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A Study on Torrefaction of Empty Fruit Bunch and Its Impact on Lignocellulosic Structure

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Abstract. Torrefaction is a thermal treatment process used for upgrading lignocellulosic biomass properties into a promising renewable energy, which is performed under inert condition at a temperature range of 200 - 300°C between 15 – 60 minutes residence times. The aim of this study was to investigate the effect of torrefaction treatment on chemical composition and energy properties at different temperature 240, 270, 300 and 330°C with different residence time at 15, 30 and 60 minutes for oil palm biomass (empty fruit bunch). The analysis demonstrated an increase degradation of biomass hence an increase of mass loss was observed due to the combined effect of temperature and treatment duration. Higher heating values was increased by 55% which attributes the energy generations from the torrefied materials. Hemicellulose and cellulose content degraded as temperature and treatment duration increased, while lignin content increased due to the decomposition of hemicellulose and cellulose which accumulated the lignin content in the torrefied biomass. This study proves that torrefied biomass can be used as biofuel as it has higher heating value, and improved the chemical and physical properties of biomass.

1. Introduction

Global environment problems continuously arising in the world that we live in hence we are moving for transition into a society driven by renewable energy sources such as solar, wind, biomass, wave and geothermal energy. In this spectrum of several different energy sources, biomass is widely available from energy crops, waste streams, woody and grassy materials and can be converted into energy through thermochemical conversions, biochemical conversions and extraction of oil from oil bearing seeds [1]. Malaysia has tremendous available agricultural biomass for immediate exploitation such as palm oil waste. Palm oil industry in this country is a major contributor in economic growth as in 2014, around 22.31 billion USD was generated from the palm oil industry and have been identified as the fourth largest source of national income [2]. Main products from palm oil industry are Crude Palm Oil (CPO), Palm Kernel Oil (PKO) and Palm Kernel Cake (PKC) which are widely used as the common ingredients for variety of food, feed and non-food products [3]. In the current practices, palm oil wastes are used for palletisation and as a feed for boiler in generating electricity, while some are just left to rot in the plantation for mulching and nutrient-recycling purposes [2]. However, biomass properties are inconvenient, particularly because of its high moisture content, a low calorific value, a hydrophilic nature and high oxygen content. In overcoming this issue, the key challenge is to develop an efficient conversion technology to improve the biomass properties in producing biofuel.

One of the common methods in upgrading the properties of palm oil biomass is by torrefaction process which act as an efficient conversion technology and offers solutions to the above problems.



Torrefaction is a thermal treatment process in the temperature range of 200°C - 300°C for a residence time between 15 and 60 minutes under inert condition. An extensive study of torrefaction process have been implemented on various types of biomass and the resulting product from torrefaction is proven to increase high energy content, exhibit brittle behaviour, become hydrophobic in nature and reduced mechanical strength. The main constituents of the oil palm waste are cellulose, hemicellulose and lignin. While the remaining contents are ash and extractives such as resins, starch, fats, sugar, proteins and minerals. This high cellulose and hemicellulose content can be converted into simple sugars and processed into biofuels or biochemical. In the present study, a lignocellulosic biomass (empty fruit bunch) will be torrefied at different torrefaction condition at temperature 240, 270, 300 and 330°C and residence time 15, 30 and 60 minutes to investigate the changes in mass loss precisely, as well as the energy properties and to see the impact of torrefaction on the lignocellulosic structures.

2. Methodology

2.1. Biomass Preparation

The biomass used in this study was empty fruit bunch (EFB) which had been collected from Lepar Hilir Palm Oil Mills, Kuantan, Pahang, Malaysia. The EFB was initially dried in the oven at temperature 105°C for 4 hours prior to the experiment in order to reduce the moisture content in the sample. The dried sample was then grinded and sieved into 0.5 to 1.0 mm particle sizes. The sample was then transferred into an airtight container before undergo torrefaction experiment.

