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Preliminary Study of Microwave Irradiation Towards Oil Palm Empty Fruit Bunches Biomass

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Abstract

In this study, torrefaction via microwave irradiation was introduced towards oil palm empty fruit bunches (EFB) samples. The samples of 10 g was fed into the quartz type crucible inside the microwave with the power input limit to 385 W. Continous nitrogen up to 50 ml/min were induced and promoted the non oxidative atmosphere in the closed crucible. This proved the increased of energy properties as high 23.6 MJ/kg for torrefied samples comparable to raw 14.8 MJ/kg. On the result of proximate analysis, fixed carbon shows the increase trends whereby the volatile matter decreased. Torrefaction has been found to improve the energy properties of oil palm EFB biomass as a fuel.

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1. Introduction

Currently, fossil fuels are the primary sources as cheap energy that powers our modern industrial civilization [1]. The other problem with fossil fuels is that they will soon run out and considerable not a good thing [2]. According to the global problem associated with the intensive use of fossil fuel have increased the interest in the use of renewable fuel worldwide and Malaysia is blessed with widely availability of such renewable resources from biomass [3]. There are better in financial gains and other advantages when used as a fuel for renewable energy power generation. The rapid consumption of fossil fuel needs an alternative replacement and the developed nations mostly are pursuing the development of biomass as an alternative method of power generation. Biomass energy or bioenergy is the largest and the most important one that has been employed in worldwide including in underdeveloped, developing and developed countries [4].

Biomass can be lignocellulosic or non-lignocellulosic material. Lignocellulosic biomass has the potential to produce sustainable clean-green energy and other bio-based materials. Compared to coal, reported by Medic *et al.* [5] the low bulk density, high moisture content, degradation during storage and low energy density of raw lignocellulosic biomass are challenges in generating agricultural residues as a cellulosic feedstock. The lignocellulosic biomass has difficulty to store and also grinding into small particles. However, there is solution of all this weakness of lignocellulosic biomass which is through the pre-treatment of biomass. Torrefaction is one of the solution methods [6].

Torrefaction of lignocellulosic biomass has attention interest because of its potential to overcome the disadvantages of current biofuel. Torrefaction improve the biomass properties to be used as energy. Phanphanich and Mani [7] mentioned that torrefaction improve grinding properties of biomass. The fuel characteristics make such as fixed carbon and heating value, closer to coal. Torrefied particles are brittle which is easy to grind with less energy consumption. The torrefaction able to increase 40% the calorific value of the biomass. However, about more than 50% of weight was lost from the biomass. Torrefaction can enhance the hydrophobic properties of biomass which can be stored even in an open environment [6]. The lignocellulosic biomass structure is damaged especially on hemicellulose from torrefaction so that the grindability of biomass is improved significantly. In other hand, the advantages torrefied biomass is suitable to be co-fired or co-gasified with coal [8] [9].

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Torrefaction of various types of biomass by electrical heating method (conventional method) has been discussed in literature. Previously, conventional heat methods comes from external firing like tube furnace, fluidized or fixed bed reactor which normally consumed a long heating duration and severe energy consumption that results in low quality products.The reaction is usually carried out at 200-300°C and the heating rates are usually kept below 50°C/min with the heating of the biomass takes place from the surface to the inside of the particle through conduction, convection and radiation and therefore higher heating rates may result in shorter processing time and also result in incomplete reaction [10]. In contrast to this, in microwave, heating takes place at a molecular level and volumetric heating is achieved [11]. Because of the difference in how heat being generated; microwave heating has many potential advantages in processing materials. Microwave heating is a selective, rapid, uniform, and energy-saving method without direct contacts with the heated materials [10]. Only few studies have been done for torrefaction of oil palm wastes, and microwaved assisted using statistical approach is undoubtedly novel in this area.

Present paper focuses on the characteristics of char production from oil palm EFB via microwave-assisted based on torrefaction process in the absence of oxygen. The effect of holding temperature, residence time on the torrefaction mass and energy yield were investigated. The correlations among parameters were analysed using statistical software. The moisture uptake percentage was also been addressed as it is an advantage for storage purpose.

2. Materials and Methods

2.1. Materials

Oil palm EFB was taken from local oil palm mill in Felda Kemahang at Jeli, Kelantan, Malaysia. The fresh oil palm EFB samples with higher moisture content were undergoes a sun-dried for 2 days drying. Then the samples were grounded using rotating grinder and sieved through progressively finer screen to the favourable particle size < 500 µm. Therefore, it will be kept for 24 hrs at 105°C before further process in order to minimal the moisture content. Only 10 g was used for each processing batch inside the microwave reactor.

