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Combustion characteristics of briquettes made from microwave-assisted co-pyrolysis products of palm shell and LDPE

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ABSTRACT

Briquettes are solids that are generally made from agricultural waste materials. Char briquettes are one of the alternative energies for daily needs. This study used char from palm shell and LDPE microwave-assisted co-pyrolysis at 450 Watts. The briquettes were made from the product of co-pyrolysis of palm shell and Low-Density Polyethylene (LDPE) with variations in the composition of 0:100, 50:50, and 100:0 and pressure of 50 kg/cm^2, 100 kg/cm^2, 150 kg/cm^2, and 200 kg/cm^2. In this research, thermogravimetry analysis (TGA) was the method used to determine combustion characteristics. This study aimed to determine the combustion characteristics, including the Initiation Temperature of Fixed Carbon (ITFC), Initiation Temperature of Volatile Matter (ITVM), Peak of weight loss rate Temperature (PT), Activation Energy (Ea), and Mass Loss Rate (MLR). The results showed that the increased briquettes pressure increases the ITVM, ITFC, PT, and EA. The higher LDPE composition in the briquettes decreased the ITVM, ITFC, PT, and Ea, but increased the MLR.

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1. Introduction

The increase in energy requirement must be balanced with the availability of consumable fuel. Alternative energy has been widely used as supporting energy. Alternative energy is available from nature such as solar energy, geothermal energy, wind, biomass, and others. One of the energies that have the potential to be an alternative energy to replace fossil fuels is biomass. Biomass supplies about 90% of the production of bioenergy worldwide [1]. Indonesia is rich in biomass which has the potential to reach around 32,773 MW [2]. Oil palm is one of the largest biomasses in Indonesia. One fresh fruit bunch of palm oil can produce 11-15% mesocarp fibre, 5.5-7% palm kernel shell, 20-23% empty fruit bunches, and Palm Oil Mill Effluent (POME) [3]. Oil palm shells have the potential to be used as a renewable energy source. It can be processed into briquettes that are used for alternative fuels [4].

Briquettes can be made from pyrolysis products to get a high fixed carbon content. Pyrolysis as one of the thermochemical decomposition processes is the popular method to handle biomass low energy density problems. The process involves heating without the presence of oxygen so that the organic material such as biomass turned into a carbon-rich solid and a volatile matter [5]. Microwave-assisted pyrolysis which was used in this study has more advantages than conventional pyrolysis. It can accelerate the chemical reaction because it is heating the raw material under a certain microwave frequency [6].

Briquettes made from plantation waste have compact and solid physical properties. Briquettes have different characteristics according to the raw material. Char briquette is one of the smokeless fuels because it contains low volatile matter, thereby can reduce indoor and outdoor pollution [7]. It can be used for cooking, smoking fish, and other. It is an alternative energy source that has the potential to be developed, and also it can be an alternative way to manage waste [8]. Plastic waste can be used as a mixture for briquettes. The plastic used is Low-Density Polyethylene (LDPE). LDPE has a highly volatile matter, so it is flammable. It has a high calorific value, so it is suitable for making briquettes [9]. These properties are appropriate for mixing LDPE with oil palm shells to make char briquettes.

The thermogravimetry analysis method was used in this study to determine the combustion characteristics of the briquettes. Combustion characteristics comprise some key parameters such as the Initiation Temperature of Fixed Carbon (ITFC), Initiation Temperature of Volatile Mater (ITVM), Peak of weight loss Temperature (PT), Mass Loss Rate (MLR), and Activation Energy (Ea). These parameters describe how the co-briquettes combustion process. Based on the combustion characteristics parameters, the composition which is more feasible to be produced on a larger scale can be determined.

2. Method

2.1. Sample Preparation

Microwave-assisted co-pyrolysis of palm shell-LDPE mixture with a composition of 100:0, 50:50, and 0:100, produced chars, which then were crushed by a grinding machine, and filtered using mesh number 30. The 2.4 g starch was mixed with 15 mL water and then cooked until it coagulated and can be used as an adhesive. A briquette sample of 3 grams as shown in Fig.1, was made by mixing starch adhesive and the char with a mass ratio of 1: 5. The briquetting pressure variations are 50, 100, 150, and 200 kg/cm^2, and the holding time is 2 minutes. Then, the briquettes are dried using the oven at 105 ºC for 20 minutes.

