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Torrefaction on agricultural residues empty fruit bunch: Effect of torrefaction processing factors on thermal properties of torrefied empty fruit bunch biochar

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Abstract

Thermal properties of torrefied empty fruit bunch biochar were investigated in this study as an alternative to be a renewable energy material for future. Holding temperature range between 200 to 300°C and residence time for 30 to 90 minutes were applied as the factors for the torrefaction process. This study observed the thermal properties of torrefied empty fruit bunch biochar by using thermogravimetric analysis (TGA) to study the thermal decomposition before and after torrefaction process. Thermogravimetric analysis was used in identifying those properties, which is dividing into three stages of dehydration, devolatilizations and decomposition of the torrefied biochar. During the dehydration, the moisture content was removed, meanwhile during the second stage (devolatilizations), the volatile matter was removed along with the removal of hemicellulose, cellulose, and lignin, while on the third stage shows the decompositions of the torrefied biochar to completely degrade.

1. INTRODUCTION

Nowadays, fossil fuels are still as the major source of energy or fuels through the world including Malaysia. The concern on the environmental effects and the depletion of fossil fuel reserves has created the intention on others energy sources especially from renewable sources to be as an alternative energy source for global production (Rasat et al., 2016a; Sirrajudin et al., 2016).

Biomass is one of the renewable energy sources that should be paid attention for its potential to be as the alternative in energy production, which is widely applied in energy conversion nowadays (Ahmad et al., 2016; Rasat et al., 2016b). Lot of research show that the biomass material categorized as availability sources that abundantly from the residue of agricultural, forestry and few industry sources (Balogun et al., 2018).

Generally, Malaysia is known to be a country that produce abundantly amount of agricultural crops waste that possessed a potential as biomass sources such as bagasse, rice husk, and oil palm. The oil palm industry is the largest industry that contribute the huge amount of biomass that are mostly in the form of waste (Lee & Ofori-Boateng, 2013).

The agriculture wastes only will be advantage in generating renewable energy source only if they undergo conversion process. The thermochemical conversion is most crucial in preparing biomass energy from agricultural waste is essential to improve the properties of biomass. As mentioned by Onoja et al. (2019), the thermal conversion of the biomass involving the range important of compound by a combination of chemical reformation and thermal decay. The conversion process takes place during the heating process in a condition either oxygen is presence or absence (Onoja et al., 2019). The most recent conversion of biomass into energy technique that widely applied in energy field is torrefaction process.

Torrefaction was defined as the process of mild pyrolysis, which operating in low temperature range of 200 to 300°C without oxygen presence but included the inert carrier gas for short residence time not more than 2 hours with heating rate < 50°C/min (Okot, 2019).

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Thus, by taking torrefaction process as an advantage, this study had been conducted to determine the thermal properties of torrefied empty fruit bunch (EFB) biochar to be as potential renewable energy sources.

2. MATERIALS AND METHODS

2.1. Sample preparation

The EFB that was used in this study was collected from oil palm fibre mills in Penang, Malaysia as shown in Figure 1.

Figure 1: Raw of empty fruit bunch fibre

The raw of EFB was undergo cleaning process by using water to remove any contaminant left in the fruit bunch. Then, the EFB was shredded into fibre and was leaved to sun-dried for 24 hours. Next, the raw materials were undergone preheated treatment in the oven at the temperature of 80±5°C for 1 hour to remove any moisture content to prevent biodegradation of the sample. The preheat treatment also allow the sample to be easily process into smaller size during grinding.

2.2. Torrefaction Process

An electrical furnace (muffle furnace of WiseTherm) was used to run the torrefaction process and there were two main factors that was investigate in this torrefaction process which is holding temperature and residence time, while was setting at 200, 250 and 300°C and 30, 60 and 90 minutes, respectively in the absence of oxygen with low heating rate at 10°C/min.

2.3. Thermogravimetric analysis

The thermal properties of torrefied EFB biochar had been determined by thermogravimetric analysis (TGA). About 0.7 mg of the torrefied biochar had been weighed for each sample before had been inserted in the TGA-DSC machine with the heating rate of 10°C/min with nitrogen gas flow rate of 50ml/min. The temperatures for combustion in TGA machine were set in range of 30-1000°C with machine running time of 1 hour and 48 minutes.

3. RESULT AND DISCUSSION

3.1. Thermal properties

In this study, the thermal properties were ascertained by examining the thermogravimetric (TG) diagram of the torrefied EFB biochar. Figure 2 illustrates the TG curves comprised of the thermal decomposition of raw and torrefied EFB biochar, which showed inverted S-shaped curves. It is clear from the diagram that the mass percentage increased with increasing torrefaction temperature. This finding was attained when the solid EFB was converted into char and the porosity of the char decreased as the torrefaction temperature increased.

According to the curves in Figure 2, EFB degradation started at 43–117°C. The result was as predictable as in the literature review, in which Sabil et al. (2013) claimed that the mass percentage steadily declined with the increasing holding temperature. Comparing Figure 2(a), (b), and (c), the trend altered greatly, specifically when the residence time rose from 30 to 60 min. Three stages of thermal decomposition of torrefied EFB biochar could be witnessed: drying, partially devolatilisation, and decomposition of biochar. This finding is agreed by Nyakuma et al. (2015) and Sabil et al. (2013) for the stages of biomass material thermal decomposition.

