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A Comparison Study on Oven and Solar Dried Empty Fruit Bunches

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Abstract

In this paper, the characteristics of empty fruit bunches (EFB) of oil palm for washed and unwashed samples of oven and solar dried are presented. The proximate, ultimate and hydrolysis analyses were carried out to find the characteristics of the samples. The higher heating values (HHV) were determined by bomb calorimeter technique and, the lower heating values (LHV) were determined via calculation. The results from the proximate analysis showed that the moisture, ash, volatile and fixed carbon of the unwashed oven dried EFB was 6.8 mf wt%, 4.8 mf wt%, 80.9 mf wt% and 14.3 mf wt%, respectively. The carbon content and other elements of the EFB are also presented in the paper. It was also found that the higher heating value and lower heating value of the unwashed oven dried sample was 18.72 MJ/kg and 17.26 MJ/kg, respectively. Furthermore, the atomic absorption spectrophotometer analysis (AAS) was conducted to determine the metal content of the EFB sample and thermogravimetri analysis (TGA) was also carried out to study the degradation behavior of the EFB.

Keywords: characteristic of EFB; washed EFB; unwashed EFB; solar drying; oven drying

1. Introduction

In Malaysia, the development and economic growth continue to affect the growing demand of energy consumption. It is reported that Malaysia has been using energy at about 340 million barrels of oil equivalent (Mboe) every year (Ministry of Energy, Telecommunications and Posts Malaysia, 1998). The total primary energy supply in Malaysia has increased steadily over the past 18 years. It is expected that the future energy demand will continue to grow at annual rate of 5–7.9 % for the next 20 years. Therefore, energy security is becoming a serious issue. It is because currently Malaysia is highly dependent on fossil fuels as energy source. The use of fossil fuel which is non-renewable energy will be depleting and creates several environmental concerns that threaten the sustainability of the ecosystem. This forced the country to start finding other alternative fuels thus the increased interest in renewable energy sources which offer clean and sustainable energy (Kannan, 1999; Ong et al., 2011).

In Malaysia, in order to promote green technology, Malaysia Green Technology Corporation was established in 1998 with the objective to setup a national energy research centre to co-ordinate various activities, specifically energy planning and research, energy efficiency, and technological research, development and demonstration (R, D&D) undertaken in the energy sector (Malaysia Green Technology, 2011). Green energy would help to minimize the degradation of the environment and reduces the greenhouse gas emissions. Among the various forms of renewable energy, biomass is considered as a primary source because Malaysia is an agriculture-based country.

The production of energy from biomass and its waste is economically viable and could help to improve the environment (Tsai et al., 2004). Palm oil industry represents the highest contributor among others and generates residues during the harvesting, replanting and milling processes. With nearly 4.70 million hectares of planted land and 416 mills operating across the country, the Malaysian palm oil industry is expected to generate over 77.24 million tonnes (dry) of biomass wastes. From that number, about 58% are oil palm fronds, 10% are empty fruit bunches, 18% are oil palm trunks and 14% are oil palm fibres and shells.

It is widely reported that this type of biomass is suitable for production of bio-oil via thermal conversion process (Bahri et al., 2010; Abdullah et al., 2011; Piarpuzań et al., 2011; Seon et al., 2010). Among various methods of thermal conversion technology process, pyrolysis is the most promising method to be considered because this technology has the ability to produce more useful and valuable bio-oil with 65-75% yield on dry feed (Abdullah, 2005; Czernik and Bridgwater, 2004).

In this study the characteristics for both the washed and unwashed EFB which were dried in the conventional oven and solar drying system separately were investigated and discussed in the following sections.

2. Materials and Methods

Several analyses including proximate, elemental and thermogravimetric (TG) analyses were carried out in the study to determine the characteristics of the washed and unwashed EFB. The metal content, chemical component and heating value of the EFB were also determined.

2.1 Samples Preparation

The biomass sample used in the study is EFB. The sample was in a whole bunch form and wet as they were collected after sterilization process. The samples were then cut into smaller size (2-3 cm) and dried until a moisture content of less than 10 mf wt% was reached. Two modes of drying were conducted in the study that is, by using a conventional oven (Mermet Oven UNB 100-500 at 105^{o}C for about 24 hours) and a solar drying system. For solar drying, the samples were dried using a mixed-mode solar dryer which consisted of six double-pass solar collectors with porous media and a drying chamber as in Figure 1. However, it took about 3 days to dry the samples. The detailed design of the mixed-mode solar drying system has been discussed in elsewhere (Aliasak et al., 2009).