2.2. Research Procedure

The briquette was put into a cup and then positioned in the centre of the heating instrument and the furnace. There are two thermocouples to measure the temperature of the briquette and the furnace. The first thermocouple was above the briquette surface.

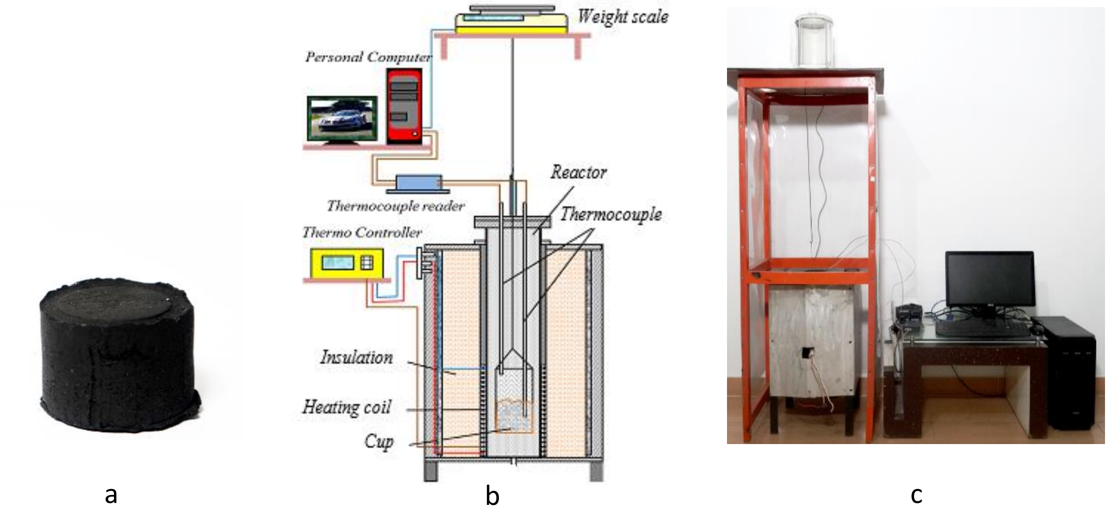

Fig. 2.(a) briquette, (b) schematic diagram and (c) pictorial view of thermogravimetry equipment.

The temperature of the briquette was recorded by datalogger software. The second thermocouple was used to measure the temperature of the furnace. The test was carried out using the thermogravimetry analysis method. Thermogravimetry analysis (TGA) is the method used to analyze the decomposition of a substance to temperature and has no limitation in heat and mass transfer at low heating rates [10], [11]. The initial temperature of the furnace was 40 ºC then increased by 20 ºC/minute until it reached 500 ºC and then held for 30 minutes. During the process, air with a velocity of 0.1 m/s is delivered from the bottom of the furnace. Data regarding mass reduction and temperature rise were taken during the test. The briquette, schematic diagram and pictorial view of the system are shown in Fig. 2.

2.3. Data Analysis

In general, the thermogravimetry method produces a graph that can be used to determine temperature value and combustion zone. Fig. 3. shows the thermogravimetry analysis graph.

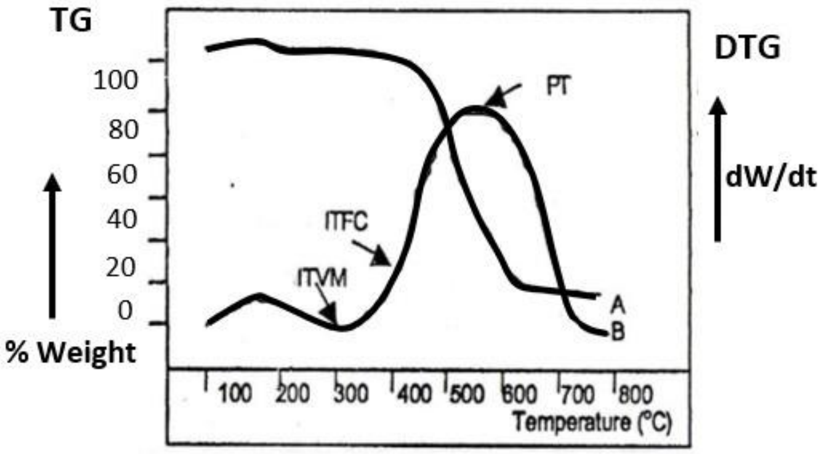

Fig. 3. Combustion zones in thermogravimetry analysis [12].

