Journal of Engineering Science and Technology
Special Issue on 4th International Technical Conference 2014, June (2015) 45 - 54

CHARACTERISATION AND POTENTIAL USE OF BIOCHAR FROM GASIFIED OIL PALM WASTES

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Abstract

This paper reports the characterisation of three types of biochars which were the by-products from a gasification process of oil palm frond (OPF), palm kernel shell (PKS) and empty fruit bunch (EFB). These biochars were produced with a medium-scale downdraft gasification process with operating reactor temperature of 650-800ºC. The characterisation of these biochars in terms of proximate and ultimate analysis, energy content, surface area and adsorption capacity were carried out to assess the potential uses of the various types of biochars. The results show that the characteristics of these biochars, in terms of carbon content and calorific value are similar and in the range of 75-91% and 26-29 MJ/kg, respectively. In terms of surface area and adsorption capacity, the OPF biochar shows significantly high value of 891 m^2/g and 250 cm^3/g. Based on this characterisation study, the potential use of these types of biochars for fuel, and soil amendment applications is considered high. OPF biochar in particular, has a high potential in activated carbon application with its very high surface area

Keywords: Gasification, Palm wastes, Biochar, Fuel, Soil amendment, Activated carbon.

1. Introduction

Biochar can be produced by the thermochemical processing of biomass, known as pyrolysis or gasification, at temperatures between 300 and 1000°C, and under low or controlled oxygen conditions [1, 2]. The gasification of biomass produces a combination of gases (syngas), biochar, and tar. Biochar can provide a practical method to mitigate global warming, even though biofuel production does emit carbon dioxide and other greenhouse gases [3, 4]. It is because biomass (plants) as a biochar feedstock is a CO_2 neutral, where the CO_2 released by the decomposition of plants will be recycled by other plants during photosynthesis, resulting in a net CO_2 release of zero. Furthermore, the biochar itself can be used in combustion to obtain energy, as soil amendment and as activated carbon [5].

Many research works on biochar have been carried out to assess its potential by investigating its characteristics. Depending on its characteristics, it has potentials to be used as fuel, soil amendment and activated carbon [1,5]. Basically, the characteristics in term of carbon content and high calorific value are necessary for fuel application. Meanwhile, the carbon content and adsorption capacity characteristics are important in soil application as well as a carbon sequestration due to the carbon stored in biochar. The biochar also has potential as an activated carbon due to the high carbon content and high surface area.

There are biomasses that have the potential to be used as a feedstock for biochar production like agricultural crop residues, forestry residues, wood waste and the organic portion of municipal solid waste (MSW). However, the biomass source has been contributed mostly from plantation and agriculture activities [6]. In Malaysia, the palm plantation activities contribute the most readily biomass source for the country. Malaysia is the second biggest palm oil producer in the world after Indonesia and the production keeps increasing due to continuous development in palm plantation. The palm plantation produces huge quantity of palm wastes such as oil palm frond (OPF), palm kernel shell (PKS), empty fruit bunch (EFB), palm trunk and mesocarp fibers [7]. According to the Malaysia Palm Oil Board (MPOB), approximately 10 % of the useable products have been produced from oil palm tree while 90% are waste products [8].

Due to the high potential of palm wastes and established gasification technologies, the palm wastes biochar from gasification process can be seen as an interesting subject to study. In fact, the palm wastes gasifications have been studied by many researchers especially in term of syngas yield [7, 9, 10]. However, specific studies on biochar from gasification are still limited [11]. Thus, the palm wastes such as OPF, PKS and EFB were selected as feedstocks for the gasification process to produce valuable biochar. These various types of biochars were studied based on their energy content, surface area, adsorption capacity, proximate and ultimate analysis. Therefore, current study was carried out to characterize the oil palm wastes biochars from gasification process to determine their potential uses in specific applications.

2. Methodology

Three types of oil palm wastes such as oil palm frond (OPF), palm kernel shell (PKS) and empty fruit bunch (EFB) were prepared. The OPF and EFB samples were chipped into smaller sizes and dried to the moisture content below 15 %. PKS size is readily ideal hence did not need any further resizing process. PKS was also dried to the similar moisture content range. The chipped OPF was in size of 3 cm length while the EFB was briquetted into cubic form with size of 3×3×3 cm^3. The prepared feedstocks are shown in Fig. 1.

