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Effect of Briquetting Pressure and Material Composition on Combustion Characteristics of Charcoal Briquettes Made from Microwave Co-pyrolysis of Palm Fiber and LDPE

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A R T I C L E I N F O

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A B S T R A C T

Microwave co-pyrolysis between biomass and plastics is a promising endeavor in producing high-quality fuels. This study aims to evaluate the combustion characteristics of briquettes using the Thermogravimetry analysis (TGA) method, including Initiation Temperature of Volatile Matter (ITVM), Initiation Temperature of Fixed Carbon (ITFC), Peak of weight loss rate Temperature (PT), Burning out Temperature (BT), Energy activation (EA), and mass loss rate (MLR). The results showed that the value of ITVM, ITFC, and PT increased as the briquette pressure increased, while the value of ITVM, ITFC, and PT decreased as LDPE plastic increased in the composition of the charcoal mixture.

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INTRODUCTION

Palm oil (Elaeis guineensis Jacq.) is one of the commodities that contributes to national income through the export of processed products such as crude palm oil (CPO) and its derivatives. Indonesia is the largest producer of palm oil in the world. Based on data from the Foreign Agricultural Service, United States Department of Agriculture (USDA), palm oil production in Indonesia will reach 46.5 million metric tons by 2024 or equivalent to 58% of global palm oil production (Official Website of the Republic of Indonesia, 2025). However, beyond this potential, the palm oil industry often produces large amounts of waste, one of which is palm oil. Palm oil fibre waste that is not properly managed will have a negative impact on the environment, especially water and soil pollution.

Palm fibre has the potential as a renewable energy source for conversion into briquettes (BPDP, 2020). Palm fibre has a high calorific value of 14,511.96 kJ/kg (Paul, Ndubuisi, Peter, John, Godspower, 2015). The initial process of making palm oil fiber briquettes is carried out through thermochemical processes such as pyrolysis. This process will produce three main products, namely bio-oil, charcoal, and gas (Caroko, Saptoadi, & Rohmat, 2023). To improve energy efficiency and briquette quality, palm fiber pyrolysis can be combined with plastics, such as Low-Density Polyethylene (LDPE) through the co-pyrolysis process. Co-pyrolysis can be done by various methods, one of which is Microwave Co-pyrolysis. This method has advantages over conventional co-pyrolysis methods , including fast and uniform heating, adjustable heating rate, and being able to improve pyrolysis efficiency (Yang, Shang, Li, Sun & Duan, 2023; Caroko, Saptoadi & Rohmat, 2020).

Microwave co-pyrolysis of palm oil fiber and LDPE plastic is an environmentally friendly alternative energy solution. This study aims to evaluate the combustion characteristics of briquettes using the Thermogravimetry analysis (TGA) method, including Initiation Temperature of Volatile Matter (ITVM), Initiation Temperature of Fixed Carbon (ITFC), Peak of weight loss rate Temperature (PT), Burning out Temperature (BT), Energy activation (EA), and mass loss rate (MLR) (Mujiarto, Suprianto & Murdjani, 2013). This research is also expected to be able to provide an overview of thermal kinetics of briquettes and recommendations as an alternative technology for environmentally friendly waste utilization.

LITERATURE REVIEW

Microwave Co-pyrolysis

It is a thermal decomposition process used to transform waste rich in organic matter, such as biomass in conditions without oxygen with an inert atmospheric gas flow. This process will break down the material into three main products, namely liquids (tar and oil), solids (char), and syngas (hydrogen, carbon monoxide, and carbon dioxide, as well as light hydrocarbon gases such as methane). Pyrolysis can be done by combining two or more raw materials called co-pyrolysis. (Ho, Lau, Chakraborty, Rajamohan & Al Arni, 2023)

One of the methods that began to be developed in co-pyrolysis was microwave co-pyrolysis. This method utilizes microwave radiation to generate heat in the raw material. Microwave co-pyrolysis has advantages such as a faster heating rate, higher energy utilization rate, faster reaction time, and higher selectivity (Hamzah, Mahdi, Veluru & Abdullah, 2024).

