

Impact of pelletisation on torrefied oil palm empty fruit bunch biochar

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Abstract. This study investigates the impact of pelletisation on the properties and performance of torrefied oil palm empty fruit bunch (EFB) biochar. Torrefaction, a mild pyrolysis process, enhances the energy density and durability of biomass, creating a more stable biochar product. Pelletisation, involving the compression of biochar into pellets, aims to improve its handling, transportation, and application efficiencies. This study examines key parameters such as the effects of pelletisation pressure, temperature, and the use of binders on the physical and chemical properties of torrefied EFB biochar. Evaluations include changes in density, bonding properties, and calorific value. Additionally, the study explores how pelletisation influences the biochar's porosity, surface area, and elemental composition. Results indicate that pelletisation significantly affects the structural integrity and functional properties of torrefied EFB biochar. Pellets exhibit enhanced bulk density and durability, which are beneficial for storage and transport. However, some reduction in surface area and porosity is observed, potentially impacting the biochar's effectiveness in applications such as soil amendment and carbon sequestration. Findings suggest that while pelletisation offers practical advantages, optimizing the process parameters is crucial to maintain the beneficial properties of torrefied EFB biochar. Overall, this study provides comprehensive insights into the trade-offs associated with pelletising torrefied EFB biochar, highlighting the potential for improved usability in sustainable agriculture and environmental management practices. Future work should focus on refining pelletisation techniques to balance mechanical benefits with the preservation of biochar's functional attributes.

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1 Introduction

Agriculture can become a great contributor to the world's sustainability and even to energy fuel sources, either by agricultural crops or residues. Several agricultural crops and residues have been applied and proven to have a high potential as an alternative to energy fuel sources; furthermore, these sources are renewable [1].

A large amount of biomass residues is available in Malaysia, which is a well-developed country comprised of both industrial and agricultural activities. According to Parveez et al. [2] based on a 2020 plantation study, the biggest agricultural industry in Malaysia is the oil palm plantation, comprising over three-quarter of nation's agricultural plantation and a total oil palm plantation area of 5.87 Mha, compared to the total agricultural plantation of 7.4 Mha consisting of natural rubber, paddy, wood and timber, coconut, cocoa, pepper, corn, kenaf, sago, and others. As palm oil is the sole primary produce of oil palm plantation, oil palm trees contain other parts (i.e., OPT, OPF, EFB, PKS, OPMF, and POME) that are wastes.

However, agricultural residues require certain pretreatment processes to be ready for energy conversion processes [3]. Numerous benefits can be obtained through biomass utilisation; thus, there is an imminent need to convert biomass materials into beneficial products. There is a wide range of technologies in existence to convert biomass into biofuels as sources of energy. These include thermochemical, biochemical, and physical processes. Biochar is one of the value-added products from biomass sources. It is a solid, high-carbon product made from organic material that is manufactured as a safe and potentially useful optional solid fuel for energy sources [4].

Simple techniques and equipment of torrefaction have received much attention from scientists as this approach can reduce production costs and time because processing and pre-processing of biomass into biochar via torrefaction only requires a short time range. While torrefaction, drying and partial devolatilisation of biomass decrease the mass of biomass without interfering with the content of the energy. In addition, these techniques enhance the solid fuel properties of biomass by depolymerising and taking away carbon dioxide (CO₂) and water (H₂O). Therefore, by decreasing the oxygen-to-carbon (O/C) ratio, the energy density and hygroscopic nature of biomass are significantly improved, as specified by the maximum number of solid content (biochar). In addition, the advantage of torrefaction is that the occurrence of fungi or mould in storage can be avoided. Torrefaction involves the decomposition of biomass, and the final products are solid (i.e., char), condensable liquid, by-product gaseous, and other organic matter [5] [6].

In addition, pelletisation provides a huge advantage for the post-processing of biomass [7]. Pelletisation also offers greater packaging and storage ability, as well as greater robustness. Torrefied pelletised biochar is good for controlling fungi, practical for movement and transportation, easy feeding into the heating chamber, and provides greater combustion power during energy transformation, hence making biomass pellets as preferable fuel compared to raw feedstock [7]. Thus, in this study, the impact of pelletisation on the torrefied EFB biochar in terms of proximate properties, energy content and physical properties were studied.

