

TORREFACTION OF PALM BIOMASS BRIQUETTES AT DIFFERENT TEMPERATURE

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Abstract

The climate change has driven towards transformation from the high energy dependence on fossil fuel to inexhaustible renewable energy such as solar, wind, mini hydro and biomass. In Malaysia, abundant of palm biomass residues are produced during the processing of fresh fruit bunch. Therefore it is inevitable to harness these bioenergy sources in order to prevent waste accumulation at adjacent to palm mills. In order to utilize such bioenergy sources and to cope with the fast growing demand of energy, combination technique of densification and torrefaction is one of the potential ways to be practised. In the present study, the physical and combustion properties of torrefied empty fruit bunch (EFB) briquettes were investigated experimentally with constant nitrogen flow rate of 1 l/min, for various torrefaction temperatures (225°C-300°C). Before torrefaction process, EFB briquettes were initially produced under controlled condition with compaction pressure of 7 MPa and briquetting temperature of 150°C. In general, the torrefied EFB briquettes were successfully produced in the present study. The results show that an increase in torrefaction temperature from 225°C to 300°C causes a significant increase in gross calorific value (from around 17400 kJ/kg to 25000 kJ/kg), fixed carbon content (from 16.2% to 46.2%) and ash content (from 2.4% to 17.2%). On the other hand, relaxed density and volatile matter decrease, from 1017 kg/m³ to 590 kg/m³ and from 73.1% to 29.7%, respectively. As a conclusion, the gross calorific value and fixed carbon content are improved due to torrefaction. In addition, it was found that gross calorific value and moisture content of the torrefied EFB briquettes fulfil the requirement for commercial briquette production as stated by DIN51731 (gross calorific value >17500 kJ/kg and moisture content <10%).

Keywords: Torrefaction, palm biomass, EFB, briquette, pellet, power plant, vehicle system

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1.0 INTRODUCTION

The climate change has driven towards transformation from the high energy dependence on fossil fuel to inexhaustible renewable energy (solar, wind, mini hydro and biomass) [1]. Renewable energy sources are abundant in Malaysia, the significant ones are biomass and solar [2]. Oil palm plantations are being actively cultivated and harvested, that cover close to five million hectares for year 2011 [3]. As a result, abundant palm biomass

residues are produced during the processing of fresh fruit bunch (FFB), such as shell, mesocarp fibre and empty fruit bunch (EFB). The amount of these residues significantly increases from year to year. Therefore, it is inevitable to harness these bioenergy sources, in order to prevent waste accumulation at adjacent to palm mills.

Briquetting is a densification method which is able to produce the product with higher energy density. In addition, this technique is a solution for difficult handling and expensive transportation procedures

[4]. Besides, the products of gasification of briquettes also have the potential to be used for vehicle system [5]. The briquettes which contain various types of palm biomass have been introduced, with the aim to utilize such bioenergy sources effectively. The first attempt to convert these palm residues into solid fuels was successfully performed about a decade ago, in which it contains mesocarp fibre and shell with starch as a binding agent [6]. Then, six years later, a technique of pulverizing palm biomass has been introduced to produce binderless briquette [7]. In the following years, several other efforts in making briquette were performed to utilize the massive production of residues during the oil extraction process from FFB, that are mesocarp fibre [4] and EFB [8]. Based on these previous studies, it can be concluded that the heating values of briquettes produced are very close or slightly higher than those of commercial briquettes.

Torrefaction is a thermal decomposition of biomass in the absence of oxygen. In addition to the enhancement of hydrophobic nature of the biomass, grindability, gasification potential and future prospects as a solid fuel are improved due to the modified structure [9]. The fuel properties of torrefied biomass are significantly influenced by torrefaction temperature, torrefaction time, and type of biomass. The torrefaction of palm biomass has been performed by Uemura *et al.* for empty fruit bunch fibre, mesocarp fibre and shell [10]. They have concluded that mesocarp fibre and shell exhibit excellent energy yield, that is higher than 95%. Meanwhile, EFB demonstrates poor energy yield of 56%.

