 (2) :29.

González-García, P. (2018). Activated carbon from lignocellulosic waste materials: Preparation, characterization, and environmental applications. *Chemical Engineering Journal*, 353, 457-472.

Hassan, S.S., Khong, H. Y. and Chang, Y.H.R. (2023). Facile preparation of scalable bambooderived activated carbon for efficient wastewater treatment, *Bio Resources*, 18 (3) 5292–5308

Isaac, K. T., Solomon, N., Janet, A., Boadu, A. N., Esther B. D., and Antonia Y. T. (2025). Characterization and environmental performance evaluation of locally manufactured P-32 and commercial activated carbons on the Ghanaian market. *Sustainable Chemistry for the Environment*, 10: 100261

- Ismail, I. S., Rashidi, N. A. and Yusup, S. (2022). Production and characterization of bamboo-based activated carbon through single-step  $H_3PO_4$  activation for  $CO_2$  capture. *Environ. Sci. Pollut. Res.* 29:12434.
- Leon, M., Silva, J., Carrasco, S. and Barrientos, N. (2020). Design, cost estimation and sensitivity analysis for a production process of activated carbon from waste nutshells by physical activation, *Processes* 8 (8):1276
- Reza, S., Yun, C. S., Afroze, S., Radenahmad, N., AbuBakar, M. S., Saidur, R., Taweeekun, J. & Azad, A. K. (2020). Preparation of activated carbon from biomass and its applications in water and gas purification, a review. *Arab Journal of Basic and Applied Sciences*, 27(1), 208–238.
- Soni, R., Bhardwaj, S. and Shukla, D.P. (2020). Various water-treatment technologies for inorganic contaminants: current status and future aspects, *Inorg. Pollut. Water*:273–295
- Tetteh, I.K., Issahaku, I. and Tetteh, A.Y. (2024) Recent advances in synthesis, characterization, and environmental applications of activated carbons and other carbon derivatives, *Carbon Trends*:100328
- Uchegbulam, I., Momoh, E.O. and Agan, S.A. (2022). Potentials of palm kernel shell derivatives: A critical review on waste recovery for environmental sustainability, *Cleaner Materials*, 6:100154.