2.2. Methods

In this study the microwave system with 2.45 GHz with the maximum power level 700 W was modified as shown in Figure 1. The torrefaction of the oil palm EFB was carried out using a microwave reactor with the nitrogen gas tank, peristaltic pump and cooling system. Several parameters were considerate in order to achieved desired torrefaction result. About 15 g of oil palm EFB was weighed and put in a quartz crucible. The crucible was place at the centre of the microwave reactor. The holding temperature used was varied from 200 until 300°C with the 15 ml of nitrogen flow. The holding temperature was also varied at 15 and 30 min residence time. After achieved the residence time, the torrefied oil palm EFB was left to cool down to ambient temperature. The samples were weighed. All experiments were duplicated to determine the range and deviation between the results.

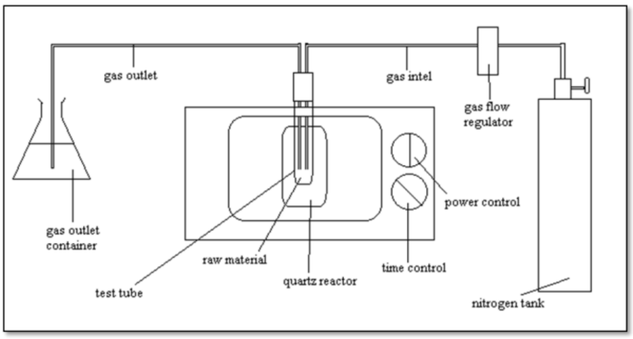

Figure 1: Schematic diagram of modified microwave reactor.

2.3. Proximate and Calorific Value Analysis

The raw and torrefied oil palm EFB were underwent the proximate analysis in order to characterize the biomass (dry basis). It can determine three categories in such of volatile, ash and fixed carbon content carried out by electric furnace.

Moisture content is obtained by using moisture analyser by having the biomass into the oven at 105°C at 180 min to remove the moisture. The test procedures ASTM D3175 and ASTM D3174 were used to determine the volatile matter and fixed carbon content respectively. The sample (1 g) was placed and heated up to 900°C for 7 min in closed crucible to prevent oxidation. The weight loss is calculated and represent as volatile matter. The remaining sample was then combusted in 3 hrs under temperature of 815°C. Weight loss is calculated as fixed carbon while ash content can obtained simultaneously. The following equation been used for proximate analysis which is Equation (1) for moisture content; Equation (2) for volatile matter; Equation (3) for ash content and Equation (4) for fixed carbon.

$$\text{Moisture content (MC) in dry basis} = (W_i - W_f)/ W_f \times 100 \quad (1)$$

$$\text{Volatile matter (VM)} = (W_i - W_f)/W_i \times 100 \quad (2)$$

$$\text{Ash content (AC)} = \frac{Weight\ of\ ash}{W_f} \times 100 \quad (3)$$

$$\text{Fixed carbon} = 100 - (MC + VM + AC) \quad (4)$$

Where Wi is the initial dry weight of sample while W_f is the final dry weight at every stage respectively.

The samples were then undergoing investigation for calorific value using adiabatic bomb calorimeter (model 1013-B Yoshida Seisakusho). This test is important to reflect the effect of microwave heating in order to enhance the biomass energy content. The standard test method (ASTM D2015) was used with

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initially the sample approximately 1 g was put into the chamber, inducing high pressure into 30 bar and connected fuse wire. Heat generated in the chamber is defined as the total heat liberated by the complete combustion of the sample. This particular value is determined by measuring the heat removed when cooling the products of combustion to a standard reference temperature. The deviation of initial and final temperature accordance of heat realese was recorded as a function of T_i and T_f. The following Equation (5) was used to determine the lower heating value (LHV).

$$LHV_{sample} = \frac{\Delta H_{water} x (m_{water}) x \Delta T}{(m_{sample})} - Lh_{vap,} H_2O \quad (5)$$

Where m_{water} is 2.74kg, deviation temperature $\Delta T = T_f - T_i$, heating value of water ΔH_{water}=4.18kJ/kg and latent heat of vaporization water, $Lh_{vap,}$ H_2O=2260 kJ/kg (at 100°C).

Using the torrefaction output, the sample was then measured the following Equation (6); (7) and (8).

$$Y_m: \frac{\text{Weight of mass after torrfaction}}{\text{Mass of raw EFB}} \quad (6)$$

$$CV_R: \frac{\text{CV of sample after torrefaction}}{\text{CV of raw oil palm EFB}} \quad (7)$$

$$Ye: Y_m \times CV_R \quad (8)$$

Where Y_m is mass yield, CV_R is ration of calorific value and Y_e is energy yield.

