Product Distribution and Characteristic from Pyrolysis of Indonesia Palm Oil Residues

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Abstract. During the production, palm oil industry generated around 4 ton of dry biomass waste such empty fruit bunch (EFB), palm kernel shell (PKS), and palm oil fiber (PF) for each 1 ton of palm oil extracted. As main industry in Indonesia, palm oil industry offered not only the oil product but also biomass waste which was potential for clean energy sources. The utilization of those biomass residue is still limited due to lack of information related to conversion method as well as characteristic of various product. This research focuses on the product distribution and characterization of biomass pyrolysis especially PKS and PF. Pyrolysis experiments were conducted using both thermogravity (TG) method and stainless steel reactor at temperature range of 450–550°C. Based on the TG method that biomass was heated up until 1000°C in nitrogen atmosphere, PKS exhibited slower decomposition process rather than PF because of high value of hardness and fixed carbon. Two strong peaks were seen clearly which the first peak correspond to hemicellulose and lignin decomposition that proceed in the temperature range of 200–300°C. While, the second peak represented to cellulose and lignin decomposition that occurred in the temperature range of 300–500°C. Pyrolysis at higher temperature initiated smaller amount of solid product due to volatilization and higher ash content. The ash composed of several chemical such as Si, Al, Ca, Mn etc which would still remain in the solid product when temperature was increased. However, the fixed carbon and heating value enhanced significantly as increasing temperature. Clearly, based on the SEM images, the biochar hold better pore structure compared to raw material. In the pyrolysis process, the volatile matter moved to gas phases and create abundant vacant as pore structure in the solid product. These results offers opportunities of better utilization of palm oil residues not only energy conversion but also other area such as adsorbent, bio-fertilizer/soil conditioning.

Keywords: Biomass pyrolysis, Palm oil residu, Biochar, Product distribution, Thermogravity profile
1. Introduction

Indonesia has huge potential of biomass for not only energy utilization but also other purposes such as chemical production, adsorbent and soil conditioning [1-2]. It is well known that the biomass utilization offers several benefits such as renewable energy and carbon neutral. One of the industry in Indonesia which owns great amount of biomass waste is palm oil industry. As largest palm oil producer in the world, Indonesia palm oil industry generates around 4 ton of dry biomass waste such empty fruit bunch (EFB), palm kernel shell (PKS), and pal oil fiber (PF) for each 1 ton palm oil extracted [3]. Indonesia government has target to increase the production of crude palm oil (CPO) around 30 million ton by 2020, so that almost 6 million of palm kernel shell and 12 million of palm kernel shell would generated [4-5]. Due to a huge amount of those two biomass, the effective technology for utilization is absolute needed. In general, the wastes are not fully utilized and continue to be used to cover the road surface in plantation areas or burnt, which contributes to increasing CO$_2$ emissions [6]. In order to enhance the competitiveness level of Indonesia palm oil Company, the effective utilization of palm oil residues should be introduced especially palm kernel shell. Thus, palm oil industry offered not only the oil product but also biomass waste which was potential for clean energy sources.

Pyrolysis is the main method for converting solid biomass, like palm kernel shell into energy by producing char, liquid tar and gases in the specifics values. Pyrolysis is defined as thermal degradation of solid fuel on condition without or limited oxygen. Those process would refine the solid product from the volatile matter and produce high energy value of material. It is well known that biomass consists of cellulose, hemicellulose and lignin at specific compositions. Cellulose and hemicellulose give most of the volatile products during the pyrolysis while the lignin content is mainly responsible for the production of biochar [7-8]. Based on the heating rate, pyrolysis process could be categorized as fast pyrolysis and slow pyrolysis. Slow pyrolysis produce relatively more biochar because of long residence time inside the reactor (hour). Fast pyrolysis has main product of liquid tar and the residence time of solid fuels within the reactor is very fast, in second order [9].

Char is the main product containing high amounts of carbon which can be used as solid fuels in other area while tar vapor and gas are by-products generated during the process containing high amounts of hydrocarbon and energy. The transforming of energy source into solid fuel forces the government, research communities and related parties to find the best method for energy generation. The product distribution such as biochar, liquid tar and gas is highly depend on the process condition of pyrolysis including temperature, heating rate, purge gas as well as particle size [7]. Beside the product distribution, the process condition also influence the yield of carbon content, porosity, heating value and ash content [10]. Thus, pyrolysis conditions could be adjusted to optimize the suitable product application. Among those parameters, temperature has main effect to the properties of pyrolysis product [11-12]. In order to optimize the energy generation, the characteristic and product distribution among the proses was absolutely needed. This paper focuses on the product distribution on pyrolysis of palm oil biomass especially palm kernel shell and palm fiber. In addition, the detail characterization of char solid product during the process were also examine.

1. Material and experiment method

2.1 Material

The palm oil residues of Palm Kernel Shell (PKS) and Palm Fiber (PF) were obtained from palm oil industry in Province of Lampung, Indonesia. Table 1 shows the proximate analysis of both samples. In order to avoid the effect of particle size, the sample were crushed and sieved to a granular size of approximately 250–500 µm.
Table 1: Proximate analysis of palm oil residues

| Sample                  | Fixed C | Volatile | Ash  |
|-------------------------|---------|----------|------|
| Palm Fiber (PF)         | 21.14   | 55.23    | 15.75|
| Palm Kernel Shell (PKS) | 30.78   | 57.52    | 2.21 |

2.2. Thermogravimetric analysis (TGA)

The thermogravimetric analyzer (TG) was used to examine the characteristic of pyrolysis process. Each 10 mg of sample was placed in the alumina pan and heated until 1000 °C with specific heating rate in the nitrogen atmosphere. Once the heating temperature reached 105°C, it was held for 30 min to completely remove moisture and provide a basis for analysis. Based on the TG process, the weight losses of the sample during the heating up in nitrogen atmosphere was recorded.

