Torrefaction of Oil Palm Empty Fruit Bunches Pellets under Mild-to-Severe Temperature Conditions through Thermogravimetric Analysis

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Abstract: Malaysia generates significant quantities of lignocellulosic wastes through the production of crude palm oil (CPO). Over the years, the accumulation of the oil palm wastes (OPW) have become an environmental burden. These problems can be addressed by pretreatment and valorisation of OPW in bioenergy as envisioned in the National Biomass Strategy (NBS-2020). However, current strategies for the OPW valorisation are inefficient and unsustainable resulting in increased environmental challenges. Therefore, this paper proposes the pelletization and torrefaction of oil palm empty fruit bunches (OPEFB). Furthermore, the thermal degradation behaviour and potential product yields from OPEFB pellet torrefaction will be examined. The results revealed that the mass yield (M_Y) decreased from 67.89% to 33.11%, whereas energy yield (E_Y) decreased from 88.29% to 49.18% as the torrefaction temperature increased from 250 °C to 350 °C. However, the energy density (D_E) increased from 1.30 to 1.49 due to the increase in higher heating value (HHV) from 22.85 MJ/kg to 26.10 MJ/kg. Likewise, the severity factor (S_F) increased from 5.89 to 8.84 with increasing torrefaction temperature. The results also revealed that effect of temperature on the torrefaction parameters; M_Y, E_Y, D_E, and HHV are slightly reduced after 300 °C. Overall, the findings demonstrate that torrefaction improved the fuel properties and energy recovery potential of the OPEFB pellets.

Keywords: Torrefaction, Oil Palm Empty Fruit Bunches, Pellets, Thermogravimetry, Malaysia doi:10.20944/preprints201803.0032.v1

1. Introduction

The oil palm industry in Malaysia accounts for 31% of global crude palm oil (CPO) [1]. However, the production of CPO generates significant wastes which currently pose waste management and environmental challenges. Consequently, the National Biomass Strategy (NBS-2020) was ratified by the government of Malaysia (GoM) to stimulate the cost-effective and efficient valorisation of 20 million tons of OPW annually through various thermochemical or biorefinery techniques [2].

As a result, various studies have examined the valorisation of OPW biomass into bio-oil, biochar and biosyngas through pyrolysis [3-5], hydrothermal carbonisation [6, 7], torrefaction [8-10] and gasification [11-13]. Current techniques have nonetheless proved inefficient and unsustainable largely due to the unfavourable biomass properties of OPW which hamper efficient thermal conversion. Furthermore, the utilisation of OPWs is prone to operational problems such as agglomeration, sintering and emission of particulate matter resulting in low conversion efficiencies [14].

Conversely, pretreatment technologies such as pelletization and torrefaction can improve the solid biofuel properties of OPWs thereby addressing the outlined operational challenges. Currently, the most widely used technique is combined *Torrefaction* and *Pelletization*, or the TOP process [15]. Studies have shown that the degradation of hemicellulose and cellulose during torrefaction disrupts the inter-particle bonding thereby resulting in brittle, friable and poor quality pellets [16]. Alternatively, pelletization before torrefaction can potentially address the attendant problems of the TOP process.

Therefore, this paper seeks to examine the effect of torrefaction on pelletized Oil Palm Empty Fruit Bunches from mild to severe temperature conditions ranging from 250 °C to 350 °C. It will examine reaction conditions, thermal degradation behaviour and potential product yield from the OPEFB pellet torrefaction through thermogravimetric analysis (TGA). The technique is a simple, timely and reliable approach widely applied to simulate and examine the thermochemical biomass conversion processes such as torrefaction and pyrolysis in the literature [17-19].

2. Experimental

The OPEFB pellets examined in this study were acquired from an oil palm mill in Johor, Malaysia. The physicochemical, thermal, kinetic and calorific fuel properties of the OPEFB pellets are presented in our previous study [20]. In this study, torrefaction was performed by TGA under nitrogen gas flow of 50 mL/min. For each run, approximately 10 mg of the pulverised OPEFB pellets of particle size 250 µm was heated from room temperature to the selected torrefaction temperatures; 250 °C, 275°C, 300 °C, 325 °C and 350 °C for a holding time of 30 mins. In the end, the mass loss and derivative mass loss data were retrieved and plotted against time in Microsoft Excel (version 2013) to obtain TG and DTG plots, respectively. Next, the degree of torrefaction was examined based on the parameters; mass yield (M_Y), energy yield (E_Y), energy density (D_E), higher heating value (*HHV*), and severity factor (S_F) in equations 1 – 5;

$$Mass\ Yield, M_Y = \frac{m_{Torrefied\ Biomas}}{m_{Raw\ Biomas}} \times 100 \tag{1}$$

$$Energy\ Yield, E_Y = \frac{HHV_{Torrefied\ Biomas}}{HHV_{Raw\ Biomas}} \times 100 \tag{2}$$

$$Energy\ Density, D_E = \frac{Energy\ Yield, E_Y}{Mass\ Yield, M_Y} \times 100 \tag{3}$$

$$Higher\ Heating\ Value, HHV = 19.85 + 9.34 \times (M_L, \%) \tag{4}$$

$$Severity\ Factor, S_F = \log\left\{t \times \exp\left(\frac{T_h - T_r}{14.75}\right)\right\} \tag{5}$$

