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Comparative analysis of the calorific fuel properties of Empty Fruit Bunch Fiber and Briquette

Bemgba Bevan Nyakuma, Anwar Johari , Arshad Ahmad, Tuan Amran Tuan Abdullah

Institute of Hydrogen Economy, Faculty of Chemical Engineering, Universiti Teknologi Malaysia,
81310 Skudai, Johor Bahru, Malaysia.

Abstract

This study was aimed at investigating the calorific fuel properties of Empty Fruit Bunches (EFB) fiber and briquette. Thermal analysis was carried out in the temperature range 30 °C to 500 °C at 10 °C/min heating rate to determine the calorific requirement, Q and specific heat capacity, $C_{p,b}$ of the EFB fuels. Calorific requirement is the total amount of heat required to raise the temperature of the feedstock to the pyrolysis peak temperature and complete the reaction. The calorific requirement for EFB and briquette was 1101.64 J/g ($C_{p,b}$ = 1482.69 J/kg K) and 1080.60 J/g ($C_{p,b}$ = 1454.36 J/kg K) respectively, with the peak temperature of 350 °C observed for EFB pyrolysis and 344 °C for briquette. It was observed that physical and chemical properties such as moisture content and binder effects influenced the heating rate and heating profile of the fuels. Briquette pyrolysis was more efficient due to lower moisture content, calorific requirement and specific heat capacity. In comparison, EFB pyrolysis showed a lower ignition temperature and the tendency to yield more pyrolysis products.

Keywords: Empty Fruit Bunch; Fiber; Briquette; Pyrolysis; Calorific requirement; Thermal analysis.

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1. Introduction

The utilization of biomass offers an environmentally friendly route for the production of clean and sustainable fuels for the future. In Malaysia the production of palm oil from oil palm (*Elaeis guineensis*) generates large quantities of solid biomass consisting of 15 % palm shell, 32 % palm fiber (mesocarp) and 53 % empty fruit bunches (EFB) [1-4]. Consequently approximately 13.4 million tonnes of EFB, palm fiber and shell are generated annually from palm oil production in Malaysia [5]. Therefore, urgent solutions are required to address the impending problems resulting from palm oil waste in the country.

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Currently palm waste in Malaysia is utilized in palm oil mills for electricity generation using boilers [6, 7], and the production of activated carbons, cellulose and fine chemicals [8]. However, a large proportion of solid palm waste is simply burned in open air, incinerated or used as landfill material. The low conversion efficiencies of these techniques have led to increased CO_2 and other greenhouse gas (GHG) emissions in the atmosphere [9]. The efficiency of biomass conversion processes can be improved by briquetting. This is a densification technique used to mechanically compact loose materials into a solid uniform fuel called briquettes. Briquettes possess low moisture, higher energy density and energy content compared to the raw materials used in their manufacture. These properties improve the thermal and combustion characteristics of the fuels such as ignition temperature, calorific value, mass and heat transfer as well as handling and storage [10-12]. In addition, the low moisture content improves the technical and economic dynamics of briquettes as fuel for pyrolysis and gasification.

Pyrolysis is the thermal decomposition of biomass into solid charcoal, liquid (pyrolysis oil) and H_2 rich gases in the absence of oxygen [12]. The pyrolysis of biomass feedstock is generally represented by the equation;

$$Biomass \xrightarrow{Heat} \sum liquid\ C_xH_yO_z + \sum gas\ C_aH_bO_c + H_2O + C(\text{char}) \tag{1}$$

Previous studies on EFB pyrolysis have examined the effects of reaction temperature, heating rate, residence time, particle size, shape and orientation, on the yield, composition and heating value of products [13-17]. Furthermore, thermal analytical techniques such as differential scanning calorimetry (DSC) and thermogravimetric analysis (TGA) have also been used in the parametric study of biomass pyrolysis [18-20]. *Yang et al.,* [21, 22] investigated the pyrolysis of palm oil waste including EFB using Thermogravimetric Analysis - Fourier Transform Infrared (TGA-FTIR) for hydrogen production. In addition, the calorific (heat) requirement for biomass pyrolysis using TGA-DSC analysis has been investigated by *Fang He et al*., [18]. The calorific requirement is the sum of heat required to raise the temperature of the feedstock to the pyrolysis peak temperature and to complete the pyrolysis reactions. It is an important parameter used in the design, operation and optimization of biomass conversion equipment. However, precise data on the calorific requirement of biomass is difficult to obtain due to the complexity and limitations of existing calculation methods.