After both the oven and solar dried samples reached the required moisture content, the samples were divided into two, labeled as; sample set 1 and sample set 2. Water washing pre-treatment was conducted on sample set 1 or known as the washed sample, while sample set 2 remained untreated or known as the unwashed sample. The washing pre-treatment was conducted in order to remove ash from the sample (Abdullah et al., 2011).

In preparing sample set 1, about 100g of the EFB was soaked in 5L of tap water at ambient temperature for about 10 minutes (Aliasak, 2011). Then, the sample was drained and dried in a conventional oven and a solar drying system separately until moisture content of less than 10 mf wt% was achieved.

2.1.1 Proximate Analysis

Analyses were carried out to find the moisture, ash, volatile and fixed carbon content of all samples. The moisture content was determined using ASTM E871 Method (Annual Book of ASTM Standard, 1998). The ash content was calculated on dry basis using NREL Standard Analytical Method (Laboratory Standard Analytical Method, 1994) while, the volatile matter content was determined using standard ASTM E872 (Annual Book of ASTM Standard, 2006)

2.2.2 Ultimate Analysis

The ultimate analysis was carried out using CHNS/O analyzer (Perkin Elmer 2400 Series II) to determine the carbon, hydrogen, nitrogen and sulphur contents of the samples. All results were given in percentage and the oxygen content was calculated by finding the difference.

2.2.3 Higher Heating Value (HHV) and Lower Heating Value (LHV)

The HHV of the samples were investigated using an Adiabatic Bomb Calorimeter (Nenken 1013-B, Japan) while the LHV was calculated according to Eq. (1) below (Energy research Centre of the Netherlands (ECN), 2005);

$$LHV_{dry}\,(MJkg^{-1}) = HHV_{dry} - 2.442(8.963H/100) \qquad (1)$$

where H is the weight percentage of hydrogen on dry basis.

2.2.4 Atomic Absorption Spectrophotometer (AAS)

To determine the metal content of the samples, an AAS (AAnalyst 100 with HG-850) was used. Samples used were in liquid form. The samples were dissolved using an acid solution prior to analysis. From this experiment, the potassium and sodium of the EFB samples were determined.

2.2.5 Thermogravimetric Analysis (TGA)

In order to find the relationship between the changes in weight and temperature of the samples, the thermogravimetric analysis experiment was conducted on all samples. The analysis was conducted using Perkin Elmer (TGA)/Pyris 1 (DSC). Each TGA was carried out using 100 ml/min nitrogen with a heating rate of $10^{o}C$/min.

3. Results and Discussion

3.1 Proximate and Higher Heating Value

The results of the proximate analysis and heating values of washed and unwashed EFB utilizing both the conventional oven and solar dryer are presented in Table 1. The initial moisture content of the EFB used in this study was considerably high which was at 103.04 mf wt% for oven dried sample and 112.12 mf wt% for solar dried sample. After treatment (cutting, washing and drying) done to the samples, the final moisture content of the washed and unwashed EFB was reduced to less than 10 mf wt%.

As shown in Table 1, the results obtained for both oven and solar dried EFB have almost similar trend. It was found that the ash content of the washed EFB for both solar and oven dried was successfully reduced. The reduction of ash is to avoid secondary reaction which will reduce the yield of the pyrolysis liquid produced. A study showed that the liquid yield decreased while the char and gas yields increase when the ash content of the biomass increased (Abdullah, 2005). Therefore, in this study it is strongly recommended to wash the EFB.

The volatile matter and fixed carbon contents of the oven dried washed EFB has reduced compared to the unwashed EFB. This could be due to the loss of biomass during water washing pretreatment which reduced some of the organic material and mineral in the samples.

However, for solar dried EFB no change in volatile matter was found. It was also found that the volatile content of solar dried EFB was higher than the oven dried EFB. This might be due to the random choosing of the sample used and the effect of slow drying at lower temperature. Biomass with high volatile matter provides high volatility that is suitable for liquid fuel production and easier to burn when used as fuel (Demirbas, 2004; Wan Azlina, 2007).

For the heating value, it is observed that the HHV of the unwashed EFB was lower compared to the washed EFB for both oven and solar dried samples. The high ash content in the unwashed sample indicated high alkali metal content which reduced the heat transfer and affected the HHV of the sample (Demirbas. 2005; Demirbas, 2002).