However, the fast growing demand requires the maximum utilization and recovery of energy [1, 11]. In this case, the combination of torrefaction and densification of palm biomass is one of the attractive options for coping with the ever increasing energy demand. One of the earliest investigations on briquettes produced by combination technique was performed by Felli *et al.* [12]. In their study, the briquettes made of wood was produced by the sequence of briquetting and followed by torrefaction. They found that after torrefaction, the wood briquettes showed an increase of approximately 15% in heating value, and a decrease approximately 73% in equilibrium moisture. On the other hand, when the residence time was increased from 0.5 to 1.5 hours, the heating value increased around 4%. A similar tendency was observed for fixed carbon content. From these results, it can be concluded that the torrefaction temperature has more significant effect on the briquettes compared to the residence time.

Similar conclusion has been made by Na *et al.* based on their investigation on the performance of pellets made of torrefied mesocarp fibre [13]. They found that reaction temperature has stronger effect on energy yield of torrefied biomass, rather than the effect of reaction time. Besides research performed by Na *et al.* [13], the study on densified palm biomass produced from the combination technique also has

been performed by Nyakuma *et al.* [9]. Nyakuma *et al.* had successfully performed torrefaction on 10g of EFB pellets that were tightly enclosed in an aluminum foil. As a result, they obtained a solid uniform fuel with improved physical and thermochemical properties. They found that the heating value of EFB pellets increased from 17.57 MJ/kg (without torrefaction) to 26.24 MJ/kg after torrefaction at temperature of 300°C. In addition, they also revealed that the energy density of EFB pellet also increased from 1.12 to 1.49 when torrefaction temperature was increased from 250°C to 300°C.

The other ways to maximize the energy utilization is by mixing the biomass with plastic waste when making briquette, such as performed by Zannikos *et al.* [14]. Recently, they have produced briquettes which contain a mixture of sawdust/straw and polyethylene plastic waste. They found that the calorific values of biomass briquettes are generally increase due to the plastic waste addition [14]. The addition of polyethylene plastic waste to the biomass briquette is an attractive option for coping with the fast growing energy demand scenario. Before their study, Kers *et al.* also have produced briquettes made of refuse derived fuel (RDF), which consists of mixture of municipal waste with 38% wood chips from soft wood, 45% disintegrated carton waste, 11% disintegrated PET bottles and 6% textile waste [15].

In the present study, the focus is mainly on the combination technique of densification and torrefaction. Based on the literature survey conducted, the physical and combustion properties of palm biomass briquettes produced from such combination technique have not been properly understood. The difference with the previous study by Nyakuma *et al.* [9], is that the present study applied torrefaction on the EFB briquettes produced under controlled condition, instead of as received pellets. In addition, the briquettes produced in the present study were torrefied one by one to avoid the effect of agglomeration on the physical and combustion properties. The performance of the torrefied EFB briquettes was compared with the standard requirement for making commercial briquette (DIN 51731) and the performance of briquette made of 100% EFB [16].

2.0 METHODOLOGY

2.1 Proximate Analysis

In the present study, empty fruit bunch (EFB) fibre was used as a raw material. It was received from Felda Lok Heng, Kota Tinggi, Johor. The EFB fibres were ground and sieved into small particles size (<500µm). Proximate analysis was conducted based on American Society for Testing and Materials (ASTM) standards. Table 1 shows the standards used for the proximate analysis of raw material and torrefied briquettes produced. Meanwhile, Table 2 shows the results of proximate analysis for the raw material (EFB).

Table 1 Standards Used for Proximate Analysis

Properties	Standard Used
Moisture Content	ASTM D3173
Volatile Matter	ASTM D3175
Ash Content	ASTM D3174

Table 2 Results of Proximate Analysis for EFB

Fixed Carbon (%)	14.00
Moisture Content (%)	7.00
Volatile Matter (%)	75.50
Ash Content (%)	3.50

Based on Table 2, the moisture content for the raw material used in the present study is found to fulfil the requirement for producing commercial briquette as stated by DIN51731 (moisture content <10%).