2 Materials and Methods

2.1 Materials

The raw material utilised for biochar production was EFB, which was sourced from a fibre mill known as HK Kitaran Sdn. Bhd. in Seberang Perai, Penang, Malaysia. First, EFB was soaked in freshwater for dust and residual oil removal. Next, it was washed, cleaned, and

separated from impurities using tap water, and dried in sunlight for 24 hours, then the EFB fibre was gathered and dried in an oven at a fixed temperature of $80 \pm 5^\circ\text{C}$ for 1 hour to lessen the content of moisture before screened into $750\mu\text{m}$ strand size using an auto-sieve shaker.

For binder, Smectite clay was chosen as the pellet binder and provided by Tolsa Group (Spain) via Keyser & Mackay (The Netherlands). The clay contains exactly 1–4nm thick surface layer with a size that totalled about $< 1\text{--}5\mu\text{m}$.

2.2 Methods

These experimental methods describe the torrefaction process of EFB and followed by pelletisation process before undergoing for proximate analysis, energy content and physical analysis.

2.2.1 Torrefaction process

Torrefaction was carried out in an electric furnace (Carbolite Gero, model CWF 1300, operating temperature of $30\text{--}3,000^\circ\text{C}$) according to holding temperature was fixed at 274°C without the presence of oxygen (O_2) under conditions of low heating rate ($\pm 10^\circ\text{C}/\text{mm}$) with 90 minutes of residence times. About 50g sample with strand sizes of $750\mu\text{m}$ was located inside the porcelain crucible and into the furnace chamber before heating. After torrefaction finished, the torrefied samples were put into a desiccator for more than 60 minutes at room temperature before measuring the weight.

2.2.2 Pelletisation process

Pelletisation of torrefied EFB biochar was done using clay as a binding agent at various ratios (10%–30%) with the addition of water (approximately 0.1 mL) to aid adhesion. Exactly, 0.70 g of the biochar and binder mixture was filled into a pellet mould and pressed with the highest pressure of 20 kN at a speed of 5 mm/min utilising the UTM [8]. After 5 s, the mould was released, the piston was removed, and the pellet was collected. Fig. 1 shows the structure of the pellet mould used in the process, as presented in the two-dimensional drawing schematic diagram. The cylindrical die comprised an opening of 10 mm in diameter, which was made of carbon steel.

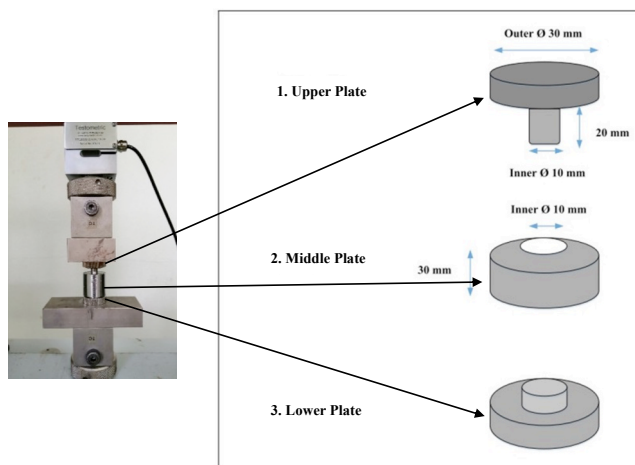


Fig. 1. Schematic diagram of pellet mould

2.2.3 Proximate analysis

To identify four components: moisture content, volatile matter, ash content, and fixed carbon, proximate analysis was conducted. The yield of various products obtained upon heating under controlled conditions was evaluated, which is important in the optimisation of any thermochemical conversion process [4]. Proximate analysis was performed using a furnace and a high precision digital scale based on ASTM D3173, and the calculations are exhibited in Equation (1) – (4).

