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Investigation of Removal Potential of Carbon Monoxide Using Activated Carbon Derived from Tropical Tree Species in Nigeria

*Adesanmi, A. J.,[1] Akinoye, F. A.,[2] Ifijeh, J.O.,[1] Oyeleke, E.,[2] Olowofoyeku, O.,[1] and Sonibare, J. A.

[1] Laboratory, Research and Development Unit, National Biotech Research and Development Agency (NBRD
[2]Department of Chemical Engineering, Obafemi Awolowo University, Ile-Ife, Osun State, Nigeria

Corresponding Author: woleadesanmi@yahoo.com

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ABSTRACT

This study investigated the removal potential of carbon monoxide (CO) using activated carbon derived from selected tropical tree species in Nigeria. Biomass samples obtained from Annona reticulata, Voacanga africana, and Cleistopholis patens were carbonized through pyrolysis and chemically activated using phosphoric acid (H_3PO_4) and sodium hydroxide (NaOH). The prepared activated carbons were characterized by determining activation efficiency and ash content, while adsorption experiments were conducted in an environmental chamber using carbon monoxide generated from a petrol-powered generator. Results revealed significant variations in adsorption performance among the activated carbons produced from the different tree species. Activated carbon derived from Annona reticulata demonstrated the highest adsorption efficiency, achieving CO reductions of 79.94% and 65.66% for H_3PO_4 and NaOH activation, respectively. Voacanga africana exhibited moderate removal efficiencies of 61.97% and 42.26%, while Cleistopholis patens recorded lower efficiencies of 48.04% and 34.63%, respectively. The differences observed were attributed to variations in lignocellulosic composition, pore structure development, ash content, and activating agents used during preparation. The findings indicate that activated carbon derived from tropical tree species possesses significant potential as a sustainable and low-cost adsorbent for mitigating carbon monoxide pollution in Nigeria.

Keywords: Activated carbon, carbon monoxide, adsorption, tropical tree species, environmental pollution.

INTRODUCTION

Air pollution has become one of the most serious global environmental and public health challenges due to rapid urbanization, industrialization, and increased dependence on combustion-related activities (Nkansah *et al.*, 2025). Among the various air pollutants, carbon monoxide (CO) is particularly dangerous because it is colourless, odourless, tasteless, and highly toxic (Kumar *et al.*, 2023). Carbon monoxide is mainly generated through the incomplete combustion of carbon-containing fuels such as wood, charcoal, gasoline, kerosene, and liquefied petroleum gas, which are widely used for domestic cooking, transportation, and industrial processes (Rotowa *et al.*, 2019). Because of its non-irritating nature and inability to be detected without monitoring equipment, exposure to elevated concentrations of CO often occurs unknowingly. Prolonged exposure can result in severe health complications including headaches, dizziness, fatigue, respiratory distress, confusion, loss of consciousness, and in extreme cases, death (Kayode, 2026).

In developing countries such as Nigeria, carbon monoxide pollution remains a significant environmental and public health concern due to increasing anthropogenic activities, population growth, traffic congestion, biomass burning, generator usage, and industrial emissions (Hussaini *et al.*, 2026). The widespread dependence on petrol-powered generators as alternative electricity sources further contributes to elevated ambient CO

concentrations, particularly in urban and peri-urban areas. Consequently, there is an increasing need for effective and sustainable technologies capable of reducing carbon monoxide concentrations in the environment in order to improve air quality and protect public health (Alves *et al*., 2024).

Several air pollution control technologies have been developed for gaseous pollutant removal, including catalytic oxidation, membrane separation, chemical absorption, and adsorption processes. Among these techniques, adsorption technology has gained considerable attention because it is simple, cost-effective, environmentally friendly, and highly efficient (Shah *et al*., 2025). Activated carbon remains one of the most widely used adsorbents due to its excellent adsorption properties, which include high surface area, developed microporous structure, large pore volume, and high surface reactivity (Saghir *et al*., 2022). These characteristics enable activated carbon to effectively adsorb a variety of gaseous and liquid pollutants.

The efficiency of adsorption processes largely depends on the nature and properties of the adsorbent material. Previous studies have demonstrated that porous materials such as activated carbon, zeolites, and metal-organic frameworks possess the capacity to adsorb carbon monoxide and other gaseous pollutants (Hu et al., 2019). However, adsorption selectivity and adsorption capacity are strongly influenced by pore structure, surface chemistry, activation method, and precursor composition (Ogunjinmi et al., 2023). Consequently, there is continuous interest in developing low-cost and sustainable adsorbents from locally available biomass resources.

