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RESEARCH ARTICLE

Technological Characterization of Biochar Derived from Oil Palm Biomass for Sustainable Energy Applications

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Abstract

The technological characterization of biochar derived from oil palm biomass is crucial for advancing sustainable energy solutions, as it offers insights into the material's potential applications in renewable energy and environmental management. In this study, the carbonization and characterization of oil palm biomass including oil Empty Fruit Bunch (EFB) and Palm Kernel Shell (PKS). The carbon contents for the various oil palm biomasses samples studied are: EFB (81.4,), and PKS (96.1), the BET surface area result showed PKS biomass of 274.6 m^2/kg compared to the 36.6 m^2/g for EFB. The analyses also indicate that oil palm biomass is biomaterial that is safe to be used for various technological applications such as Activated Carbon (AC) for use as adsorbent, soil amendment, solid fuel energy, energy storage material and in carbon sequestration.

Keywords: Activated Carbon; Biomass; Biochar; Characterization; Energy; Technology

Introduction

With pollution rising and fossil fuel supplies running low, it is imperative that we reevaluate how we use the energy resources and explore various renewable energy sources in order to meet the world's expanding energy needs (Manju et al., 2024). Biomass is a significant source of renewable energy that contributes to the economy, sustainability and energy security of the world. Biomass use is of high concern in developing nations as these nations have a mainly agricultural and forestry-based economy. The use of biomass as a raw material for bioenergy relies on the state-of-the-art technology for transforming biomass into manageable value-added products (Mohamad et al., 2011). Natural biomass is a source of renewable energy and material, the biomass's bulk elemental structure comprises of (reducing abundance order): C, O, H, N, Ca and K (Kostyniuk, 2024).

It usually involves Si, Mg, Al, S, Fe, P, Cl, and Na at reduced concentration. Mn, Ti and other components can be regarded as traces. The use of different components of crops generating activated carbon from lignocellulosic biomass has many benefits in the activated carbon manufacturing process: the precursors are varied, abundant and renewable (González-García, 2018). Because of the current state of the world's climate, which is unstable due to the effects of global warming and climate change, we must act immediately and adopt sustainable and environmentally friendly products (Raihan et al., 2024). Since fossil fuel is depleting, there is an urgent need to use any sort of biomass as renewable sources by turning it into different types of green fuels (Kalak, 2023).

Technologies for transforming biomass into bioenergy differ from ordinary combustion to greater temperature and pressure heat procedures such as pyrolysis and gasification (Mohamad et al., 2011). Extensive study has been carried out to create value-added products such as EFB paper pulp, EFB and OPT bioethanol, OPT furniture, EFB organic fertilizer, POME and renewable energy effluent (Johan et al., 2018). However, there has been restricted study focusing on the use of oil palm biomass for the manufacturing of biochar (Awalludin et al., 2015; Johan et al., 2018). The objectives of this work are to examine the carbonization of oil palm biomass including oil Empty Fruit Bunch (EFB) and Palm Kernel Shell (PKS) and to characterize the carbonaceous products for surface morphology, elemental analysis and surface area.

Methodology

Samples preparations

The biomasses were dried in an oven for 48 hrs at 105°C in order to reduce its moisture content until it was less than 10 wt% dry basis. The samples were grounded into powder and the powder was screened using 200 mesh sieves and put in plastic bags for future use.

Pyrolysis of the sample

Firstly, the precursor material were prepared on a boat vessel and introduced into an electrically-heated horizontal furnace, but before heating, a flow of nitrogen at 100 mL/min from the compressed gas cylinder was passed through the installation to eliminate the presence of oxygen and create the inert conditions required for complete pyrolysis. In each test, 50-100g of sample was heated from ambient temperature to 500 ^{0}C at gradual heating rate of 5^{0}C/min, and maintained for 2 h to allow sufficient time for complete pyrolysis. It is worth noting that the pyrolysis temperature of 500 ^{0}C was selected because the key properties of material, such as pore structures and surface area are sufficiently develop at around that temperature.

Characterization of the Samples

Morphology and eelemental aanalysis

The morphology of the sample was monitored through a scanning electron microscope (SEM, Nova NanoSEM 230, FEI, USA). SEM employs beams of electrons focused on materials surface for observation of topographical information; however, the SEM information is limited to only the sample surface. The elemental composition of the sample was determined by characterizing with EDX technique. The X-rays spectrum of various elements is separated by EDX system into an energy spectrum which is analyzed by the software.

Brauner-Emmet-Teller (BET) analysis

The specific surface area was measured by the adsorption/desorption of N_2 at temperature of 77 K using an automated device (Micromeritics ASAP 2020). Before the analysis, the samples were out gassed at 300 ºC for 4 h. The surface area and pores size distribution were obtained using the Brauner-Emmet-Teller (BET) and BJH calculations.

