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Sustainable Production and Characterization of Activated Carbon from Palm Kernel Shell: Assessing Its Potential for Industrial Applications

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Abstract: *The objective of this study is to produce and comprehensively characterize activated carbon derived from palm kernel shell, aiming to explore its potential as an efficient adsorbent in various industrial applications. The palm kernel shell was initially carbonized in an electric furnace at an elevated temperature of 700°C for a duration of two hours, followed by chemical activation using concentrated H_2SO_4 at 900°C for one hour. The resultant activated carbon was subjected to a rigorous characterization process in accordance with the ASTM standard methods. The results revealed a relatively low moisture content of 10%, an ash content of just 1%, an impressive iodine number of 552.15, indicating substantial adsorption capacity, and a slightly acidic pH value of 4.6. These findings demonstrate that the activated carbon produced exhibits desirable physicochemical properties, suggesting its potential application in water purification, gas adsorption, and as a catalyst support in various chemical processes. This research contributes to the development of value-added products from agro-waste, promoting sustainable practices and offering a viable solution for waste management.*

Keywords: *Activated carbon, Palm kernel shell, Carbonization, Gas Adsorption, Electric Furnace*

INTRODUCTION

Carbon is a naturally abundant non-metallic element which forms the basis of most living organisms. It is the fourth most abundant element in the universe after hydrogen, helium and oxygen, and it plays a very crucial role in the health and stability of the planet through the Carbon cycle (Singh, 2024). This cycle is extremely complex and it illustrates the inter connection between organism on earth (Düsing *et al.,* 2019). Scientist, industries and consumers alike use different forms of carbons and carbon containing compounds in many ways such as activated carbon and carbon in its active form which can be used to purify water among other uses and applications. Activated carbon (AC) is a generic term for a family of many carbonaceous materials none of which can be characterized by a structural formula (Sharma *et al.,* 2022). It is perhaps one of the most important types of industrial carbon materials and is prepared by carbonization and activation of a large number of raw materials of organic origin such as wood, coal liquids etc., (Sarathchandran *et al.,* 2021).

Characteristics of AC depend on the physical and chemical properties of the raw materials as well as method of activation (Gao *et al.,* 2020; Heidarinejad *et al.,* 2020). The process for preparing activated carbon (AC) involves carbonization and activation of the carbonized product by physical or chemical activation (Wazir *et al.,* 2022). The carbonization process enhances the carbon content and to create an initial porosity in the clur while activation further develops the porosity and creates some ordering of the structure hereby generating a highly porous solid as the final product (Mbarki *et al.,* 2019; Nicolae *et al.,* 2020). One major drawback of naturally occurring organic substances as precursors for activated carbon is that the resulting pore size distribution cannot be controlled (Hassan *et al.,* 2020; Sosa *et al.,* 2023). This led to the use of synthetic resins and polymers such as polyvinyl chlorides and Zoolytes (Marin, 2022; Alkathiri *et al.,* 2020). The last few decades have witnessed increasing technological advancement that requires the use of activated carbons in a wide range of applications involving adsorption (Mariana *et al.,* 2021). As a result of increasing demand for adsorbent, locally available carbonaceous materials have proven worth ling for producing Activated carbon (Ukanwa *et al.,* 2019; Periyasamy *et al.,* 2020). Activated carbon, also called activated charcoal, is a form of carbon processed to have small. low-volume pores that increase the surface area available for adsorption or chemical reactions. Activated is sometimes substituted with active. Activated carbon is a form of carbon species that is processed and prepared to have high porosity and very large surface area available for adsorption (Ganjoo *et al.,* 2023).

