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Thermogravimetric analysis of empty fruit bunch

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Abstract. This paper presents the characteristics of empty fruit bunch (EFB) using thermogravimetric analysis (TGA) and shows its potential as a renewable energy sources. A set of data were collected from the thermal reaction and plotted in mass or percentage of the initial mass against either temperature or time, respectively. In the thermogravimetric analysis, mass, temperature and time were considered as base measurements and important data for derivative thermogravimetric (DTG) curve were analysed while many additional measures could be derived from these three base measurements. It was observed that heating rate of 8.5^{o}C/min and air flow rate of 85mL/min provided a maximum weight loss rate of 0.209%/ ^{o}C at the temperature of 313.5^{o}C and the derivative weight peak of -0.1895mg/^{o}C at 292^{o}C. The time taken to reach the maximum temperature of 899.9^{o}C was 46.74 minutes, and ΔT endo-up reflected minimum point of -0.2^{o}C at 15.82 minutes and maximum ΔT endo-up of 888^{o}C at 42 minutes. Heat flow endo-up also showed that the minimum heat flow was 15.39mW at 15.85 minutes and reaching the peak heat flow endo-up of 47.73mW at 43.27 minutes.

1 Introduction

Nowadays, the growth in the energy demand worldwide and severe environmental condition pushed to consider renewable energy sources such as solar, wind, wave and tidal, geothermal, hydro, biomass energies as an alternative energy sources [1]. Particularly, renewable resources are providing significant energy for the countries under rapid economic development. With such advantage of using renewable energy, Malaysia government has turned the attention towards palm oil industrial in Malaysia. Malaysia has the capability of contributing lignocellulosic biomass in more than 90% in total with a massive delivering of 5.4mil ton hectare of oil palm [2]. For instance, in year 2005, palm oil industries were projected to produce approximately 15 million tonnes (301,000 barrels per day) [3]. In recent years, huge replanting activity, expanding mill capacity and improvement on palm oil exchange rate have given the opportunity to utilize oil palm as renewable energy sources. On the other hand, after the massive production of oil palm, the solid wastes such as empty fruit brunch (EFB), mesocarp (MF), and palm kernel shell (PKS) were left over and can be reused

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as energy sources. EFB is a by-product of Fresh Fruit Bunch (FFB) following the removal of the nut, which could be used to produce useful fuels. The presence of high amount of fixed carbon makes EFB to be a potential renewable energy sources.

Fully utilizing the EFB's lignocellulose would be an alternative solution as renewable energy. In rough estimation, palm oil would obtain approximately 4kg of lignocellulosic biomass including EFB's cellulose, hemicellulose and lignin [4,5]. The cellulose's content in EFB's palm oil is in the range of 37.3% - 46.5% whereas hemicellulose content is 25.3% - 33.8% and lignin of 27.6% - 32.5%, respectively [6]. As a result, EFB was found to be potential for fermentation production of bioethanol due to its high cellulose content. This energy is usually obtained via thermochemical treatments, such as pyrolysis, gasification, and combustion [3]. Through thermochemical treatment, EFB could be used to produce ethanol as pre-treatment was required to render the cellulose fibre more amenable to the action of hydrolytic enzymes.

Oil palm has the highest yielding oil crop compared to other crops such as soybean, sunflower, rapeseed with the advantage of 10:1 ratio [6]. From the high yielding of oil palm, a fermentation process could be deployed to generate bio-ethanol from sugar or starch. From the palm tree, empty fruit bunch (EFB) has the highest sugar content compared to other parts and is suitable to produce bio-ethanol through pyrolysis and fermentation or hydrolysis. The percentage of both ultimate and proximate analyses were used to indicate the energy content within EFB itself and upon combustion with the required amount of air as well as other composition of gases released during the combustion through traditional method of water retting process [7]. In proximate analysis, EFB would consist 83.86% of volatile matter, 18.3% of fixed carbon and 13.65% ash with the moisture content of 14.28%. Due to high volatile matter in EFB, the ignition towards EFB was possible at the temperature of 190°C, whereas the fixed carbon determines the amount of heat and energy produced during the burning processes. It was found that ultimate analysis from EFB after combustion showed 2.4% potassium oxide and it is the highest percentage compared to magnesium oxide (0.23%), silica (0.19%), phosphorous pentoxide (0.18%) and calcium oxide (0.13%) [8].