Microwave co-pyrolysis is known to be able to accelerate the rate of thermal decomposition and produce a good quality product. Teng, Yu, Shen, Ni & Ma (2025) evaluate the thermal characteristics of microwave co-pyrolysis between eucalyptus wood (EW) and polypropylene (PP) plastic. The results showed that co-pyrolysis between EW and PP showed a synergistic effect that significantly reduced activation energy and accelerated the reaction rate. Suriapparao & Vinu (2021) evaluate the synergistic effects of microwave co-pyrolysis between biomass (peanut shells, bagasses, rice husks, Prosopis juliflora, wood sawdust) and LDPE and PIP plastics. The results show that co-pyrolysis is able to increase energy efficiency to 62-70% compared to single biomass pyrolysis. Research results Dong, Yue, Bai, Chen, Wang & Bu (2024) showed that microwave co-pyrolysis between peanut shells and LDPE plastics increased the bio-oil yield obtained by 12-30% compared to the control treatment. Microwave co-pyrolysis also produces charcoal products with a high calorific value of 29,475 MJ/kg (Du, Zhang, Hu, Yang, Liu & Wang, 2023).

METHODOLOGY

Preparation of Raw Materials

The raw materials used in this study are a mixture of palm oil fiber charcoal and LDPE from microwave co-pyrolysis with a power of 450W. Before being used for testing, the raw materials are first mashed using a blender machine, then sifted with a 30 mesh sieve. This process aims to obtain a homogeneous sample. The variations of materials used are shown in Table 1.

Table 1. Material Variations

No	Composition Variations (Palm Fiber : LDPE)	Pressure Variations (kg/cm2)
1.	100:0	
2.	75:25	
3.	50:50	50,100,150,200
4.	25:75	
5.	0:100	

Before testing, a proximate analysis of raw materials is carried out to evaluate their chemical properties, such as moisture content, volatile content, ash content, and carbon bonded. The results of the proximate test analysis are shown in Table 2.

Table 2. Results of Proximate Analysis of Raw Materials

Material	Composition (wt.%)			
	Until Air	Until Volatile	Until Item	Carbon Bound
100% Fiber Charcoal	8.52	20.84	5.39	70.64
Charcoal Fiber 75%	7.88	24.84	4.86	67.29
Charcoal Fiber 50%	7.08	19.82	5.65	73.10
Charcoal Fiber 25%	5.50	24.14	2.61	70.36
100% LDPE Fiber Charcoal	6.00	26.50	2.63	70.86

Specimen Making

The process of making test specimens can be called the briquette process (Kebede, Berthe & Zergaw, 2022). Briquettes are carried out by weighing 12 grams of material. The adhesive used is a mixture of starch flour weighing 2.4 grams and 15 ml of water. Then, the finished adhesive is re-weighed by 2.4 grams and mixed with the finished material. Next, the process of making briquettes is by printing materials with pressures of 50, 100, 150, and 200 kg/cm2. Each briquette has a mass of ± 3.06 grams.

Specimen Testing

Before testing, the briquettes are first dried using an oven at 105°C for 30 minutes. The briquette combustion test was carried out with an initial temperature of 40°C and a heating rate of 20°C/minute until the temperature reached 500°C. During the testing process, the thermocouple is placed right on the top surface of the briquette and it is assumed that the temperature of the entire surface of the briquettes is evenly distributed. The thermocouple used for the testing process is two pieces to measure the temperature of the briquettes and the temperature of the chamber. The blower is placed at the bottom of the furnace and circulates air at a speed of 0.1 m/s. Data recording is carried out during the combustion process. The schematic of the combustion test apparatus is shown in Figure 1.