The terms; m, t, T_h and T_r in Equations 1 – 5; represent the mass of torrefied or raw biomass, time (minutes), reaction (torrefaction) temperature and reference temperature (100 °C), respectively. Consequently, the parameters; M_Y, E_Y, D_E, HHV, and S_F were estimated from the residual mass (R_M) and mass loss (M_L) during the TGA torrefaction of the pellets.

3. Results & Discussion

The TG and DTG plots for the torrefaction of OPEFB pellets are presented in Figures 1 and 2, respectively. The results revealed that mass loss increased with increasing temperature during the torrefaction of the OPEFB pellets.

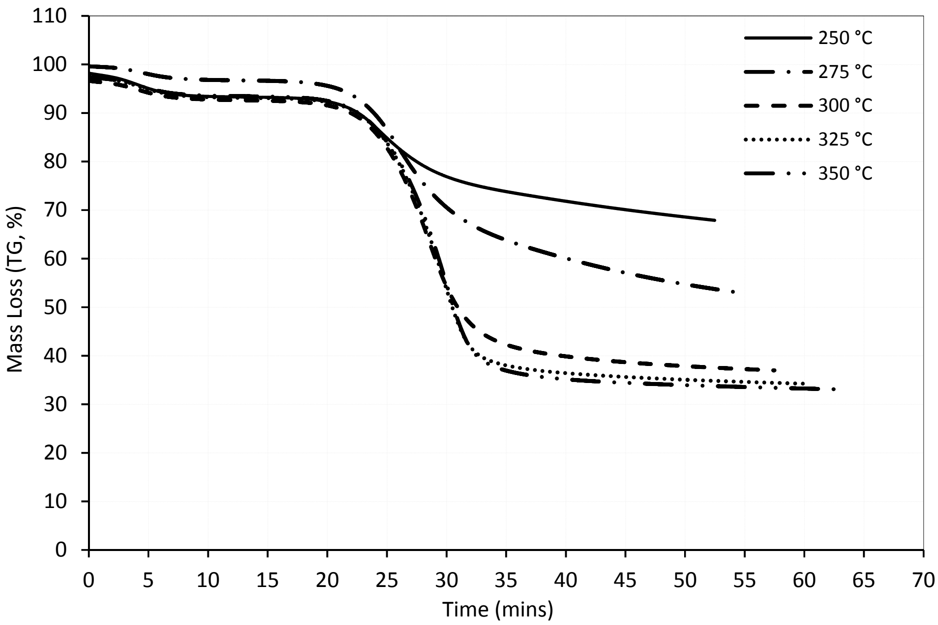

Figure 1: TG Plots for Torrefaction of OPEFB Pellets

The temperature dependency of torrefaction is due to its effect on the decomposition of lignocellulosic biomass components. The decomposition of biomass during torrefaction can be ascribed to the degradation of hemicellulose, and partial decomposition of cellulose and extractives. As a result, the high mass loss (M_L) and decrease in residual mass (R_M) during the OPEFB pellets torrefaction can be ascribed to the loss of *holocellulose* and extractives.

Table 1 presents the residual mass (R_M) and mass loss (M_L) during the torrefaction of OPEFB pellets. As observed, the mass loss increased progressively whereas the residual mass decreased during torrefaction of OPEFB pellets from 250 °C to 350 °C. Since the residual mass (R_M) is the mass of the fuel remaining after the process, it can be termed the solid product or mass yield (M_Y) of torrefaction. Likewise, the mass loss (M_L, %) is an indication of liquid and gas products of torrefying the OPEFB pellets.

Table 1: Time Profiles and Residual Mass for OPEFB Pellet Torrefaction

Temperature (°C)	Mass Loss (%)	Residual Mass (%)
250	32.11	67.89
275	46.91	53.09
300	62.99	37.01
325	65.74	34.26
350	66.89	33.11

Based on the results in Table 1, it can be surmised that torrefaction of the fuel above the 300 °C does not result in significant change in mass loss or residual mass. Therefore, the torrefaction of OPEFB pellets should be limited between 250 °C and 300 °C.