a) Moisture content

Moisture content was analysed using a moisture analyser (model MX-50). A sample pan was placed on the sample support and the reading was reset to 0g. Then, the samples less than 3g were placed onto the sample pan. The analysis started after the heating cap was closed and the reading was recorded after the signal was triggered. The determination of moisture content in the samples is according to the formula presented in Equation (1).

$$\text{Moisture Content (\%)} = \frac{W_i \text{ (g)} - W_f \text{ (g)}}{W_f \text{ (g)}} \times 100\% \quad (1)$$

W_i = Initial weight; W_f = Final weight

b) Volatile matter

The proportion of volatile matter was determined using furnace. First, the weight of the crucible without cap and the weight of the crucible containing 1g of the sample without cap were determined, followed by weighing the crucible with its cap containing 1g of the sample. Then, the sample was heated for about 7 minutes at 900°C and was taken out of the oven and left to cool before weighing. Equation (2) was used to determine the percentage of volatile matter.

$$\text{Volatile Matter (\%)} = \frac{W_i \text{ (g)} - W_f \text{ (g)}}{W_i \text{ (g)}} \times 100\% \quad (2)$$

W_i = Initial weight; W_f = Final weight

c) Ash content

The sample from the previous volatile matter analysis was utilised without the crucible cap, located in the furnace, and burnt to 815°C for 3 hours. Then, the samples were removed to cool before weighing using the analytical balance. The ash content formula is shown by Equation (3).

$$\text{Ash Content (\%)} = \frac{\text{Weight of residue (g)}}{\text{Weight of sample (g)}} \times 100\% \quad (3)$$

d) Fixed carbon

The percentage of fixed carbon was counted by subtracting the percentage of moisture content, volatile matter, and ash content of every sample by 100%. Equation (4) was used to calculate the fixed carbon of the sample.

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

MC = Moisture content; VM = Volatile matter; AC = Ash content

2.2.4 Energy content

The calorific value was ascertained with an adiabatic bomb calorimeter (model 1013-B, Yoshida Seisakusho) based on ASTM D2015. The ideal weight of the sample is slightly higher than 1 g to avoid invalid combustion.

2.2.5 Physical analysis

Various analyses were performed to assess the physical traits of the torrefied pelletised biochar, which included the pellet's density and durability.

a) Density

The density of the sample was calculated using the ratio of the weight to volume of the sample using Equation (5).

$$\text{Density (g/cm}^3\text{)} = \frac{\text{Mass (g)}}{\text{Volume (cm}^3\text{)}} \quad (5)$$

b) Durability

About 500g of the samples was inserted into the durability testing machine. The machine was rotated approximately 50 ± 2 rounds/min for 10 minutes. This test quantifies the quality of the pellet by measuring the percentage of broken pellets. The formula to calculate the durability percentage is shown in Equation (6).

$$\text{Durability (\%)} = \frac{\text{Remaining sieved pellet mass (g)}}{\text{Initial pellet mass (g)}} \times 100\% \quad (6)$$

3 Results and Discussion

3.1 Proximate Properties, Energy Content and Physical Properties

Fig. 2 displays the summary of proximate properties, energy content, and physical properties of torrefied pelletised biochar. Based on Fig. 2(a), the moisture content decreased from 13.88% (raw EFB) to 6.13% (torrefied EFB biochar) during torrefaction. This occurrence is mostly the result of the torrefaction state (holding temperature of 274°C and residence time of 90 minutes) which led to deoxygenation [9]. This result proved that the vaporisation of moisture occurred during torrefaction [10].

However, the moisture content increased once the torrefied EFB biochar was densified into pellets. From Fig. 2(a), the values of moisture content for each torrefied pelletised biochar are 6.96%, 7.52%, 8.14%, 8.87%, and 9.65% at binder ratios of 10%, 15%, 20%, 25%, and 30%, respectively. The increase of moisture content for pelletised biochar could be due to the addition of water to the clay binder to aid cohesion in the pelletisation process.

