JOURNAL OF MECHANICAL ENGINEERING, SCIENCE, AND INNOVATION

ITATS

Research Article

Characteristics of Char and Tar from the Pyrolysis Process of Brem Waste with Temperature Variations Using a Rotary Kiln System

Journal of Mechanical Engineering, Science, and Innovation
e-ISSN: 2776-3536
2025, Vol. 5, No. 1
DOI: 10.31284/j.jmesi.2025.v5i1.6558
ejurnal.itats.ac.id/jmesi

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Abstract

One of the processes to obtain new renewable fuels is pyrolysis. This process produces alternative fuels, namely Char (charcoal), tar (bio-oil) and gas. Tar (bio-oil) can be processed into biodiesel. Pyrolysis is the process of breaking down (decomposing) biomass through a heating process with little or no oxygen. Research Pyrolysis of Rotary Kiln System with Brem, Plastic and Durian Peel Waste Biomass on Char and Tar Characteristics. This research was carried out by directly testing the pyrolysis of a rotary kiln system with brem, plastic and durian peel waste biomass. The test parameters use temperature variations of 523K, 573K, 673K, 773K, and 873K. Testing for each biomass is carried out separately, not mixed. The aim of the research is to determine the characteristics of char and tar from each biomass including calorific value, mass, volume and density. Research results the highest char calorific value is 11181.1 cal / gram with plastic waste biomass. The highest calorific value was obtained from tar from plastic waste, which was 14211.3 cal/gram. The highest density value was between 0.9-0.93 grams/ml in biomass from brem waste, plastic waste, durian skin waste.

Keywords: *pyrolysis, heater, rotary kiln, char, tar*

Received: September 6, 2024; Received in revised: February 18, 2025; Accepted: February 24, 2025
Handling Editor: Eky Novianarenti

INTRODUCTION

As the reduction of fossil fuels in the world this is encouraging innovation was carried out on other alternative energy sources [1]. Coal reserves only last until 2112, and it will become the only fossil fuel in the world after 2042 [2]. One process to obtain new renewable fuel is pyrolysis. This process produces alternative fuels, namely Char (charcoal), tar (bio-oil) and gas. Tar (bio-oil) can be processed into biodiesel [3]. Pyrolysis is the process of breaking down (decomposing) biomass through a heating process with little or no oxygen [4]. Biomass in the pyrolysis process will undergo chemical structure breakdown into the gas phase [5]. The temperature of the pyrolysis process is between 500 – 800 ℃ [4].

The relative amounts of the main pyrolysis products (Char, Tar and Gas) depend on the operating parameters, nature of the biomass and type of pyrolysis process [4]. Decomposition of biomass at a temperature of 400 – 550 ℃ (medium temperature) produces bio-oil in a short time. The higher the temperature, the possibility of gas products increasing. Meanwhile Char is produced at low temperatures [6]. In the pyrolysis process, tar (bio-oil) production can be divided into 3 temperature ranges (i) fast pyrolysis (≥500 ℃) (ii) slow pyrolysis (low biomass heating rate) and (iii) low temperature carbonization (≤ 400 ℃) [7]. Biomass can come from industrial waste, plantations, livestock. Biomass contains hydrocarbon compounds so it can be used as fuel and electricity generation [8]. Pyrolysis research has been widely carried out in both fixed bed and rotary pyrolysis kilns. Fixed bed pyrolysis research uses organic and non-organic materials, such as: cow dung [9], mahogany wood [10], plastic waste [11]–[14], brem waste [15], bagasse [16]–[18], durian skin [19], [20], oil palm bunches [21]. Rotary kiln pyrolysis research uses organic and non-organic materials, such as durian skin [22], mahogany wood [8], [23], tire waste [24], solid waste [25].

Brem is one of the typical snacks of Madiun city, East Java, Indonesia. Brem is produced from the fermentation process of glutinous rice extracted from starch. The waste that has been taken from brem production in the factory is 1.5-3 tons per month, so it has great potential as biomass in the pyrolysis process [26]. One of the waste products that is difficult to decompose is plastic waste. Indonesia is a very large contributor of plastic waste, namely 1.29 million metric tons [27]. Durian is one of the typical fruits of Asia and Indonesia. Durian skin is biomass because it contains lignocellulose (lignin, cellulose, and hemicellulose) which is decomposed by pyrolysis into organic components such as phenol, alcohol, ketone, aldehyde, and ester [28]

From previous research, in the rotary pyrolysis kiln there is biomass from brem waste, plastic waste, and durian skin with a heating furnace. However, equipment with furnaces is not optimal in achieving pyrolysis temperatures. Biomass still uses durian skin, the parameters taken are char and tar. Therefore, in this study the biomass used was brem waste, plastic and durian skin. There are many in Indonesia, especially in the city of Madiun. This biomass was chosen because it contains the elements C and H, which are hydrocarbon elements.