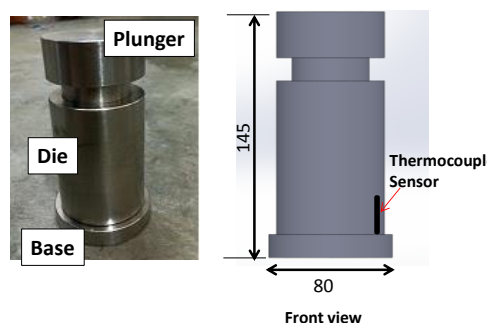
2.2 Determination of Gross Calorific Value

Gross calorific values of the raw material and the torrefied briquettes were determined by using a bomb calorimeter, model LECO AC350. The value for the EFB fibre is 16689 kJ/kg.

Based on the result, it can be said that the calorific value for EFB is lower than the minimum requirement as stated by DIN51731 (17500kJ/kg). Therefore, in the present study, the torrefaction was performed on the briquettes produced to improve the calorific value.

2.3 Briquetting Process

The briquetting process was performed by using Instron Machine 600dx. The briquettes with diameter around 50mm and mass of 48g were produced by using a die set made of stainless steel, as shown by Figure 1. A hole for thermocouple sensor was made inside the die wall in a way such that the horizontal distance between the sensor and the pulverized EFB (inner wall of die part) is around 3mm. For heating purpose, the die part was covered with coil heater as shown by Figure 2 and was insulated to prevent heat loss. Both the thermocouple and coil heater were connected to a temperature controller to maintain the heating temperature at the desired value.

**Figure 1** Die set and respective thermocouple location**Figure 2** Briquetting process using Instron Machine 600dx

Briquetting process was performed at constant compaction pressure of 7 MPa and constant heating temperature of 150 °C, to produce 100% EFB briquette. The same condition was applied for each briquette production because in the present study, the important independent variable is torrefaction temperature. Initially, the pulverized EFB was compressed without heating for 30 minutes. Then, the EFB was continuously compressed at the desired temperature for another 30 minutes. After that, it was left at room temperature for cooling process. Finally, the briquette was taken out from the die set and was placed at ambient condition for a week to obtain stability and rigidity [5].

2.4 Torrefaction Process

The torrefaction was performed by an experimental setup as shown by Figure 3. The internal diameter of the reactor was around 10 cm. A type-K thermocouple was used to measure the temperature near the specimen (vertical distance about 5 mm from the specimen). The temperature controller was used to maintain the torrefaction temperature.

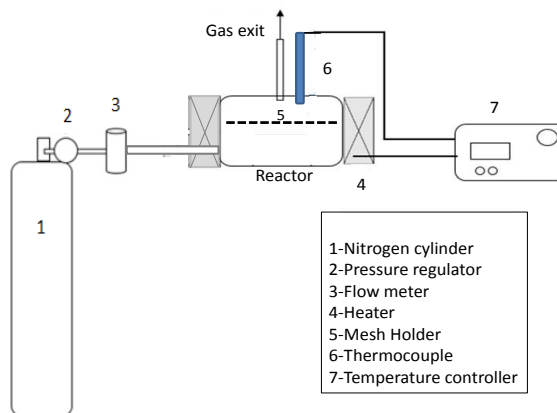


Figure 3 Experimental setup for torrefaction

In the present study, torrefaction temperature was varied between 225 °C -300 °C with 25 °C increment. Initially, the EFB briquette was placed on the mesh holder and was put into the reactor. Then, the reactor was purged for 1 hour with nitrogen to remove air from the tank and to prevent the contact between the specimen and air. Then, the specimen was torrefied at desired temperature for 30 minutes. Finally, the specimen was allowed to cool to room temperature before it was taken out from the reactor. Throughout the experiment, the flow rate of nitrogen was set to 1 l/min.