The results of the charcoal briquette combustion test include data on mass reduction and temperature increase which are processed in graphical form. For the TGA, the evolution with the temperature of weight loss (TG) and the weight loss rate (DTG) was gained by co-pyrolysis [12]. The DTG was calculated using the formula:

$$\frac{dW}{dt} = -\frac{1}{W_0}\left(\frac{dW_t}{dt}\right) \tag{1}$$

To reveal the synergistic effect between the co-reactants, the difference in weight loss (DW) was often defined based on the synergistic effect of each material during pyrolysis [13], [14].

$$\Delta W = W_{blend} - (x_1 W_1 + x_2 W_2) \tag{2}$$

The integral method can be used to determine the kinetic parameters, activation energy, and pre-exponential factor of co-pyrolysis of biomass with polymers [13], [15], [16]. In addition, the co-pyrolysis process was assumed to be a first-order reaction [13], [16]. The kinetics calculation for the co-pyrolysis of biomass with polymers was based on the Arrhenius equation. This equation can be used to explain the reactions that occur during this process:

$$\frac{dx}{dt} = Aexp\left(-\frac{E}{RT}\right)(1-x) \quad (3)$$

where A is the pre-exponential factor, t is time, T is temperature and E is the activation energy, and x is the weight loss fraction or co-pyrolysis conversion, which can be calculated by the equation:

$$x = \frac{W_0 - W_t}{W_0 - W_f} \quad (4)$$

where W_0 is the mass of the sample at the beginning, Wt is the mass at time t, and W_f is the mass at the end of the co-pyrolysis process. For a constant heating rate H during co-pyrolysis, H = dT/dt. Rewriting and arranging the above formulas through integration gives us a new equation:

$$ln\left[\frac{-ln(1-x)}{T^2}\right] = ln\left[\frac{AR}{HE}\left(1-\frac{2RT}{E}\right)\right] - \frac{E}{RT} \quad (5)$$

For most values of E and the temperature range of co-pyrolysis, the expression ln [AR/HE(1–2RT/E)] in the proposed equation is essentially constant. Thus, if the left side is mapped against 1/T, a straight line will be achieved. From the slope, -E/R, the activation energy E or Ea can be found. Moreover, by taking the temperature at which $W_t = (W_0 + W_f)/2$ in the place of T in the intercept term of the equation (5), the pre-exponential factor A can also be determined.

3. Results and Discussion

From data logger extraction, processed data was shown in Fig. 4 which contains 3 curves. The red-coloured curve shows the temperature changes during the combustion process. It can be seen that 1000 s was needed for the temperature to increase from the ambient to the peak temperature at around 500 °C. Then, the blue curve shows the briquette mass reduction in nearly linear trend so that the green curve which shows the mass reduction per second appears to be constant.