2.3 Pyrolysis experiment

Experiments were performed at atmospheric pressure with a nitrogen atmosphere using a stainless steel reactor tube as shown in Fig. 1.

![Pyrolysis apparatus for biomass waste](image)

**Figure 1.** Pyrolysis apparatus for biomass waste

An electrical furnace equipped with thermocouples for monitoring and controlling the operation temperature. After the reactor was constant at a temperature of 450–550°C, the slow pyrolysis was happened inside the reactor and produced char, tar vapor, and gases. While the solid product of char was trapped in the filter, the generated gas and tar were removed from the bottom of the reactor. The standard of scanning electron microscopy (SEM), proximate analysis and heating value analysis were used to evaluate the characterization of char solid product.
3. Result and Discussion

![TGA and DTG Curves for Palm Kernel Shell and Palm Fiber](image)

Figure 2. TGA and DTG Curves for Palm Kernel Shell and Palm Fiber

Fig. 2 shows pyrolysis characteristics of both palm fiber (PF) and palm kernel shell (PKS) using the TG DTA indicated that PKS resulted slower on decomposition process than PF due to the hardness and fixed carbon content. Both PF and PKS experienced a small weight loss as temperatures approached 200 °C because of moisture evaporation. By considering the decomposition temperature of those biomass major components, two strong peaks was exhibited as shown in the Fig. 2. The first peak correspond to hemicellulose and lignin decomposition that proceed in the temperature range of 200 – 300°C. While, the second peak represented to cellulose and lignin decomposition that occurred in the temperature range of 300 – 500°C [13]. The total weight loss of PKS was smaller than PF so that the PKS would produce more char solid product than PF at similar pyrolysis temperature. In other word, the PF would suitable for producing liquid and gas product than solid char product.

![Product Distribution of Solid Product, Water and Ash Content for Palm Kernel Shell at Different Temperature](image)

Figure 3. Product Distribution of Solid Product, Water and Ash Content for Palm Kernel Shell at Different Temperature
Fig. 3 shows the effect of temperature on the amount of solid product and ash content from PKS pyrolysis. Clearly, the solid amount was decreased at increasing temperature due to thermal cracking. It was well known that the thermal cracking, decarboxylation, and depolymerization were preferred at high temperatures [14]. Thus, based on the product amount, the higher temperature was preferred for producing the gas product while the lower temperature was suitable for producing the solid product. In order to utilize the solid product for various purposes such as energy sources and adsorbent, the parameter of ash content was essential. Based on the Fig. 3, the ash content of solid product declined as elevated temperature. This tendency was contrary to amount of solid product. The ash composed of several chemical such as Si, Al, Ca, Mn etc which would still remain in the solid product when temperature was increased. While the amount of total solid product decreased at higher temperature, the fraction of ash content increased. Therefore, high temperature of pyrolysis would initiate the smaller amount of solid product but also increasing the ash content.

![Figure 3. The Temperature Effect on the Amount of Solid Product and Ash Content from PKS Pyrolysis.](image)

Fig. 4 shows the temperature effect on fixed carbon and heating value within the solid product from PKS pyrolysis. As well known that the fixed carbon had main controls to determine the heating value of solid fuel. Obviously, both parameters indicated similar trends at different temperature as seen at Fig.4. The fixed carbon and heating value enhanced significantly as increasing temperature. This result agreed to the TG decomposition process that thermal energy and cracking would force the volatile matter leaving the solid product so that the weight losses would rise and enhance the content of fixed carbon. This fixed carbon was not only important parameter for energy utilization but also adsorbent material [15]. Carbon material was one of the good adsorbent for various purposes such as water treatment, gas purification as well as gas pollution prevention controls. By combination on results of Fig 3 and Fig 4, the high temperature of pyrolysis produced small amount of solid fuel but contain high amount of fixed carbon and heating value.

![Figure 4. The Temperature Effect on Fixed Carbon and Heating Value of Solid Product for Palm Kernel Shell (PKS) Biomass.](image)
Fig. 5 shows the comparison of SEM (Scanning Electron Microscopic) image between raw material of PKS and biochar solid product with different magnification. For both application of energy and adsorbent, the pore structure of the biochar plays important role for combustion performance and active site adsorption, respectively. Clearly, based on the SEM images, the biochar hold better pore structure compared to raw material of PKS. In the pyrolysis process, the volatile matter moved to gas phases and create abundant vacant as pore structure. The pore structure enhanced better porosity and diffusion of oxygen into material so that the combustion performance improved. In other hand, the available pore structure also would increase adsorption capability of bichar for specific component.
4. Conclusion

Based on the TG-DTG data, two strong peaks were seen clearly which the first peak correspond to hemicellulose and lignin decomposition (200 – 300°C) while the second peak represented to cellulose and lignin decomposition (300 – 500°C). PKS exhibited slower decomposition process rather than PF because of high value of hardness and fixed carbon. Pyrolysis at higher temperature initiated smaller amount of solid product but contain high amount of fixed carbon, ash content and heating value. The SEM images shows that biochar have better pore structure compared to raw material due to volatilization of volatile matter during the pyrolysis process. These results were important for the optimization of energy conversion and other utilization such as adsorbent, bioreductor, and soil conditioner.

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