Fig. 1. a) OPF, b) PKS, and c) EFB Feedstock.

The feedstocks were gasified using medium scale downdraft gasification with reactor capacity of 500 kg/hour. The gasification process used open-top gasifier with continuous supplied of feedstock. The process was operated in temperature range of 650-800 ºC. Due to the closed loop and tar recycle system, the gasification process produced two main products which were syngas and biochar. The syngas flowed out through piping system meanwhile the biochar was collected at the bottom side of gasifier. The gasification system for biochar production is shown in Fig. 2.

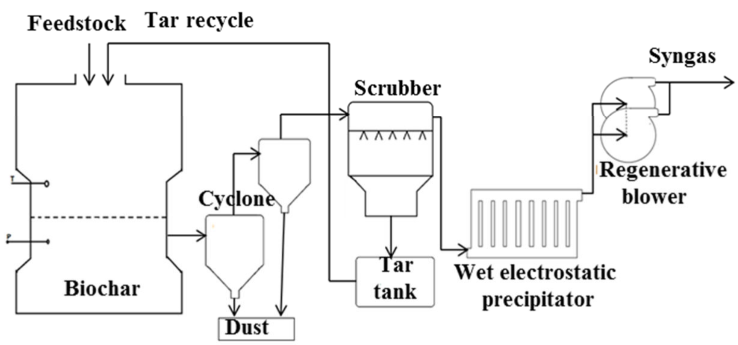

Fig. 2. Gasification system of palm wastes biochar production.

The palm wastes feedstock and biochar samples characteristics were investigated in terms of their calorific value, elemental content, surface area and adsorption capacity. The calorific value was determined by using IKA-WERKE bomb calorimeter. 5 mg of sample was used for every experiment and it was repeated by three times to obtain the average value. The proximate analysis was carried out to determine moisture, volatile matter, ash and fixed carbon content of the samples based on ASTM D3172 – ASTM D3175. In addition, the ultimate analysis was also carried out to determine carbon, hydrogen, nitrogen and oxygen content by using CHNS-O analyzer. Most elements in the sample were known through the detection of resulted graph peak but the oxygen content was determined by the difference of the total percent of elements. Meanwhile, Brunauer–Emmett–Teller (BET) method was applied to determine specific surface area by using Micromeritics Gemini Analyzer at -196 ºC with N_2 adsorption. Besides the surface area, BET also enables to study adsorption and desorption capacity of the samples. The pore volume and size of the samples were determined using Barrett-Joyner-Halenda (BJH) model. The micropore volume and size were calculated by using t-Plot micropore volume and size. Figure 3 shows the samples of biochars from palm wastes gasification.

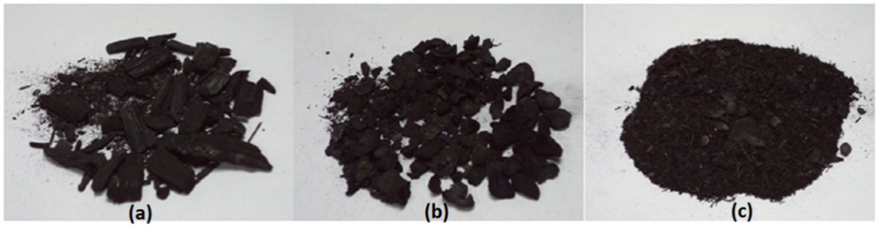

Fig. 3. Palm wastes biochar; a)OPF, b)PKS and c)EFB biochar.

3. Results and Discussion

3.1. Proximate and ultimate analysis

Table 1 shows the proximate and ultimate analysis of OPF, PKS and EFB feedstock. It shows low moisture content with 6%, 8.44% and 5.18% for OPF, PKS and EFB, respectively. The fixed carbon and ash content of these samples are 17% and 1% for OPF, 27% and 1.23% for PKS, and 3.45% and 8.79% for EFB respectively. In term of volatile matter, they show high values with the range of 76-83%. High value of volatile matter is important for the gasification process due to the tendency of solid fuel to be converted into the syngas. In term of elemental content of these feedstock, it shows no significant different which carbon, hydrogen, nitrogen and oxygen content in range of 42-50%, 7-9.7%, 0.5-1.0% and 39-49% respectively for OPF, PKS and EFB. Based on this ultimate analysis, the empirical formulas for OPF are $CH_{0.16}N_{0.01}O_{1.16}$, PKS $CH_{0.19}N_{0.01}O_{0.78}$ and EFB $CH_{0.17}N_{0.02}O_{1.19}$.