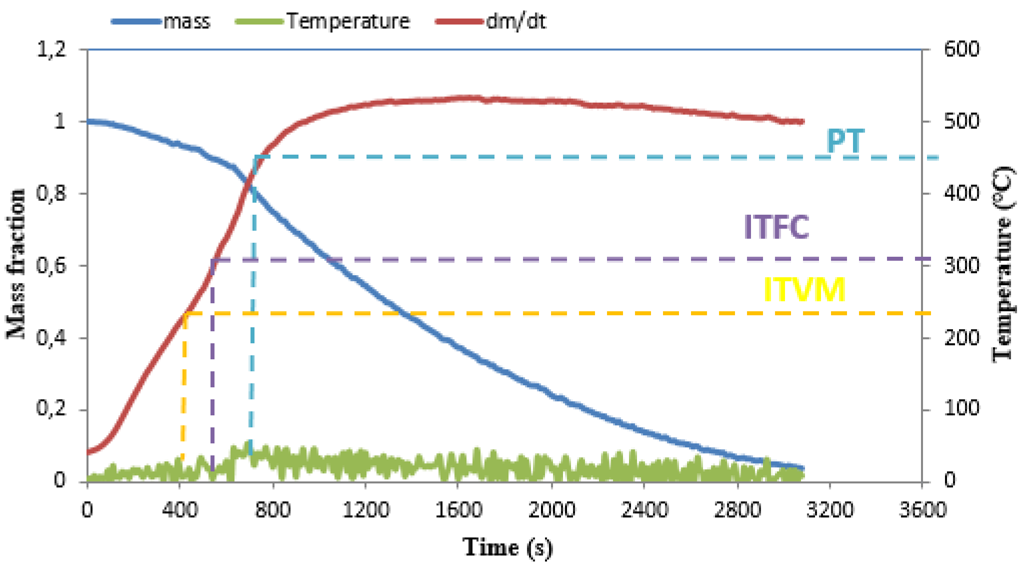

Fig. 4. Combustion characteristics of oil palm-LDPE briquette.

3.1. Proximate Analysis

The chemical properties of char briquettes were measured through proximate analysis. The proximate analysis used the ASTM D121 standard as the analysis procedure. The result of the proximate analysis was shown in Table 1.

Table 1. Proximate analysis of char briquette from palm Shell-LDPE co-pyrolysis.

Analysis	Component	Composition Ratio (palm shell : LDPE) 100:0 wt.%	50:50 wt.%	0:100 wt.%
Proximate	Moisture Content	2.48	2.15	1.98
	Volatile Matter	5.20	6.72	7.33
	Ash	9.51	8.03	9.90
	Fixed Carbon	82.80	83.25	80.79

3.2. Initiation Temperature of Volatile Matter (ITVM)

Experimental data show that in all briquette samples, ITVM increases with increasing pressure. As pressure increase, the briquette density becomes higher and the porosity becomes lower. This condition makes the heat harder to get into the briquette. Therefore, a briquette with 200 kg/cm^2 pressure needs a higher temperature to initiate the devolatilization process. Fig. 5 shows the ITVM on 3 briquette compositions at 4 different pressure variations.

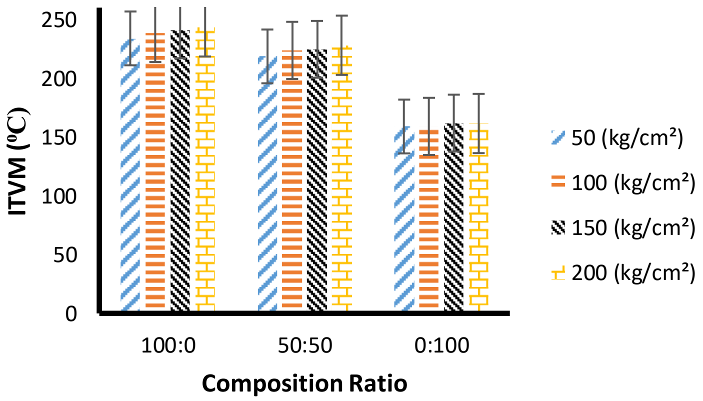

Fig. 5. Initiation Temperature of Volatile Matter

As can be seen from Fig. 5, char briquette from palm shell has the highest ITVM as a consequence of a low volatile matter content. Previous work also found that bio-coal with a low volatile matter content released the volatiles at relatively high temperatures [17]. The study also said that the devolatilization process correlates with the presence of three main biomass components: lignin, cellulose, and hemicellulose. The proximate analysis found that the palm shell raw material has the least volatile matter content, so the char briquette from this raw material has the highest ITVM.

3.3. Ignition Temperature of Fixed Carbon (ITFC)

The ignition temperature of a fuel is generally lower for higher volatile matter content [18]. Char briquette made from LDPE waste has the lowest ITFC. This condition occurs because the LDPE char briquette has more volatile matter content. This result has a similarity to the previous study which found

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that lignite coal is the easiest coal to ignite because of its high volatile matter content [19]. The comparison of ITFC value can be seen in Fig. 6.