Hence, this study is thus aimed at experimentally determining the calorific (heat) requirement for EFB and briquette pyrolysis using the method proposed by *Fang He et al.,* [18] taking into account that the calorific (heat) requirement for EFB and briquette pyrolysis has neither been investigated nor reported previously.

2. Experimental

2.1 Materials

The Empty Fruit Bunch (EFB) fiber and briquette were acquired from Felda Semenchu Sdn Bhd, Johor Bahru, Malaysia. The EFB was dried open air, shredded and pulverized in a high speed crusher (Kimah Malaysia, Model RT 20) fitted with a 1 mm screen. The powdered EFB was consequently sieved in a Retsch analysis sieve (D-42759, Haan Germany) with 800 micron screen to obtain samples with particle size < 800μm suitable for DSC analysis [21]. The grinding and sieving procedures were also repeated for the briquette sample. Proximate analysis was carried out using ASTM standard techniques. The heating value (HHV) of the EFB fiber and briquette was determined using a bomb calorimeter (Model C2000 IKA calorimeter system). The pyrolysis of the EFB fiber and briquette was carried out using a computerized Perkin-Elmer DSC 7 thermal analyzer. The powdered EFB samples were placed in an aluminium crucible with a lid and heated in the DSC furnace from 30 °C to 500 °C at a constant heating rate of 10 °C/min using N_2 (gas flow rate of 25ml/min) as sweeping gas. After each run the furnace was cooled and the DSC results of each run were analysed in Microsoft EXCEL to determine the calorific requirement for each fuel during pyrolysis.

Nomenclature

$C_{p,b}$	Specific heat capacity of biomass	J kg^{-1} K^{-1}
$C_{p,ch}$	Specific heat capacity of char	J kg^{-1} K^{-1}
$C_{p,cr}$	Specific heat capacity of crucible	J kg^{-1} K^{-1}
DSC	Differential Scanning Calorimetry	
dT	Temperature change during pyrolysis	K
dt	Rate of DSC experiment run	s
EFB	Empty Fruit Bunches	
FTIR	Fourier Transform Infra-Red Spectroscopy	
HHV	Higher heating value	MJ kg^{-1}
H_p	Heat flow caused by reaction heat of biomass pyrolysis	J kg^{-1} s^{-1}
$m,_b$	Mass of biomass	kg
$m,_{ch}$	Mass of char	kg
$m,_{cr}$	Mass of crucible	kg
Q, Q_{total}	Caloric heat requirement of biomass pyrolysis	J
Q_{in}	Heat of incoming stream	J
Q_{out}	Heat loss	J
Q_p	Reaction heat of biomass	J
SEM	Scanning Electron Microscopy	J
T	Temperature	K
t	Time	s

2.2 Methods

In this study, the calorific requirement of the EFB fuels was determined experimentally using DSC analysis. The use of DSC analysis to determine the calorific heat requirement takes into account the state, mass changes, and composition of the fuels. Therefore precise data on the influence of biomass characteristics, temperature and reaction on the calorific heat requirements of the fuels can be determined.

During biomass pyrolysis, the total heat supplied to the sample and crucible during the DSC runs is given by [18];

$$\frac{dQ_{b+cr}}{dt}\Big|_{m,o} = m_b C_{p},_b \frac{d\mathrm{T}}{dt} + m_{cr} C_{p},_{cr} \frac{d\mathrm{T}}{dt} + m_b \dot{H}_p \qquad (2)$$

Baseline correction can be effected by eliminating the heat transferred to the crucible during DSC analysis.