Based on the description that has been presented, researchers are interested in conducting research on the manufacture of alternative fuel from processed waste, plastic and durian skin using the pyrolysis method using a rotary kiln system using a heater. This research was carried out by directly testing the pyrolysis of a rotary kiln system with brem, plastic and durian peel waste biomass. The test parameters use temperature variations of 523K, 573K, 673K, 773K, and 873K. Testing for each biomass is carried out separately, not mixed. The aim of the research is to determine the characteristics of char and tar from each biomass including calorific value, mass, volume and density. The expected result in this research is a new fuel consisting of charcoal (char) and bio-oil (tar) which can be used as a replacement for fossil fuels.

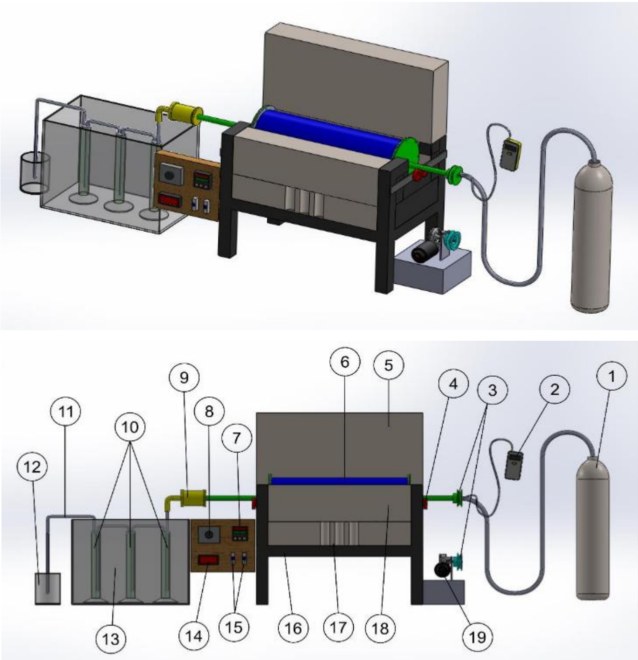

Figure 1. Rotary Pyrolysis Equipment

METHODS AND ANALYSIS

This research is experimental research which aims to investigate the possible influence of independent variables (pyrolysis temperature variations) on dependent variations (char mass, char volume, tar mass, tar volume and heating value) in the experimental group.

The biomass of plastic and durian skin is cut into small pieces of 1cm^2. The biomass of brem waste, plastic and durian skin is dried in the sun to reduce the water content. After drying, it is put in a closed place. Before testing, the biomass is dried for 120-180 minutes at a temperature of 383 – 398K in a drying machine until the water content is <2%. After drying, the biomass sample is put into the machine for pyrolysis. This process is carried out on all biomass and at each temperature variation.

Pyrolysis Test Procedure

As shown in Figure 1, a 500 g sample of dry brem waste (Biomass) was taken and put in pyrolysis tube (6). The pyrolysis tube was placed on the pyrolysis device and a pipe from the Nitrogen tube (1) and the outlet pipe were installed. This tube is held by the bearing (4). After the tube is installed on the tube table (16), the cover (5) is closed. The heater (17) is installed on the tube table. To reduce the heat loss, a Lightweight Brick (18) is installed on the tube table and cover. N_2 gas from the Nitrogen tube with a flow rate of 3 liters/minute is channeled into the pyrolysis heating chamber until the O_2 content is <2% of the volume of the heating chamber, then open the valve and discharge into the pyrolysis tube so that the O_2 gas comes out. The pyrolysis tube (2) is rotated using low speed electric motor power (19) with belt and pulley (3), namely 60-70 Rpm and the tube is heated to varying temperatures 523K, 573K, 673K, 773K, and 873K for 3 hours. The temperature is measured by thermocouple (3). The pyrolysis temperature of the heater is controlled by dimmer (8) and PID Controller (7), where the ignition is controlled by electricity meter (14) and MCB (15). After the temperature rises, the atomic bonds in the biomass are broken, which is indicated by smoke coming out through the outlet pipe to the measuring cup (10) in the aquarium (13). The aquarium contains water + ice so that the temperature is set to remain at 273K. Smoke that is not contained in the measuring cup (10) will come out through the pipe (11) and be collected in the measuring cup (12).