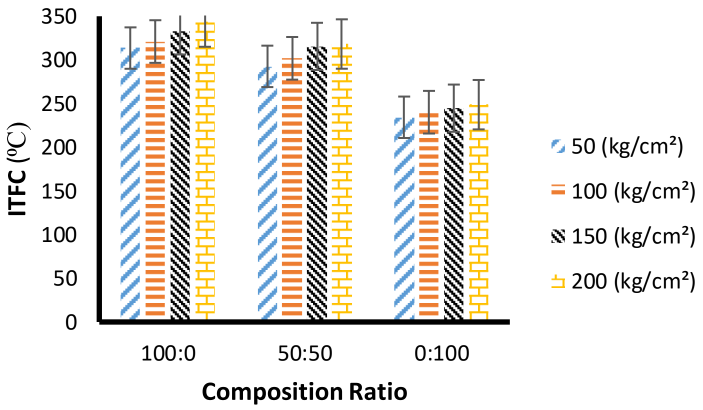

Fig. 6. Ignition Temperature of Fixed Carbon.

Fig. 6 shows that char briquette from oil palm shell has the highest ITFC. This condition occured because the palm kernel shell contained less volatile matter than LDPE. Therefore, palm shell briquette had a high ignition temperature.

3.4. Peak of Weight Loss Temperature (PT)

PT values show a decrease with increasing LDPE in the composition. The LDPE char briquette has the lowest average PT. This phenomenon was related to fixed carbon content. Previous research found that higher fixed carbon content in a fuel leads to higher peak temperature [20]. The research conducted an experiment that used Coal-I with 34.24% fixed carbon content and Coal-II with 31.68% fixed carbon content, using thermogravimetry analysis. The result of the experiment was Coal-I had a higher peak temperature than Coal-II at three heating rate variations.

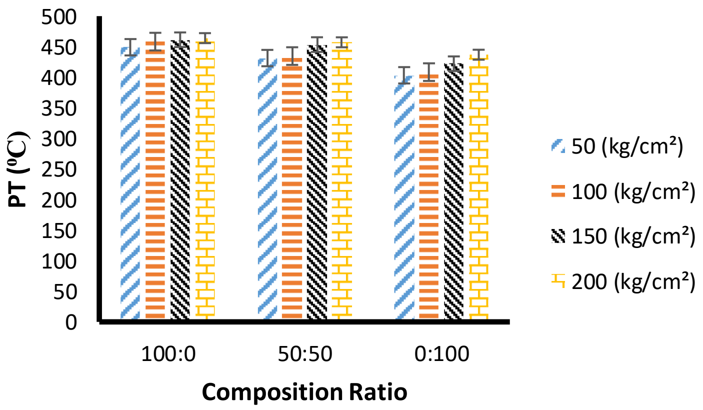

Fig. 7. Peak of Weight Loss Temperature.

The peak temperature data of this study is shown in Fig. 7. It appears that the average value of PT on LDPE char briquette is the lowest because LDPE raw material has the least fixed carbon content, namely 80.79%. The other variations contain slightly more fixed carbon than LDPE, so the difference between the PT is insignificant.

3.5. Activation Energy (EA)

Activation energy can be obtained in the following way, such as for bricks with a composition of 50:50 and a pressure of 50 kg/cm$^{2.}$ Create a plot between 1/T and ln[-ln(1-x)/T^2] so that a graph was obtained as shown in Fig. 8.