2.2. Torrefaction Experiment

Torrefaction experiment was carried out using a vertical-stainless steel reactor with 39.7 cm long and 1.9 cm internal diameter as shown in the schematic diagram in figure 1. An amount of 2 – 3 g of EFB were approximately measured and placed in the reactor to undergo torrefaction process. The reactor was flushed with nitrogen gas at a flow rate of 10 mL/min for 5 minutes in order to create an inert condition in the reactor. Afterwards, the EFB was heated to the desired torrefaction temperature of 240, 270, 300 and 330°C by an electric furnace with residence time 15, 30 and 60 minutes. Various torrefaction temperatures and residence time were applied to study the effect of mass loss, energy properties and changes of lignocellulosic structures in the biomass. After the completion of torrefaction experiment, the furnace and the carrier gas were switched off. The reactor was then allowed to cool at ambient temperature and the torrefied sample was collected and weighed to measure the mass loss. The experiment was repeated for three times for each temperature and residence time to enhance data reliability and the average reading is presented in this study.

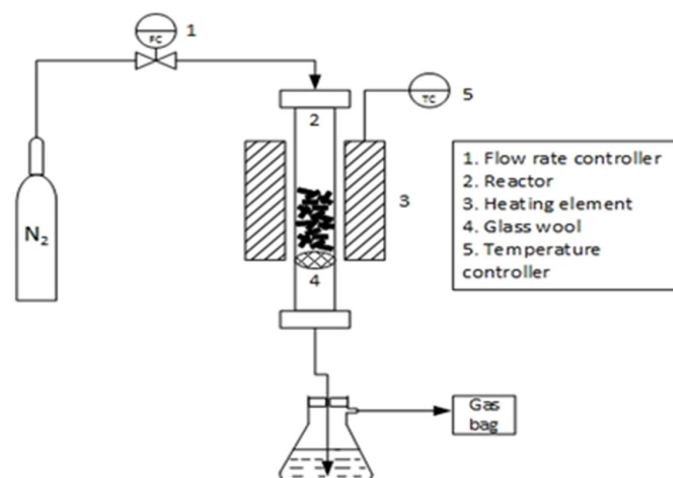


Figure 1. Schematic diagram of vertical tubular reactor

2.3. Property Analysis of Torrefied Empty Fruit Bunch

The mass yield, energy yield and mass loss are calculated using equation (1), (2) and (3). Calorific value analysis of the raw and torrefied empty fruit bunch was carried out using Model 1341 bomb calorimeter

$$\text{Mass yield}(\%) = \frac{m_{\text{torrefied}}}{m_{\text{raw}}} \times 100\% \quad (1)$$

$$\text{Energy yield} = \text{Mass yield} \times \frac{\text{HHV}_{\text{torrefied}}}{\text{HHV}_{\text{raw}}} \times 100\% \quad (2)$$

$$\text{Mass loss}(\%) = \frac{m_{\text{raw}} - m_{\text{torrefied}}}{m_{\text{raw}}} \times 100\% \quad (3)$$

2.4. Determination of Chemical Composition

The chemical compositions of EFB were determined according to TAPPI standard T 203 test methods. Hemicellulose, cellulose and acid-insoluble materials (lignin) content were determined for raw and torrefied samples. Acid-insoluble materials consisting by majority of lignin, were determined by quantitative acid hydrolysis with 72% H₂SO₄ according to T-249 em-85. The holocellulose content which is consist of hemicellulose and cellulose was determined according to T429 cm-10, Wise method [4].

3. Result and Discussion

3.1. Mass Loss, Energy Yield and Higher Heating Value

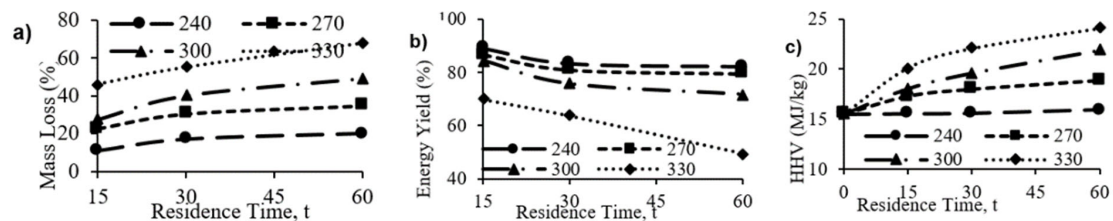


Figure 2. (a)Mass loss, (b)Energy yield and (c)Higher heating value of torrefied EFB at different temperature and residence time