2.5 Determination of Physical Properties of the Torrefied EFB Briquettes

Physical characteristics of the torrefied EFB briquettes were investigated in terms of relaxed density, compressive strength and mass yield. The density of the briquettes was determined by using stereometric method as proposed by Rabier *et al.* (2006) [19]. The volume of the briquettes was measured using callipers and then the mass was determined using a precision mechanical balance.

During torrefaction, mass loss occurs due to the drying, heating and partial devolatilization process [17]. Therefore, mass yield is an important characteristic to determine the mass remained after torrefaction. Here, mass yield (y_{mass}) is obtained from the Equation 1 [18],

$$y_{mass} = (\text{mass after torrefaction} / \text{mass of sample before torrefaction}) \times 100 \quad (1)$$

Meanwhile, the compressive strength of the torrefied briquettes was determined by using Instron 600dx machine. Each torrefied briquette was placed between two metal plates horizontally. The load was continuously applied on the briquette until fracture was detected. The fracture point was detected when there was a sudden drop of force applied.

2.6 Determination of Combustion Properties of the Torrefied EFB Briquettes

Combustion characteristics of the torrefied EFB briquettes were investigated in terms of gross calorific value, energy density (energy per unit volume), moisture content, volatile matter, fixed carbon content and ash content. Energy density is obtained from the Equation 2,

$$\text{Energy density} = \text{gross calorific value} \times \text{relaxed density} \quad (2)$$

Meanwhile, the methods for proximate analysis and determination of gross calorific value have been explained in Sections 2.1 and 2.2, respectively.

3.0 RESULTS AND DISCUSSION

In this section, the physical and combustion properties of the torrefied EFB briquettes are discussed. The comparison with standard requirement DIN51731 and performance of 100% EFB briquette without torrefaction was also performed. In addition, the performance of the torrefied EFB briquettes in terms of compressive strength and ash content is also compared with that of the commonly used local briquette that contains mesocarp fibre and shell [6].

3.1 Physical Properties

Figure 4 shows the images of EFB briquettes that were torrefied under various temperatures. Generally, it can be said that the torrefied EFB briquettes have been successfully manufactured. Based on thermogravimetric (TGA) analysis performed by Nyakuma *et al.*, the devolatilization of EFB fibre already occurs within the torrefaction temperature range used in the present study [17]. As shown by Figure 4, when the torrefied temperature is increased, surface colour of the torrefied briquettes becomes darker. This is mainly due to the increase in fixed carbon content when the torrefaction temperature is increased, as will be demonstrated later.

Figure 5 shows the results of relaxed density for the torrefied EFB briquettes. Here, the average relaxed density of the EFB briquettes before torrefaction was around 1264 kg/m³. Therefore, it can be said that when torrefaction is applied on the EFB briquettes, relaxed density significantly decreases. Furthermore, when torrefaction temperature is increased, the relaxed density decreases. This is mainly due to the reduction of mass yield when the temperature is increased, as demonstrated by Figure 6. The reduction of mass yield is mainly due to the removal of volatile matter during torrefaction within the said temperature range.

