

Torrefaction of Nigerian Palm Kernel Shell into Solid Fuel

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Abstract: Palm kernel shell (PKS) which is a waste from oil palm tree was torrefied to improve its properties as a solid fuel. The study on Palm kernel shell torrefaction was performed under various temperature and time of 200°C, 220°C, 240°C, 260°C, 280°C, 300°C and 40, 80, 120 minutes respectively using a horizontal tubular type reactor made of stainless steel. The electric furnace surrounding the reactor was used to regulate its temperature. An elemental (CHNS) analyzer was also used to get the carbon, hydrogen, nitrogen & sulphur contents. The calorific value was measured using a bomb calorimeter. The mass yield, energy yield, ash content, moisture content, volatile matter content and fixed carbon content were calculated. The results of the study indicate that increase in torrefaction temperature decreased the mass & energy yield of Palm kernel shell. The carbon content of Palm kernel shell increased while hydrogen and oxygen content decreased after torrefaction which resulted in higher heating value of 5 to 20%. Ash content and fixed carbon content of palm kernel shell were observed to have increased with reduction in the moisture and volatile matter therein. It therefore follows that Palm kernel shell possess valuable potentials to supplement the energy supply of Nigeria through sustainable renewable energy technologies.

Keywords: Palm Kernel Shell, Torrefaction, Solid Fuel, Pretreatment, Biomass

1. Introduction

Presently, the concerns about the price fluctuation of oils, its high demand and climate change have been a hot issue in the international policy discussion. In the light of this, biomass a promising renewable energy source has been suggested as an alternative energy source, which will in no small measure reduce the world demand on oil (petroleum). Biomass accounts for approximately 15% of global primary energy use and 38% of the primary energy use in developing countries. [Lisardo *et al*, 2001] noted that biomass is considered as a sustainable and renewable energy sources with the highest potential to contribute to the energy needs of modern society and to replace the existing conventional fuel which is subject to depletion as they are consumed. In the context of biomass for energy, it means that plant based material which is derived from the reaction between carbon (IV) oxide in the air, water and sunlight through photosynthesis produce carbohydrates that form the building block of the biomass [Peter, 2002]. For ages, the energy stored in the chemical bonds of the biomass has been exploited by burning it as a fuel. One important factor considering the use of biomass as energy sources is to

improve the global warming issue since burning new biomass contributes no new carbon (iv) oxide to the atmosphere because replanting biomass ensures that the carbon (iv) oxide is absorbed and returned for a cycle of new growth [Zakir *et al*, 2011]. Despite this, biomass is considered to be one of the key renewable resources of the future at both small and large scale levels. It already supplies 14% of the world's primary energy consumption. On average, biomass produces 38% of the primary energy in developing countries. In many industries where agricultural products are being processed, it has been common practice to use organic waste or biomass residues as fuel for production of the energy needed for processing [Yoshimitsu *et al* 2011]. Biomass is biological material derived from living or recently living organisms. It most often refers to plants or plant derived materials. Therefore, the intent of this research work is to explore palm kernel shell (PKS) with a view to determining its bio energy status and whether or not it would form a good substitute for that obtained from petroleum.

Sources of Biomass

The sources of biomass are as shown in figure 1 below:

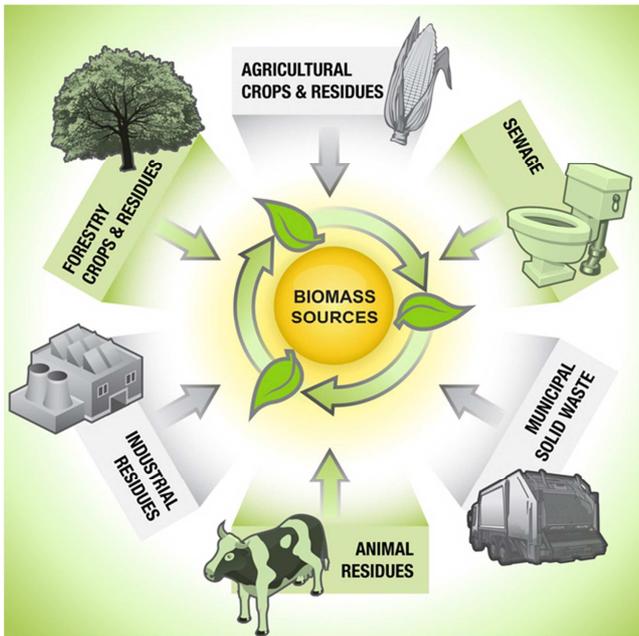


Figure 1. Diagram showing sources of biomass.