The conversion of EFB into useful fuel could be done in either fast or slow pyrolysis or even through gasification. A quick pyrolysis, conducted at higher temperature (>400 °C) and over a shorter home time (<30 s), is more ideal since it tends to give a higher liquid product yield [9]. Production of bio-oil from EFB could be performed by quick pyrolysis, either without or with a catalyst presence and it can be done in a fluidized-bed, fixed bed or auger type system. Beside pyrolysis, solvolysis, another sort of thermochemical process, has been utilized to convert EFB into bio-oil [8].

TGA could furnish a straightforward process and analysis method such as proximate analysis, heating value, and hemicellulose/cellulose/lignin ratio, which are the parameters of more noteworthy criticalness influencing kinetics energy [10]. Furthermore, deconvolution of Derivative Thermogravimetric (DTG) curve is proposed to calculate the substance of hemicellulose, cellulose and lignin and the utilization of non-linear regression techniques for the correlation substance of moisture, fixed carbon, volatile component and ashes consisting of carbon, hydrogen, oxygen, nitrogen, sulphur and higher heating value, HHV [3]. Moreover, TGA or DTG graphs help analyse the reaction of feedstock against the condition perimeter setup for the analysis. The objective of this paper was therefore to identify the characteristic of empty fruit bunch (EFB) and show its potential as renewable resources through Thermogravimetric Analysis. This would provide a better understanding of the behaviour of solid fuel during combustion, thermochemical and biochemical conversions.

2 Materials and methods

A test was carried out with the dry shredder EFB beforehand to avoid contamination for later non-isothermal experiment. In this experiment, a small amount of the EFB was placed in the alumina crucible and placed into a furnace for continuous heating under controlled temperature at the rate of 8.5°C per minute with the air flow rate of 85mL/min. The reaction of the EFB inside the furnace was recorded automatically into the log system providing various selection of feedstock weight, temperature and time difference. The recorded data on the TGA and DTG provide the percentage of ultimate analysis, proximate analysis and chemical structure for the EFB. The extracted information from TGA and DTG would be valuable for later analysis on gasification of EFB.

3 Results and discussion

Fig. 1 shows TGA and DTG of EFB over temperature raging from 0°C to 899.9°C. EFB underwent three main stages degradation: drying and evaporation of light components (phase one), devolatilization of cellulose and hemicellulose (phase two) and decomposition of lignin (phase three) [11]. The first phase of drying and evaporation of light components ranged from 97.85°C to 196.5°C. The drying and evaporation of EFB caused the mass reduction from 99.3758% to 96.8547% with 2.5211% weight losses at a rate of 0.025%/°C. A significant drop of weight in the temperature range of 196.5°C to 510°C indicated phase two of devolatilization of cellulose and hemicellulose of EFB with wt% of EFB reduced from 96.85% to 31.206%. In phase two, total weight losses were 65.648% in the total temperature increment of 313.5°C at a rate of 0.21%/°C. When temperature reached 510°C, which is phase three, a slow and stable mass loss was observed as the degradation of lignin compounds and other strong chemical bond compounds were left over for long and high temperature degradation. The weight of EFB reduced from 31.2% to 11.05% at the end of the analysis. The rate of weight loss was 0.0516%. It was also observed that a maximum temperature of 900°C was unable to complete combustion due to its 11.056% inorganic components [12].

As for DTG, phase one started with an intensive mass loss of -0.061mg/°C at 53°C and this was followed up with a second derivative weight peak of -0.1895 at 292°C. From DTG, EFB components underwent combustion within the temperature from 272°C to 314°C. The remaining components underwent combustion within the range of 450°C and 510°C. From the analysis, a minimum gasification temperature would be around 900°C to complete gasification process [13]. TGA and DTG also showed mass losses with an increase in temperature and heating rate in the furnace [14].

