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PRODUCTION AND CHARACTERIZATION OF MICROWAVE-ACTIVATED PALM KERNEL SHELL (*ELAEIS GUINEENSIS JACQ.*) ACTIVATED CHARCOAL

Lina Lestari[1], Sapto Raharjo[2], I Nyoman Sudiana[3], La Ode Rusman[4], Siti Manikam[5]
Faculty of Mathematics and Natural Sciences, Universitas Halu Oleo, Indonesia

lina.lestari@uho.ac.id

ABSTRACT
Research has been conducted on the production and characterization of activated charcoal of palm kernel shells (*Elaeis Guineensis Jacq.*) by microwave. This study aims to determine the efficiency of charcoal production and its quality after microwave activation so that the test results can provide information that palm kernel shells can be utilized as raw material for making briquettes as an alternative fuel. The experimental stages include drying of palm kernel shells, carbonization with a carbonization reactor, grinding, sieving with 70 mesh and 80 mesh sieves in stages, and activation with microwave. Charcoal characterization includes moisture content, ash content, volatile matter, fixed carbon, and calorific value. The results showed that the production efficiency of the carbonization reactor was 62.2%, the charcoal formation rate was 4.4444 kg/hour, and the material requirement rate was 7.1429 kg/hour. Charcoal can be activated by microwave at 150 watts for 2 minutes, 3 minutes, and 4 minutes. Activated charcoal decreased in moisture content from 5.900% to 4.4834%, decreased volatile matter from 19.1357% to 14.4250%, and increased ash content from 6.1234% to 7.5697%. Fix carbon increased from 68.8409% to 73.5219%, and the calorific value of charcoal increased significantly from 5400.00 cal/gr to 7532.27 cal/gr. It can be concluded that microwave-activated charcoal meets the quality requirements as an ingredient for making briquettes as an alternative fuel. The implication of this research is the new finding that microwave-activated palm kernel shell charcoal has potential as a briquette-making material with better quality than charcoal without activation.

Keywords: Carbonization, Activation, Microwave, Moisture Content, Ash Content, Volatile Matter, Calorific Value.

Corresponding Author: Lina Lestari
E-mail: lina.lestari@uho.ac.id

INTRODUCTION

The increase in the area of oil palm (*elaeis guineensis jacq.*) plantations has implications for the increase in the amount of biomass waste produced (Babinszki et al., 2021). Palm kernel shell is one of the largest palm oil processing wastes, reaching 60% of the production of kernel oil. The shell is the hard part of the oil palm fruit that serves to protect the contents or kernel of the oil palm. Similar to coconut shells, palm kernel shell waste can also be processed into an artificial solid fuel as an alternative fuel called briquettes. Based on previous research, the chemical composition of oil palm shells consists of carbon 50.70%, hydrogen 6.15%, nitrogen 1.71%, oxygen 34.70%, ash 6.50%, and cellulose (Aziz et al., 2019).

The utilization of palm kernel shells for briquetting requires an appropriate method, especially in preparing the shell material into charcoal. Charcoal is a solid material produced from the thermal degradation of biomass under conditions of little or no oxygen. In the process of charcoal production or carbonization, water and volatile matter are released, while the carbon remains. Carbonization temperature will greatly affect the charcoal produced so that determining the right temperature will determine the quality of the charcoal (Rodrigues et al., 2023).

Compared to charcoal, activated charcoal is more practical, attractive and clean. Activation can break hydrocarbon bonds by oxidizing surface molecules. This is very necessary to enlarge the pore surface area of charcoal (Yulianti et al., 2019). Activation also aims to reduce volatile matter so that the briquette flame rate is low and expand the pore, namely by breaking hydrocarbon bonds or oxidizing surface molecules so that the charcoal changes its properties, namely its surface area increases and affects adsorbs (Lestari, Raharjo, et al., 2023). Activation treatment reduces water content and volatile matter. However, ash and carbon levels increase. If volatile matter is high, combustion can start at low temperatures, which indicates that the charcoal is easy to ignite and burn. However, this will cause the combustion process to become rapid and uncontrollable (Raharjo et al., 2023).

Microwaves lie between infrared radiation and radio waves in the electromagnetic spectrum region. Microwaves are waves with wavelengths between 0.001 and 1m and frequencies between 300 and 0.3 GHz. Microwaves can theoretically be converted into heat through interaction with dielectric materials. Carbon materials are generally good microwave absorbents, they are easily heated using microwave radiation. This character makes carbon materials able to transform due to microwave heating, resulting in new carbon with desired properties or characteristics (Udyani et al., 2019). The novelty in this study is the character of palm kernel shell charcoal that changes due to microwave heating, namely an increase in fix carbon and heating value. This increase is attributed to the evaporation of water and volatile matter during microwave activation. The research aims to highlight the potential of microwave heating in altering carbon materials to achieve desired properties and characteristics.