The Basic Process of Operation in a Biomass Conversion via Torrefaction

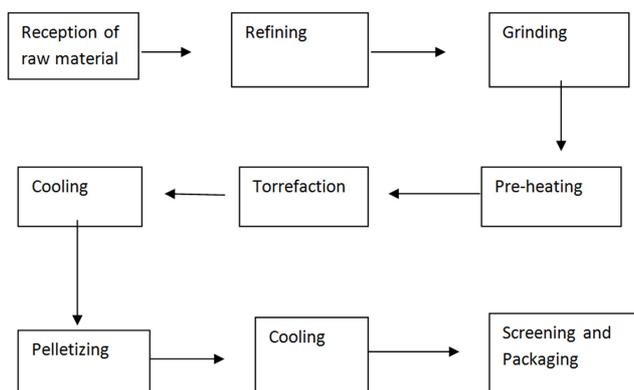


Figure 2. Show basic process of biomass torrefaction.

Figure 2 above shows basic process of operation in a biomass via torrefaction from the storage of biomass the material has to be refined first for purity and ground to smaller particles of a required size. After that, the material is heated actively; this is one important operation during the process since the drying requires big amount of heat. Then torrefaction step afterward will roast the biomass with the temperature of 200-300°C and without oxygen. Next step is that the material must be cooled since it may explode when it gets in contact with the oxygen. After which is the pelletizing process which improve the qualities and increase the volumetric energy density of the solid product. Then it gets to another cooling process which prevents high reactive fine matter with the oxygen. Final step is the screening process which put to check the product quality and packaging of the solid product for further handling and delivery process.

However, torrefaction process is preferred to the traditional combustion of PKS because of its environmental friendly

output. In order to adopt this or any other biomass sample for any of the thermochemical processes their physical and chemical properties need to be determined with a view to adopting their most valuable conversion method. For instance [Miskam *et al*, 2009] characterised saw dust from local furniture manufacturers in Malaysia in order to determine its potential as feedstock for cyclone gasifier. They found that ground saw dust is a better option than large size particles for the gasifier. In the same vein [Muafah *et al*, 2011] introduced aggregated matrix method as alternative and quick method for characterizing biomass for thermochemical process.

A study on torrefaction of rice husks, sawdust, peanuts husks, bagasse and water hyacinth under various temperature and residence time of 250°C, 270°C, 300°C and 1hr, 1.5hrs, 2hours respectively were carried out. Based on the study, the percentage of mass and energy yield decreased, calorific value of the torrefied product increased and moisture and volatile matter contents decreased with the increase in the temperature and residence time with the findings that temperature has more effects on torrefaction process than the residence time [Anuphon *et al*, 2010]. Meanwhile the ash and fixed carbon contents increased when the temperature increases. However, it majorly decreased when the residence time increased. A study focused on the torrefaction of pinewood at temperature and residence time of 230, 250 and 280°C and 1, 2 and 3 hours respectively. It was reported that the carbon content increased with the increase in the temperature and residence time. Hydrogen and oxygen contents decreased with the increase in the temperature and residence time, while nitrogen content was almost constant [Gevers *et al*, 2002].