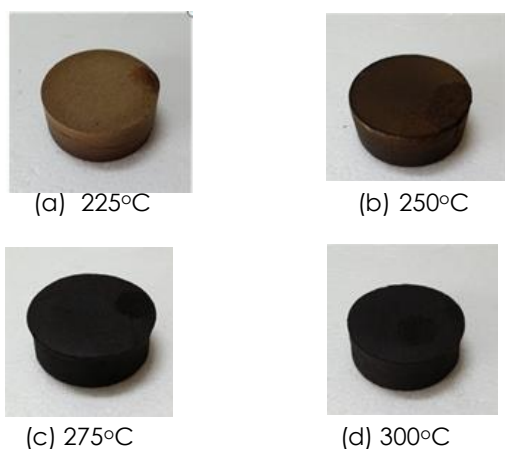


Figure 4 Images of EFB briquettes torrefied under different temperature

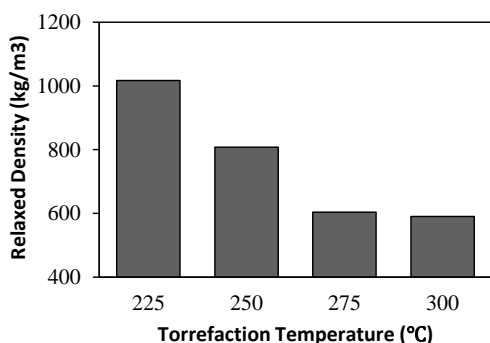


Figure 5 Relaxed density of torrefied EFB briquettes

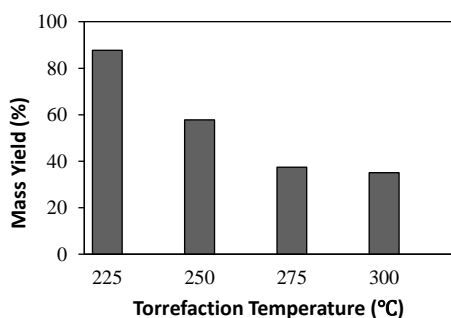


Figure 6 Mass yield of torrefied EFB briquettes

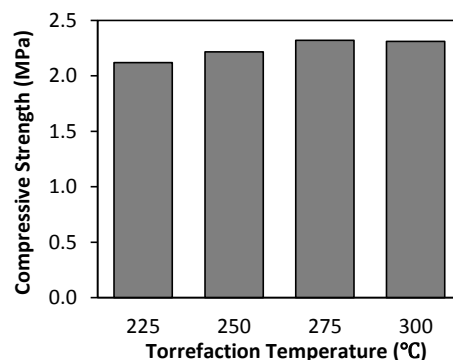


Figure 7 Compressive strength of torrefied EFB briquettes

Figure 7 demonstrates compressive strength of the torrefied EFB briquettes. In general, it can be said that the compressive strength varies within the range of 2.1 MPa to 2.3 MPa. If compared to the strength of EFB briquettes without torrefaction (6.5 MPa), the values obtained in the present study are lower. This is mainly caused by the deterioration of the adhesive characteristics belong to the torrefied EFB briquettes. In details, within the temperature range of the present study, the lignin that acts as a natural binder somehow experiences thermal degradation. This statement is supported by findings made by Chen and Kuo [20]. Even though the compressive strength of the torrefied EFB briquette is significantly lower than that of the EFB briquette without torrefaction (around 6.5 MPa) [16], it is still competitive compared to the compressive strength of the commonly used local briquette with mesocarp fibre and shell content [6].

3.2 Combustion Properties

Figure 8 demonstrates the calorific value of the torrefied EFB briquettes produced under different temperature. The figure shows that when torrefaction temperature is increased, gross calorific value also increases. This is mainly due to the increase in fixed carbon content when torrefaction temperature is increased, as shown by Figure 10. It can be said that the calorific values of the torrefied EFB briquettes fulfil the minimum requirement stated by DIN51731 (>17500kJ/kg) regardless of torrefaction temperature.

