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Thermogravimetric Analysis of the Fuel Properties of Empty Fruit Bunch Briquettes

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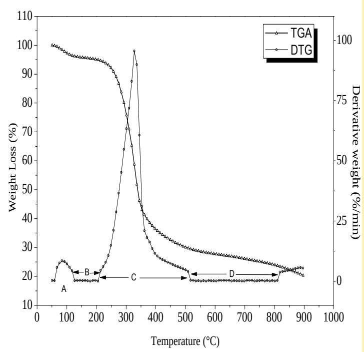
Graphical abstract



Abstract

The thermochemical properties of biomass are largely influenced by the nature, yield and composition of the feedstock. In addition, the low moisture content, energy density and solid uniform structure of briquettes have been reported to improve heat and mass transfer during thermochemical conversion. Hence, this study is aimed at investigating the thermochemical properties of Empty Fruit Bunch (EFB) briquettes using Thermogravimetric analysis (TGA). The heating value (HHV), ultimate and proximate analysis was determined using standard ASTM techniques. Consequently, the thermal decomposition behavior of the fuel was determined by heating the sample from 50°C to 900°C in a thermogravimetric analyzer (TGA) at 10°C per min heating rate. The ultimate and proximate analysis revealed that EFB briquette contains low moisture content, ash content and high fixed carbon, volatile matter content while the HHV was 17.57 MJ/kg. In addition, TGA results indicated thermal decomposition of the fuel occurs in four stages. Devolatization commenced at 206°C with a peak devolatization temperature (T_{max}) of 325°C resulting in 70% weight loss.

Keywords: Briquette; characterization; empty fruit bunch; thermogravimetric; heating value

Abstrak

Ciri-ciri termokimia biojisim sebahagian besarnya dipengaruhi oleh alam semula jadi, hasil dan komposisi bahan mentah. Di samping itu, kandungan kelembapan yang rendah, kepadatan tenaga dan struktur briket seragam yang kukuh dilaporkan boleh meningkatkan haba dan jisim semasa penukaran termokimia. Oleh itu, kajian ini bertujuan untuk mengkaji sifat termokimia briket Buah Tandan Kosong (EFB) menggunakan Termogravimetri analisis (TGA). Nilai pemanasan (HHV), muktamad dan analisis proksimat telah ditentukan menggunakan teknik ASTM standard. Akibatnya, tingkah laku penguraian terma bahan api itu ditentukan dengan memanaskan sampel dari 50°C hingga 900°C dalam analisa TGA dengan kadar pemanasan 10°C per min. Analisis muktamad dan proksimat menunjukkan bahawa briket EFB mengandungi kandungan kelembapan rendah, kandungan abu dan karbon tetap dan kandungan bahan mudah meruap yang tinggi manakala HHV adalah 17.57 MJ/kg. Di samping itu, keputusan TGA menunjukkan penguraian haba bahan api yang berlaku dalam empat peringkat. Devolatization bermula pada 206°C dengan suhu devolatization maksimum (T_{max}) 325°C yang mengakibatkan berat hilang sehingga 70%.

Kata kunci: Briket; pencirian; buah tandan kosong; termogravimetri; nilai pemanasan

1.0 INTRODUCTION

The rising costs of fossil fuels and growing concerns about global warming have reiterated the calls for the adoption of alternative sources of energy such as biomass. However, the transition from fossil based fuels to clean and sustainable sources of energy requires a comprehensive understanding of the technical and socio-economic dynamics of renewables.

Biomass is considered an environmentally friendly and sustainable source of energy for the future [1, 2]. It can be easily converted into liquid, gas and solid fuels via thermochemical and biological routes such as pyrolysis, combustion, digestion. In Malaysia, the annual production of crude palm oil generates large quantities of lignocellulosic biomass. These include shell, kernel, fronds and empty fruit bunches (EFB) which constitutes the largest proportion of palm waste. The EFB consists of the empty husks resulting from the extraction of palm oil from the fresh fruit bunches (FFB) [3].

However, the valorization of palm waste has the potential to create a clean and sustainable energy economy for Malaysia. Currently, palm waste such as EFB is used as boiler fuel, fertilizer or as raw material in the manufacture of plywood, briquettes and other value added products [4, 5]. However, large quantities of the palm waste are simply burned in air, incinerated or used as landfill material [4]. This has resulted in increased emission of greenhouse gases such as CO_2 SO_x, and methane into the atmosphere. Hence scientists in Malaysia are exploring more efficient routes for converting palm waste into value added products in a bid to reduce the nation's GHGs emission and create a biomass based energy economy.

