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RESEARCH ARTICLE

Combustion characteristics of palm pressed fibres biochar and sub-bituminous Malaysian coal

Safana Aminu Aliyu*, Nurhayati Abdullah, Fauziah Sulaiman, Sadik Umar

School of Physics, Universiti Sains Malaysia, 11800 USM Pulau Pinang, Malaysia

* *Corresponding author: basalihe2@gmail.com*

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Abstract

In this research, the combustion properties of coal and biochar were investigated and compared to identify the potentiality of biochar for coal replacement application. Biochar is derived from the pyrolysis of palm pressed fibre (PPF) at 400 °C. Thermogravimetric analysis (TGA) was used to study the combustion profiles of the materials. The biochar and coal were combusted via thermogravimetric analysis from ambient temperature to 800 °C at 10 °Cmin^{-1} of heating rate. From the results, biochar showed the high calorific value of 27.30 MJkg^{-1}compared to that of coal 26.21 MJkg^{-1}. Furthermore, biochar comprised the greater content of carbon and fixed carbon. Although, during combustion, coal releases high heat of 0.052 W than biochar which gave 0.049 W. This reveals that the biochar produced from PPF can be a perfect competitor against coal for heat generation. This finding could assist in promoting the application of biomass as an alternative to fossil fuel.

***Keywords*: TGA, combustion, biochar, coal**

INTRODUCTION

The burning of coal generates more CO_2 emissions than combustion of both oil and natural gas by 1.5 and 2 separately (Epstein *et al.*, 2011). Malaysia is not an exception in the use of fossil fuels for power generation. As at 2010, the coal generation in Malaysia is derived majorly from six mines in Sarawak. There are about 1724 million tonnes of coal resources of which 274 million tonnes are identified, 347 million tonnes indicated and the balance of 1102 million tonnes as inferred (Oh *et al.*, 2010). Presently, community and political sensitivities to environmental problems and energy security have focused on the promotion of non-fossil fuel energy sources instead of fossil fuels. Renewable energy sources such as small hydropower, solar, wind, geothermal and biomass have presently contributed 14% of total world energy consumption, of which 62% is biomass (Nakomcic-Smaragdakis and Dragutinovic, 2016).

The oil palm wastes generated from palm oil industry in Malaysia are among the most excellent biomass residues. These wastes consist of palm pressed fibres, kernel shell and empty fruit bunch usually at palm oil mills. Palm trunks and palm fronds are generated at plantations (Uemura *et al.*, 2011). These oil palm residues contain diverse chemical composition and high heating value of about 18-19 MJkg^{-1} (Lam *et al.*, 2015). Moreover, in each kilogram of palm oil, there are about four kilograms of dry biomass (Sulaiman *et al.*, 2010). Fiber and shells are utilized as fuel in the palm oil mill to power the processing plants (Sulaiman *et al.*, 2011).

Pyrolysis conversion process is one of the prominent method through which biomass is converted into three significant by-products namely solid char, bio-oil and gases (Sukiran 2008; Abnisa *et al.*, 2013). Biochar is produced during the pyrolysis of biomass materials. The biomass is heated in the absence of oxygen at a temperature range of 300 to 1000 °C. Biochar is described as charred organic matter, which can be used to improve the soil quality through sequestering carbon in the soils and reduces greenhouse gas (GHG) emission. It is a steady carbon compound that can stay on the ground for over hundreds of years (Sulaiman *et al.*, 2011; Abdullah and Sulaiman 2013). In addition, biochar is made up of char, ash, and durable biomass materials. In this research, the combustion of biochar derived from pyrolysis of fibre at 400 °C and sub-bituminous Malaysian coal was investigated. Thermogravimetric analysis (TGA) was used to study the combustion behaviour and profiles of biochar and coal.

EXPERIMENTAL

Materials

Sub-bituminous coal was supplied by a company based in Sarawak, Malaysia. Palm pressed fibres (PPF) was collected from oil palm mill located in Nibong Tebal, Pulau Pinang, Malaysia. These biomass materials were the by-products from different procedures such as pressing and nut cracking in the milling process industries where crude palm oil is generated. The moisture content of the biomass as received was 13.1%. The biomass sample was dried for 24 hours at 105 °C for moisture removal.

Pyrolysis experiment of the fibre was conducted three times separately using a stainless steel reactor with 150 mm length and 70 mm internal diameter. The reactor was fed with raw biomass and place inside the electric furnace and heated to 400 °C at a constant rate of 10 °Cmin^{-1} for I hour. The K-type thermocouples were used to monitor the reactor temperature. For each experiment run, nitrogen gas was used as a reaction gas at 2 litres per minute.