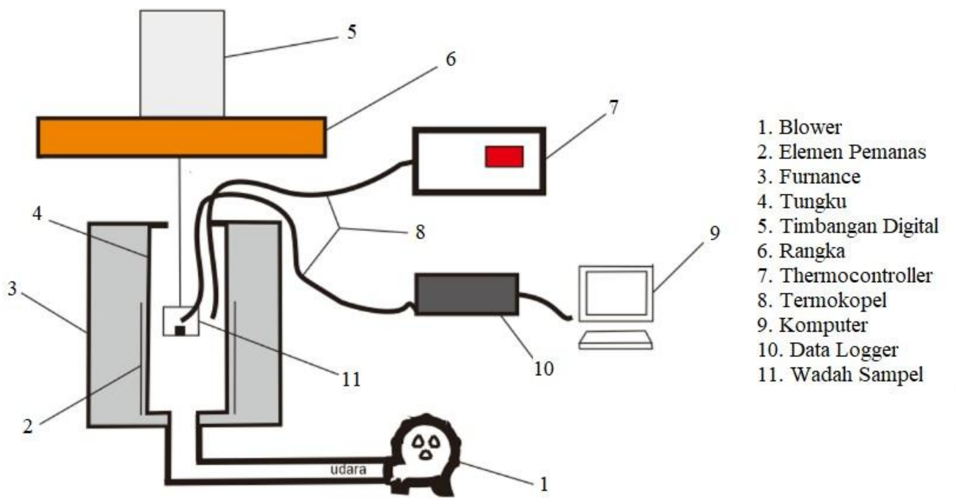

Figure 1. Combustion Test Equipment Scheme

Data Analysis

Data analysis was carried out using the Thermogravimetric Analysis (TGA) method to determine combustion characteristics including Initiation Temperature of Volatile Matter (ITVM), Initiation Temperature of Fixed Carbon (ITFC), Peak of weight loss rate Temperature (PT), Burning out Temperature (BT), Activation energy (EA), and mass loss rate (MLR).

RESEARCH RESULTS

This study evaluates the effect of variations in the composition of palm oil fiber charcoal with LDPE plastic and bricketing pressure on the combustion characteristics of briquettes. The results of the study are shown in Figure 2-7. The results of the study show:

1. The brixing pressure is directly proportional to the ITVM value, while the composition variation is inversely proportional to the ITVM value (Figure 2).

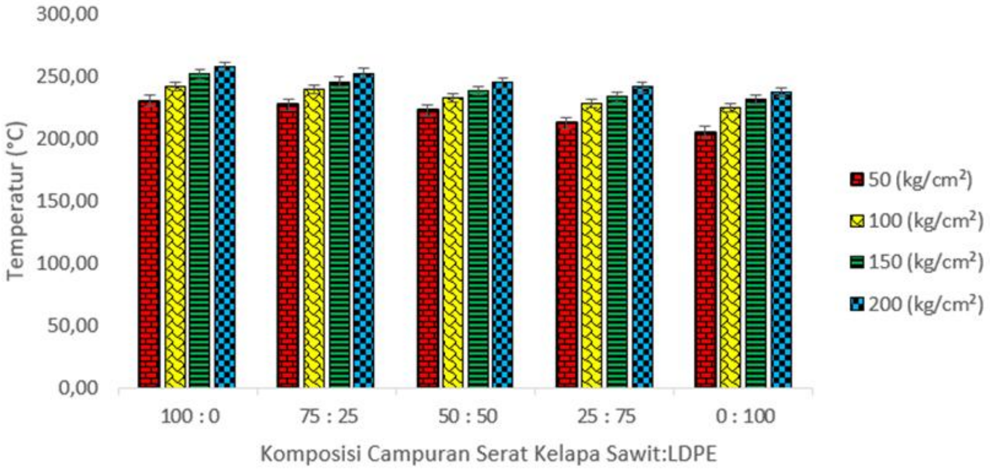

Figure 2. ITVM Value

2. The addition of LDPE plastic is inversely proportional to the ITFC value, while the britting pressure is directly proportional to the ITFC value (Figure 3).

