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Extraction of bio-oil during pyrolysis of locally sourced palm kernel shells: Effect of process parameters

J.O. Ogunkanmi[a], D.M. Kulla[a], N.O. Omisanya[a,b], M. Sumaila[a], D.O. Obada[a,*], D. Dodoo-Arhin[c,d,*]

[a] Department of Mechanical Engineering, Ahmadu Bello University, Zaria, Nigeria
[b] National Automotive Design and Development Council, Zaria, Nigeria
[c] Department of Materials Science and Engineering, University of Ghana, Legon, Ghana
[d] Institute of Applied Science and Technology, University of Ghana, Legon, Ghana

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ABSTRACT

The aim of this study was to determine the effect of particle size, pyrolysis temperature and residence time on the pyrolysis of locally sourced palm kernel shells and to characterize the bio-oil products. Pyrolysis experiments were performed at pyrolysis temperatures between 350 °C and 550 °C and particles sizes of 1.18 mm, 2.36 mm and 5 mm for a residence time not greater than 120 min. The maximum bio-oil yield was 38.67 wt% at 450 °C for a feed particle size of 1.18 mm with a residence time of 95 min. It was observed that the percentage of liquid collection was 28% of the total biomass feed for particle size of 1.18 mm. In terms of the effect of temperature, the lowest bio-oil yield was 28% of the total biomass feed at temperature of 550 °C. For the variation in residence time and the associated effects, the maximum liquid product was 38.67 wt% of biomass feed, at a particle size of 1.18 mm for 95 min. As observed, the optimum residence time was 95 min as times either side led to a decrease in the liquid yield. The bio-oil products were analysed by Fourier Transform Infra-Red Spectroscopy (FTIR) and Gas Chromatography-Mass Spectrometry (GC-MS). The FTIR analysis showed that the bio-oil was dominated by phenol and its derivatives. The phenol (38.44%), 2-methoxy-phenol (17.34%) and 2, 6-dimethoxy phenol (8.65%) that were identified by GC-MS analyses are highly suitable for extraction from bio-oil as value-added chemicals. The highly oxygenated oils can therefore be upgraded in order to be used in other applications such as transportation fuels.

1. Introduction

Biomass has been recognized as a major renewable energy source to supplement declining fossil fuels. It is a popular form of renewable energy and currently, biofuel production is becoming much promising. Transformation of energy into useful and sustainable forms that can fulfil and suit the needs and requirements of the work force in the best possible way is the common concern of scientists, engineers and technologists. From the view point of energy transformation, pyrolysis is more attractive among various thermochemical conversion processes because of its simplicity and higher conversion capability of biomass into bio-oil [1]. Biomass utilization gives the possibility of generating value-added products such as chemicals, activated carbon, sandpaper production etc. which means an attractive economic and technological solution [2–4]. Among the palm oil wastes, palm kernel shell (PKS) has a great

* Corresponding authors at: Department of Mechanical Engineering, Ahmadu Bello University, Zaria, Nigeria.
E-mail addresses: doobada@abu.edu.ng, ddodoo-arhin@ug.edu.gh (D. Dodoo-Arhin).

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potential as a source of biomass to develop renewable energy sources. Since the PKS produced from palm oil mills is abundant, cheap and does not require significant effort to collect, it is currently used as a low energy efficiency fuel for industrial applications, for instance, boilers [5].

Converting palm kernel shells to bio-oil under a thermal process provides a greater benefit to use as biomass energy to replace fossil fuels, and it minimizes the disposal problems associated with the generation of agricultural by-products. Omoriyekomwan et al. [6] studied the catalytic fixed bed and microwave pyrolysis of palm kernel shells using activated carbon and lignite char (LC) as catalysts. It was observed that the addition of catalyst increased the bio-yield but decreased the selectivity of phenol in the fixed bed. The highest concentration of phenol and total phenolics in the bio-oil were obtained at 500 °C. Kabir et al. [7] devolatilized oil palm mesocarp fibre (OPMF) and palm frond (PF) by pyrolysis to oils, bio-oils and biochars. In particular, the OPMF-oil and PF-oil were produced to a maximum yield of 48 wt% and 47 wt% bio-oils at 550 °C and 600 °C, respectively.