The biochar and coal were combusted via thermogravimetric analysis (TGA). It was carried out in the presence of oxygen at 10

°Cmin^{-1} heating rate, a sample size of 250-355 μm and the samples were heated from ambient temperature to about 800 °C. The model Perkin Elmer STA 6000 thermogravimetric analyser is used. The combustion rate (CR) and heat release during combustion were computed with the equations shown below (Faizal *et al.*, 2010).

$$\text{Combustion rate} = \frac{\text{Total mass of burnt briquette}}{\text{burning time}} \qquad (1)$$

$$\text{Heat Release} = \text{Calorific value} \times \text{Combustion rate} \qquad (2)$$

Proximate analysis was carried out according to ASTM E871 for moisture content, ASTM E872 for volatile matter and ASTM E1755 - 01 for ash content. The fixed carbon was determined by subtracting the sum of moisture, ash and volatile matter from 100 wt%. Elemental analysis was conducted to analyze the percentage of carbon (C), hydrogen (H), nitrogen (N), sulphur (S) and oxygen (O). The elemental analysis was performed using Perkin Elmer 2400 analyzer, 2 - 2.8 mg of sample was used to measure the percentage weight of each element present. The higher heating value (HHV) was determined using a bomb calorimeter system IKA C 200, oxygen station C248 with an empty water hose. For each test run, about 0.5 - 0.8g of the sample was measured and placed in the crucible joined to the thread from the ignition wire, closed and oxygen gas was pumped in. The physiochemical properties of raw biomass are shown in Table 1 (Kong *et al.*, 2014; Abdullah and Gerhauser 2008; Sulaiman and Abdullah 2011; Mahmood *et al.*, 2015; Abnisa *et al.*, 2013; Wan Asma 2012; Yuliansyah and Hirajima 2012; Uemura *et al.*, 2011).

Table 1 Physiochemical properties of palm pressed fibres.

Properties (wt%)	Fibre	Literature
Carbon	46.37	45.03
Hydrogen	5.52	6.15
Nitrogen	0.59	0.94
Sulphur	0.12	---
Oxygen[b]	47.47	47.89
Moisture content	6.2	8.6
Volatile content	77.15	78
Ash content	7.02	5.8
Fixed carbon	15.83	7.6
Calorific value (MJkg^{-1})	19.06	19.06

[a] Weight percentage dry basis (wt%). [b] By difference.

RESULTS AND DISCUSSION

Characterization

The primary distribution products of biomass pyrolysis are shown in Fig. 1 they are biochar, gas and condensable liquid. Biochar yield is high followed by liquid and gas respectively. It was reported that the lignocellulosic components of biomass and pyrolysis temperature played a vital role in the pyrolysis products yield (Jahirul *et al.*, 2012). The bio-oil and gas yields were associated with the decomposition of cellulose and hemicellulose, while biochar is mainly from the lignin content of biomass. A similar observation has been reported for other biomass materials (Jahirul *et al.*, 2012).

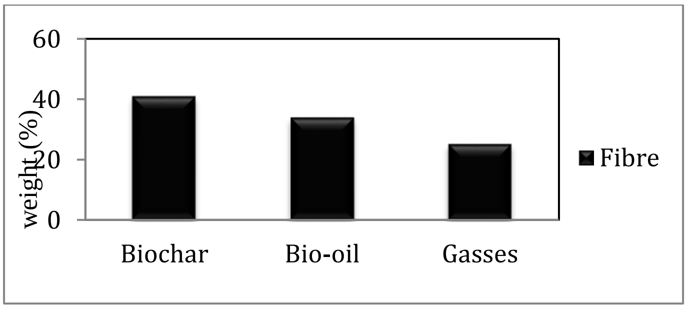

Fig. 1 Yield distribution of pyrolysis products.

Physiochemical properties of Biochar and Coal

The proximate, elemental analysis and calorific value of biochar and coal are shown in Table 2. The results disclose that the physiochemical properties of the materials were almost similar. However, biochar contained high moisture, volatile matter and fixed carbon, and low ash content than coal. The elemental analysis results showed that coal holds in high hydrogen and nitrogen while biochar comprehends high carbon and oxygen. The calorific value of 27.30 and 26.21 MJkg^{-1} were recorded for biochar and coal, respectively. Based on the physiochemical properties, biochar has shown a remarkable potentiality to replace coal. Though the fixed carbon, carbon content and calorific value of the biochar could be improved at higher temperatures, it would also reduce the volatile matter content which could be useful during the combustion of biochar. The significant benefits that biomass has as a combustion fuel are the high volatility and high reactivity of the fuel and the resulting char. Though, biomass contains high oxygen content in comparison with solid fossil fuels (Demirbas, 2004).

Table 2 Physiochemical properties of biochar and coal.

Proximate analysis (wt%)		
Properties	**Biochar**	**Coal**
Moisture content	3.80	2.50
Volatile matter	43.20	42.05
Ash content	6.37	6.44
Fixed Carbon[b]	50.43	49.01
Elements analysis (wt%)		
Carbon	57.81	56.66
Hydrogen	4.93	7.91
Nitrogen	0.96	1.16
Oxygen[b]	36.30	34.27
Calorific value (MJ/kg)	27.30	26.21

[a] Weight percentage dry basis (wt%). [b] By difference.