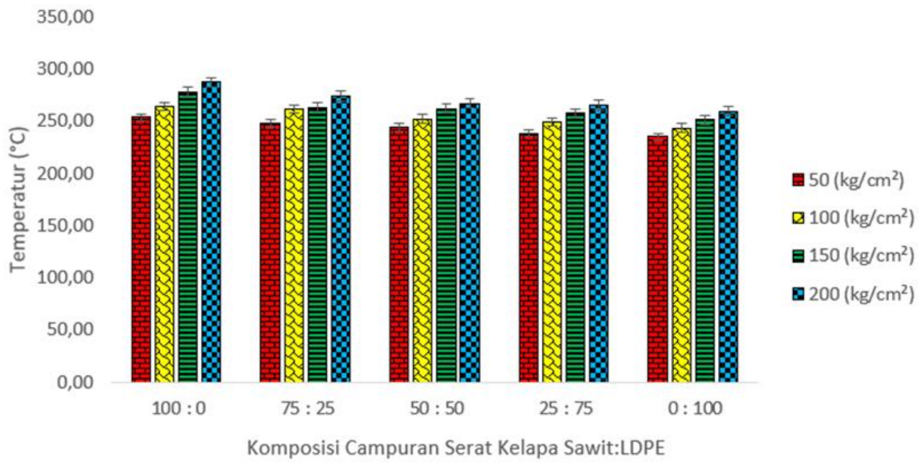

Figure 3. ITFC Value

3. Variations in composition and briquette pressure affect PT values during the briquette firing process (Figure 4).

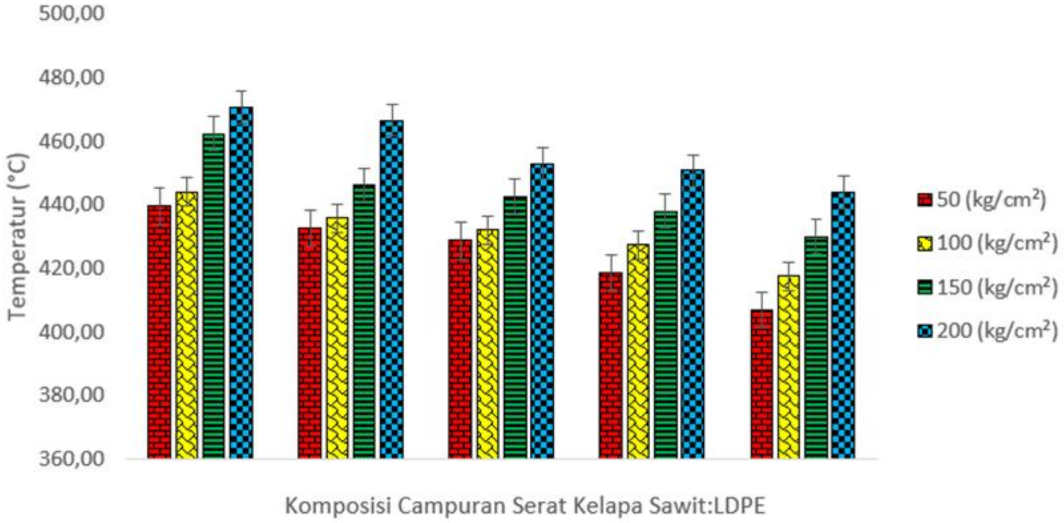

Figure 4. PT Value

4. The addition of LDPE plastic increases the BT value during the briquette burning process (Figure 5).

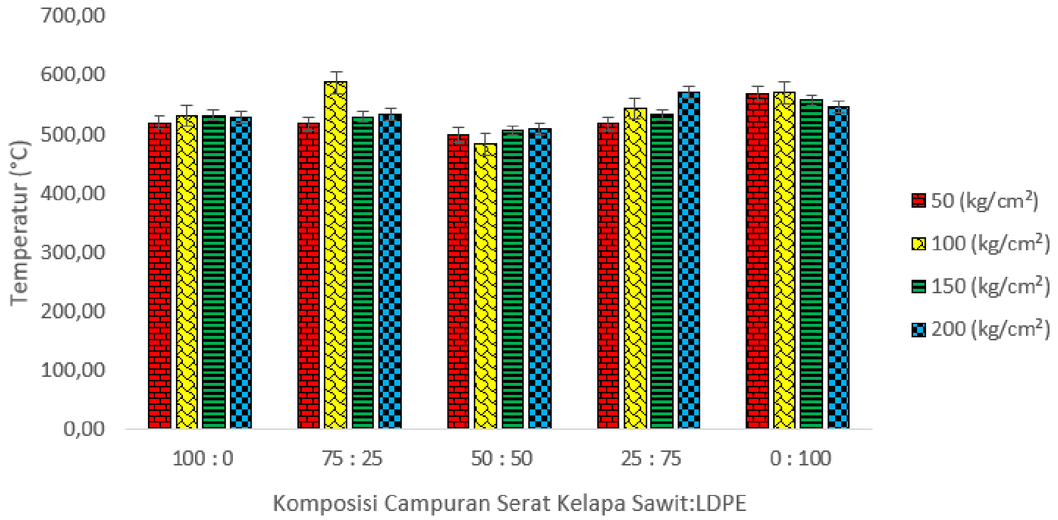

Figure 5. BT Value