This work aims at investigating the potential of torrefaction to improve the properties of palm kernel shell [PKS] as a solid fuel. Carbon (IV) oxide is one of the greenhouse gases that enhances radiation forces and contributes to global warming, causing the average surface temperature of the earth to rise in response, which the vast majority of climate scientists agree will cause major adverse effects. The main source of this carbon (IV) oxide comes from fossil fuels which produces around 21.3 billion tonnes (21.3 gigatonnes) per year. Increase in the population causes an increased demand for fuel of which these fossil fuels are non-renewable. The fast rate of deforestation and low rate of replacement has simultaneously reduced the availability of firewood. The quest for cleaner fuel in the developed country also lead to a series of research into what and what can be used to generate heat without having to burn Fossil fuel. Hence the need for a less industrial and food competing materials which is the palm kernel shell.

The objectives of this work include

- To improve the properties of palm kernel shell as a solid fuel via torrefaction.
- Determination of combustion characteristics such as volatile content, nitrogen, carbon, oxygen, sulphur, fixed carbon, moisture content, hydrogen content and ash content
- Determination of effect of reaction temperature on torrefied products.

2. Materials and Methods

2.1. Sample Preparation

The raw palm kernel shell (PKS) is acquired from Jenkes palm oil mill. With Impurities removed and left over grinded into smaller particle size (230µm), the raw PKS is dried under temperature 115°C for 24hours to remove its extrinsic moisture. The dried PKS is stored in a low humidity cabinet for further process and analyses.

2.2. Torrefaction Process

Torrefaction of the biomass waste (PKS) is carried out using a horizontal tubular type reactor made of stainless steel with a 50mm internal diameter. A prescribed amount of biomass waste (4g) was weighed and put in a ceramic boat. The boat was placed at the centre of the reactor. The temperature of the reactor was raised to different desired levels i. e. 200°C, 220°C, 240°C, 260°C, 280°C and 300°C at 40, 80 and 120minutes by an electric furnace surrounding the reactor. Cooling is done through the help of the two condensers. The experiment is repeated 5 times for PKS; the initial and final weight of the PKS is recorded for the evaluation of the mass yield after torrefaction using the equation by (Bergman *et al*, 2005a).

$$Mass\ yield(\%) = \frac{product\ weight}{Raw\ material\ weight} \times 100 \quad (1)$$

2.3. Ultimate Analysis

The ultimate analysis i. e. carbon C, hydrogen H, nitrogen N and sulphur S contents is carried out on raw and torrefied PKS by using an elemental (CHNS) analyzer. Oxygen O is determined using the equation by (Yang *et al*, 2006)

$$O(\%) = 100 - C(\%) - H(\%) - N(\%) - S(\%) - ash(\%) \quad (2)$$

2.4. Calorific Value Analysis

The calorific value (HHV) of raw and torrefied PKS is measured using bomb calorimeter. The value is used to determine energy yield for each sample using the equation by (Bergman *et al*, 2005b)

$$Energy\ yield(\%) = mass\ yield \times \frac{HHV\ product}{HHV\ raw\ material} \quad (3)$$

2.5. Proximate Analysis

Moisture content (MC) was measured as follows. A prescribed amount of sample (2g) was weighed in a ceramic boat and was placed in an electric oven maintained at 115°C after drying for 24hours the sample was weighed every 1hour until we had a constant weight.

$$MC(\%) = \frac{wi-wf}{wi} \times 100 \quad (4)$$

wi = initial weight

wf = final weight

Volatile matter content (VC) was determined as follows

A prescribed amount of sample (2g) was heated in an electric furnace; the temperature was raised to 800°C for seven minutes in a partially enclosed boat placed in a furnace in accordance with BSI standard. The boat was Retrieved and left to cool. The weight of the refuse left content was determined from the equation.

$$vc(\%) = \frac{wi-wf}{wi} \times 100 \quad (5)$$

Ash content was determined as follows, a prescribed amount of sample (2g) was weighed in a ceramic boat and was placed in an electric furnace to 800°C. After 3hours the furnace was turned off and was allowed to cool. The boat containing the ash was weighed.

$$Ash\ content(\%) = \frac{wf-wb}{wi-wb} \times 100 \quad (6)$$

wb = weight after heating for 3hours

Fixed carbon (FC) was determined by computation of the differences between 100 and the sum of the moisture content, volatile matter content and ash content of the samples as shown.