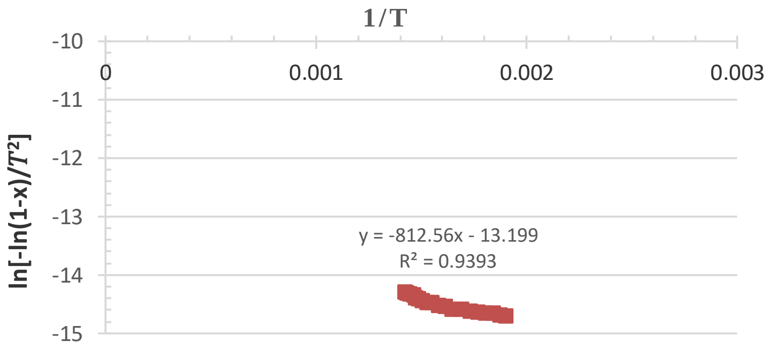

Fig. 8. Linear Equation for Calculating Activation Energy

Activation energy of 6.75 kJ/mol could be obtained by referring to equation (5), and using ideal gas constant, R = 8.314 J/K^{-1}mol^{-1} and a gradient of a linear equation, y = -812.56x -13.199, as shown in Fig. 8. For the other composition, the activation energy was computed using the same method. The result of the calculation of activation energy in 3 composition variations and 4 pressure variations is shown in Table 2.

Table 2. Activation Energy (Ea)

	Activation Energy (kJ/mol)		
Composition (palm shell:LDPE)	**100:0**	**50:50**	**0:100**
Pressure (kg/cm²)			
50	7.53	6.75	6.63
100	7.64	6.93	6.96
150	8.39	8.04	7.12
200	9.29	8.18	7.36

An increase of activation energy (Ea) was found in every variation of the briquette proportional to the pressure increase. This phenomenon might be caused by porosity. As the pressure increased, the porosity of the briquette became lower. This condition made the air could not get into the briquette to develop enough stoichiometric mixture [21]. Thus, combustion was harder to occur. Table 2 shows that the higher compaction pressure leads to the higher activation energy.

As shown by Table 2 that for every pressure, the highest Ea was found in palm shell briquette, whereas the lowest EA was in LDPE briquette. The addition of LDPE to the char briquette mixture tended to decrease activation energy.

3.6. Mass Loss Rate (MLR)

The experiment found that briquette from LDPE waste has the highest mass loss rate. Such condition was strongly related to volatile matter content [22]. The proximate analysis showed that LDPE contains more volatile matter than palm shells. So, the briquette from LDPE was more likely to burn faster than that from palm shell. The mass loss rate of each briquette was shown in Fig. 9.

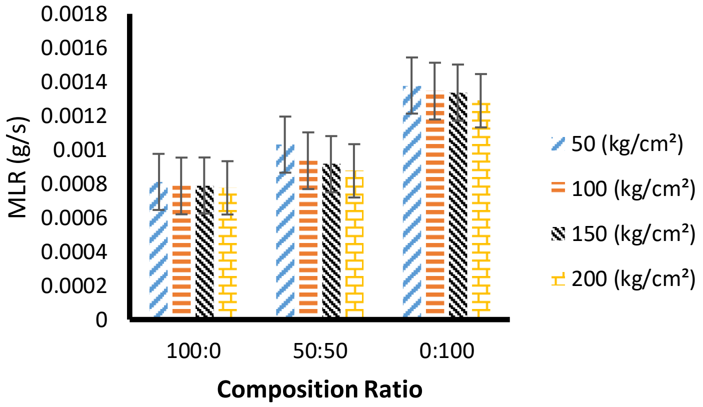

Fig. 9. Mass Loss Rate.

It can be seen that char briquette from palm shell has the lowest mass loss rate. As the LDPE composition increased, the char briquette burnt faster and so the burning time became shorter. Therefore, LDPE composition increased the mass loss rate of the char briquette.

4. Conclusion

Combustion characteristics of briquettes made from microwave-assisted co-pyrolysis products of palm shell and LDPE were investigated through thermogravimetry analysis. The conclusion could be drawn as the following:

1. The compaction pressure affected the characteristics of the briquette. The results showed that the increase of compaction pressure from 50 kg/cm^2 to 200 kg/cm^2 increased the ITVM, ITFC, PT, and Ea.
2. The variations in the composition of briquette raw materials also affect their characteristics. The increase of LDPE composition in the briquette decreases the ITVM, ITFC, PT, and Ea.
3. The increase of LDPE composition in the briquette increases the MLR value due to more volatile matter contained in LDPE.

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