Figure 2(a) shows the changes of mass loss at different torrefaction temperature and residence time. The mass loss increased due to the cumulated effect of reaction temperature and duration time. At mild torrefaction temperature, 240°C and 270°C, the increased of mass loss are 9% and 12% respectively. A significant increase of mass loss occurred at high torrefaction temperature of 300°C and 330°C by 21% and 22%. The higher mass loss at severe treatment caused by higher degradation of the chemical constituent of the lignocellulosic biomass used in this study. At higher temperature, the thermal decomposition of hemicellulose occurred, releasing volatiles and gaseous products such as water (H₂O), carbon monoxide (CO), carbon dioxide (CO₂), acetic acid and other organics [5]. As shown in figure 2(b), the energy yield is decreased by 6, 7, 12 and 20% at 240, 270, 300 and 330°C respectively. The energy yield is depended on the mass loss and higher heating values as calculated using equation (2). A significant decreased of energy yield at severe treatment of 330°C for 60 minutes is due to the significant increase of mass loss at higher torrefaction temperature. Nevertheless, the energy generations which is attributes by higher heating values (HHV) which represents the maximum amount of energy embedded per gram of a material is increased by 3, 21, 41 and 55% at

240, 270, 300 and 330°C with increasing reaction time as shown in figure 2(c). The energy value ranged from 15.94 – 24.09MJ/kg as increasing reaction temperature and duration time.

3.2. Changes on Chemical Composition of Empty Fruit Bunch

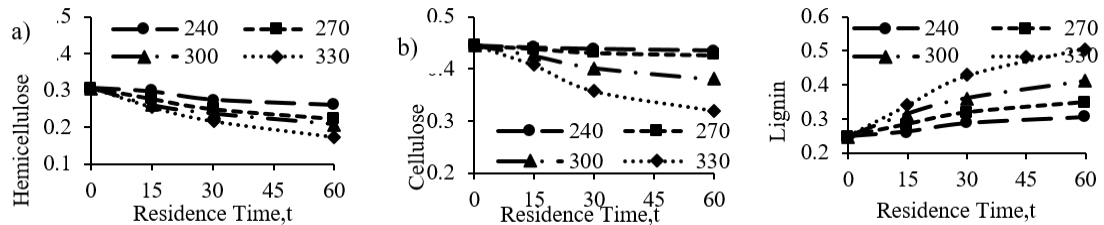


Figure 3. (a)Hemicellulose, (b)Cellulose and (c)Lignin content of torrefied EFB at different temperature and residence time

The changes in the chemical compositions includes hemicellulose, cellulose and lignin content in the torrefied EFB as shown in figure 3(a), (b) and (c). Hemicellulose, cellulose and lignin are known to decompose at temperature 225 - 300°C, 305 - 375°C and 250 - 500°C respectively [5]. Hemicellulose content showed a significant reduction with increasing severity of torrefaction as shown in figure 3(a). It is clear that hemicellulose is severely affected by torrefaction, even at temperature as low as 240°C it degrades by 15%. Further increasing the temperature to 330°C, it degraded by 43%. Hemicellulose are more sensitive to thermal degradation and giving more degradation products such as furfural [6]. Cellulose content in the biomass is slowly decrease at low torrefaction temperature 240°C by only 2% and further increase the temperature to 330°C, it degrades by 28%. Cellulose content was influenced significantly when severe torrefaction temperature above 300°C was applied. Cellulose degradation starts at about 230°C and becomes significant only at temperature level above 290°C as stated by Chen and Kuo (2011) [7]. Lignin content showed an increasing trend in this study as showed in figure 3(c). Lignin content increased by 23% and 104% at 240°C and 330°C respectively. This is due to the effect of thermal treatment, which from the decomposition of hemicellulose and cellulose content, the lignin content was accumulated in the torrefied biomass hence the increasing trend observed.

4. Conclusions

In this study, torrefaction process for empty fruit bunch at temperature 240, 270, 300 and 330°C for 15, 30 and 60 minutes residence time was successfully performed. Increasing the torrefaction temperature and time lead to increase in mass loss, decrease the energy yield and definitely increase higher heating value of the biomass. Changes in chemical compositions in the biomass shows that hemicellulose is degraded by 43%. Cellulose content is slowly decreased by 28%. Lignin content is increased with severity of torrefaction due to the effect of decomposition of hemicellulose and cellulose content, as it accumulated in torrefied biomass, hence the increasing trend observed. From this study, the torrefied biomass occurred to be more suitable to be used as biofuel as it has higher heating values, as well as the chemical and physical properties. The result of this study can be used as a guide for the production of high energy density solid biofuel from other lignocellulosic biomass.

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