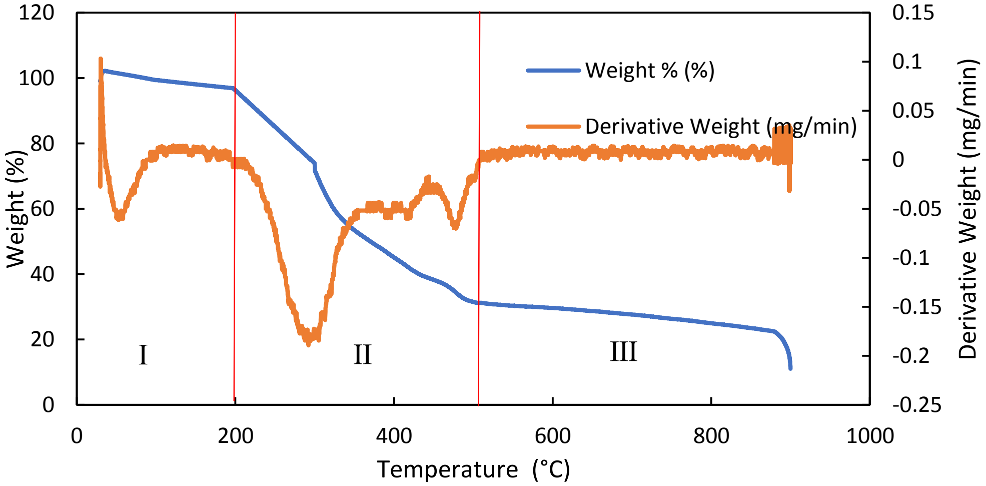

Fig. 1. TGA and DTG of EFB

3.1 Others sample details of EFB

To have a better understanding on EFB, other characteristics were taken into consideration. Fig. 2 shows the comparison between time against ΔT endo-up and temperature. ΔT endo-up indicates a difference between the maximum and minimum temperature during endothermic process. The initial temperature started at 29.71℃ and ΔT endo-up started at 0.065°C. When the temperature increased ΔT endo-up gradually increased before a significant drop at temperature of 325.7°C with -0.2°C of ΔT endo-up as the devolatilization occurred at 440°C. Slowly the ΔT endo-up increased back to 0.49°C at the temperature of 455.7°C and a second significate drop of ΔT endo-up at the minimum point of -0.16°C was at the temperature of 480.43°C. The second drop of ΔT endo-up was observed before the degradation of lignin compounds hitting the minimum value of ΔT. The delta temperature increased rapidly from -0.16°C to 0.78°C at the temperature between 480.11°C and 511.27°C. When the temperature reached 511.27°C, the degradation of lignin occurred, causing the chemical composition of EFB reaction under high temperature degradation. At high temperature, the delta *T* increased gradually from 0.78°C to 1.61°C. The total time taken for the TGA was approximately 46.74 minutes. For drying and evaporation (phase 1), the heat flow endo-up reached the maximum point of 31.17mW at 9.1 minutes. After the completion of drying and evaporation, the first fall of ΔT was at 15.69min with -0.2°C, indicating that the EFB was not absorbing the heat before the devolatilization of hemicellulose and cellulose of the EFB component. In the early stage of devolatilization, ΔT increased and the maximum devolatilization of EFB occurred at 22 minutes with the maximum ΔT of 0.49°C. Right after the devolatilization (phase 2), ΔT dropped rapidly and reached the minimum delta temperature of -0.16°C in 1 minute. Chemical bonds took the longest time of 20 minutes to reach the maximum ΔT of 1.61°C in phase 3 of decomposition of EFB. When all the chemical bonds of EFB were broken down, ΔT endo-up became smaller.