The mass results of char and tar (bio-oil) obtained from variations temperature, analyzed mass percentage and biomass volume. The Char and Tar (bio-oil) formed are measured heating value at each temperature of 523K, 573K, 673K, 773K, and 873K.

RESULTS AND DISCUSSIONS

Char Characteristics

Char characteristics resulting from the pyrolysis process of 500 grams of brem waste with temperature variations of 523K, 573K, 673K, 773K, and 873K for 3 hours. The initial mass of each biomass is 500 grams.

From Figure 2, data is obtained that the higher the temperature in the pyrolysis process, the lower the mass of char produced. The highest mass value of brem waste char/charcoal was found at a temperature of 523K, namely 234.4 grams and the smallest was at a temperature of 873K, namely 112.3 grams. The highest mass value of plastic waste char/charcoal is at a temperature of 523K, namely 495 grams and the smallest is at a temperature of 873K, namely 15 grams. The highest mass value of durian skin waste char/charcoal was at a temperature of 523K, namely 154.6 grams and the smallest was at a temperature of 873K, namely 117.4 grams. The devolatilization process for brem waste and durian skin at a temperature of 523K, the final char mass is almost the same because both contain a lot of water, with the final result being a solid residue of 22.46% char from Brem waste char and 23.48% Durian Skin waste char. Char in durian skin waste, the higher the pyrolysis temperature, the smaller the mass of char formed in accordance with research by Nuriana et al [19]. This is because the temperature of 498-773K evaporates the water content, cellulose, hemicellulose and lignin decompose, thus affecting the weight of the material after the carbonization process. The pyrolysis of plastic waste starts at a temperature of around 450 K and results quickly with increasing temperature to around 773K and then the mass decreases slowly to the final temperature. The final solid residue yield is approximately 3%. In plastic waste at a temperature of 873K the char yield is 3%, this is in accordance with research [29]. The results of the breakdown of cellulose at 573-873K mostly produce oxygenated compounds such as acetaldehyde. As the temperature rises above 873K, it produces increased hydrocarbon gas, this indicates a secondary tar reaction. Then as the solid residence time increases, the amount of tar produced increases up to a temperature of 1073K.

At a temperature of 523K only water evaporation occurs and some of the C-C atomic bonds (the lowest bond energy) are decomposed. Because only water and some of the C-C atomic bonds are decomposed, the char mass becomes the largest. Plastic char mass is most due. The atoms that make up the plastic core are Carbon (C), Hydrogen (H) and several additional atoms of Oxygen (O), nitrogen (N), Chlorine (Cl), Fluorine (F), and

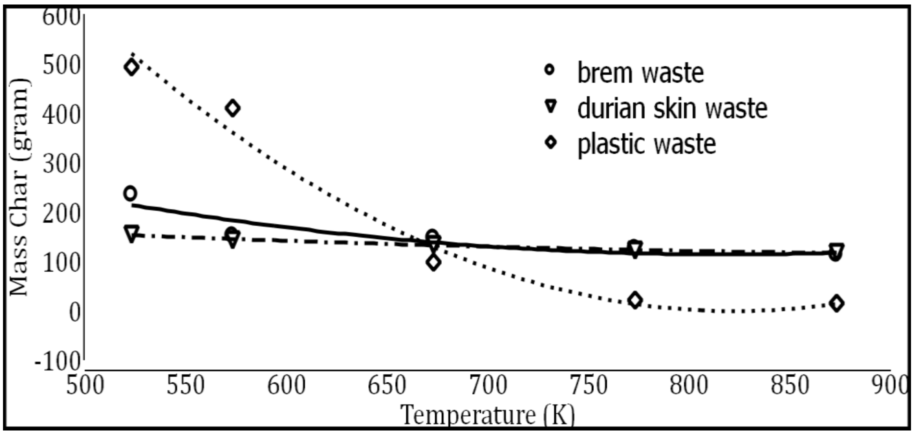

Figure 2. Mass graph of char from pyrolysis results of biomass waste brem, plastic waste and durian skin waste