Catalytic intervention in pyrolysis has received a lot of attention because of the significant increase in phenol rich bio-oils. However, the methods involving the use of catalysts have associated cost effects and require high pressures for reaction. Thus it is important to evaluate low cost approaches and indeed the effect of process parameters in bio-oil production especially in developing economies. In this study, we investigate the effects of the particle sizes of PKS on the production of bio-oil, char and gas, and further investigate the influence of pyrolysis temperature and residence time on the optimum bio-oil yield without catalytic intervention.

2. Materials and methods

2.1. Raw material collection and analysis

Samples of the palm kernel shell were collected from Oloje Oil Palm Industry in the South Western Region of Nigeria. The palm kernel shells were sun dried for 7 days to reduce the moisture content below 10%, after which they were crushed and sieved using U.K standard sieve sizes or openings of 1.18 mm, 2.36 mm and 5 mm (standard mesh numbers (US):16, 8 and ISO respectively) to produce the desired particle sizes. The proximate and ultimate analyses were done according to the ASTM (D-3175) standard test method [12] and results presented in Table 1.

2.2. Experimental procedure

The obtained palm kernel shells were subjected to pyrolysis in an externally heated in-house built fixed bed reactor system which was made of mild steel. The effective length of the reactor was 300 mm with diameter of 90 mm. Dry sand with a thermal conductivity of 0.27 W/m K was used as insulation material considering the operating temperatures (350, 400, 450, 500 and 550 °C) of the fixed bed pyrolysis plant and its availability. The connecting pipe was 900 mm with diameter of 19.04 mm, which was connected on the cover plate of the reactor at both ends with the help of nipples. The schematic diagram of the fixed bed pyrolysis system is shown in Fig. 1. The reactor was manually filled with 1.5 kg of the palm kernel shells. The reactor was then externally heated at different temperatures (350, 400, 450, 500 and 550 °C) via a manual charcoal furnace equipped with a digital thermocouple (Kane-May KM340, −50 °C ≈ 1500 °C) and the pyrolysis residence time for each operation was recorded. Pyrolysis vapour was condensed into liquid in the ice bath-cooled condenser while the non-condensable gases were flared to the atmosphere. The bio-oil products and char were weighed to calculate the percentage of the yield. The effect of PKS particle size, pyrolysis temperature and residence time on the yield of the pyrolysis products were investigated.

The functional groups present in the bio-oil obtained at optimum conditions were identified using Fourier transform-infrared (FTIR) spectroscopy. A Magna-IR550 Nicolet Madison Spectrum series II FTIR device with a resolution of 1.0 cm^{-1} was used to investigate the functional groups presents in the bio-oil within the range of 400 cm^{-1}–4000 cm^{-1}. The gas chromatography- mass spectroscopy (GC-MS) analysis of the bio-oil product was performed in accordance with ASTM E2997 standard [14] using Agilent Technologies GC 6890N with 5973N mass selective detector (MS). The oven temperature was started at 35 °C for 2 min, increased to 250 °C at a rate of 20 °C min^{-1} and held at this temperature for 20 min. The injector port temperature and the detector temperature were set at 280 °C. The carrier gas, helium, was set at a flow rate of 47.5 l per min and the split ratio of the injector port was set at 50:1. An amount corresponding to 0.03 g of bio-oil was used and diluted with methanol HPLC grade to the volume of 0.5 ml using a vial. After that, the mixture was shaken and filtered. Finally, 1.0 µl of mixture was injected with a 5.0 µl syringe into the GC-MS apparatus.

Table 1
(Comparison of proximate and ultimate analysis of kernel shells obtained in current work with literature).

Proximate analysis	Value (wt%)					Ultimate analysis	Value (wt%)				
	As-Used	Ref.5	Ref. 6	Ref.11	Ref.13		As-Used	Ref.5	Ref. 6	Ref.11	Ref.14
Moisture	5.69	11.00	14.90	6.33	9.4	Carbon	46.92	49.74	49.90	44.29	44.56
Volatile matters	69.10	67.20	74.68	62.82	82.5	Hydrogen	8.95	5.32	5.25	9.01	5.22
Fixed Carbon	23.49	19.70	23.68	19.10	1.4	Nitrogen	1.15	0.08	0.36	2.37	0.4
Ash	1.72	2.10	1.64	11.75	6.7	Sulphur	2.35	0.16	0.95	1.20	0.05
						Oxygen	40.63	44.86	43.54	43.13	49.77