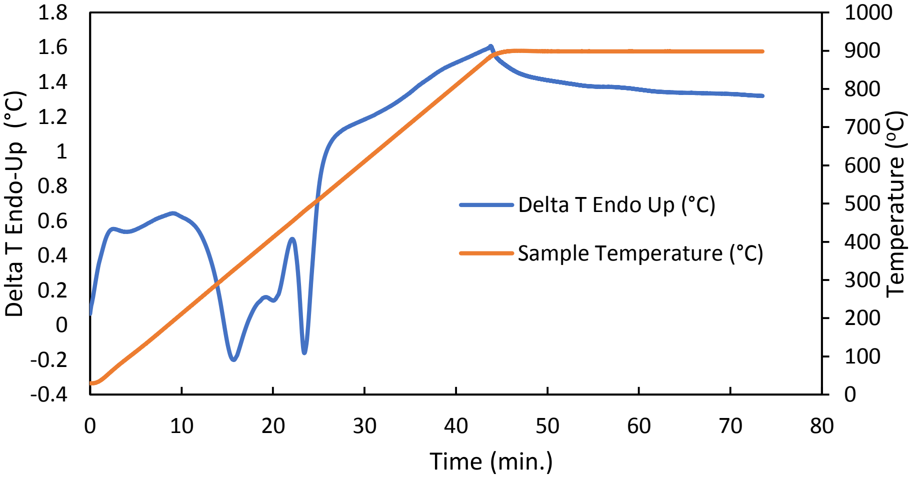

Fig. 2. Time against ΔT Endo-up

Fig. 3 shows temperature and time reaction on heat flow endo-up of EFB. In drying and evaporation (phase 1), the heat flow endo-up reached the maximum point of 31.17mW at 9.1 minutes. Once the drying and evaporation completed, heat flow endo-up decreased and reached minimum value of 15.27mW at 15.69 minutes. The devolatilization (phase 2) took place at 22 minutes and the maximum point of heat flow was 28.5mW. The decomposition in phase three reached the highest points of the heat flow rate of 48.05mW at the time of 43.7mintues. In conjunction of temperature against heat flow endo-up, the temperature of the phase 1 was 194.13°C, whereas phase 2 devolatilization experienced decreasing heat flow endo-up in the temperature ranging from 200°C to 326°C and there was a slight increment of heat flow (maximum values of 28.51mW) at the temperature of 453.2°C. Prior to entering phase three, there was a drop of heat to 48.05mW at the temperature of 884.85°C.

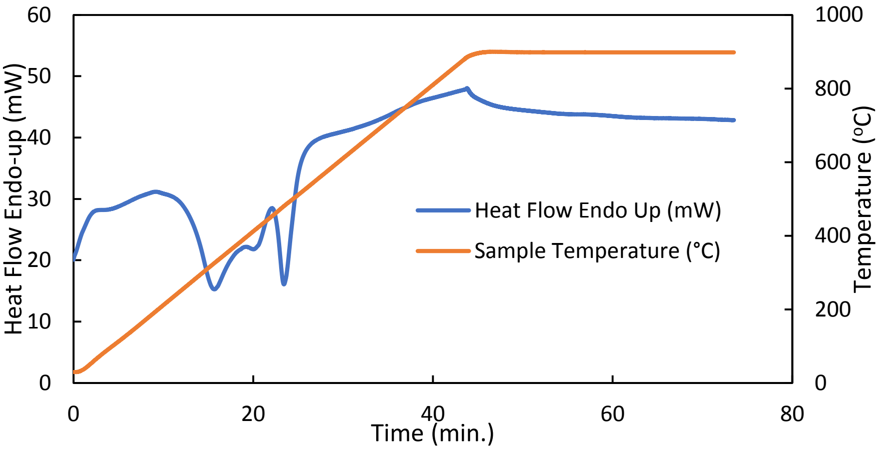

Fig. 3. Time against Heat Flow Endo-up

Fig. 4 shows temperature profile over time. The analysis started at 29.71°C (controlled room temperature). As the time increases temperature increases with the rate of 8.5°C/min (point 1 taken at 0.1min and 29.69 °C, point 2 at 1.3min, 69.88 °C). The temperature reached maximum value of 899.9 °C at 46.74 minutes, which was then similar until the end of the analysis.

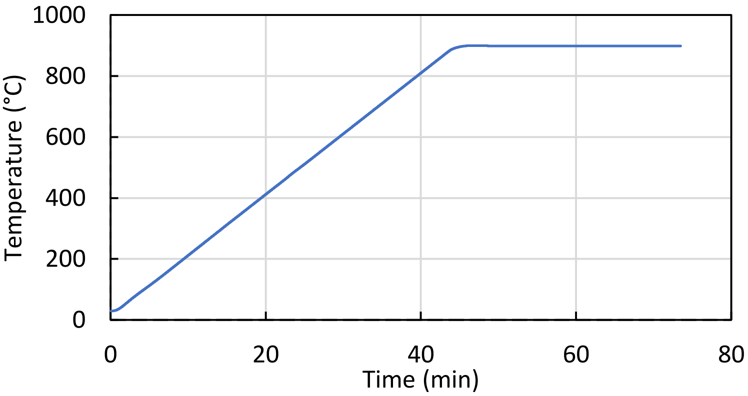

Fig. 4. Temperature against time

4 Conclusion

A study on the thermogravimetric analysis of empty fruit bunch (EFB) was carried out to determine weight loss over temperature and time. The analysis showed that the minimum temperature required to break down all the organic chemical component of EFB was at 900°C with an approximate period of 46.74 minutes. Through TGA, the reactions of EFB in each phase towards heat flow, ΔT endo-up, and time have shown significant changes due to increment of temperature. Analysis of EFB under TGA and DTG at heating rate of 8.5°C/min also showed the maximum weight loss rate of 0.209%/°C at the temperature of 313.5°C and the derivative weight peak of -0.1895mg/°C at 292°C.

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