Pyrolysis and gasification are considered to be promising technologies for valorizing palm waste in Malaysia [6]. The physical and thermochemical properties of biomass largely influence the gas yield and composition of pyrolysis and gasification [7]. Hence, an in-depth understanding of the physical and thermochemical properties of palm waste is required for pyrolysis and gasification applications. In addition, biomass properties such as moisture, volatile matter, ash, fixed carbon, elemental composition, heating value and particle size are vital in understanding the nature of thermochemical conversion [8, 9]. The thermal properties and decomposition behavior of various biomass fuels have been investigated using differential scanning calorimetry (DSC) and thermogravimetric analysis (TGA) [10-12].

Therefore, this study is aimed at analyzing the thermochemical properties of Empty Fruit Bunch (EFB) briquettes using thermogravimetric analysis (TGA). The EFB briquette properties such as moisture, volatile matter, ash, fixed carbon, elemental composition and heating value will be analyzed in the study. The decomposition behavior of the briquette and EFB briquette thermal properties such as ignition temperature, peak temperature and devolatization characteristics will also be presented.

■2.0 EXPERIMENTAL

The EFB briquette used in this study was acquired from Felda Semenchu Sdn Bhd, Johor Bahru, Malaysia. The raw material EFB fibers were dried, shredded and compacted into uniform solid briquettes using a briquetting machine. The average dimensions of the briquettes are 4.9 x 2.5 x 0.8 cm. The briquettes were pulverized in a high speed crusher machine (Kimah Malaysia, Model RT 20) fitted with a 1000 µm screen.

The resulting briquette powder was sieved in a Retsch analysis sieve (D-42759, Haan Germany) before ultimate analysis using LECO 932 CHNS analyzer. Proximate analysis was carried out according to ASTM standard techniques for determining the moisture content, volatile matter, ash content and fixed carbon content of biomass fuels. The higher heating value (HHV) of the EFB briquette was determined using a bomb calorimeter (IKA calorimeter system, Model C2000).

A Fourier Transform Infra-Red spectroscopic (FTIR) analyzer (Model Perkin Elmer Spectrum One) with a scan resolution of 0.5 cm^{-1} to 64 cm^{-1}, scan range 4000 cm^{-1} to 500 cm^{-1} and scan number 16, was used to analyze and obtain the IR spectrum of the sample.

Consequently, the thermal decomposition behavior of the fuel was determined using a thermogravimetric analyzer (TGA) Model Mettler Toledo TGA/SDTA 851. Approximately 14.13 mg of the briquette was placed in an Aluminum sample holder and heated from 50 °C to 900 °C at 10 °C/min heating rate using nitrogen (N_2) (flow rate of 25 ml/min) as the sweeping gas.

■3.0 RESULTS AND DISCUSSION

3.1 Fuel Characterization

The ultimate and proximate analyses of EFB briquette is presented in Tables 1 and 2 respectively. The ultimate analysis of the EFB briquette was similar to the results reported by Lahijani and Zainal [4] and Mohammed *et al.* [6] for empty fruit bunches (EFB). This indicates that the compaction of EFB fibers into briquettes did not significantly change the elemental composition of the EFB fibers despite the improved physical properties of the briquettes.

Table 1 Ultimate analysis of EFB briquette (wt. %)

Element	EFB Briquette	EFB [a]	EFB [b]
Carbon	43.15	43.52	46.62
Hydrogen	5.73	5.72	6.45
Nitrogen	1.20	1.20	1.21
Sulfur	0.04	0.66	0.035
Oxygen (diff)	49.88	48.90	45.66

[a] Lahijani & Zainal [4]; [b] Mohammed *et al* [6].

Considering *C, H, O,* as the main biomass constituent elements, the empirical formula $CH_{1.59}O_{0.88}$ was determined from the ultimate analysis of the briquette. In comparison, the empirical formula for EFB deduced by [4] was $CH_{1.46}O_{0.84}$.

Similarly, the briquette contained trace amounts of nitrogen and sulfur content indicating the thermal conversion of the fuel will result in low concentrations of SOX and NOX. The briquette is therefore an environmentally friendly fuel for thermochemical conversion. Table 2 presents a comparative analysis of the proximate analysis of EFB briquette and EFB obtained by [4, 6].