5. The higher the briquette pressure, the greater the EA value. Meanwhile, the more LDPE plastic content in the charcoal mixture, the smaller the EA value (Figure 6).

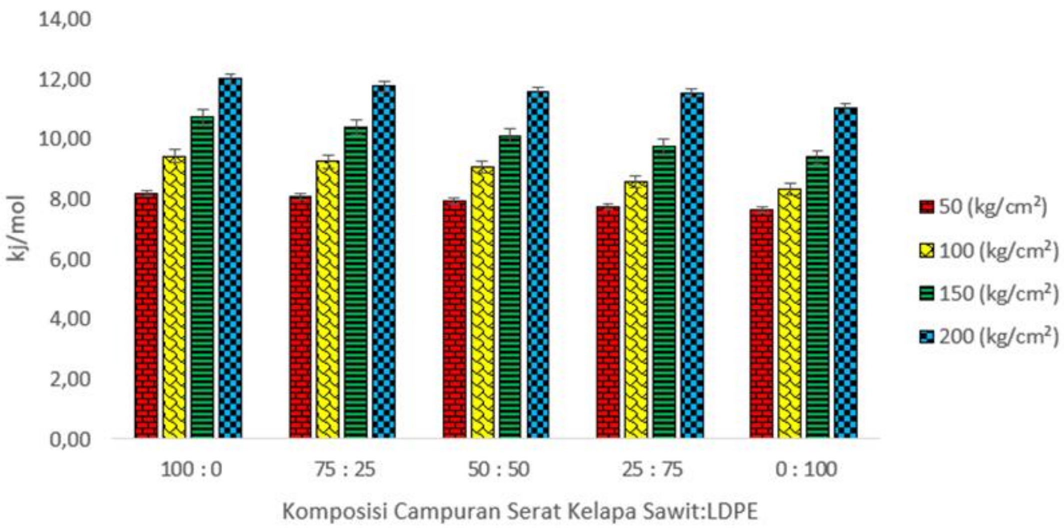

Figure 6. EA Values

6. The higher the content of LDPE plastic in the charcoal composition, the greater the MLR value. Meanwhile, the greater the briquette pressure, the smaller the MLR value (Figure 7).