3. Results and Discussion

3.1. Mass Yield

The mass yield of torrefaction products is shown in Figure 2. Solid fraction (bio-char) yield decreases with an increase of torrefaction holding temperature. In trend of result, mass yield also decreased with increased of residence time and the holding temperature. It might explain the severity of thermal exposure would lead to extend further the decomposition of empty fruit bunch. As hemicellulose degrades most within the torrefaction temperature range, would expect a higher mass loss in biomass with high hemicellulose content [12].

Higher weight loss at 30 min was obtained comparable to 15 min residence time. Meanwhile, the highest mass yield value for oil palm EFB torrefied is achieved at 83.8% in 15 min, while 72.9% at 30 mins at low temperature (200°C). On the other hand, the mass yields gradually decrease over the range of microwave holding temperature. Increasing the microwave holding temperature increases the heating exposure during torrefaction process, thus results in secondary cracking and depolymerization occurs between 225 and 325°C for hemicelluloses [13].

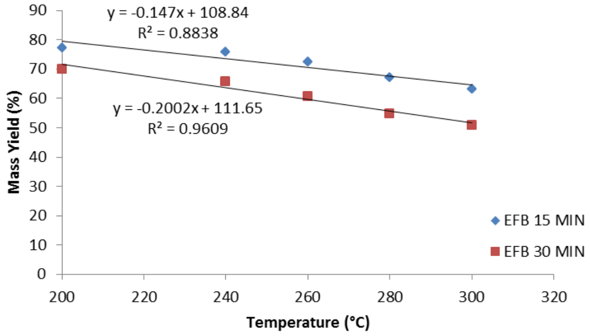

Figure 2: Effect of holding temperature and residence time on the mass yield.

3.2. Proximate Properties

The proximate analysis revealed oil palm EFB value in different categories: moisture content (6-8%), volatile matter (85-73%), ash (0.25-0.96%) and fixed carbon (6-22%) as illustrated in Figure 3 and 4. Based on the result, raw oil palm EFB exhibits the highest moisture content 8.1%. Moisture content expressed as the quality of water per unit mass of dry solid. The amount of moisture in biomass is reflecting the handling and storage conditions. The highest volatile matter content was attained 82.01% at holding temperature of 200°C in 15 min residence time while lower content as 72.88% at holding temperature 300°C in 30 min. These trends shown the effect of decreasing residence time and holding temperature might approach the increasing of volatile matter contents. The reported by Sjaak & Koppejan [14], high volatile matter content biomass and low char content makes biomass a highly reactive fuel giving a faster combustion rate during the volatilization phase than other fuels such as coal. Besides that, according to Quaak *et al.* [15] reported that the biomass was decomposed into volatile gases and solid char during this process. Typically, biomass has high volatile matter content which is more than 80% compared to coal which had low volatile matter content which is less than 20%. Therefore, lower volatile content matter might closer the torrefied biomass to coal.

On the other hand, the highest ash content in torrefied oil palm EFB was attained 1.08% and the lowest was 0.2% while 1.04 and 0.25% for 30 and 15 min residence time respectively. In the trends of recorded result the percentage of ash content increased when the holding temperature and residence time increased. Meanwhile, higher ash content attributes to lower calorific value. As reported by Akowuah *et al.* [16] said that the non-combustible component of biomass was found to be 2.6% known ash. An impurity of ash that will not burn, fuels with low ash content are better suited for thermal utilisation than fuels with high ash content. Higher ash content in a fuel usually leads to higher dust emissions and affects the combustion volume and efficiency. Biomass ash does not contain toxic metals like

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coal ash. Ash composition is important to prevent the corrosion. The combustion temperature significantly affects the total yield of ash from biomass.

Another parameter is fixed carbon which observing in raw and torrefied oil palm EFB. The trends observed the highest value are 8.25 and 17.89% in raw and 30 minute of residence time. In counterparts at 15 min residence time, shown the value varies from 9.59 to 17.7% at 200 to 300 °C torrefaction holding temperature. Therefore, more time necessary needed rather than desired various temperatures to improve the heating value. As predicted, the increases of temperature and residence, the fixed carbon will definitely increase. The fixed carbon is the fraction that remaining after releases of volatiles, keep out the ash and moisture contents. Fixed carbon gives a rough estimate of the heating value of a fuel and acts as the main heat generator during burning [16]. Carbon content is physically approach by effect of heating source and it would attribute the changes of heating value. Thus, higher carbon content will have a higher heating value.

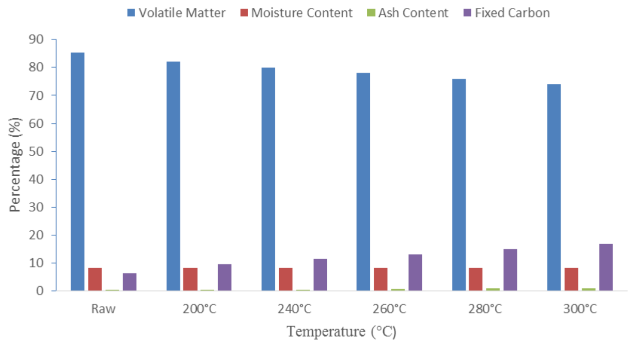

Figure 3: Proximate properties for oil palm EFB in 15 min torrefaction residence time.