$$\frac{dQ_{cr}}{dt} = m_{cr} C_{p},_{cr} \frac{d\mathrm{T}}{dt} \tag{3}$$

Therefore by subtracting the baseline *Eqn 3* from *Eqn 2* gives the result;

$$\frac{dQ}{dt}\Big|_{m,o} = \Big|_{m,o} m_b C_{p},_{b} \frac{d\mathrm{T}}{dt} + m_b \dot{H}_p \tag{4}$$

Integrating *Eqn. 4* yields the expression;

$$Q\Big|_{m,o} = \int_0^t \Big|_{m,o} m_b C_{p},_{b} \frac{d\mathrm{T}}{dt} + m_b \dot{H}_p \; d\mathrm{t} \tag{5}$$

Therefore the calorific requirement of the biomass can deduced from by *Eqn. 5*.

3. Results and discussion

3.1 Proximate Analysis and Heating Value (HHV)

The results for heating value (HHV) and proximate analyses of the fuels are presented in *Table 1*. The samples contain a high percentage of volatile matter (> 70 %), low moisture content (< 10 %), ash content (< 5 %), and fixed carbon (< 20 %).

Table 1. Proximate analysis of EFB fuels.

Fuel	Moisture, M_{ad}	Volatile Matter, V_{ad}	Ash, A_d	Fixed carbon, FC_{ad}	HHV (MJ kg)
EFB	8.43	82.53	4.97	4.08	17.97
Briquette	8.17	71.83	4.56	15.44	17.57

Subscripts: "ad", air-dried basis; "d", dry basis.

The HHV for EFB (17.97 MJ/kg) is consistent with findings in literature [13-14]. However, the HHV of both EFB fuels (~ 18 MJ/kg) is lower than bituminous coal (~ 26 MJ/kg), petcoke (~ 29 MJ/kg) [23]. This is due to the high oxygen content, low fixed carbon (FC) and low density on a volume basis of the fuels [12, 23]. However studies by [24] indicate that the degradation of lignin is aided by high moisture content in biomass.

3.2 Calorific Requirement

The pyrolysis of biomass usually occurs in four (4) stages namely; drying (~100 °C), initial stage for heating biomass (100-300 °C), biomass degradation and char aggregation (200-600 °C) and secondary cracking of volatiles into char and non-condensable gases [18, 19, 23]. Figure 1 presents normalized curves for the DSC analysis of EFB fiber and EFB briquettes under pyrolysis conditions. It is important to note that the curves only present the DSC analysis of the fuels from 30 °C to 450 °C as no significant mass loss was observed beyond this temperature.

The DSC analysis of the EFB fuels showed multiple endothermic peaks signifying the different stages of biomass pyrolysis. The complete pyrolysis of EFB briquette showed a smoother heating profile compared to the EFB fiber. A single peak was observed for drying both fuels, with a larger more intense endothermic peak recorded for EFB fiber and onset drying temperature of 56 °C. The onset drying temperature for the EFB briquette was observed at 59 °C with a lower calorific requirement compared to EFB fiber. Total moisture removal for the fuels was completed at 140 °C.

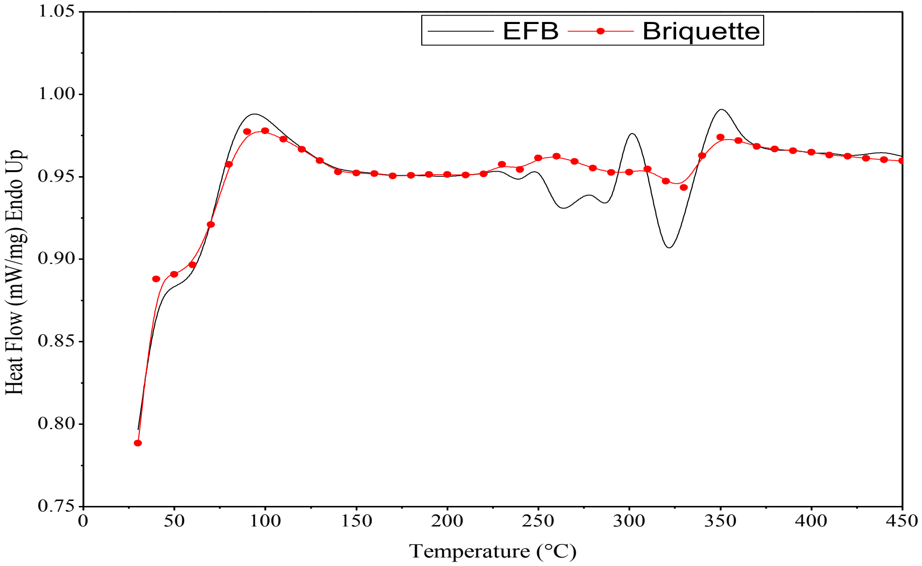

Fig. 1. DSC curves of EFB and Briquette.