$$FC(\%) = 100 - (MC + VC + AC) \quad (7)$$

3. Results and Discussion

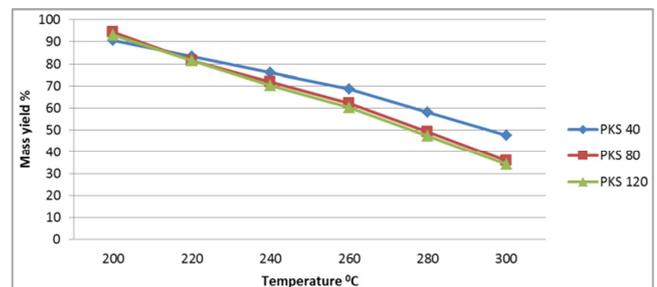


Figure 3. Graph of mass yield of PKS.

It is evident from the graph above that the percentage of mass yield decreased with the increase in the torrefaction temperature.

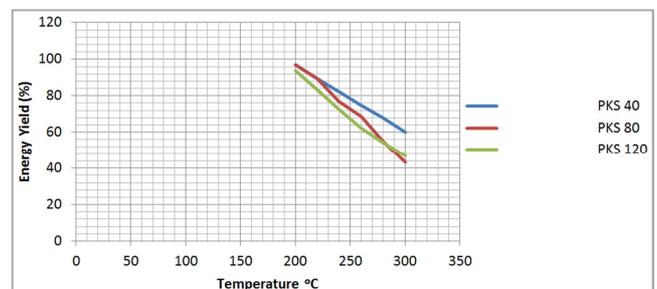


Figure 4. Graph of Energy yield of PKS.

From figure 4 above it show that the percentage of energy yield decreases with the increase in the torrefaction temperature. This observation is the same with the findings of

(Amin & Murni 2011).

Table 1. Proximate, Ultimate and Calorific Value Analysis of Torrefied PKS.

Time(min)	Temperature°C	MC%	VC%	FC%	ASH%	C%	H%	N%	S%	O%	HHV(MJ/Kg)
RAW PKS		1.74	83.38	10.50	4.38	46.76	5.85	0.89	0.12	42.32	18.16
40	200	2.06	76.14	15.23	2.25	48.72	6.56	1.17	0.22	41.01	19.68
	220	1.77	75.35	17.50	3.57	48.90	5.83	1.12	0.17	40.34	19.69
	240	1.48	74.56	19.77	4.89	49.08	5.10	1.07	0.12	39.67	19.70
	260	1.19	73.77	22.04	6.21	49.26	4.37	1.02	0.07	39.00	19.72
	280	0.92	75.15	21.25	5.62	49.90	3.92	1.07	0.00	39.45	19.86
	300	0.65	76.53	20.46	5.03	50.54	3.47	1.12	0.07	39.90	20.00
80	200	0.96	79.30	17.52	5.47	51.52	5.32	0.85	0.05	36.75	18.88
	220	0.98	76.48	19.29	5.92	51.18	5.00	0.94	0.04	36.87	19.62
	240	1.00	73.66	21.06	6.37	50.84	4.68	1.03	0.03	36.99	20.35
	260	1.02	70.84	22.83	6.82	50.50	4.36	1.12	0.02	37.11	21.09
	280	0.70	73.63	20.51	6.69	51.49	4.06	1.08	0.01	36.61	20.59
	300	0.38	76.42	18.19	6.56	52.48	3.76	1.04	0.00	36.11	20.09
120	200	0.80	49.00	39.31	13.02	48.46	4.68	1.10	0.00	32.68	22.80
	220	0.76	56.28	33.78	10.71	49.36	4.53	1.10	0.00	34.24	22.17
	240	0.72	63.56	28.25	8.40	50.26	4.38	1.10	0.00	35.80	21.54
	260	0.68	70.84	22.72	6.09	51.16	4.23	1.10	0.02	37.36	20.91
	280	0.63	58.07	32.86	8.39	53.07	3.97	1.14	0.00	33.37	21.86
	300	0.58	45.30	43.00	10.69	54.98	3.71	1.18	0.02	29.38	22.80