Table 2 Proximate analysis of EFB briquette (wt. %)

Biomass Component	EFB Briquette	EFB [a]	EFB [b]
Moisture	8.17	7.80	5.18
Volatile Matter	71.83	79.34	82.58
Fixed Carbon	15.44	8.36	8.97
Ash	4.56	4.50	3.45
HHV, MJ/kg (dry basis)	17.57	15.22	17.02
LHV, MJ/kg (dry basis)	16.22	13.88*	15.59*

[a] Lahijani & Zainal [4]; [b] Mohammed *et al* [6]. * Calculated from HHV

The proximate analysis showed that the EFB Briquette contains low moisture content (< 10 %), ash content (< 5 %), and fixed carbon (< 20 %). The volatile matter content was > 70 % which is comparable with the findings of Lahijani and Zainal [4] and Mohammed *et al.* [6] for EFB.

However, the fixed carbon content of the briquette was significantly greater than the values reported for EFB in table 2. This may be due to the thermal and physicochemical properties of the briquette. Fixed carbon is the solid carbon found in char obtained after the devolatization or pyrolysis of biomass. It is not a static property of biomass fuels since the conversion of volatile matter (VM) in biomass into char is largely dependent on the heating rate [7]. Hence, the high fixed carbon observed in the briquette, compared to the EFB, is due to the solid uniform nature of the briquette, which results in a slower heating rate and consequently high char formation during devolatization. In addition, this indicates that the thermochemical conversion of the EFB briquette will favor solid products over gases and liquids.

Furthermore, that the volatile matter to fixed carbon ratio of EFB briquette is > 4.0, which is consistent with other biomass fuels [7]. However the fuel ratio defined as the ratio of volatile matter to fixed carbon (FC/VM) for the briquette (0.21) is greater than EFB (0.11). This indicates that the ease of ignition and burnout for EFB fibers is more favorable than EFB briquette. This will result in lower ignition temperature, burnout temperature and uniform burning profile for EFB fibers compared to the briquette.

The higher heating value (HHV) of the EFB briquette was 17.57 MJ/kg which is lower than the values of HHV for coal due to the high oxygen content, low fixed carbon content and low density [7, 13]. However, the HHV of the briquette is greater than the EFB. This is due to the high fixed carbon content and the uniform solid nature of the briquette fuel that ensures greater mass and heat transfer during thermal conversion. The lower heating value (LHV) of the briquette was calculated from the relation [7];

$$LHV = HHV - hg\left(\frac{9H}{100} + \frac{M}{100}\right)$$

The lower heating value (LHV) is a measure of the thermal efficiency of a system.

3.2 Thermal Analysis

The TGA/DTG curves for the EFB briquette are presented in Fig. 1. The parameters ignition temperature *(T_{ign})*, maximum temperature *(T_{max})*, transition temperature *(T_g)* were deduced from the TGA/DTG curves. The overall sample weight loss per unit time was 1.88 % min $^{-1}$. From Figure 1, it can be deduced that EFB briquette decomposition occurs in four (4) stages; drying (A), heating (B), devolatization (C) and char aggregation (D).

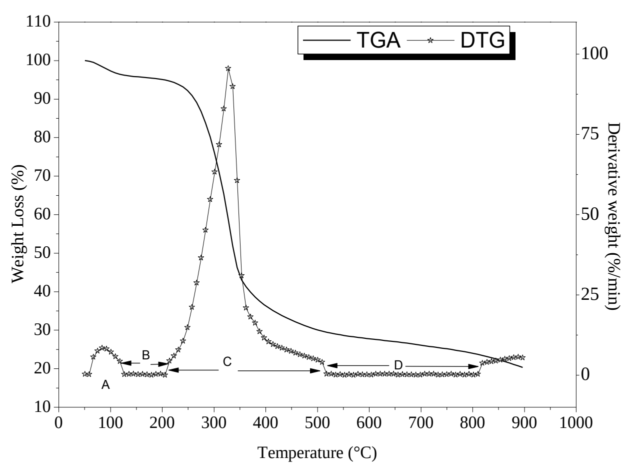


Figure 1 TGA/DTG curve of EFB Briquette

The fuel ignition temperature (T_{ign}) signifying the onset of devolatization was 206°C. The peak temperature of devolatization was 325°C and is denoted as glass transition *(T_g)* or maximum temperature *(T_{max})* as deduced from the TGA/DTG graph.