Combustion of Biochar and Coal

It was previously stated that for a solid fuel to ignite and burn quickly, it must contain a reasonable percentage of volatile matter. It was observed that high moisture and ash contents could lead to ignition and other combustion difficulties (Demirbas 2005, Saidur *et al.*, 2011). Based on this reason, biochar and coal were subjected to combustion at 10 °Cmin$^{-1,}$ and the results of combustion profiles acquired using DTG is shown in Fig. 2.

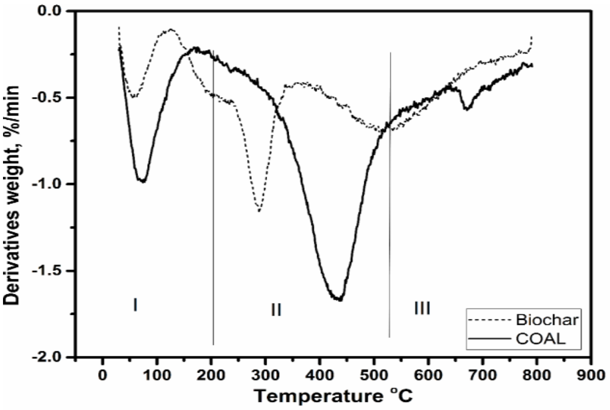

Fig. 2 DTG curves for the combustion of biochar and coal.

Table 3 Temperature intervals for different zones.

Materials	Temperature intervals (°C)		
	First zone	**Second zone**	**Third zone**
Biochar	30 - 140	140 - 356	356 - 780
Coal	30 - 200	200 - 557	557 - 780

The combustion temperature starting from 30 to around 800 ^{o}C is partitioned into three zones as shown in Table 3. It is seen from the figure that all the materials displayed a comparable peak between the temperature of 30 and 200 ^{o}C. This peak could be ascribed to dehydration of moisture during the combustion. However, inside the primary zone (I), coal showed most high weight reduction of 8.825 wt% and a peak temperature of 77 ^{o}C, while biochar demonstrated weight reduction of 3.382 wt% and a peak temperature of 59 ^{o}C as seen in Table 4.

Table 4 Weight loss of materials at different zones, % by weight.

Zones	Biochar (wt%)	Coal (wt%)	Peak temperature (^{o}C)	
			Biochar	Coal
I	3.382	8.825	59	77
II	12.00	29.603	287	440
III	20.247	10.278	513	671

Zone II began from 140 and lasted to around 560 ^{o}C. This zone showed the most considerable weight reduction and most astounding peak temperature, and ignition temperatures. As apparent from Table 4, coal showed the most elevated weight reduction of 29.603wt% compared with biochar which has 12.00 wt%. The temperature extends between 356 and 780 ^{o}C is perceived as zone III. It can be seen from Fig. 2 that the rapid combustion of biochar proceeded in this zone with a most extreme weight reduction of 20.247 wt% as listed in Table 4. This could be because of continuation of biochar decomposition in the third zone. The ignition temperature of the materials in Table 5 were 254 ^{o}C and 368 ^{o}C for biochar and coal. The burnout temperatures values recorded were 788 and 770 ^{o}C for biochar and coal.

Table 5 Peak and burnout temperatures of materials.

Materials	Temperature (^{o}C)		Heat release (W)
	Ignition	Burnout	
Biochar	254	788	0.049
Coal	368	770	0.052

The combustion period for materials was around 45 minutes. The amount of fuel consumed, and time taken to reach burnout temperature for each fuel was ascertained. The time taken was evaluated and found to be 44 and 42 minutes for biochar and coal individually. Likewise, the burning rate and heat release from the initial temperature to burnout temperature was additionally determined as displayed in Table 5.

As seen from Fig. 2, the materials showed diverse conduct amid combustion particularly inside zone II and III. In this manner, the amount of fuel consumed ought not to be equivalent since the time taken for each fuel to approach the burnout temperature is additionally not equal. As apparent from the Fig. 2, coal indicated high reactivity and therefore brought about high burning rate and heat discharge of 0.052 W in comparison to the biochar with 0.049 W. Biochar fuel discharge less amount of heat since it is less reactive as shown in the figure which prompted moderate amount of fuel consumed.

Equivalently, combustion of biochar may require higher temperature and longer burning time to finish the conversion. This might be because of the presence of a lot of inorganic material. In addition, biochar portrayed continued high rate of decomposition (weight loss) in the third zone than coal see Table 4. It can, therefore, be presumed that biochar fuel could be viewed as steady since it might deliver heat for an extended period than coal. The heat generated from biomass combustion is seen as economical, environmentally friendly and significantly effective (Nussbaumer 2003). A quantity of CO_2 is released into the environment during the burning of biomass fuels. However, the same amount is consumed from the environment during the growth of biomass plant. This cycle makes the biomass energy to be regarded as CO_2 neutral (Demirba, 2005).

CONCLUSION

Combustion characteristics of biochar derived from pyrolysis of palm pressed fibre, and coal was investigated. The investigations revealed that biochar material had shown remarkable features like that of coal. And, therefore could be regarded as one the potential material for heat generation in replacement to coal and giving way to clean environment with less CO_2 in the atmosphere.

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