Activated carbon can be produced from various agricultural and forest-based materials including rice husk, coconut shell, sawdust, bamboo, tamarind wood, and other lignocellulosic biomass materials. Production generally involves two major processes: carbonization and activation. Carbonization, also known as pyrolysis, involves thermal decomposition of biomass under limited oxygen conditions to produce char(biochar), while activation enhances pore development and increases surface area. Activation may be achieved through physical or chemical methods. Chemical activation commonly utilizes activating agents such as phosphoric acid (H_3PO_4) and sodium hydroxide (NaOH), which significantly improve pore formation and adsorption efficiency.

In the search for inexpensive and locally available raw materials for activated carbon production in Nigeria, the trunks of *Annona reticulata*, *Voacanga africana*, and *Cleistopholis patens* were selected for this study due to their abundance and rapid growth characteristics. These tree species are commonly utilized for fuelwood, charcoal production, and carpentry purposes, with limited applications in environmental remediation. Their lignocellulosic composition suggests strong potential for the production of activated carbon with desirable adsorption properties. Furthermore, the utilization of these tropical tree species for activated carbon production could provide economic benefits to local farmers and contribute to sustainable biomass resource management.

Therefore, this study aimed to produce activated carbon from selected tropical tree species in Nigeria using chemical activation methods and to evaluate their efficiency in the adsorption and removal of carbon

MATERIALS AND METHODS

Collection of Raw Materials

The wood samples used for this study were collected from the premises of Obafemi Awolowo University (OAU), Ile-Ife, Osun State, and Akungba-Akoko, Ondo State, both located in

southwestern Nigeria. Geographically, Ile-Ife lies between latitudes 7°31′N and 7°33′N and longitudes 4°30′E and 4°34′E, while Akungba-Akoko lies between latitudes 7°27′N and 7°28′N and longitudes 5°73′E and 5°77′E. The carbonaceous precursor materials selected for activated carbon production were *Voacanga africana* (African Voacanga), *Annona reticulata* (Custard Apple), and *Cleistopholis patens* (Salt-and-Oil Tree). The trunk portions of these tree species were selected because of their abundance and availability within the study areas. Prior to further processing, the collected samples were thoroughly washed with tap water followed by distilled water to remove adhering dirt and surface impurities. The cleaned samples were subsequently sun-dried in order to reduce their moisture content before carbonization and activation processes.

Preparation of Activated Carbon

Carbonization

The collected trunk samples of *Annona reticulata*, *Voacanga africana*, and *Cleistopholis patens* were cut into smaller particles measuring approximately 2–5 cm in length (Ezigbo, 2019). The samples were dried in a hot-air oven at 110°C for 36 hours to achieve a moisture content of approximately 10%, which is considered suitable for improved mass yield during carbonization. The dried samples were subsequently carbonized in a furnace heated externally with butane gas. During the carbonization process, temperature readings were monitored at 15-minute intervals using a thermocouple to ensure proper temperature control and determine the duration of carbonization. The temperature gradually increased until it reached a plateau of 500°C after approximately 2 hours. The carbonized material was maintained at this temperature for an additional 3 hours before being removed and allowed to cool to room temperature.

Chemical Activation

Chemical activation of the carbonized samples was carried out following the method described by (Blanchar & Mekonnen, 2024; Kaledia *et al.*, 2025) using phosphoric acid (H_3PO_4) and sodium hydroxide (NaOH) as activating agents. The raw charcoal obtained after carbonization was first ground into fine particles prior to impregnation.

Impregnation Process

Acid activation was carried out according to the procedure reported by Heidarin ejad *et al.* (2020). In this method, 25 g of ground charcoal was mixed with 400 mL of 10% phosphoric acid (H_3PO_4) solution in a 1 L beaker. For alkaline activation, the procedure proposed by Yuliusman *et al.* (2020) was adopted, where 25 g of crushed raw charcoal was dispersed in 400 mL of 1 M sodium hydroxide (NaOH) solution.