According to Fig. 2(d), performing torrefaction at holding temperature of 274°C and residence time of 90 minutes, greatly enhanced the fixed carbon content of the torrefied EFB biochar (26.40%) in comparison to the raw EFB (4.28%). This is because torrefaction increases the components of char [11]. However, the carbon content decreased slightly once the torrefied EFB biochar was densified into pellets. The values of fixed carbon for each

torrefied pelletised biochar are 26.12%, 25.77%, 24.98%, 23.24%, and 22.43% for binder ratios of 10%, 15%, 20%, 25%, and 30%, respectively.

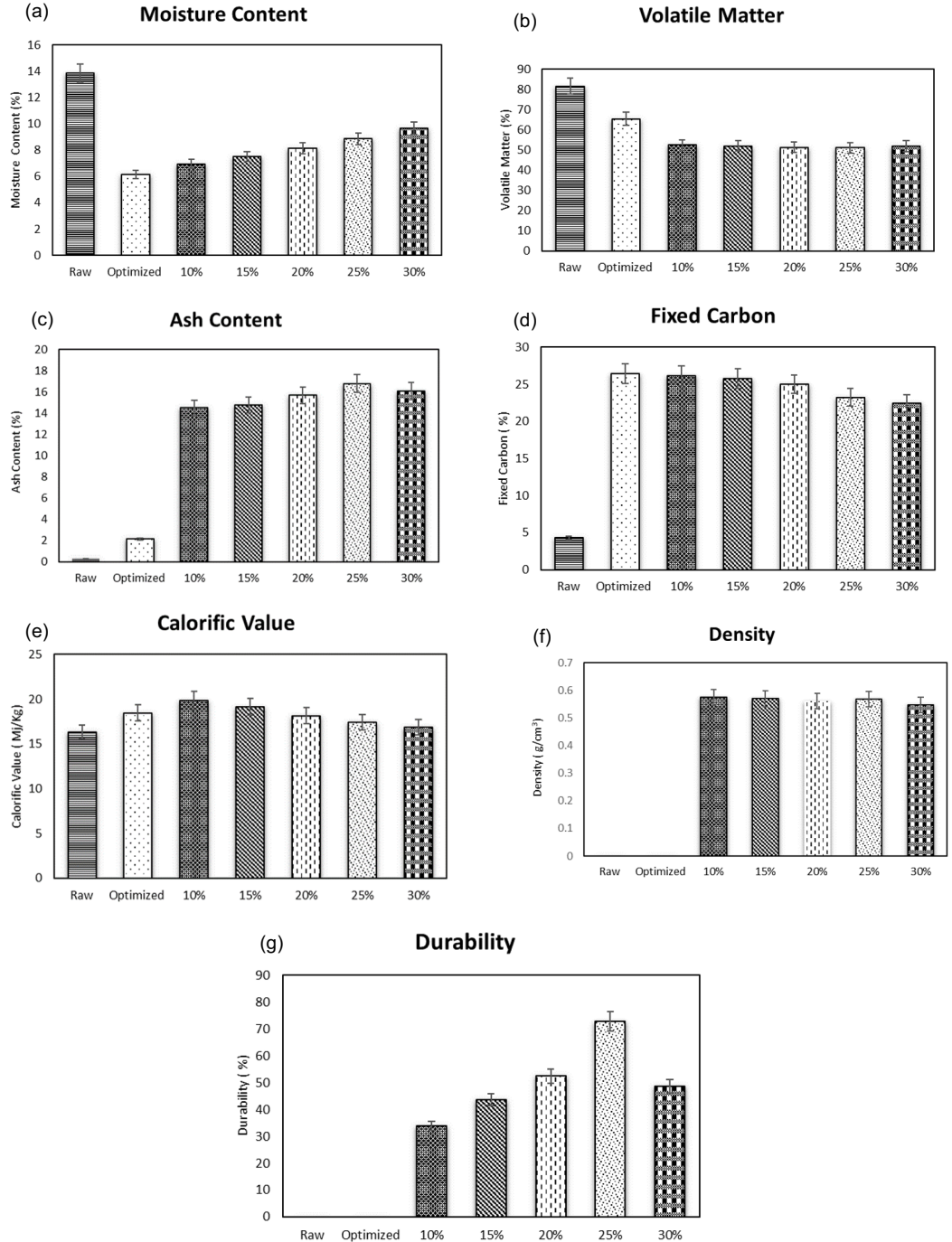


Fig. 2. Proximate properties (a) moisture content, (b) volatile matter, (c) ash content (d) fixed carbon; Energy content (e) calorific value; Physical properties (f) density (g) durability of torrefied pelletised biochar