The first stage is EFB dehydration, in which EFB moisture was expelled at a temperature below 105°C, as Sabil et al. (2013) expected. The thermal degradation of torrefied EFB biochar was affceted by the devolatisation of organic matter that became gas and liquid. Therefore, the volatile matter content and the moisture content are the result of the thermal degradation of torrefied EFB biochar and the elimination of hemicellulose too. Devolatilisation took place during the second stage of thermal decomposition between 106 and 450°C, which caused the drop of mass percentage between 40% and 70% with an increase in the torrefaction temperature from 200 to 300°C.

Hemicellulose and cellulose were removed at 118–400°C (Chen et al., 2018; Kim et al., 2012). Generally, the temperature range of the hemicellulose degradation partially overlaps that of cellulose degradation, and its DTG curves appears as a shoulder rather than a well-defined peak (Grønli et al., 2002). The maximum weight loss of the control occurred at 367°C, which can be attributed to thermal degradation of the cellulose (Kim et al., 2012).

The derivative thermogravimetric (DTG) curves can also assess the rigorousness of torrefaction on EFB biochar. The curves are shown in Figure 3, which illustrates the thermal decomposition of raw and torrefied EFB biochar. Hemicellulose and cellulose disintegrated at 340°C in raw EFB. At the same time, lignin too disintegrated at the temperature range of 200–375°C.

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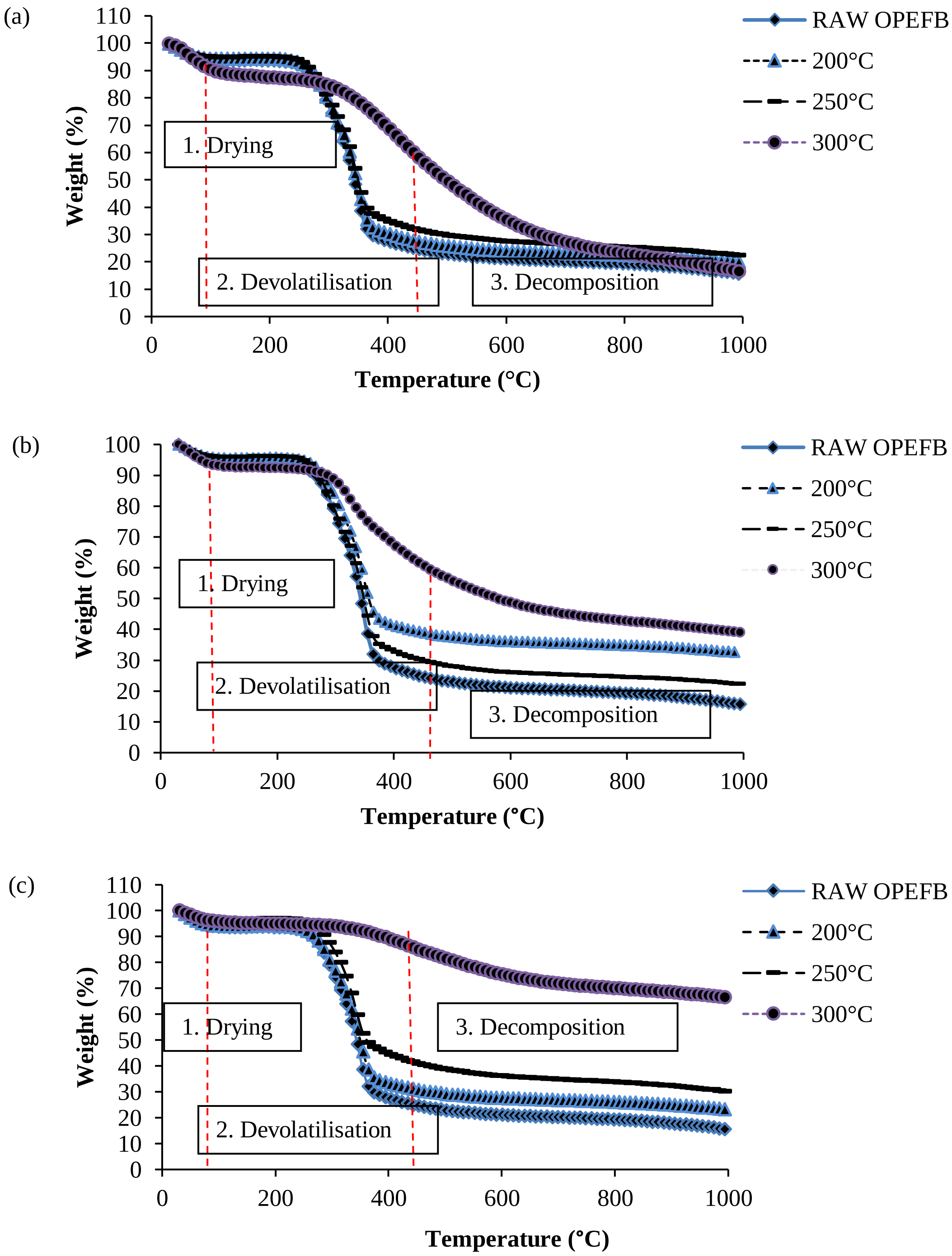