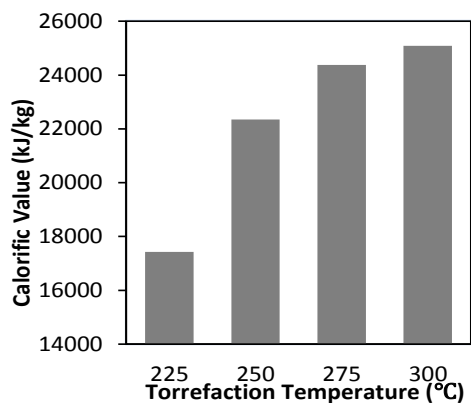


Figure 8 Gross calorific values of torrefied EFB briquettes

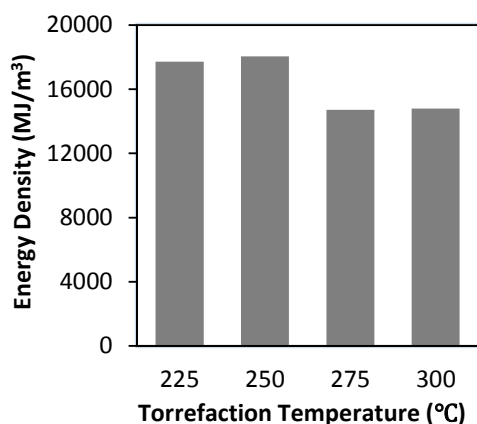


Figure 9 Energy density of torrefied EFB briquettes

Figure 9 shows the energy density of the torrefied EFB briquettes. Based on our previous study [16], the energy density of EFB briquette without torrefaction is around 22000 MJ/m³. As shown by Figures 8 and 9, even though the gross calorific values of the torrefied EFB briquettes are higher than that of EFB briquette without torrefaction, the energy densities are lower. This is mainly due to the significant reduction in relaxed density when the EFB briquettes were torrefied.

Figure 10 shows the result of proximate analysis for torrefied EFB briquettes. Based on the figure, the values of moisture content are within the range of 6%-8%, thus fulfil the requirement as stated by DIN51731 (<10%). By referring Table 2, it can be said that the values of moisture contents of the EFB briquettes do not experience obvious change after torrefaction. The figure shows that when the torrefaction temperature is increased, fixed carbon content also increases while volatile matter decreases. This causes the surface of the briquettes to be darker and calorific value becomes higher when torrefied at higher temperature. The figure also shows that ash content increases when the torrefaction temperature is increased. In this case, the significant decrease in volatile matter with an

increase in torrefaction temperature causes the portion percentage of ash to increase. Overall, the values of ash content exceed the limitation as stated by standard DIN51731(0.7%). However, the ash contents of the EFB briquettes torrefied at 225°C, 250°C and 275°C are found to be very competitive if compared to the ash content of the commonly used local briquette (5.8%) [6].

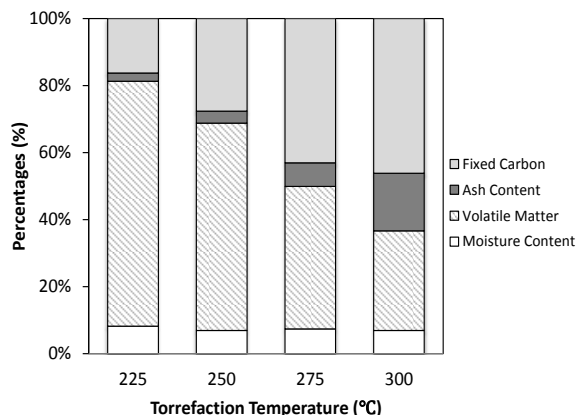


Figure 10 Result of proximate analysis for torrefied EFB briquettes

4.0 CONCLUSION

The physical and combustion properties of the torrefied EFB briquettes were investigated for various torrefaction temperatures. Generally, it can be said that the torrefied EFB briquettes were successfully produced.

Based on the results obtained, when the torrefaction temperature is increased, the mass yield and corresponding relaxed density decrease. Meanwhile, the values of compressive strength are close to each other regardless of the temperature. Furthermore, the values of compressive strength are considered competitive if compared to that of commonly used palm biomass briquette that contains mesocarp fibre and shell.

All values of calorific value and moisture content fulfill the production requirement for commercial briquette (DIN51731). Meanwhile, the values of ash content exceed the limitation as stated by the standard. However, if compared to the ash content of the commonly used briquette, it is still considered competitive, except for the case of torrefaction temperature 300°C.

The present experimental study also elucidates that the torrefaction temperature plays a significant role in affecting the relaxed density, mass yield, calorific value, volatile matter, fixed carbon and ash content. Overall, it can be concluded that certain combustion properties of EFB briquette such as calorific value and fixed carbon content are improved due to torrefaction. However, in terms of

physical properties, mass yield and corresponding relaxed density deteriorate.

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