3.2 Ultimate Analysis

The EFB consisted mainly of carbon, hydrogen and oxygen with small amounts of sulphur and nitrogen content. Samples with higher nitrogen and sulphur contents will produce higher nitrogen oxides and sulphur oxides released when burning which is bad for the environment.

Overall, the results of the ultimate analysis (as in Table 1) for both solar and oven dried EFB were consistent. The methods of drying whether by solar or oven drying does not affect much the values of C, H, N, S and O in the EFB samples.

3.3 Chemical Component

The chemical content of the EFB consists of cellulose, hemicelluloses and lignin is presented in Table 1. Cellulose decomposes at $220\text{-}300^{o}C$, hemicelluloses at $300\text{-}340^{o}C$ while lignin only decomposes at $750\text{-}800^{o}C$ (Yang et al., 2004). Data for the samples were unavailable due to experimental constraints. For biomass with high content of cellulose, the liquid product derived may contain acids, aldehydes, alcohols, ketones, heterocyclic derivates, ester and phenolic compounds. However, samples with high lignin content may probably produce high unwanted polycyclic aromatic hydrocarbon (PAHs). PAHs are highly toxic that can result to health problems (Tsai et al., 2007; Nor Amani et al., 2010).

3.4 Atomic Absorption Spectrophotometer Analysis (AAS)

The results from the AAS are presented in Table 2. It is observed that the potassium and sodium contents of both solar and oven dried washed EFB were significantly lower compared to the unwashed EFB. Samples with low ash content will result in lower potassium and sodium content and vice versa as they are proxy of ash. The results for both solar and oven dried samples were also consistent indicating that the method of drying did not affect the content of the potassium and sodium in the EFB sample.

3.5 Themogravimetric Analysys (TGA) and Derivative Thermogravimetric Analysis (DTG)

To study the effect of water washing treatment on EFB sample, TGA was conducted on all four samples. The results obtained are presented in Figures 2 and 3 with different stages of decomposition curves. The first stage occurred at temperature below than 200^{o}C. In this early stage, the moisture of all four samples was removed. The weight loss of the samples recorded at this stage was less than 10%. The second stage of the decomposition occurred at temperature 200-350^{o}C which represented the decomposition of hemicelluloses and cellulose. At this stage, the weight loss of all samples was higher than 50%. The drop in these weights is due to the liberation of volatile hydrocarbon from rapid thermal decomposition of hemicelluloses and cellulose. The weight loss of EFB dried using a solar drying system is higher compared to the sample dried in an oven. This is due to the different volatile content of those samples. Samples with high volatile and lower carbon contents will cause an early degradation of carbon.

At temperature of higher than 350^{o}C, the decomposition rate was faster for the washed EFB and slower for the the unwashed EFB for both oven and solar dried samples. The extrapolated onset temperature of the washed and unwashed EFB for both oven and solar dried samples was at the same point (260^{o}C) as shown in Figure 2. The extrapolated onset temperature is the temperature at which the weight loss begins.

In Figure 3, the derivative peak temperature of the oven and solar dried washed and unwashed EFB was at 337 ℃, 320 ℃, 328^{o}C and 311^{o}C respectively. The peak indicated bigger changes on the rate of the weight loss curve. The condition is also known as the inflection point. The weight loss in the third stage is not as momentous as in stage 2 due to the slow carbonization of lignin as can be clearly seen in the wide and flat DTG curve. About 80% of the lignin weight is lost at a very low rate from ambient temperature to 800^{o}C. Beyond 800 ℃, the weight-loss rates increased slightly with a total weight loss of about 90% was achieved. The DTG curve of washed samples was shifted slightly to the right due to the reduction of the ash content.

4. Conclusions

The characteristics of EFB of oil palm for washed and unwashed samples of oven and solar dried were studied in this paper. It was found that the ash content of the washed EFB for both solar and oven dried was successfully reduced. For the heating value, it is observed that the HHV of the unwashed EFB was lower compared to the washed EFB for both oven and solar dried samples. The EFB consisted mainly of carbon, hydrogen and oxygen with small amounts of sulphur and nitrogen content. The methods of drying whether by solar or oven drying does not affect much the values of C, H, N, S and O in the EFB samples. It is observed that the potassium and sodium contents of both solar and oven dried washed EFB were significantly lower compared to the unwashed EFB. The results for both solar and oven dried samples were also consistent indicating that the method of drying did not affect the content of the potassium and sodium in the EFB sample. Samples with high volatile and lower carbon contents will cause an early degradation of carbon. The DTG curve of washed samples was shifted slightly to the right due to the reduction of the ash content. From this study, it was clearly seen that the method of drying had not affected the characteristics of the washed and unwashed EFB. The results showed that the ash content of both solar and oven dried EFB were successfully reduced after washing treatment. The HHV of the solar dried washed EFB was higher compared to the other samples. Samples with lower ash content will result in lower potassium and sodium content; hence improve the liquid product yield when fast pyrolysis process is carried out. Furthermore, the contents of C, H, N, S and O of both solar and oven dried washed and unwashed EFB were consistent. The weight loss of the washed EFB at a temperature higher than 350^{o}C is faster compared to the unwashed sample for both solar and oven dried EFB. In regard to producing clean energy, solar dried biomass should be encouraged as it will produce the desired quality at much lower costs.