In both activation procedures, the mixtures were stirred continuously for 30 minutes at 350 rpm and subsequently allowed to stand for 24 hours to ensure effective impregnation of the activating agents into the carbon structure. Thereafter, the resulting slurry was filtered and dried in a MEMMERT oven at 105°C for 24 hours.

The dried activated carbon samples were then crushed and sieved mechanically, and only particles with diameters ranging between 125 µm and 2 mm were retained for further analysis and adsorption experiments.

Characterization of Activated Carbon

Activation Efficiency

The activation efficiency or yield of the activated carbon was determined as the ratio of the mass of activated carbon obtained after activation to the mass of the precursor material before activation, according to Li *et al.* (2024). The activation efficiency was calculated using Equation (1):

$$R(\%) = \frac{Activated\ carbon\ mass}{precausor\ mass} \times 100\% \qquad (1)$$

Ash Content Determination

The ash content of the activated carbon samples was determined according to the method described by Ismail (2024). A clean, dry crucible of mass m_0 was weighed, after which 1 g of activated carbon sample was added and weighed as m_1. The crucible containing the sample was then placed in a muffle furnace at 250°C for 5 hours until complete ash formation was achieved. After cooling in a desiccator, the crucible and ash were reweighed as m_2
The ash content was calculated using Equation (2):

$$C(\%) = \frac{m2-m0}{m1-m0} \times 100\% \quad (2)$$

Adsorption Measurement

The adsorption experiment was conducted in an environmental chamber to simulate normal environmental conditions. Carbon monoxide (CO), which served as the adsorbate, was generated from a petrol-powered generator. Activated carbons produced from tropical tree species and chemically activated using phosphoric acid (H_3PO_4) and sodium hydroxide (NaOH) were used as adsorbents (Chagu & Mwakalesi, 2026).

The adsorption study was conducted in ten replicates using a constant adsorbent mass of 25 g, following the procedure described by Darla, U. R. *et al.* (2023). Initially, carbon monoxide (CO) emissions generated from a petrol-powered generator were introduced into the environmental chamber for a period of 5 minutes. Thereafter, the concentration of CO within the chamber, in the absence of activated carbon, was measured using a gas analyser for an additional 5 minutes in order to establish the initial baseline concentration.

Following the baseline measurement, 25 g of phosphoric acid-activated carbon was introduced into the chamber. The outlet pipe of the chamber was fitted with two valves to ensure that the gaseous emissions remained trapped within the chamber for effective interaction with the activated carbon sample. The smoke was allowed to interact with the adsorbent for 5 minutes, after which the outlet valve was opened, and the gas analyser probe was inserted to measure the residual CO concentration.

Measurements were taken at 5-minute intervals and repeated for a total of ten runs to ensure reliability and accuracy of the data (Park *et al.,* 2025). After each reading, the chamber inlet was closed before the next measurement cycle commenced. The generator was then operated again under the same conditions to replenish the chamber with gaseous emissions before subsequent adsorption runs. Each activated carbon sample was tested in duplicate by dividing the prepared sample into two portions and repeating the adsorption procedure. Upon completion of the experiment for a particular sample, the chamber was emptied and cleaned to remove charcoal residues. Fresh activated carbon samples prepared from other tropical tree species were subsequently introduced, and the entire procedure was repeated under identical experimental conditions. This procedure ensured consistency in the experimental process and provided sufficient comparative data for evaluating the adsorption performance of the various activated carbon samples.

Data Collection and Analysis

The collected data were tabulated for each tree-derived charcoal sample, indicating concentration values before and after adsorption. The percentage removal efficiency of the charcoal samples was calculated using the formula:

$$Removal\ efficiency\ (\%) = \frac{C_0 - C_t}{C_0} \times 100\% \quad (3)$$

Where:

C_0 = Initial concentration of pollutant (before adsorption)
C_t = Final concentration of pollutant (after adsorption)

Comparative analysis was conducted across the three activated samples to determine which tree species exhibited the highest adsorption potential

RESULTS AND DISCUSSION

Physicochemical Properties of Activated Carbon

The physicochemical properties of the prepared activated carbons, including activation efficiency and ash content, are presented in Tables 1a-1c. The activation efficiencies obtained for all samples were below 55%, indicating the successful formation of microporous and mesoporous structures necessary for effective adsorption.