Table 1 also shows the elemental content of OPF, PKS and EFB biochars. It shows that carbon is the highest content in biochar followed by oxygen, nitrogen and hydrogen. Carbon and nitrogen content in biochar increased meanwhile oxygen and hydrogen content decreased compare to the original feedstock. Hence, the carbon content show significant increase while oxygen content show significant decrease in term of their content. The oxygen content of original feedstock decreased obviously when forming biochar due to the oxygen is highly reactive element at elevated temperature. The oxygen was released as a volatile matter involved in several chemical reactions to form syngas and other by-products during the gasification process.

In fact, the carbon content is important to recognize its potential as carbon base applications. The palm wastes have moderate carbon material with shares of 43%, 50% and 42% for OPF, PKS and EFB, respectively. In general, the following palm wastes were gasified at temperature above 650 ºC which adequate temperature to fully carbonized them into biochar. In term of carbon content in palm wastes biochars, they have very high carbon content with 91%, 81% and 75% for OPF, PKS and EFB biochar respectively. Based on the European-Biochar [12], these biochar are considered as favorable biochar due to high carbon content which are higher than 60%. During the gasification process, the

OPF shows the highest rate of carbonization process with carbon intensity change by 48% followed by PKS and EFB with 31% and 33% of carbon intensity change. It indicates that OPF is better feedstock in biochar production compared to other palm wastes. Nevertheless, the PKS and EFB are still favorable feedstock for biochar production. Besides, these biochars carbon content were higher compared to the other biochars from switch grass, hardwood and corn stover biochar as reported by Brewer et al. [13].

Table 1. Proximate and ultimate analysis of OPF, PKS and EFB feedstock and biochar.

	OPF	PKS	EFB
Proximate analysis for feedstock (%)			
Moisture	6.00	8.44	5.18
Volatile matter	76.00	71.81	82.58
Fixed carbon	17.00	26.96	3.45
Ash	1.00	1.23	8.79
Ultimate analysis for feedstock (%)			
Carbon	42.88	50.42	42.08
Hydrogen	7.06	9.74	7
Nitrogen	0.52	0.52	0.99
Oxygen	49.54	39.32	49.93
Ultimate analysis for biochar (%)			
Carbon	91.00	81.00	75.00
Hydrogen	1.00	1.00	2.00
Nitrogen	2.00	3.00	2.00
Oxygen	6.00	15.00	21.00

High carbon content in biochar is also important as a carbon sequestration in soil application. Many studies have shown that the biochar is ideal to use in soil amendment as a carbons sequestration as reported by Duku et al. [14] and Galinato et al. [15]. Basically, the carbon content in the original biomass is easy to degrade due to the low grade of carbon content. Nevertheless, the carbon content in the biochar has ability to stable for long time period due to the pyrogenic carbon formed as reported by Shenbagavalli and Mahimairaja [16]. The stable structure of carbon in biochar was obtained due to the heat treatment during the carbonization process via gasification. When it being applied for low temperature application such as a soil amendment in agriculture activities, it is enable to stable for long time period. Thus, huge quantity of carbon is being stored in biochar to avoid carbon release into atmosphere. As claimed by ZeroPoint Clean Tech Inc. Company [17], each ton of biochar produced represents approximately 3.5 tons of carbon dioxide removed from the atmosphere. When biochar is continuously produced, it results in the decrease of carbon footprint in atmosphere thereby reducing the greenhouse gases effect for the greener environment.

Biochar has also been shown to increase the fertility of soil resulting in decreased need for fertilizers and irrigation. Moreover, the use of biochar for soil amendment application can also stimulate the mineralization, reduce the nitrous oxide (N_2O) emission, reduce the ammonia (NH_4) and nitrate (NO_3^-) losses to offer a mechanism for developing slow release fertilizers as reported by Clough et al. [18]. Thus, the biochar use in soil application is proposed to improve the soil quality as well as to act as a carbon sequestration method to reduce carbon footprint for greener environment.