Nevertheless, the results of fixed carbon and for the torrefied pelletised biochar do not really reflect the trend of energy content (calorific value). Fig. 2(e) shows the trend of calorific value for raw EFB, torrefied EFB biochar, and torrefied pelletised biochar at different binder ratios. The calorific value increased from 16.30 MJ/kg (raw EFB) to 18.46 MJ/kg for the torrefied EFB biochar. This is mainly because of the torrefaction conditions (holding temperature of 274°C and residence time of 90 minutes) that led to deoxygenation [9], which resulted in the rise of fixed carbon content and the decline in the oxygen element [12].

The calorific value for the torrefied pelletised biochar at 10% binder increased to 19.85 MJ/kg compared to the torrefied EFB biochar (18.46 MJ/kg), and the values declined to 19.16, 18.14, 17.42, and 16.87 MJ/kg at binder ratios of 15%, 20%, 25%, and 30% respectively. The increase in the calorific value only for 10% binder of torrefied pelletised biochar does not exactly represent the reduction in fixed carbon content of the torrefied EFB biochar to the torrefied pelletised biochar. The calorific value would decline according to the decrease of the fixed carbon content as the calorific value is directly relative to the fixed carbon content.

For the effect of densification on the torrefied pelletised biochar, the pelletisation process at a low percentage of clay as a binder proved that the densification should increase the energy content (calorific value) of the torrefied pelletised biochar. This is because clay is a chemically non-reactive compound that does not have a significant impact on the calorific value of the pelletised biochar, and clay only the torrefied pelletised biochar tackiness. However, the calorific value would reduce in the presence of excess percentage of clay as a binder, as shown in Fig. 2(e). This is because clay is viewed as a chemically non-reactive compound that reduced the torrefied material in pellets [13].

Fig. 2(b) presents the values of volatile matter for raw EFB, torrefied EFB biochar, and torrefied pelletised biochar at different binder ratios. The volatile matter decreased from 81.54% for raw EFB to 65.32% for the torrefied EFB biochar during torrefaction. The gradual decrease of volatile matter is caused by the devolatilisation of organic matter in EFB during torrefaction [14].

The same trend also happened for the volatile matter from the torrefied EFB biochar to the torrefied pelletised biochar, with the values of 52.42%, 51.91%, 51.18%, 51.09%, and 51.82% for 10%, 15%, 20%, 25%, and 30% binder, respectively. Hence, densification could reduce the volatile matter content and the prepared pelletised biochar could resemble the nature of coal [15] because lower volatile matter helps in achieving complete burning of the fuel [16].

Based on Fig. 2(c), a significant change could be observed for the ash content percentage. The ash content increased from 0.30% (raw EFB) to 2.15% for the optimised torrefied EFB biochar. This phenomenon has been happen regarding the increase of ash content for the torrefied material [17]. The increase could also be seen for the torrefied EFB biochar that was pelletised, with the ash content of 14.5%, 14.8%, 15.7%, 16.8%, and 16.1% for each pelletised biochar at 10%, 15%, 20%, 25%, and 30% binder, respectively.

4 Conclusion

The study discovered that energy content (calorific value), because of the indirect impact of densification (i.e., pelletisation), somewhat rose, which happened for the torrefied pelletised biochar at the lowermost binder proportion in comparison to the non-pelletised torrefied material. The densification with the addition of a low percentage of clay helps in achieving complete burning of the pellets. In addition, the use of clay as the binder at a low percentage improved the durability of the pelletised biochar, where the clay is not chemically reactive in influencing the energy content of the pellets.

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