Results and discussion

Morphology of the oil palm biomasses

It can be noted that the EFB sample in Figure. 1 showed a material particle that is made up of heavily bounded strong cells. Sectional pictures of raw material indicate that the particles are surrounded by heavy cell structures with some cavities or porous. The sample at different magnification displayed large and organized porosities network that can favor adsorption process. Other study reported similar observation (Hossain et al., 2016)**.**

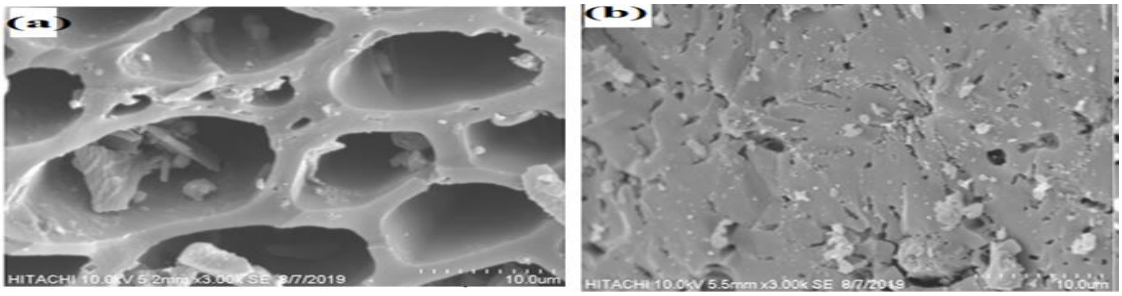

Figure 1. Morphology of (a) EFB (b) PKS

However, the PKS sample in Figure 1b has non uniform porosities in throughout. All over the samples there are noticeable porosities with variable diameters. A certain structural deformation has been noted in the sample surface. Due to the impact of a elevated temperature, some relocation and removal of cell wall matrix was noted in the samples. Similar findings had been reported by palms (Hossain et al., 2017). The porosity is an important property which has a significant application for activated carbon development.

Table 1. EDX results of EFB and PKS

Element	Weight (%)		Atom (%)		Formula	
	EFK	PKS	EFK	PKS	EFK	PKS
C	81.41	95.74	91.04	97.80	C	C
O	3.85	1.59	3.23	1.22	O	O
Mg	0.51	-	0.28	-	MgO	-
Si	1.77	1.12	0.85	0.49	SiO_2	SiO_2
P	2.62	-	1.14	-	P	P
Cl	2.54	-	0.6	-	Cl	Cl
K	7.30	1.54	2.51	0.48	K_2O	K_2O
Total	100	100	100	100		

The EDX results of EFB, and PKS are shown in Table 1 as element in weight percentage (wt %). Accordingly, the elemental contents of the compacted biomass pellets were measured using Scanning Electron Microscope (SEM-EDX). The EDX analysis reveals that the major and minor elements in most forms of oil palm biomass are Si, Mg, K and P. The analyzes also show that the biomass is a biomaterial that can be used safely for different application and for disposal if needed under certain conditions as it does not contain poisonous heavy metals such as Pb, Cd, Hg and Cr (Awalludin et al., 2015). According to the information, oil palm biomass can generally be used as an outstanding biomass fuel for soil amendment applications as well as for AC production. AC can be prepared from a wide range of raw materials with a high carbon content and low inorganic content (Ioannidou and Zabaniotou, 2007). Carbonaceous materials, including AC, have unique structural characteristics and functionality, and one common feature of all carbon adsorbents is that they all contain rich active surface functional groups vital to the surface chemistry of carbon products. Carbon-rich organic materials are the most common precursors used for AC preparation (Hidayu and Muda, 2016).

Furthermore, the contents of N and S determine the quantity of unwanted emissions, i.e. NOx, SOx. Based on the present finding, the oil palm biomass does not contain S and N, this means that it is a cleaner and more environmentally friendly.

BET specific surface area

The specific surface area, pore volume and pore sizes of the EFB and PKS biomasses are presented in Table 2. Clearly, the surface are for PKS is higher than that of EFB and thus, demonstrated to be potentially good for activation into AC. It is also noteworthy to mention that the activation process will greatly enhance the surface area, previous study have reported similar argument (Kiman et al., 2018).

Table 2. The specific surface area, pore volume and pore sizes of the EFB and PKS.

Sample	S_{BET} (m^2/g)	Pore volume (cm^3/g)	Pore size (Å)
EFB	3.6038	0.387997	289.481
PKS	274.6791	0.461558	33.607

Previously, Silas et al. (2018a) showed that the Hm-Co_3O_4/ACM adsorbent demonstrated higher adsorption capacity because of the higher BET surface area which provides abundant active site for adsorption to take place. The authors further found that the specific surface area, pore volume and the structure are factors that influence adsorbent characteristics. A full range N_2 isotherm is shown in Figure 2, it indicates the qualities of a porous media containing type IV adsorption/desorption isotherm, similar isotherm plots are earlier reported (Silas, et al., 2018b).