Activated carbon forms a large and important class of porous solids, which have found a wide range of technological applications. Basically, activated carbon is a solid porous black carbonaceous material and tasteless. Another definition for activated carbon defined by Alothman *et al.,* (2023) is a porous carbon material, usually chars, which have been subjected to reaction with gases during or after carbonization in order to increase porosity. Activated carbon is distinguished from elemental carbon by the removal of all non-carbon impurities and the oxidation of the carbon surface. They are so-called amorphous as they have crystalline characteristics, even though they may not show certain features, such as crystal angles and faces, usually associated with crystalline state that have shown from the X-ray studies. Although interpretation of the X-ray diffraction patterns is not free from ambiguities, there is general agreement that amorphous carbon consists of plates in which the carbon atoms are arranged in a hexagonal lattice, each atom, except those at the edge, being held by covalent linkages to three other carbon atoms. The crystallites are formed by two or more of these plates being stacked one above the other (Guo, 2021). Although these crystallites have some structural resemblance to a larger graphite crystal, differences other than size exist (Low *et al.,* 2021). From all the definitions, it can be summarized that activated carbon is a black, amorphous solid containing major portion of fixed carbon content and other materials such as ash, water vapor and volatile matters in smaller percentage. Besides that, activated carbon also contains physical characteristic such as internal surface area and pore volume. The large surface area results in a high capacity for absorbing chemicals from gases or liquids (Heidarinejad *et al.,* 2020). The adsorptive property stems from the extensive internal pore structure that develops during the activation process. Activated carbon is carbon produced from carbonaceous source materials such as nutshells, coconut husk, peat, wood, coir, lignite, coal, and petroleum pitch. Activated carbon is produced by one of the following processes; physical reactivation and chemical activation.

MATERIALS AND METHODS

2.1 Materials

i. Muffle furnace (Carbolite furnace made in England serial No.2083015.Type RWF12120)
ii. Crucible
iii. Filter paper
iv. Beakers
v. Spatula
vi. Thermometer
vii. Measuring cylinder
viii. Mortar and pestle
ix. Electronic Weighing balance
x. Wash bottle
xi. Electric oven (Carbolite hot air oven made in England. Serial no.20803020, TypePF120)
xii. pH meter
xiii. Palm kernel shell

2.2 Reagents

i. Sulpuric acid
ii. Distilled water
iii. Ethanol

2.3 Sample Collection/ Preparation

The sample (Palm Kernel Shell) was collected from Jefia, Effurun, Delta State. After the collection of the sample, it was for sundried for about two days.

2.4 Preparation of Activated Carbon

The activated carbon was prepared in two stages:

i. Carbonization
ii. Chemical activation

2.4.1 Carbonization of Samples

The sample (palm kernel shell) was carbonized inside a muffle furnace. The carbonization was done at a temperature of 700°C for two (2) hours in the furnace. The carbonized palm kernel shell was allowed to cool at room temperature after which it was grounded to a powdered form using a mortar and pestle.

2.4.2 Chemical Activation of Sample (Palm Kernel Shell)

After the carbonization of the sample, it was activated chemically by impregnating it with 98.07% H_2SO4 acid on an impregnation ratio of 1:1. This was done by mixing 77.9g of the carbonized palm kernel shell with 77.9ml of H_2SO4. The solution was mixed together by properly stirring it with a stirring rod. The resulting paste was then placed in a furnace at a temperature of 900°C for 45mins (activated temperature) and this was done to increase its porosity. The resulting activated carbon was then allowed to cool to room temperature and washed thoroughly in a beaker with distilled water and allowed to settle below the water and complete removal of the residual sulphuric acid was achieved by repeated washing and decantation. The final slurry was filtered using a funnel and filter paper and transferred into an oven at a temperature of 120°C after drying, the dried activated carbon was then transferred into an air tight container to prevent adsorption moisture.

2.5 Characterization of Activated Carbon

2.5.1 Determination of pH

The standard test method for determination of activated carbon pH ASTM D 3838-80 was used. 1.0g of activated carbon (PAC) was weighed and transferred into a beaker. 100ml of distilled water was measured, added and stirred. The samples were allowed to stabilize and decanted, then the pH of the filtrate was measured using a pH meter.