Temperature is an important parameter in biomass pyrolysis. Therefore identifying the pyrolysis peak temperature, which is the maximum temperature of pyrolysis, is vital for understanding the characteristic mechanism of the process. This parameter influences the product composition and yield of biomass pyrolysis [23]. Table 2 presents the onset, peak and burnout temperature for pyrolysis of the EFB fuels.

Table 2. Pyrolysis reaction temperatures for EFB and Briquette.

Pyrolysis Stage	Fuel	Onset Temp °C	Peak Temp °C	Final Temp °C
Drying of Biomass	EFB	56	-	140
	Briquette	59	-	140
Heating of Biomass	EFB	140	-	220
	Briquette	140	-	220
Biomass Degradation	EFB	220	300	320
	Briquette	220	260	330
Char Aggregation	EFB	320	350	360
	Briquette	328	344	450

During the heating stage (140 and 220 °C) no peaks were observed for both EFB fuels. However, the degradation process (220 – 330 °C) resulted in multiple endothermic peaks. Three small sized peaks were observed for the briquette while four peaks of different sizes were observed for EFB. Furthermore, thermal decomposition of both fuels commenced at 220 °C which is consistent with the findings of *Yang et al.,* [22]. In the final stage, one endothermic peak was observed for biomass heating and char aggregation. The process commenced at 320°C and 328 °C for EFB and briquette respectively. The pyrolysis peak temperature for EFB was observed at 350°C and 344 °C for briquette pyrolysis.

The calorific requirement and specific heat capacity of the EFB and briquette can be calculated from the *Eqn 6* [25];

$$\Delta H = \int_{T_1}^{T_2} C_p \, dT \tag{6}$$

The $C_{p,b}$ values for EFB and briquette presented in Table 3 were found to be in agreement with $C_{p,b}$ values for biomass in literature [18, 26, 27]. *Sharma & Rao* [27] deduced the $C_{p,b}$ value, 1212 J/kg K from the pyrolysis of rice husk. *Liliedahl & Sjostrom* [26] investigated the pyrolysis of pine wood using the $C_{p,b}$ value 1670 J/kg K. However C_p is not a unique property of biomass, hence different values can be obtained for the same fuel depending on the heating rate, particle size and moisture content [23].

Table 3. Calorific requirement, q and specific heat capacity, c_p, for EFB and Briquette.

Fuel	Calorific requirement, Q (J/g)	Specific heat capacity, C_p (J/kg K)
EFB	1101.64	1482.69
Briquette	1080.60	1454.36

The results indicate that the calorific heat requirement for the pyrolysis of EFB (1101.64 J/g) is greater than the briquette (1080.60 J/g). This is due to the higher moisture content and non-uniform heating profile of the dispersed fuel particles in the EFB sample. However, the lower calorific requirement and specific heat capacity $C_{p,b}$ of the briquette may be due to the influence of the briquette binder which acts as a catalyst during pyrolysis. In addition, the binder may be responsible for the lower pyrolysis peak temperature of 344 °C observed for the briquette compared to 350 °C for EFB.

Conclusion

The heating value (HHV), specific heat capacity, $C_{p,b}$ and the calorific requirement for EFB and briquette pyrolysis was carried out using DSC thermal analysis. The results showed that physical and chemical properties such particle size, moisture content and binder significantly influence the heating rate and the heating profile of EFB and the briquette. In addition to improved handling and storage, the pyrolytic conversion of the briquette was found to be more efficient due to its lower moisture content, calorific requirement and specific capacity.

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