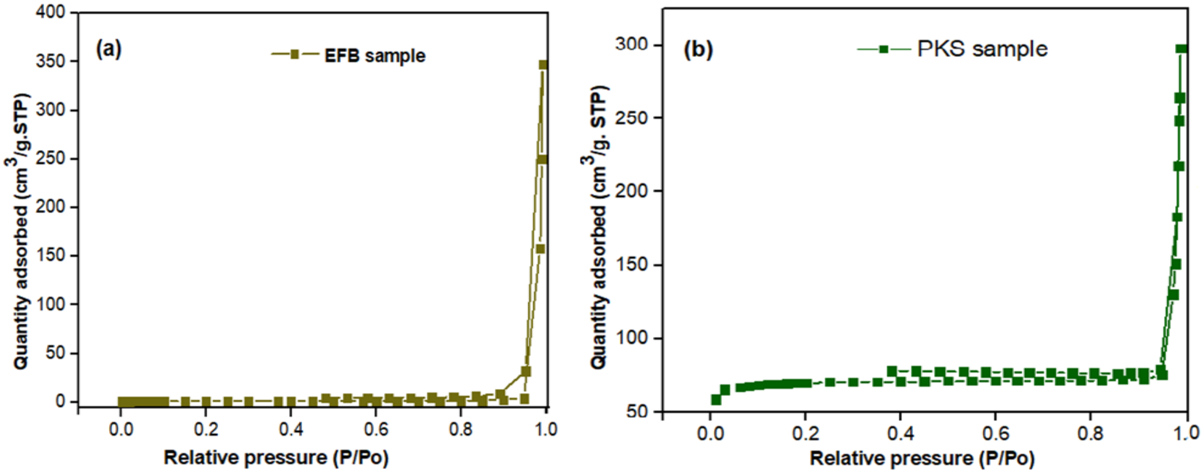

Figure 2. A full range N_2 isotherm of (a) EFB and (b) PKS

The technique of pore allocation analysis Barrett, Joyner, and Halenda (BJH) is commonly used for calculations on mesopores where it is intended as the normal D 4641/87 ASTM technique (Silas, et al., 2018b) hence, Figure 3 demonstrates the materials ' pores distribution. The average pore width for EFB and PKS are 7 and 12 respectively which confirmed the presences of mesopores.

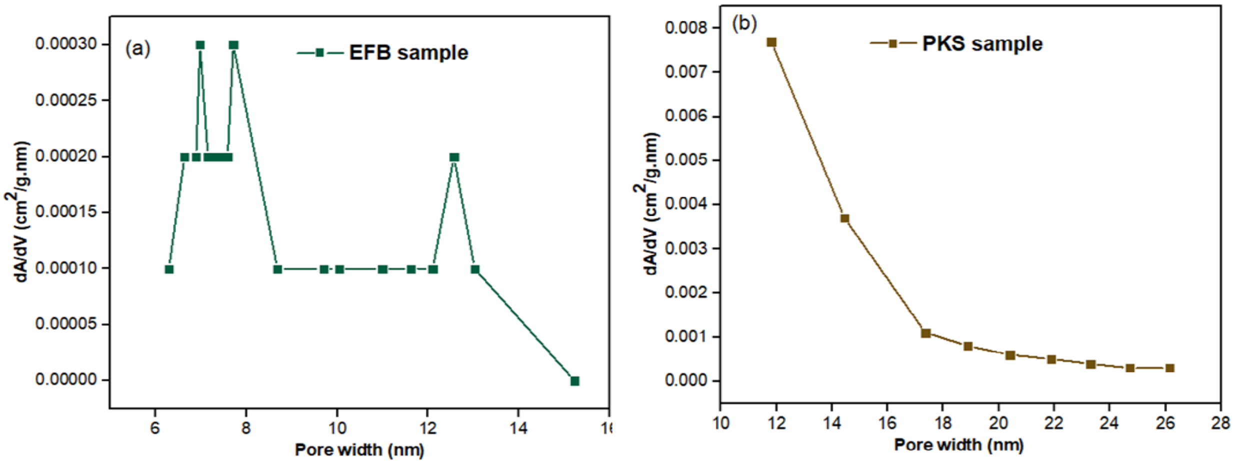

Figure 3. The pores distribution of the (a) EFB and (b) PKS

The analyses also indicate that oil palm biomass is a biomaterial which is safe to be used for various technological applications such as Activated Carbon (AC) for use as adsorbent, soil amendment, solid fuel energy, energy storage material and in carbon sequestration.

Conclusion

In this work, the processes involved in oil palm biomasses (EFB and PKS), the utilization of oil palm waste biomasses that were carbonized and characterized has demonstrated to be promising for the development of activated carbon. According to these SEM results, there are visible porosities that are of about variable diameters all over the samples. Some relocation and removal of cell wall matrix has been observed in the samples due to the effect of a high temperature. Based on this result, the hierarchy of carbon content oil palm biomasses studied was PKS> EFB. Furthermore, the BET surface area result showed that the highest porosity was demonstrated by the PKS biomass, based on this finding, the PKS can be said to be the best option for development of activated carbon.

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Authors contribution: Kiman Silas: Worked on conceptualization, results and figures/tables, Habiba Danjuma Mohammed: Worked on the methodology, and experimenta, Umar Abdullahi Isah: Worked on introduction and abstract, Yusuf Madu Meshelia: Worked on conclusion and aper review

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