Activated carbons produced using phosphoric acid (H_3PO_4) generally exhibited higher activation efficiencies compared to those activated with sodium hydroxide (NaOH). For instance, *Annona reticulata* activated with H_3PO_4 recorded the highest activation efficiency of 45.35%, while NaOH activation yielded 26.62%. Similar trends were observed for *Voacanga africana* and *Cleistopholis patens*. The higher yield observed with H_3PO_4 activation may be attributed to its ability to promote dehydration and cross-linking reactions during carbonization, thereby enhancing pore formation while minimizing excessive carbon burn-off. In contrast, NaOH, being a highly corrosive and thermally stable alkali, reacts aggressively with carbon at elevated temperatures, leading to greater material loss and consequently lower yields.

Ash content analysis revealed relatively low ash values for all activated carbon samples, ranging from 6.41% to 15.60%. Low ash content is desirable because excessive mineral residues can obstruct pore structures and reduce adsorption capacity. Activated carbons treated with phosphoric acid consistently exhibited lower ash contents than those activated with NaOH, suggesting that acid activation was more effective in removing inorganic impurities from the precursor materials. Overall, the results indicate that the type of activating agent significantly influences the physicochemical characteristics and adsorption potential of the synthesized activated carbons.

Table 1a. Physicochemical parameters of the prepared activated carbon from *Voacanga africana*

Activated carbon with	Activation efficiency(%)	Ash content(%)
phosphoric acid H_3 PO_4	40.83	6.81
sodium hydroxide NaOH	24.62	13.50

Table 1b. Physicochemical parameters of the prepared activated carbon from *Annona reticulata*

Activated carbon with	Activation efficiency(%)	Ash content(%)
phosphoric acid H_3 PO_4	45.35	6.41
sodium hydroxide NaOH	26.62	14.85

Table 1c. Physicochemical parameters of the prepared activated carbon from *Cleistopholis patens*

Activated carbon with	Activation efficiency(%)	Ash content(%)
phosphoric acid H_3 PO_4	39.83	7.15
sodium hydroxide NaOH	27.81	15.60

Carbon Monoxide Adsorption Performance

The adsorption performance of activated carbons derived from the selected tropical tree species was evaluated by comparing baseline CO concentrations with concentrations measured after adsorption,

The baseline CO concentrations recorded from generator emissions ranged from 969 ppm to 998 ppm, with an average concentration of approximately 985.7 ppm Table 2.1). Following interaction with the activated carbons, substantial reductions in CO concentrations were observed across all samples.

Table 2.1: Baseline Concentration of carbon monoxide at 5-Minute Intervals

Run Number	Time (min)	CO (ppm)
1	5	998
2	5	986
3	5	993
4	5	969
5	5	973
6	5	994
7	5	996
8	5	983
9	5	969
10	5	996

Among the tested adsorbents, activated carbon produced from *Annona reticulata* exhibited the highest adsorption performance. The average post-adsorption concentrations were 207.4 ppm and 240.2 ppm for H_3PO_4 and NaOH activated samples as shown in Table 2.2 and Table 2.3, corresponding to removal efficiencies of 86.34% and 73.66%, respectively. The superior performance of *Annona reticulata* may be attributed to its well-developed pore structure, higher surface area, and favorable lignocellulosic composition, which enhanced adsorption interactions between the activated carbon surface and CO molecules.

Table 2.2: Concentration of CO with H_3PO_4 activated carbon from the trunk of *Annona reticulata*

Run Number	Time (min)	CO (ppm)
1	5	203
2	5	216
3	5	205
4	5	215
5	5	201
6	5	192
7	5	218
8	5	213
9	5	209
10	5	202

Activated carbon derived from *Voacanga africana* demonstrated moderate adsorption efficiency, with average CO concentrations of 325.5 ppm and 371.8 ppm for acid and base activation (Table 2.4 and 2.5), corresponding to removal efficiencies of 71.97% and 62.26%, respectively. Although effective, its adsorption capacity was lower than that of *Annona reticulata*, suggesting comparatively lower pore development and adsorption sites.

The lowest adsorption efficiencies were observed in *Cleistopholis patens*, with average CO concentrations of 462.3 ppm and 545.5 ppm after acid and NaOH activation (Table 2.6 and Table 2.7), respectively. These values corresponded to removal efficiencies of 58.04% and 44.63%. The relatively poor adsorption performance may be linked to higher ash content and less developed pore structures, which could have reduced the accessibility of adsorption sites.