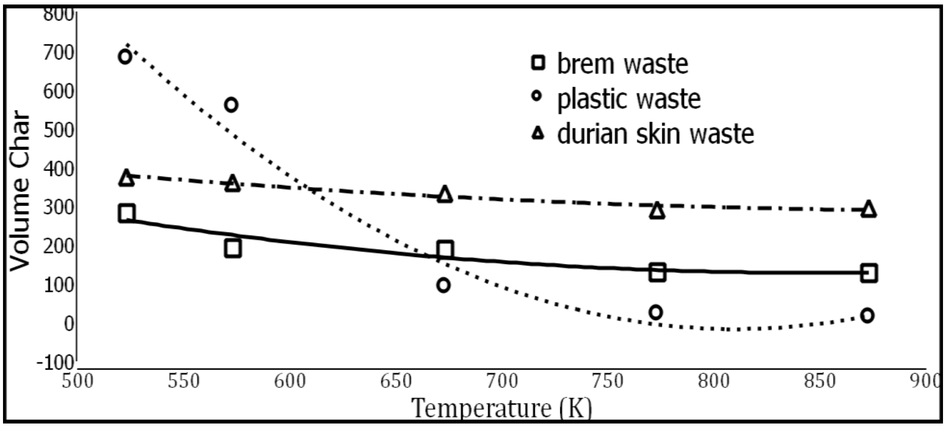

Figure 3. Char volume graph from pyrolysis results of biomass waste brem, plastic waste and durian skin waste

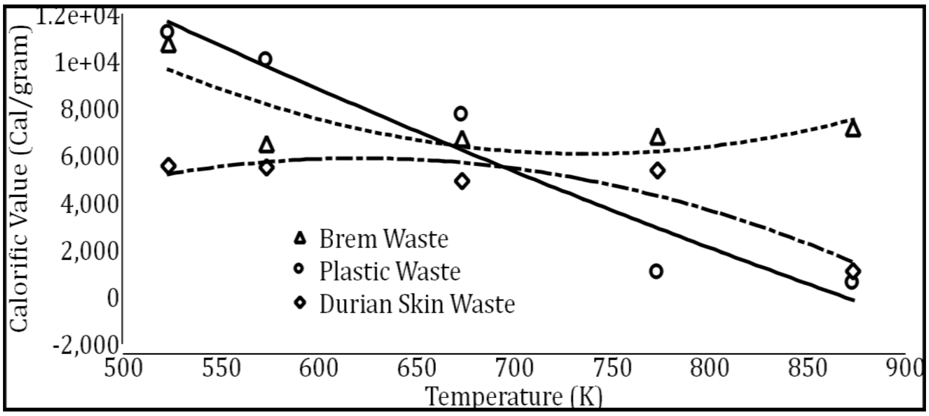

Figure 4. Calorific value graph of char from pyrolysis of biomass brem waste, plastic waste and durian skin waste

sulfur (S). So the atomic bonds of the small elements Oxygen (O), nitrogen (N), Chlorine (Cl), Fluorine (F), and sulfur (S) are released first. Currently Durian skin proportionally contains high cellulose elements (50-60%) and lignin content (5%) and low starch content (5%)[30]. Elements containing water whose atomic bonds are broken first. Brem waste char with Sugar Content 65.18 gr Starch 4.56 gr Water 18.87 gr Total acid 1.58 gr Fat 0.11 gr Protein 0.42 gr Dissolved solids 1.34 gr, elements of water content, Starch, Water, acids, fats, proteins, dissolved solids whose atomic bonds are easily separated leaving C-H bonds in sugar.

In Figure 3 is the final volume of char due to the influence of variations in temperature and heating rate resulting from pyrolysis of mahogany wood powder. In this graph the trend is almost the same as the char mass.

From Figure 4 it can be seen that at a pyrolysis temperature of 673 K the calorific value of char in each biomass has a value between 4900 -7800 Cal/gram. The calorific value of durian skin waste char at a pyrolysis temperature of 773K is 5382.36 Cal/gram, close to Nuriana et al. research of 6,274.29 Cal/gram with a pyrolysis temperature of 723K [19] and M. Syahri et al's research of 6339.6473 Cal /gram. [20] and Kemas Ridhuan et al., 2017 [31] amounting to 5726.1789 cal/gram. The average calorific value of brem waste in the picture is 7589.664 cal/gram, close to research by Majedi et al., 2019 [32] of 8669.136 Cal/gram and is still higher than the calorific value of char, the calorific value of wood charcoal. The lowest char calorific value of brem waste, plastic waste, durian skin waste is 6487.990651 Cal/gram, 567.4954491 Cal/gram, 1083.77 Cal/gram. This calorific value is still higher than the calorific value of wood charcoal by burning. The calorific value of sono wood charcoal is 229.01 cal/gr, mahogany wood charcoal is 299.22 cal/gr, teak wood charcoal is 230.58 cal/gr, jackfruit wood charcoal is 242.9 cal/gr, and waru wood is 242.2 cal/gr.[33]. The higher the calorific value of plastic, the lower the value, because for plastic the bonds are double, so everything breaks down, leaving only ash and elements other than C and H.