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Tables and Figures

Table 1: The properties of washed and unwashed EFB (Umi Kalsom, 1997; Sun, 1999; Law, 2007; Abdullah and Gerhauser, 2008)

Component/Property (mf wt%)	Literature values	Measured			
		Oven Dried EFB (Washed)	Oven Dried EFB (Unwashed)	Solar Dried EFB (Washed)	Solar Dried EFB (Unwashed)
Proximate Analysis					
Moisture content	-	8.19	6.83	8.27	8.35
Ash content	5.36, 7.4	2.77	4.79	2.38	4.32
Volatile Matter	83.86, 71.2	77.03	80.92	85.10	85.1
Fixed carbon content	10.78, 18.3	20.20	19.29	12.52	10.58
Heating Values					
HHV (MJ/kg)	19.35	19.54	18.72	19.75	18.77
LHV (MJ/kg)	na	18.07	17.26	18.18	17.55
Ultimate Analysis					
Carbon	49.07,	48.35	47.49	48.82	47.77
Hydrogen	45.00	6.56	6.59	6.64	6.73
Nitrogen	6.48, 6.40	1.75	1.66	1.79	1.81
Sulphur	0.70, 0.25	0.31	0.34	0.35	0.38
Oxygen	<0.10, 1.06	43.03	43.92	42.40	43.31
	38.29,				
	47.30				
Chemical Component					
Cellulose	42-63	na	na	na	na
Hemicellulose	22-33	na	na	na	na
Lignin	10-37	na	na	na	na

Table 2: Potassium and sodium content of EFB

Characterization	Oven Dried EFB (Washed)	Oven Dried EFB (Unwashed)	Solar Dried EFB (Washed)	Solar Dried EFB (Unwashed)
Potassium (ppm)	122	1369	113	1321
Sodium (ppm)	14.3	26.9	11.4	23.7
Ash reduction (%)	42	-	45	-