2.5.2 Determination of Iodine

1g of the dried carbon was transferred to a dry glass stoppered 250ml Erlenmeyer flask. 10ml of 5% v/v hydrochloric acid was pipetted into the flask. The flask was swirled until the carbon was wetted the contents were allowed to boil for 30secs.then the flask and its contents were allowed to cool to room temperature, then 100ml of 0.10N iodine solution was added by pipette the flask was stoppered immediately and shook vigorously for 30 secs. Thereafter it was filtered by gravity through a filter paper immediately after the 30 secs of shaking. The initial 21ml of the filtrate was discarded and the remainder was collected in a clean beaker. Then the filtrate in the beaker was stirred with a glass rod and 50ml of it was pipetted into a 250 ml Erlenmeyer flask. The 50 ml sample was titrated with 0. 10molar concentration of sodium thiosulphate solution until the yellow colour has almost disappeared. Then about 1ml of starch solution was added and titration continued until the blue indicator colour just disappears.

That is;

$$I=B-S/B\times 300.14 \quad (1)$$

I=Iodine number

B=Blank in ml

S = Sample Titre in ml

2.5.3 Determination of Moisture Content

The standard test method for ash content, ASTM D2867-70 was used. The sample was put into a pre-dried crucible and the weighed crucible was placed in a preheated oven (at 150°C) and allowed to dry to constant weight for 3hrs.

That is;

$$Moisture\ content\ (\%) = \frac{Loss\ in\ weight\ on\ drying}{Initial\ sample\ weight} \times 100 \quad (2)$$

2.5.4 Determination of Ash Content

The standard test method for ash content, ASTM D2866-70 was used. A crucible was pre-heated in a muffle furnace at 650°C for 1hr, cooled in a desiccator and weighed. 1.0g of activated carbon sample was transferred into the crucible and reweighed. The crucible containing the sample was then placed in the muffle furnace at 650 °C for 4hrs. It was removed and allowed to cool in a desiccator to room temperature (30°C) and reweighed again. The ash content was calculated using the equation below.

That is;

$$Moisture\ content\ (\%) = \frac{Ash\ Weight}{Dry\ \ weight} \times 100 \quad (3)$$

RESULTS AND DISCUSSION

The results gotten from the experiment was tabulated, as displayed in Table-1.

Table-1 Results of the Experiment

Parameters	Units	Results	ASTM Range
Ph Value		4.6	
Iodine Value	Mg/g	552.15	1-14max
Moisture Content	%	10	≤ 10 Max
Ash Content	%	1	< 8 Max

The characteristics of the produced activated carbon as presented in Table-1 showed a low amount of moisture and ash content, indicating that the particle density is relatively small. This result shows that activated carbon produced from palm kernel shell is an excellent raw material for adsorption. Iodine number is a fundamental parameter used to characterize activated carbon performance. It is a measure of the micro pore content of the activated carbon and is obtained by the adsorption of iodine from solution by the activated carbon sample. The microspores are responsible for the large surface area of activated carbon particles and are created during the activation process. It is in the micro pore that adsorption largely takes place. The value (of iodine number) obtained for the produced activated carbon (552.15) is greater than the value obtained for fluted activated carbon (229.90). The pH of the produced activated carbon was found to be 4.6, thus making the activated carbon to be very acidic. The acidic nature or content of the produced activated carbon, could be attributed to the effect of the activating agent used (sulphuric acid). However, it is very important to note that most activated carbon can function at any pH value depending on the nature of activating agent used.

CONCLUSION

This study has shown that activated carbon could be recovered from palm kernel shell mesocarp, a renewable, cheap and abundant waste. Also, the result of this study could provide activated carbon consumers with cost effective and environmentally friendly alternative sources. The activated carbon prepared from palm kernel shell at an activating time of two (2) hours and a carbonization temperature of 700°C using sulphuric acid (H_2SO_4) gave a good yield of ash and moisture content. Therefore, carbonization temperature of 700°C and activating time of 2 hours using palm kernel shell is an excellent method of producing activated carbon with a high surface area.

CONFLICT OF INTEREST

There is no conflict of interest for this research work.

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