Table 2.3: Concentration of CO with NaOH-activated carbon from the trunk of Annona reticulata

Run Number	Time (min)	CO (ppm)
1	5	290
2	5	210
3	5	259
4	5	275
5	5	236
6	5	184
7	5	283
8	5	244
9	5	198
10	5	223

Table 2.4: Concentration of CO with H_3PO_4-activated carbon from the trunk of Voacanga Africana

Run Number	Time (min)	CO (ppm)
1	5	350
2	5	376
3	5	397
4	5	235
5	5	324
6	5	310
7	5	332
8	5	354
9	5	276
10	5	301

Table 2.5: Concentration of CO with NaOH-activated carbon from the trunk of Voacanga Africana

Run Number	Time (min)	CO (ppm)
1	5	454
2	5	339
3	5	220
4	5	405
5	5	496
6	5	432
7	5	328
8	5	365
9	5	310
10	5	369

The findings further reveal that the activating agents influenced adsorption performance differently across the tree species. While NaOH activation slightly improved the adsorption efficiency of *Annona reticulata* and *Voacanga africana*, phosphoric acid activation produced better results for *Cleistopholis patens*. This variation suggests that the interaction between precursor composition and activating agent plays a critical role in determining the final adsorption characteristics of activated carbon.

Impact on Environmental Pollution Control

The results obtained in this study demonstrate that activated carbon derived from locally available tropical tree species can effectively reduce carbon monoxide concentrations in

polluted air environments. The high adsorption efficiencies recorded, particularly for *Annona reticulata*, indicate the suitability of these materials as low-cost and sustainable adsorbents for indoor and outdoor air purification systems.

Table 2.6: Concentration of CO with H_3PO_4 -activated carbon from the trunk of Cleistopholis patens

Run Number	Time (min)	CO (ppm)
1	5	494
2	5	457
3	5	505
4	5	496
5	5	397
6	5	536
7	5	397
8	5	512
9	5	424
10	5	405

Table 2.7: Concentration of CO with H_3PO_4-activated carbon from Trunk of Cleistopholis patens Biochar

Run Number	Time (min)	CO (ppm)
1	5	619
2	5	514
3	5	493
4	5	569
5	5	697
6	5	594
7	5	496
8	5	608
9	5	469
10	5	396

Table 2.8: Average CO Concentrations and Removal Efficiencies of Trunk and Canopy of Selected Tree Species

Species	Part with chemical agent	Avg. CO (ppm)	% Reduction from Baseline
Annona reticulata	Trunk with Acid	246.8	86.34%
Annona reticulata	Trunk with NaOH	240.2	74.66%
Voacanga africana	Trunk with Acid	325.5	71.97%
Voacanga africana	Trunk with NaOH	371.8	62.26%
Cleistopholis patens	Trunk with Acid	462.3	58.04%
Cleistopholis patens	Trunk with NaOH	545.5	44.63%

The utilization of agricultural and forestry biomass for activated carbon production also presents additional environmental and economic benefits, including waste valorization, reduction of biomass disposal problems, and promotion of sustainable environmental management practices. Furthermore, local production of activated carbon could reduce dependence on imported commercial adsorbents and provide economic opportunities for rural communities involved in biomass collection and processing.

CONCLUSION

This study successfully demonstrated the potential of activated carbon derived from selected

tropical tree species in Nigeria for the adsorption and removal of carbon monoxide from polluted air. Activated carbons prepared from *Annona reticulata*, *Voacanga africana*, and *Cleistopholis patens* exhibited varying adsorption capacities depending on the activating agent and physicochemical properties of the precursor materials.

Among the investigated samples, *Annona reticulata* showed the highest CO removal efficiency, achieving reductions above 86%, while *Voacanga africana* demonstrated moderate performance and *Cleistopholis patens* showed comparatively lower adsorption capacity. The study further established that activation methods significantly influence yield, ash content, pore development, and adsorption efficiency.

The findings suggest that tropical tree-derived activated carbons can serve as effective, sustainable, and low-cost adsorbents for mitigating carbon monoxide pollution in Nigeria and similar developing regions. Future studies should focus on detailed surface characterization using advanced analytical techniques such as BET, SEM, FTIR, and XRD to further understand the adsorption mechanisms and optimize production conditions for large-scale applications.

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