The effect of torrefaction reaction temperature on the Elaeis Guineensis Empty Fruit Bunch (EFB) pellet durability and calorific value

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Abstract. Empty Fruit Bunch (EFB) are not being fully utilized for energy production due to its high moisture content, low density, having bulky characteristics and low calorific value. In order to improve characteristic of Elaeis Guineensis empty fruit bunch as fuel, pre-treatment process is necessary to overcome these shortcomings. Therefore, the aim of this research is to examine the effect of torrefaction reaction temperature on the Elaeis Guineensis pellet energy characteristics. The observed pellet qualities include the pellet durability and calorific value of the pellet. The torrefaction of empty fruit bunch was conducted in a fixed-bed reactor at 200°C, 220°C, 240°C and 260°C. The torrefied sample was pelletized, analysed and tested to examine the characteristics of empty fruit bunch biomass as fuel. The pelletization process was carried out by using the cold single press pelletizer and using cassava starch as binder. At higher torrefaction temperature, the decomposition of cellulose and lignin become more prominent. At the torrefaction temperature 260°C, the gross calorific value is the highest due to the removal of moisture, release of volatile matter and the decomposition of biomass components such as hemicellulose, cellulose and lignin which resulted in energy densification. By comparing the torrefied empty fruit bunch at 260°C with the untorrefied empty fruit bunch, it was found that the torrefaction increased the energy densification and pellet qualities of empty fruit bunch that can be utilized as biomass energy sources in renewable energy.

1. Introduction
Petroleum derivative asset is constrained and in close exhaustion as it is a non-sustainable power source. Hence, this subsequent deficiency and consumption of fuel assets of non-sustainable energy resources, changes in the weather and climate had risen significant issues such as environmental pollution, air pollution, and acid rain. Biomass energy is identified as a standout among the encouraging contender for elective economical and ecologically amicable energy assets. These bio-renewable resources can be used as co-products in various products and application such as bioenergy and bio-based products. Fortunately, Malaysia is one of the world’s largest oil palm producer producing an enormous amount of biomass squander from its millings and plantation activities, the massive amount of biomass waste is usually not being fully utilized, disposed and recycled to be

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converted into biomass energy sources. The oil palm waste favourable characteristics of combustion proved that it can reduce the dependency on coal in power generation [1]. This is possible to reduce consumption of non-renewable energy source as fuel used in the generation of power in Malaysia.

Mesocarp fibre and the palm kernel are the biomass residues being used for power generation due to better characteristics of fuel when compared to the empty fruit bunch (EFB). EFB are not being fully utilized due to the fact that it has high moisture content (up to 70 wt%), presence of minerals and having bulky characteristics which made the empty fruit bunch having low calorific value. In order to improve characteristic of *Elaeis Guineensis* empty fruit bunch as fuel, pre-treatment process is necessary to overcome these shortcomings. Therefore, the aim of this research is to examine the effect of torrefaction reaction temperature of *Elaeis Guineensis* empty fruit bunch on the *Elaeis Guineensis* pellet energy characteristics.

Torrefaction is a thermal pre-treatment of biomass process that is conducted in the temperature range of between 200℃ to 300℃ under inert atmosphere (without the presence of oxygen) to enhance the fuel properties. The energy densification increases as the empty fruit bunch undergo the torrefaction process [2]. Torrefaction affects cellulose, hemicellulose, and lignin of empty fruit bunch at different temperature depending on the torrefaction residence time and temperature. Light torrefaction results in moisture release. Meanwhile, mild and severe torrefaction results in decomposition of hemicellulose and cellulose, more volatile matter is released therefore resulting in high energy density. Torrefaction above 300℃ is not recommended due to excessive devolatilization. Hemicellulose in the lignocellulose components will be decomposed to form CO₂ and H₂O.

Pelletization process of biomass enhance the transport and storage properties of biomass. Pelletization, as a densification process, gives a steady quality, low moisture content, high energy content and homogenous shape and size solid energy carrier that encourages the logistic management [3]. Pelletization of torrefied materials produces “black pellets” and it has a positive monetary effect at numerous focuses in the supply chain. The black pellets have lower CO₂ equivalent emissions than conventional white pellets according to life cycle assessments as claimed [4].

2. Methodology

2.1 Biomass sample

_Elaeis Guineensis_ empty fruit bunch was obtained from Bintulu, Sarawak. The collected empty fruit bunch from palm oil mill are bulky, wet, oily and spiky as shown in Figure 1.

![Figure 1. Empty fruit bunch](image)

First, the raw empty fruit bunch were collected from palm oil mill. It was sun dried for 1 day in order to reduce its moisture content. After that, the empty fruit bunch was shredded and ground to reduce the size of the empty fruit bunch. Smaller size of the empty fruit bunch increases the surface area and thus promotes efficient torrefaction process. 0.25 mm particle size was obtained by using the sieve shaker. The ground EFB with the desired particle size was separated into two; one part for raw EFB pellets and the other half was for terrified ones.
2.2 Torrefaction

2.2.1 Torrefaction temperature
The torrefaction process was carried out under an inert condition at different temperatures in nitrogen gas for 20 minutes. The temperature ranging in this research is 200°C, 220°C, 240°C, 260°C to study the effect of torrefaction of empty fruit bunch at different temperature.