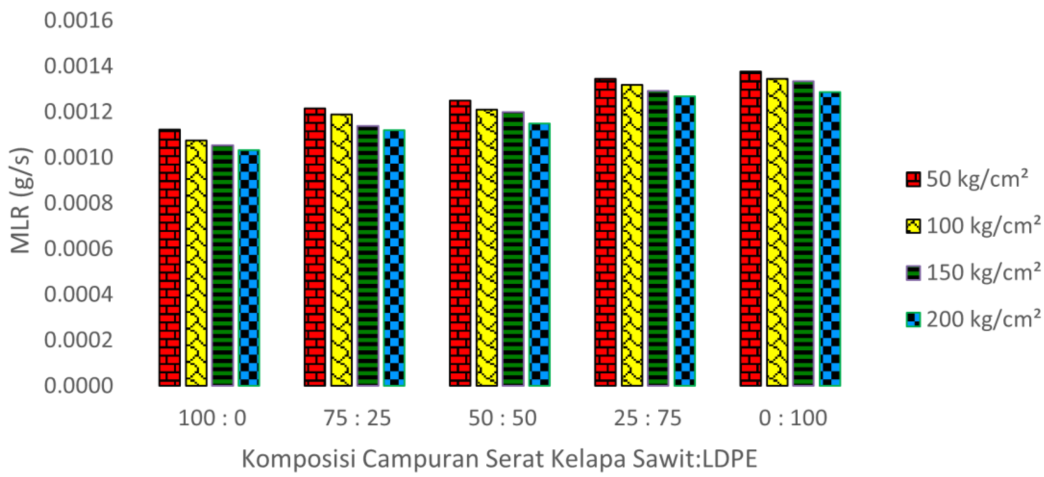

Figure 7. MLR Values

DISCUSSION

Initiation Temperature of Volatile Matter (ITVM)

ITVM is the temperature of the fuel at which the rate of mass reduction of the sample begins to increase. This is characterized by the speed of the mass that begins to decrease and increase rapidly. Based on the graph shown in Figure 2, it can be seen that the higher the brimming pressure, the greater the ITVM value. Meanwhile, the value of ITVM is inversely proportional to the composition of the mixture, where the more LDPE plastic content, the smaller the value of ITVM, but the decrease is not significant. The highest ITVM value was shown at a composition variation of 100:0 with a brimming pressure of 200kg/cm^2 of 257.23°C. The lowest ITVM value is shown at a composition variation of 0:100 with a brimming pressure of 50 kg/cm^2 with a value of 204.78°C. The higher the pressure, the more water is lost, so the lower the moisture content of the briquettes. The higher the moisture content, the lower the quality of the briquettes and the lower the pressing pressure, the higher the volatile content in the briquettes (Mujiarto, Suprianto & Murdjani, 2013).

***Initiation Temperature of Fixed Carbon* (ITFC)**

ITFC is a combustion chamber temperature where the rate of mass reduction increases during the beginning of the combustion process. Based on the graph shown in Figure 3, it can be seen that the more LDPE plastic content in the charcoal mixture, the smaller the ITFC value. Meanwhile, the higher the briquette pressure, the greater the value of ITFC. The highest ITFC value is shown at a composition variation of 100:0 with a brimming pressure of 200kg/cm² of 287.23°C. The lowest ITFC value is shown at a composition variation of 0:100 with a brimming pressure of 50 kg/cm² of a value of 235.01°C.

***Peak of Weight Loss Rate Temperature* (PT)**

PT is also known as Peak of Weight Loss Rate Temperature is the temperature of the fuel where the rate of mass reduction begins to reach the highest level. Based on the graph shown in Figure 4, it can be seen that the higher the brimming pressure, the higher the PT value. This is because the denser a briquette is, the more it can increase the burning temperature of the briquettes. Meanwhile, the value of PT is inversely proportional to the composition of the mixture, where the more LDPE plastic content, the smaller the value of PT. The highest PT value was shown at a composition variation of 100:0 with a brimming pressure of 200 kg/cm² of 470.57°C and for the lowest PT value was shown at a composition variation of 0:100 with a brimming pressure of 50 kg/cm² of 406.78°C. Pure biomass has the highest PT value than any other material. This is because the fixed carbon content in pure biomass has high levels so that it can cause high temperatures in the briquettes (Caroko & Muhammed Iqbal Naim, 2015).