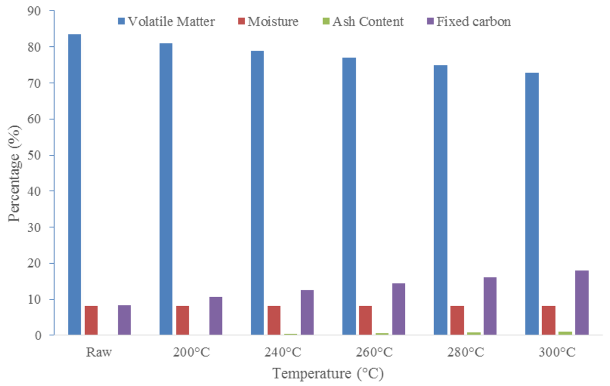

Figure 4: Proximate properties for oil palm EFB in 30 min torrefaction residence time.

3.3. Calorific Value

The standard measurement of energy content in fuel is heating value, sometimes called the calorific value or heat of combustion. In order to discuss more specifically, the calorific value yield of torrefied sample are plotted against torrefied temperature as shown in Figure 5. The calorific value was attained at 21.4 and 23.6 MJ/kg in 15 and 30 min residence time respectively. In the trends of result shown, calorific of oil palm EFB is coherent with the factor of residence time and temperature aligned as reported by Zanzi *et al.* [17]. The increase in the calorific value is due to decrease in the moisture content and an increase in the carbon content of the samples. As expected the fixed carbon also shown similarity trends correspond to the increasing of calorific value.

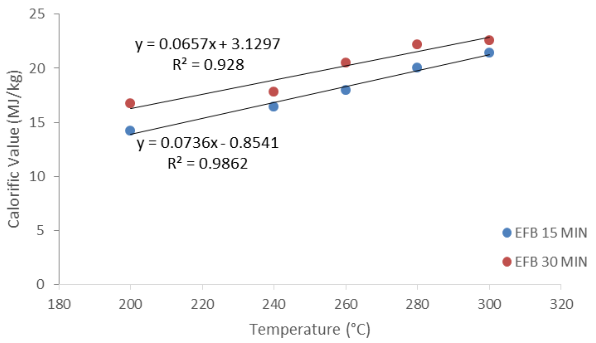

Figure 5: Calorific value in 15 and 30 min torrefaction residence time.

3.4. Energy Yield

The Equation (8) was used to define the energy yield of various ranges holding temperature of torrefied oil palm EFB. Reported by Poudel and Oh [18] said that parameters such as the energy yield, the composition of the torrefied products, and the calorific value must be considered to obtain the optimum torrefaction temperature. The energy yields of oil palm EFB are slightly decreased from 78 to 54% depending on the residence time as shown in Figure 6. The same trend goes for both parameters with the longer residence time would have low energy yield. The difference value in residence time mainly based on poor mass yield and it also exhibit moisture loss during the treatment.

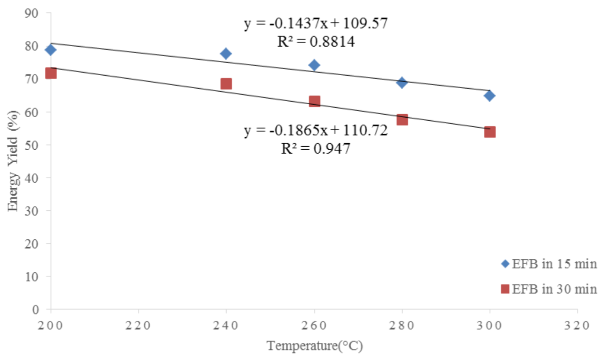

Figure 6: Energy yield at various holding temperatures in 15 and 30 min torrefaction residence time.

4. Conclusion

Torrefaction is one of the methods to change oil palm EFB into a fuel. Torrefaction has been found to improve the physical properties of biomass as a fuel. In other hand, product, measured in terms of mass yield,

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energy yield and energy density, is influenced by the following parameters which is torrefaction holding temperature, type of lignocellulose biomass and residence time. Based on this study, result from proximate analysis, calorific value had proved that the torrefaction process viable new technology to upgrading biomass. The critical temperatures were fuel dependent and therefore the results indicate that careful optimisation is required for all fuel types to maximise the benefits of torrefaction whilst maintaining a good energy yield.

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