2.2.2 Torrefaction reactor
The fixed-bed reactor, the heating furnace is equipped with the temperature controlled, was used in this experiment to control the torrefaction temperature. The heating furnace was connected with the nitrogen gas tank to supply the nitrogen into the heating furnace. Initially, the ground EFB was placed inside the reactor and the nitrogen is used in the purging process for 15 minutes. An average of 2-gram glass wool was placed inside the reactor followed by 10 g of grinded empty fruit bunch placed in the same reactor. The reactor, gasket and head were weighed beforehand. Air was removed from the tank by purging process before torrefaction experiment is initiated. Then, the EFB sample was heated at the desired temperature for 20 minutes with a continuous nitrogen flow. After the torrefaction process was completed, the torrefied empty fruit bunch was allowed to cool into room temperature before it was taken out from the reactor.

2.3 Pelletization
The pelletization process was carried out by using the cold single press pelletizer and using cassava starch as binder. The ratio applied to make this pellet was 10% water, 20% binder and 70% empty fruit bunch as this are the most suitable pellet mixing ratio using the cassava starch [3]. The die used in the study have a die diameter of 10 mm, with the hydraulic system that able to compress the material into pellet form. 1.5 g of sample was mixed with binder, inserted into die and compressed at 3 tons pressure.

2.4 Pellet properties testing

2.4.1 Pellet durability
The durability of empty fruit bunch pellet were tested by using the sieve shaker. The torrefied and the untorrefied pellet was tumbled for 10 minutes. The pellet was placed on the top of the stack of sieve shaker, the mesh number used in the tumbling process were 8, 18, 35 and 50 with the nominal sieve opening of 2.35 mm, 1.00 mm, 0.50 mm and 0.30 mm respectively. The mass of pellet was weighed before and after the tumbling process to examine the mass loss due to the tumbling process. The durability percentage was then determined by using the equation (1) by taking in the initial mass and final mass of the pellet after the tumbling process as the data in the calculation.

\[
\text{Durability} = 100 - \left( \frac{\text{mass initial} - \text{mass final}}{\text{mass initial}} \right) \times 100\%
\]

(1)

2.4.2 Calorific value
For the calorific value determination, empty fruit bunch pellet sample were cut into small pieces weighing at 0.5 g for each sample analysis. The sample was then placed on the crucible, cotton was tied to the ignition wire and the cotton was placed on the crucible containing sample. 30 bar oxygen was supplied into the bomb. The bomb was then placed into the outer jacket which thermally insulate the entire apparatus. The calorific value was shown on the monitor of the display, the calorific value determination method was repeated for all sample.

3. Result and discussion

3.1 EFB torrefaction mass yield
Result depicted in table 4.1.1 and figure 4.1.1 show the temperature of the torrefaction reaction and the percentage of the mass yield in this study. The temperature of this study is 200°C, 220°C, 240°C
and 260°C. Lignocellulosic biomass consists of three major components which made up of hemicellulose, cellulose and lignin. When empty fruit bunch treated with the torrefaction process, these components were started to be decomposed and this contributed to the decreased of mass yield of empty fruit bunch. The solid yield percentage decreased as the temperature of the torrefaction increased, the gas and liquid percentage increase as the temperature of the torrefaction increased. The yield percentage signifies the loss of material from lignocellulosic biomass, the solid material decomposed while the liquid material evaporated and this lead to the reduction of the moisture content on the torrefied empty fruit bunch. Torrefaction improved the densification of energy in high carbon contents, the energy density of torrefied empty fruit bunch increases with the temperature of the torrefaction process [5].

### Table 1. Yield percentage of torrefaction reaction.

| Torrefaction temperature (°C) | % solid yield | % liquid yield | % gas yield |
|-------------------------------|---------------|---------------|------------|
| 200                           | 78.7          | 15.7          | 5.6        |
| 220                           | 73.1          | 19.9          | 6.99       |
| 240                           | 49.6          | 35.2          | 15.2       |
| 260                           | 38.4          | 42.6          | 19.0       |

The percentage of the solid yield for the torrefaction temperature of 200°C, 220°C, 240°C and 260°C are 78.7%, 73.1%, 49.6% and 38.4% respectively. However, the trends for the liquid yield and the gas yield increase with the temperature of the torrefaction. The percentage of liquid yield are 15.7%, 19.9%, 35.23% and 42.6% respectively and the gas yield percentage are 5.6%, 6.99%, 15.2% and 19.0% respectively. This is due to the removal of liquid and gases from the biomass components. The solid yield percentage showing the decrease trend as the solid component such as hemicellulose, cellulose and lignin are being decomposed more rapidly during the torrefaction process as the torrefaction temperature are increased. This is supported by [2] which stated that light torrefaction results in release of moisture, low molecular weight volatiles resulting in slight increase in energy density. Conversely, mild and severe torrefaction results in decomposition of hemicellulose, cellulose, and lignin, more volatile release resulting in high energy density. Torrefaction can be classified into light, mild and severe torrefaction in temperature range 200°C to 235°C, 235°C to 275°C and 275°C to 300°C respectively.