Tar Characteristics

From Figure 5, data is obtained that the higher the temperature in the pyrolysis process, the greater the volume of tar from the waste biomass of brem and durian skin produced. This data is in accordance with research by Edi Munarwan 2019 [15], Rahmatullah et al, 2019 [28]. In tar from plastic biomass at a temperature of 523K there is no tar volume. At a temperature of 573K tar has begun to form. Starting from 573K, the temperature of the tar formed increases sharply and will increase further with increasing temperature. This is because a higher heating level has a shorter reaction time and the temperature required for the sample to decompose is also higher. So the large instantaneous thermal energy is used to break the atomic bonds surrounding C, so that more tar and gas are formed [10]. Similar research whereas the temperature increases, the tar formed will increase [35], [36].

Figure 6 shows that with increasing pyrolysis temperature, on average the calorific value of bio-oil from brem, plastic and durian skin waste biomass will increase. For bio-oil from brem waste, the highest calorific value is at a temperature of 773K, namely 2982.50982 cal/gram. Meanwhile, the calorific value of tar from durian skin waste is 5394.1221cal/gram at a temperature of 873K.

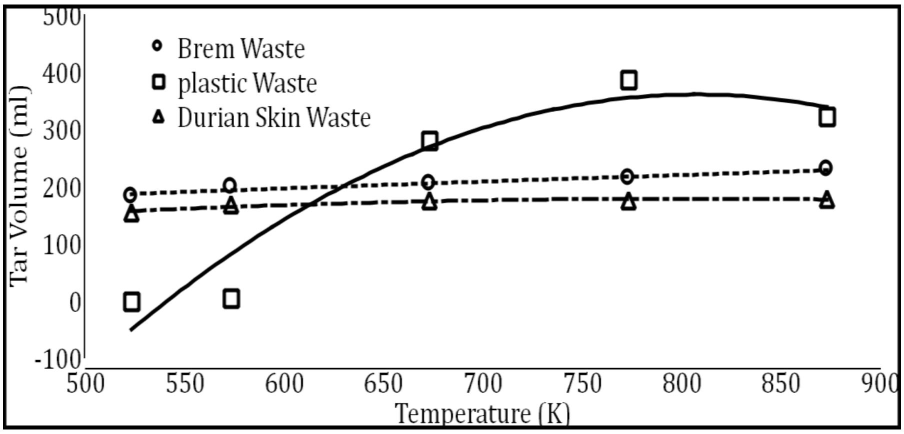

Figure 5. Tar Volume graph from pyrolysis of biomass brem waste, plastic waste and durian skin waste

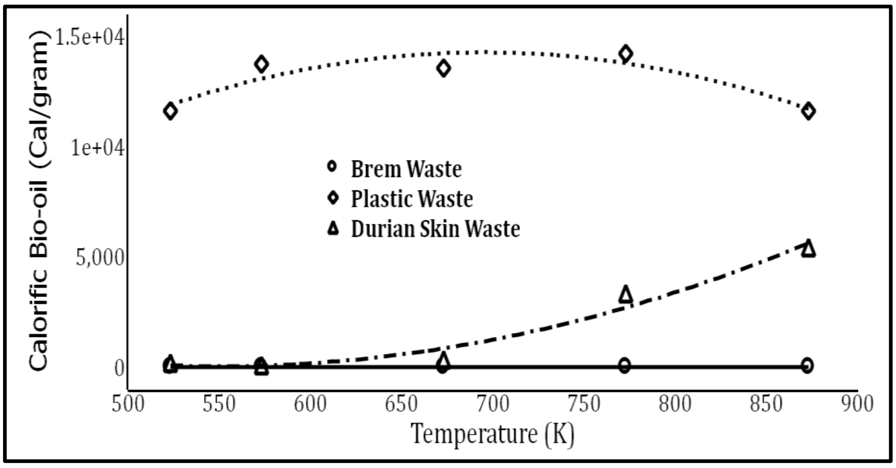

Figure 6. Calorific value graph of tar from pyrolysis of biomass from brem waste, plastic waste and durian skin waste