In addition, two peaks were observed in the DTG curve of the sample. The small peak between observed from 58°C to 128°C denoting the drying process of the reaction. Sample weight loss during this stage was 3.8%. The second peak between 206°C and 518°C signifies the devolatization of the sample. During this stage of the reaction, the condensable and non-condensable matter in the fuel is thermally decomposed into gases, char and tar. Sample weight loss during this step of the reaction is 70% of initial sample weight. The TGA/DTG temperature and weight loss profile of the sample is presented in Table 3.

Table 3 TGA/DTG profile of EFB briquette

Stage	Process	Onset (°C)	End (°C)	Wt % Loss	Time (mins)
A	Drying	58	128	3.83	3.90
B	Heating	128	206	5.06	7.80
C	Devolatization	206	518	70.55	23.40
D	Char aggregation	518	900	79.71	42.47

The results in Table 3 indicate that the thermal decomposition of the briquette from 50°C to 900°C resulted in ~ 80% of the sample. Hence, higher heating rates and temperatures greater than 900°C are required to ensure complete decomposition of the briquette into the desired products of thermal conversion.

3.3 Fourier Transform Infra-Red Spectroscopy (FTIR)

The elemental and functional group composition of the fuel was analyzed using Fourier Transform Infra-Red (FTIR) spectroscopy. The distribution of elements and functional groups in the fuel is vital for determining the composition and distribution of pyrolysis products [14]. The FTIR spectra for the EFB briquette fuel is presented in Figure 2.

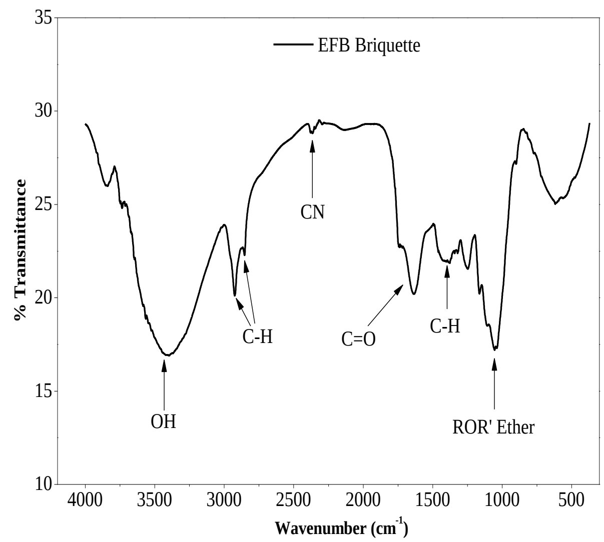


Figure 2 FTIR Spectra of EFB Briquette

The broad O-H stretching vibrations between 3200 and 3400 cm^{-1} indicate the presence of alcohols. The medium intensity band observed in 2368 cm^{-1} is due to nitrile C-N functional group which confirms the presence of nitrogen as indicated in the ultimate analysis of the briquette. The FTIR spectra also indicated two bands of strong intensity in the region 2800 and 3000 cm^{-1} typical of C-H stretching vibrations found in CH_3 and CH_2, and the C-H deformation vibrations usually observed between 1350 and 1475 cm^{-1} for alkenes. The broad intensity band between 1600 and 1750 cm^{-1} indicates the presence of C=O stretching vibrations typical of ketones and aldehydes. In addition the bands observed between 1000 and 1300 cm^{-1} may also be due to the presence of ether groups. From the FTIR analysis of the fuel, the following gases H_2, CO, CO_2, CH_4, and C_mH_n can be accurately predicted for briquette pyrolysis.

4.0 CONCLUSION

The thermochemical properties of EFB briquette were analyzed in this study. The results showed that the fuel contains low moisture content, ash content, fixed carbon, high volatile matter content. In addition nitrogen and sulfur were present in trace quantities indicating thermal conversion of the fuel will result in very low concentrations of SOx and NOx. The TGA results showed that the thermal decomposition of the fuel occurs in four stages with devolatization commencing at 206°C. The devolatization process peaks at 325°C and denoted as T_{max} resulting in 70% weight loss of the sample. The results show that EFB briquette is an environmentally friendly fuel and thermochemical conversion will yield the required products of pyrolysis and gasification.

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