### 3.2 Pellet durability

Table 2 shows the pellet durability average percentage for the biomass that had been torrefied and the untorrefied raw empty fruit bunch. The highest pellet durability was the biomass pellet that had undergo torrefaction at 220°C which is 94.2 % durability, 0%, 89.94, 92.77% and 91.21% for the untorrefied, 200 °C, 240 °C and 260 °C respectively. The pellet durability of the untorrefied pellet is 0% as the pellet is destroyed completely during the tumbling process, the untorrefied pellet is the raw biomass that is remain untreated and it shown as the weakest pellet that have no durability. Figure 2 shows the bar graph with its standard error bar of the pellet durability. Small value of standard error indicates that the data collected from the analysis is near with the average value or the durability of the replicates are consistence throughout the analysis. When the standard error bars do not overlap, it is an indication that the difference may be significant. Statistical analysis was performed to draw a conclusion. The one-way analysis of variance (ANOVA) was used to determine whether there are any statistically significant differences between the means of four groups of torrefaction reaction temperature and p-value of 0.0395 was obtained. Since the p-value is less than the set significance level which is 0.05, the data is considered statistically significant.
3.3 Calorific value

Calorific value is an important solid fuel characteristic as it determines the combustion efficiency in the combustion chamber. Besides, it is one of the key parameters to evaluate the quality of the biomass characteristic as fuel that can be determined by using the bomb calorimeter [6,7]. Theoretically, the raw biomass having low calorific value and the torrefaction process can increase the calorific value in a biomass and improve its properties as fuel. The analysis was conducted to observe the effect of torrefaction at different temperature and the different is characteristic of torrefied biomass and raw biomass calorific value.

The Calorific Value (CV) or High Heating Value (HHV) are the important properties in fuel. As the biomass is being used as the fuel, it must have high CV in order to compete with another fuel resources such as coal. The normal rate of Calorific Value for raw biomass is around 13%. The torrefaction process affect the volatile release which resulting in high energy release, higher torrefaction reaction will produce higher biomass gross calorific value [8-10]. This is supported by a researcher by stating that mild and severe torrefaction temperature ranging from 235°C to 300°C have more volatile release which will resulting in high energy density [2].
respectively. This is due to the torrefaction that improve the energy densification of the empty fruit bunch. As the temperature of the torrefaction increase, the energy densification also increased. The untorrefied raw empty fruit bunch was ascertained to be having the lowest calorific value. Torrefaction can increase the energy densification and remove water from the raw biomass [11]. It is also worth noting that torrefaction increase the quality of the fuel properties of biomass as the moisture content had been drastically dwindled during the torrefaction process [12]. A proper material for the gross calorific value analysis is a pellet that remain intact during the analysis so that the material placed in the bomb will be fully burned and precise reading of gross calorific value can be earned.

The calorific value is the important parameter in the determination of the fuel characteristic in biomass. Raw empty fruit bunch biomass possesses 13.908 MJ/Kg energy while the torrefied empty fruit bunch having calorific value of 17.504 MJ/Kg. The difference in the calorific value is caused by the densification of energy due to the torrefaction process [13]. Torrefaction at 260℃ proved to have an intermediate effect on the empty fruit bunch biomass such as the decomposition of biomass material and volatile release that basically increased the gross calorific value for the empty fruit bunch [4, 14].

The p-value obtain from the ANOVA was 0.003, thus the alternative hypothesis can be accepted. Therefore, there is a significant difference between the mean value of the reaction temperatures due to the release of the volatile and energy densification during the torrefaction reaction [15,16].

4. Conclusion

Based on this study, the analysis showed that the torrefaction increased the energy yield in the raw empty fruit bunch. Besides, as the temperature of the torrefaction increased, the gross calorific value for the torrefied empty fruit bunch increased steadily. Additionally, the yield percentage of the empty fruit bunch is affected by the temperature of the torrefaction, the yield percentage of the empty fruit bunch decreased steadily as the temperature of the torrefaction increased. It can be concluded that the objectives of this study are achieved as the properties of empty fruit bunch biomass can be observed and examined through the analysis and the effect of torrefaction on the empty fruit bunch are able to be determined. Torrefaction improved the fuel characteristic of the raw empty fruit bunch biomass, it is a process of energy densification that increase the gross calorific value. It is recommended that the torrefaction temperature is not exceeding 300℃ as the biomass components such as hemicellulose, cellulose and lignin is being excessively devolatilized at the torrefaction temperature above than 300℃. Excessive devolatilization lead to loss of solid yield of biomass in the torrefaction process which will increase the ash content and volatile matter in empty fruit bunch biomass.

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