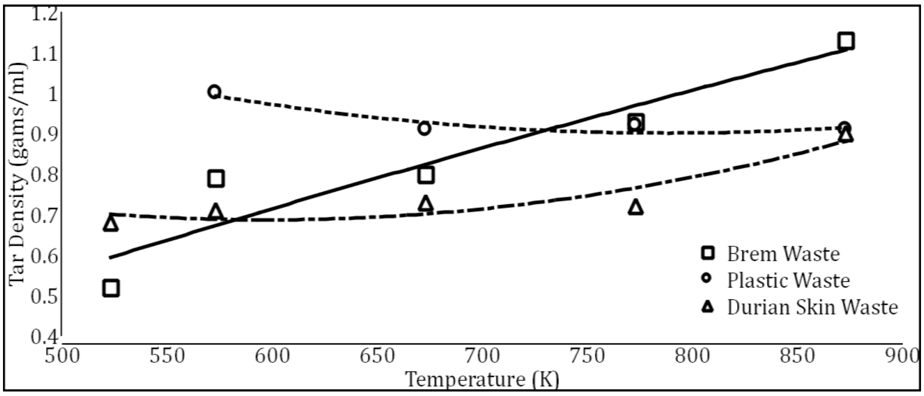

Figure 7. Density graph of tar from pyrolysis of biomass from brem waste, plastic waste and durian skin waste

The calorific value of bio-oil from plastic waste is 11590.71369 - 14211.330872 cal/gram. Which is almost the same as the calorific value of diesel at 10342 cal/gram. The calorific value of bio-oil from plastic waste will increase with increasing temperature [37].

In Figure 7 above shows that pyrolysis with brem waste biomass produces the highest density at a temperature of 873K with a value of 1.13 gr/ml. While the lowest density shows at a temperature of 523K with a value of 0.52 gr/ml. This is due to the effect of increasing temperature which causes faster evaporation so that the mass is reduced more. With plastic biomass, the density of bio-oil (tar) at a temperature of 300oC is 1 gr/ml. This is because the pyrolysis process in polypropylene (PP) plastic waste forms bio-oil (tar) at temperatures above 573K so that the density value becomes large due to the water content factor in the biomass. The density of bio-oil (tar) at a temperature of 400oC is 0.91 gr/ml. because at a temperature of 623K rapid pyrolysis has occurred so that the density value is low. The density of bio-oil (tar) at a temperature of 500 ℃ produces a value of 0.92 gr/ml. because at a temperature of 773K, rapid pyrolysis has occurred so that the resulting density is low. The density of bio-oil (tar) at a temperature of 873K produces a value of 0.91 gr/ml. because at a temperature of 873K, rapid pyrolysis has occurred so that the resulting density is low. Previous research by Handi Wahyu B. (2020:40) obtained the highest bio-oil (tar) density results at temperatures of 523K and 573K of 1 gr/ml while the lowest density value at a temperature of 623K was 0.87 gr/ml. With durian skin biomass, the effect of pyrolysis temperature on the density of durian skin tar using 500 grams of biomass, temperature variations of 523K, 573K, 673K, 773K, and 873K with a time of 3 hours. From the graph above, it shows that with increasing pyrolysis temperature, the density of tar produced increases. The density obtained from durian skin tar at a temperature of 523K is the lowest, which is 0.68 gr/ml. Meanwhile, the density results at temperatures of 573 to 773K are almost the same, ranging from 0.71 gr/ml to 0.73 gr/ml, significantly different from the density results at a temperature of 873K, which is 0.9 gr/ml, which is the highest density result. The higher the temperature in the pyrolysis process, the density of brem, plastic and durian skin waste produced tends to increase. The higher the temperature, the more atomic bonds in biomass molecules are broken (C-C, C-O, C-H, H-O) so that the number of atoms in the molecule will be less and it will be denser. This causes the density to increase.

CONCLUSIONS

The higher the temperature in the pyrolysis process, the mass and volume of char from brem, plastic and durian skin waste produced decreases. The higher the temperature in the pyrolysis process, the calorific value of char from brem, plastic and durian skin waste produced decreases but is still higher than the calorific value of wood charcoal by burning. The higher the temperature in the pyrolysis process, the mass and volume of tar from brem, plastic and durian skin waste produced increases. The higher the temperature in the pyrolysis process, the calorific value of tar from brem, plastic and durian skin waste produced tends to increase. The higher the temperature in the pyrolysis process, the density of brem, plastic and durian skin waste produced tends to increase.

ACKNOWLEDGEMENTS

DECLARATION OF CONFLICTING INTERESTS

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article for our colleagues

FUNDING

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