3.2. Energy content analysis

Figure 4 shows the calorific value (LHV) for OPF, PKS and EFB feedstock and their biochar. The LHV of OPF, PKS and EFB feedstock are 16 MJ/kg, 19 MJ/kg and 16 MJ/kg, respectively. Due to the carbonization process, the energy content of biochars significantly higher compared to the original feedstock with 27 MJ/kg, 29 MJ/kg and 27 MJ/kg for OPF, PKS and EFB biochar respectively. It means the energy content significantly increase during the carbonization process by 69%, 53% and 69% for OPF, PKS and EFB respectively. It was due to the high rate vaporization of lower energy content elements such as oxygen, hydrogen and nitrogen when gasified to leave carbon as a major residue which has high calorific value.

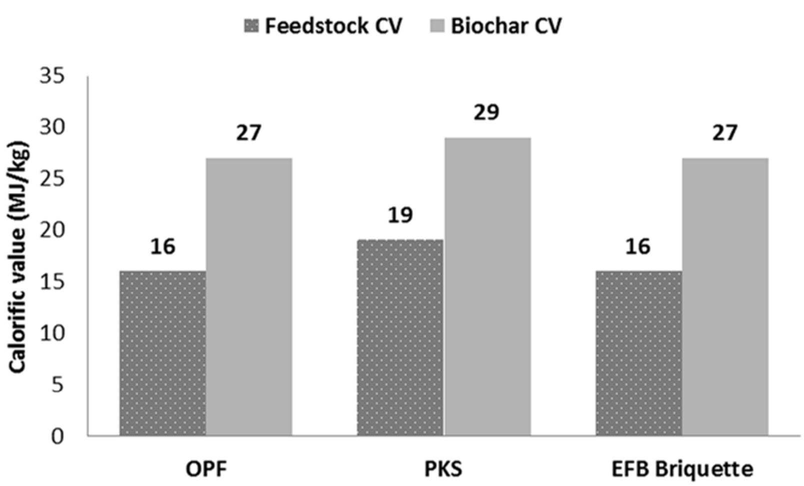

Fig. 4. Calorific value comparison of palm wastes feedstock and their biochars.

In fact, the high LHV of these biochars are comparable to the high rank of coal which about 28.9 MJ/kg as reported by Lee et al. [5] and Li et al. [19]. Thus, the biochars have high potential to be applied in similar with coal applications. The coal is a well-known fuel has been used in power generation such as gasification hence the biochar yield is possible to be used as fuel in gasification process. It means the biochars have very high ability to be recycled in gasification process to further increase the energy conversion process. The fuel recycle process is very important to improve the gasification process efficiency. It means more solid fuel will be converted into the syngas. In fact, the previous research using EFB biochar for gasification process was carried out by Salleh et al. and they concluded that EFB biochar is ideal to replace coal in power generation activities [20]. Therefore, it strongly justify that palm wastes biochars have high potential to be used as fuel in power generation activities due to the no significant different characteristic between them. The use of palm wastes biochars as a recycle fuel can avoid excessive wastes management thereby reduces the management cost. Thus, the recycle use of biochar is highly recommended in power generation to improve its efficiency and the revenue.

3.3. Brunauer–Emmett–Teller (BET) method analysis.

Table 2 shows the results were obtained from BET method analysis such as surface area, micropore area, micropore volume and adsorption capacity of biochars. The surface area of OPF was very high namely 857.31 m^2/g compared to the PKS and EFB with 23.73 m^2/g and 95.83 m^2/g respectively. The high surface area of OPF biochar indicates that it has more porous structure and more tiny pores as compared to the others. In Fig. 5, it also showed the adsorption capacity, micropore area and volume of the biochar samples. These results also showed that OPF biochar has the highest value. It indicates that these values are highly dependent on surface area of the biochar. Besides, these palm wastes biochar surface area were higher compared to the other biomass such as switch grass, hardwood and corn stover biochar as reported by Brewer et al. [13]. Based on Brewer et al. study, the highest surface area of biochar was 50.2 m^2/g that was produced from a slow pyrolysis process of switch grass as a feedstock. Therefore, these palm wastes biochars were found to be much better in terms of surface area.