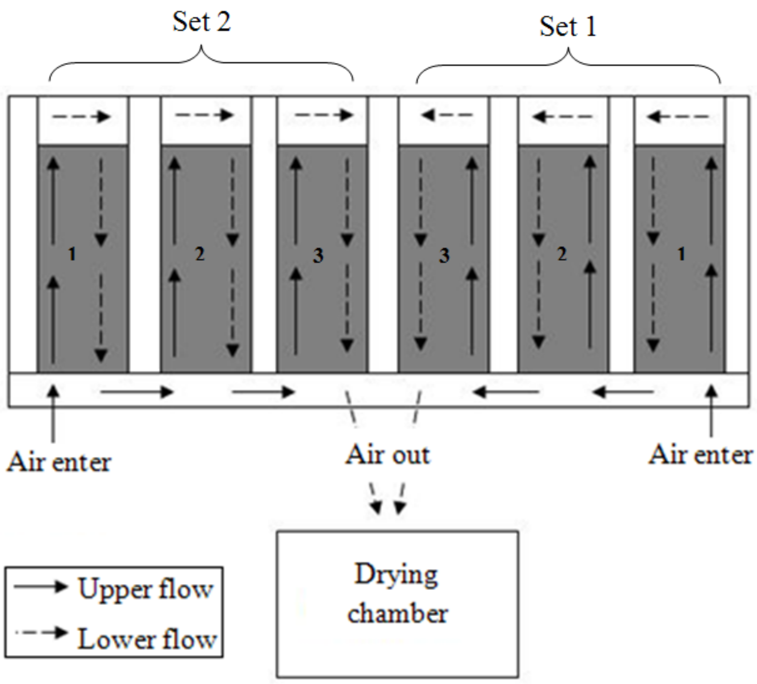

Figure 1: Configuration of the solar drying system

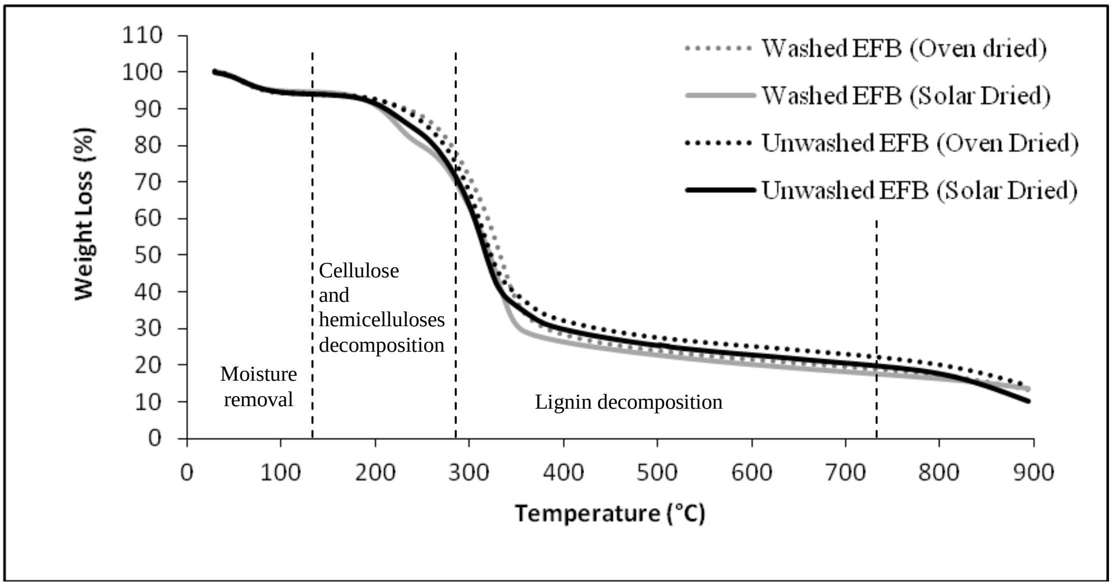

Figure 2: Thermogravimetric (TG) Curve of Washed and Unwashed EFB

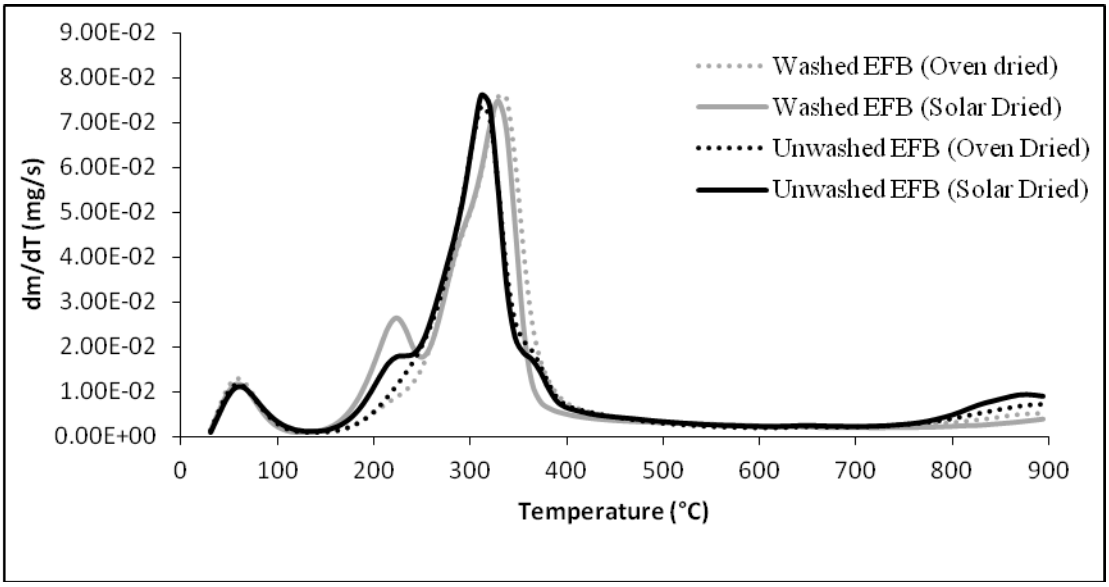

Figure 3: Derivative Thermogravimetric (DTG) Curve of Washed and Unwashed EFB