3.1. Ultimate Analysis

Carbon, hydrogen, nitrogen, sulphur and oxygen contents of the raw and torrefied PKS is summarized in table 1. It could therefore be seen that C: C bond increases as the Carbon content increase, while C: H and C: O bonds decreases as the Hydrogen and Oxygen contents decreases with the increase of torrefaction temperature. Also, the Carbon contents increases by 10-20% with the increase in the torrefaction temperature. The percentage of Hydrogen decreases by 9-29% with increase in the torrefaction temperature. Meanwhile, the percentage of Oxygen decreases by 6-21% with increase in torrefaction temperature. The change in nitrogen content fluctuates with a slight difference of 0.13% which is being considered as constant. The percentage of sulphur content is

maintained low i. e. below 1% with the increase in the torrefaction time. Low sulphur content in the torrefied PKS allows it to be an environmental friendly fuel.

3.2. Calorific Value

The HHV of torrefied PKS increases with the increase in the torrefaction temperature.

3.3. Proximate Analysis

The moisture, volatile matters, ash and fixed carbon contents of the raw and torrefied PKS is summarized in Table 1. The fixed carbon contents and ash contents for torrefied PKS increases while its moisture contents and volatile matter contents decrease.

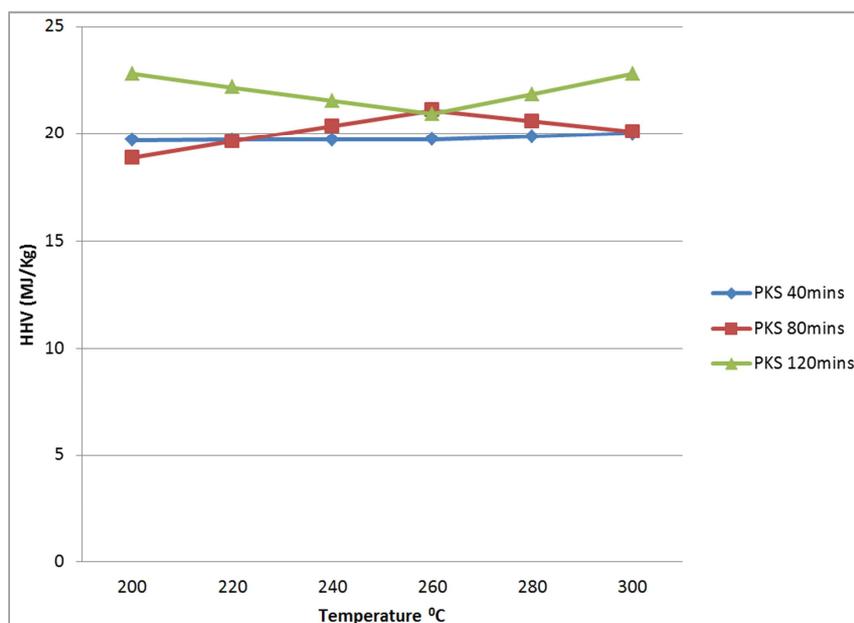


Figure 5. Graph of Higher Heating Value against Temperature.

4. Conclusion

In this study, torrefied palm kernel shell (PKS) which is typical agricultural wastes was prepared for experiment using different temperatures and time. The experimental results from figures 1 & 2 show that the mass and energy yield of torrefied PKS decrease with the increase of the torrefaction temperature and time. The fixed carbon contents and Ash contents of torrefied PKS increases while the moisture and volatile matter contents decreases. The Carbon contents increases while Hydrogen and Oxygen contents decreases. The Nitrogen content is constant with the increase of the torrefaction temperature and time. The Sulphur content of the torrefied PKS is maintained low i. e. below 1% which makes it an environmental friendly fuel. The HHV of torrefied PKS increases within the range of 5 to 20% with the increase of the torrefaction temperature and time. It is therefore evident from the forgoing that torrefaction significantly improved the properties of PKS as a solid fuel.

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