***Burning out Temperature* (BT)**

BT is a fuel temperature where the rate of mass reduction begins to stabilize or tends to slow down. Based on the graph shown in Figure 4, it can be seen that the addition of LDPE plastic to the charcoal mixture is directly proportional to the value of BT. The highest BT value is shown at the composition variation of 75:25 with a brimming pressure of 100 kg/cm² of 587.71°C and the lowest BT value is shown at a composition variation of 50:50 with a brimming pressure of 100 kg/cm² of 482.39°C.

***Energy Activation* (EA)**

Activation energy can be interpreted as the minimum energy that must be needed for a chemical reaction to occur. Based on the graph shown in Figure 5, it can be seen that the higher the brimming pressure, the higher the EA value. Meanwhile, the EA value is inversely proportional to the composition of the mixture where the more LDPE plastic content, the smaller the EA value. The highest EA value is shown at a composition variation of 100:0 with a brimming pressure of 200 kg/cm² of 12.01 kJ/mol and the lowest PT value is shown at a composition variation of 0:100 with a brimming pressure of 50 kg/cm² of 7.66 kJ/mol.

The greater the briquette pressure will have an impact on the increase in the value of EA with an average of 13.49%, while the more the composition of the LDPE mixture, the EA experiences an average decrease of 2.62%. So it can be known that the higher the pressing pressure on the briquettes, the tighter the pores on the briquettes will be, so the combustion process will be more difficult so that the briquettes require greater activation energy. The use of raw materials and adhesives will result in differences in the levels of volatile matter and carbon bonded. The higher the volatile matter content will cause faster burning time and lower EA values (Syarief, Fadliyanur, Suryanta, Napitupulu, Hakim, Ramadhasari & Galang, 2022).

Mass Loss Rate **(MLR)**

MLR shows the magnitude of the decrease in the mass of the sample material at any given unit of time. Based on the graph shown in Figure 6, it can be seen that the addition of LDPE plastic causes the MLR value to increase further. Meanwhile, the higher the briquette pressure, the lower the MLR value. The largest MLR value was found in the composition variation of 0:100 with a brimming pressure of 50 kg/cm² of 0.00138 g/s. The lowest MLR value was found in the composition variation of 100:0 with a brimming pressure of 200 kg/cm² of 0.00112 g/s. This proves that pressure variation affects the length of the firing time.

CONCLUSIONS AND RECOMMENDATIONS

Testing the combustion characteristics of palm fibre and LDPE mixed charcoal briquettes resulting from microwave co-pyrolysis of 450 W with brimming pressures of 50 kg/cm², 100 kg/cm2, 150 kg/cm2, and 200 kg/cm2 showed the following conclusions:

1. The value of ITVM, ITFC, PT has increased as pressure increases and decreases as the content of LDPE plastic in the composition of palm oil fiber charcoal mixture increases. Meanwhile, the BT value tends to fluctuate due to the increasing content of LDPE plastic in the composition of the palm fiber charcoal mixture.
2. The higher the briquette pressure, the EA value increases which is caused by the briquette ignition process will take longer.

This test shows that the material content of each material affects the values of ITVM, ITFC, PT, BT, EA, and MLR. Materials with high volatile matter will more easily reach the ITVM point at low temperatures. Materials that have high fixed carbon actually produce high temperatures at the time of ITFC. Pressure variations can affect the results of combustion tests i.e. ITVM, ITFC, PT, BT, EA, and MLR. From this study, it can be concluded that the higher the pressure on the briquettes, the longer the ignition and combustion of the briquettes and the higher the temperature of the briquettes.

FURTHER STUDY

This research has limitations in terms of raw materials used. Therefore, further research is recommended to use other raw material variations for comparison. Raw materials can be in the form of biomass of the same kind, such as empty bunches and oil palm shells, as well as other biomass and other types of plastics such as Polyethylene Terephthalathe (PET), Polypropylene (PP), and Polystyrene (PS). This aims to evaluate the advantages of each raw material in producing briquettes with the best quality and optimal combustion.

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