Besides, the biochar with high carbon content and high surface area has high potential as an activated carbon application. The uses of biochar as an activated carbon will contribute to the high technology application which has a very high market value. The activated carbon commonly used as gas and water filtration, water and sewage treatment, gas-solid separation and some processing applications as reported by Poinern et al. [21] and Gundogdu et al. [22]. Normally, the surface area of activated carbon is within 400-1400 m^2/g. Based on the range of activated carbon surface area, the OPF biochar potentially can be used for that application. Moreover, the previous study on biochar as an activated carbon has been conducted by Carrier et al. [23] shown that carbon content of activated carbon lower than 79% with surface area in range 441-570 m^2/g. Thus, it was strongly justify that OPF biochar is ideal to be used in activated carbon applications.

Table 2. BET method analysis of palm wastes biochar.

	OPF	**PKS**	**EFB**
BET SA (m^2/g)	857.31	23.73	95.83
Micropore area (m^2/g)	740.80	23.38	87.71
Micropore volume (m^3/g)	0.35	0.01	0.04
Adsorption capacity (m^3/g)	280.00	10.00	35.00

Figure 5 shows adsorption capacity graph of OPF, PKS and EFB biochar. The adsorption capacity is important to determine the potential applications of biochar for agricultural activity and activated carbon application. As high the adsorption capacity means better quality of biochar. Basically, the adsorption capacity highly depends on surface area of the sample. The high surface area represents a more porous structure form of biochar which results to the high adsorption capacity. The results showed that OPF biochar has a very high adsorption capacity with 280 cm^3/g compared to the PKS and EFB biochar with 10 and 35 cm^3/g respectively. The adsorption capacity is also important in soil application to adsorb the organic and nutrient for plant use. Moreover, it also has ability as water retention for the plant.

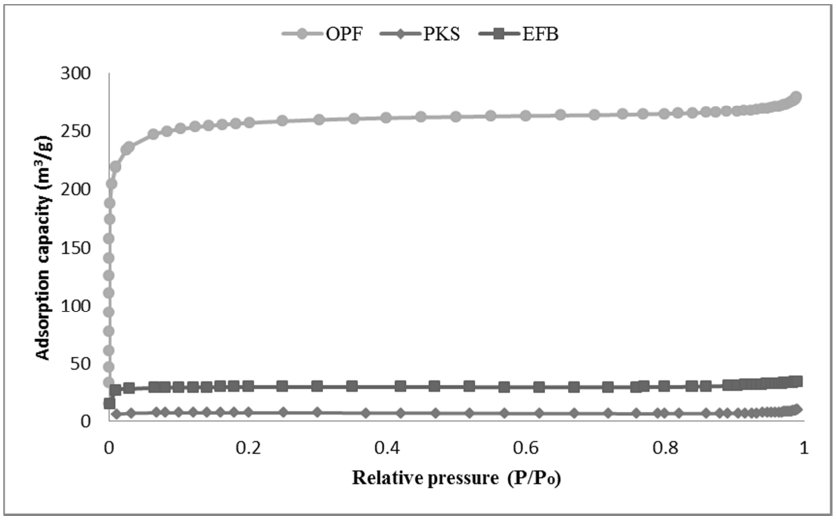

Fig. 5. Adsorption capacity of palm wastes biochar.

4. Conclusions

The palm wastes gasification using a medium scale gasifier produces biochars which found to have a very high potential in various engineering applications. These biochars have potential to be used as a fuel, soil amendment material and inactivated carbon applications. In term of fuel and soil amendment applications, biochars from OPF, PKS and EFB are ideal but in term of activated carbon applications, only OPF biochar can be used at it produced very high surface area. When the biochars from gasification are used as recycle fuels, it will improve the efficiency of that thermochemical process as well as reduce the excessive wastes. By using these biochars in soil application, it can serves as a carbon sequestration method to reduce carbon footprint for greener environment. The use of OPF biochar as an activated carbon will add value to the OPF waste thus should be explored further. The biochars from these palm wastes gasification are very valuable materials for economic purposes as well as as an effective way to reduce the carbon footprint

Acknowledgement

The authors would like to express their gratitude to Universiti Kebangsaan Malaysia for supporting this research through the Arus Perdana (AP-2012-010) and HEJIM (INDUSTRI-2012-033) research grants.

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