Figure 2: TGA curves of torrefied EFB biochar for different residence times of a) 30 min, b) 60 min, and c) 90 min

(a)

(b)

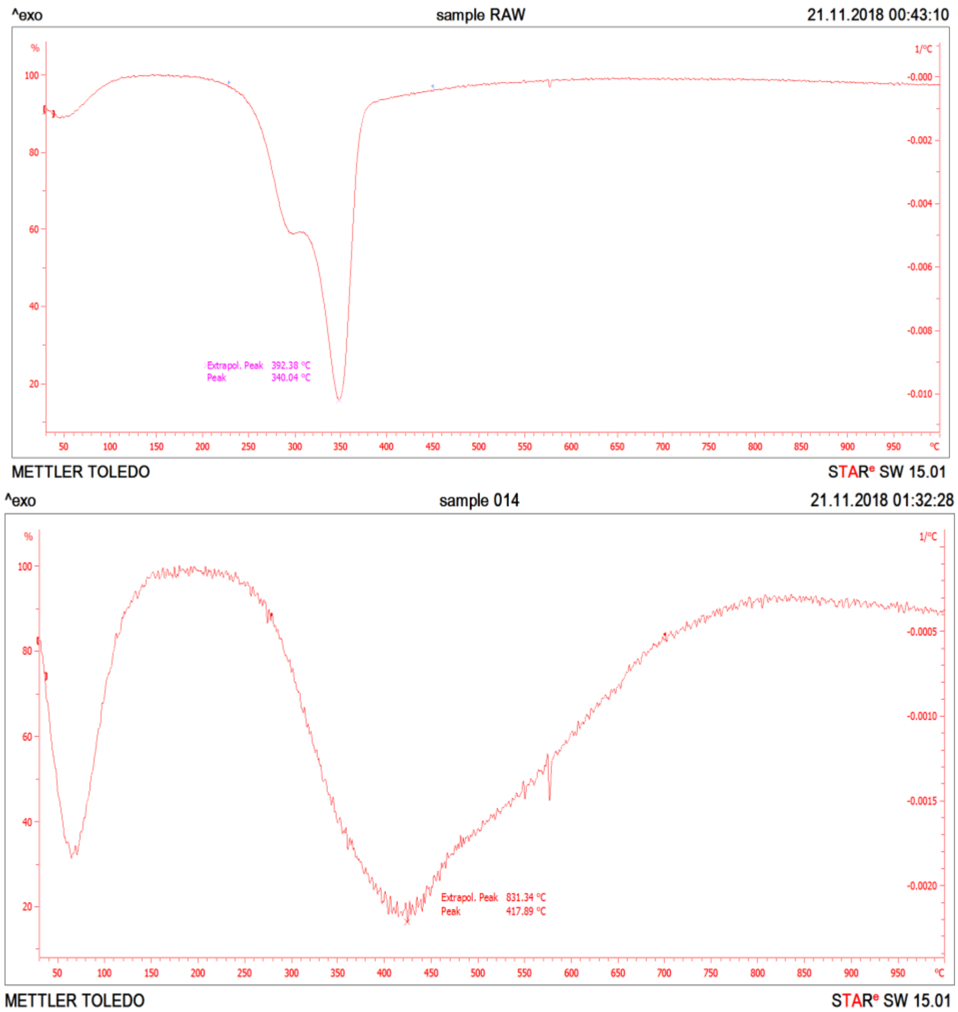

Figure 3: DTG curves of a) raw EFB and b) torrefied EFB biochar

As thermal decomposition took place, hemicellulose and lignin were thermally decomposed earlier than cellulose. The DTG curves of the torrefied EFB biochar display a wider and asymmetrical shape in comparison to raw EFB, suggesting that partial degradation of hemicellulose and cellulose took place during torrefaction (Nyakuma et al., 2015). The third stage of the degradation profile illustrates that the EFB biochar had totally degraded to ash.

In summary, the thermogravimetric and DTG analysis illustrate that the torrefied biochar slowly degraded to ash after the decomposition of hemicellulose, lignin, and cellulose. The devolatilisation and decomposition phases are not clearly identified at high torrefaction temperatures due to highest holding temperature for those torrefaction process in this study only at 300°C. Like the degradation process shown in DTG curves, the degradation of torrefied biochar occurs in a timely manner as the temperature increases.

4. CONCLUSION

The thermal properties of torrefied EFB biochar had been observed by TG and DTG curves by showing the thermal degradation of those torrefied biochar. The degradation was divided into three stages which are dehydration, devolatilizations and decomposition of char. During the dehydration, the moisture and water content is removed between of 40 to 100°C. At second stage, the volatile matter is removed along with hemicellulose, cellulose, and lignin between of 200 to 500°C. The third stage shows the decompositions of the biochar to completely degrade.

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