The DTG plots for the torrefaction of OPEFB pellets are presented in Figure 2. Similar to the trends observed in the TG plots, the size of the DTG plots increased with increase in the severity of torrefaction temperature.

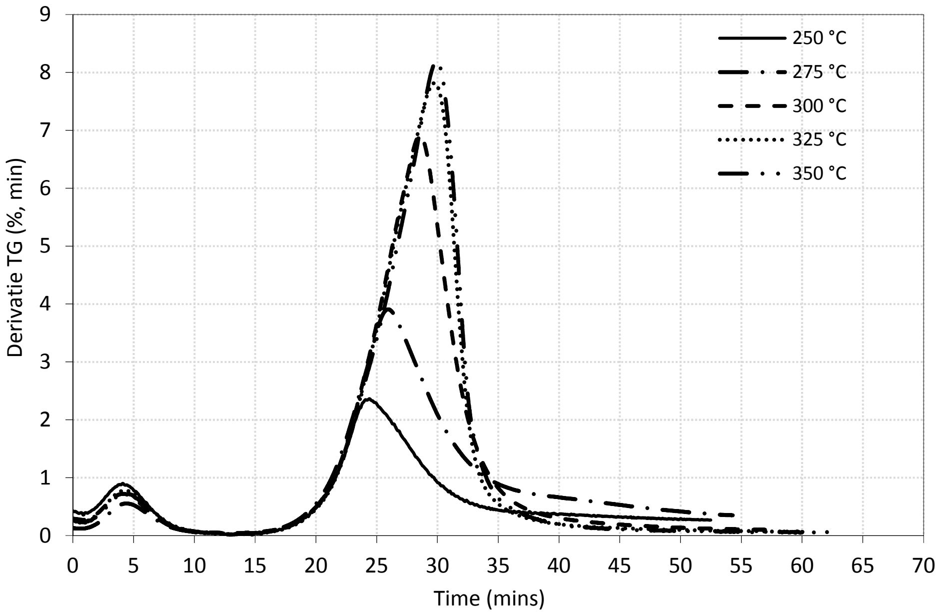

Figure 2: DTG Plots for Torrefaction of OPEFB Pellets

As observed, the size of DTG curves increased proportionately from 250 °C to 300 °C with increase in the torrefaction temperature. However, the change in the size of the plots did not differ markedly after 300 °C. This may somewhat suggest that temperature did not significantly influence the process beyond 300 °C. However, this requires further tests particularly at holding times or torrefaction temperatures higher than 30 minutes and 350 °C, respectively.

Next, the mass yield (M_Y), energy yield (E_Y), energy density (D_E), higher heating value (*HHV*), and severity factor (S_F) were estimated from the residual mass (R_M) and mass loss (M_L) during the TGA torrefaction of the pellets as presented in Table 2.

Table 2: Parameters for OPEFB Pellets Torrefaction

Torrefaction Temperature (°C)	Mass Yield (M_Y, %)	Energy Yield (EY, %)	Energy Density (D_E)	HHV (MJ/kg)	Severity Factor (S_F)
250	67.89	88.29	1.30	22.85	5.89
275	53.09	73.22	1.38	24.23	6.63
300	37.01	54.21	1.46	25.73	7.37
325	34.26	50.68	1.48	25.99	8.10
350	33.11	49.18	1.49	26.10	8.84

The results in Table 2, reveal that the mass yield (M_Y) decreased from 67.89% to 33.11%, whereas the energy yield (E_Y) decreased from 88.29 to 49.18% with increase in the torrefaction temperature. However, the energy density (D_E) increased from 1.30 to 1.49 due to the increase in higher heating value (HHV) from 22.85 MJ/kg to 26.10 MJ/kg. Likewise, the severity factor (S_F) increased from 5.89 to 8.84 with increase in torrefaction temperature.

The heating values of the torrefied OPEFB pellets were in the range reported for sub-bituminous and bituminous coals. Hence, the torrefied fuels can be termed bio-coal due to their similarities with various ranks of coals. Overall, the results indicate torrefaction improved the fuel properties and energy recovery potential of the OPEFB pellets.

4. Conclusion

The study examined the torrefaction of OPEFB pellets through thermogravimetric analysis (TGA) from 250 °C to 350 °C or under mild to severe conditions. The results revealed that the mass yield (M_Y), and energy yield (E_Y), decreased whereas the energy density (D_E), higher heating value (*HHV*), and severity factor (S_F) increased at higher temperatures. However, the results showed that effect of temperature on the torrefaction parameters was somewhat diminished after 300 °C. Nonetheless, torrefaction improved the fuel properties and energy recovery potential of the fuel.

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