In this research, charcoal production uses a kiln drum model carbonization reactor that has been tested for white teak wood material (Lestari, Saleh, et al., 2023). The purpose of this experiment is to determine the production efficiency of the carbonization reactor in producing charcoal, the carbonization rate, and the rate of palm kernel shell material demand. This is very important to ensure that the carbonization reactor functions economically. Furthermore, charcoal is activated using microwave because it provides advantages, including relatively small energy required, faster heating, even heating, and a high level of safety (Zulaechah et al., 2017). This experiment aims to determine the right activation power and time for the activation process of palm kernel shell charcoal. Furthermore, the purpose of this study is to measure the moisture content, ash content, volatile matter, fixed carbon and calorific value of charcoal and activated charcoal. Characterization of these parameters is important to review whether the activated charcoal is feasible to be used as material for making briquettes as alternative energy. The benefit of this research is to contribute to the repertoire of material science about changes in the character of microwave-activated palm kernel shell charcoal so that it has the potential as a briquette-making material with high caloric value and efficient production methods.

METHOD

Tools and Materials

The tools used in this research are a carbonization reactor, 70 mesh and 80 mesh sieves, balance sheet, infrared thermometer, microwave for activation, furnace and cup for proximate test, which includes water content, ash content, volatile matter, a set of DSC (Differential Scanning Calorimeter) tools to measure calorific value. The materials of this research are oil palm shells, plant branch waste for carbonization, and water to extinguish the charcoal.

Research Procedure

The working procedure carried out in this study is as follows:

Preparation Stage

The steps taken in this process are drying the palm kernel shells and carbonizing fuel with solar heat.

Carbonization Stage

Palm kernel shell waste that has been further nested using a carbonization reactor with the following process:

a. Cutting the palm kernel shell 7 cm before putting it in the carbonization reactor
b. Measuring palm kernel shell mass (m_1)
c. Putting the palm kernel shells into the reactor that has been designed before, so that it fills 80% of the reactor.
d. Inserting the igniting material into the igniting chamber
e. Close the top of the reactor to ensure that no oxygen enters,
f. The igniter is switched on
g. Measuring the temperature in the reactor through the chimney. Temperature measurement aims to control the temperature in the reactor to be constant at the highest temperature.
h. Observe from the air control hole on the chimney, to make sure the charcoal material has burned completely or not. At a certain time, dense smoke comes out of the chimney
i. Once the smoke from the chimney is no longer dense, it is clearer, indicating that the carbonization process has been completed.
j. Extinguishing the fire in the reactor by sprinkling the charcoal with water, then removing the charcoal.
k. Drying the charcoal
l. Calculating the mass of charcoal (m_2)

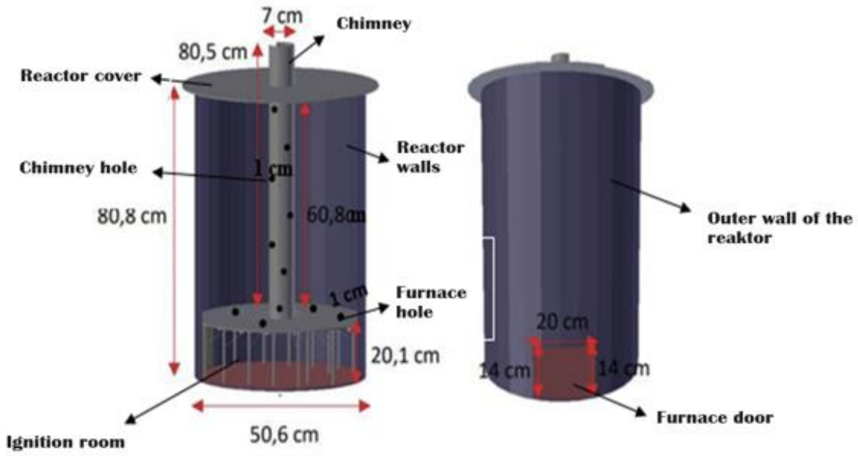

Figure 1. Carbonization reactor system design

Charcoal Production Efficiency Calculation

Production efficiency is measured using the following formula:

$$EP\ (\%) = \frac{m_2}{m_1} \times 100\%$$

Description:

EP (%): Production Efficiency (%)

m_1 : Mass of carbonized palm kernel shell (kg)

m_2 : Charcoal mass (kg)

Carbonization Rate Calculation

The rate of carbonization can be measured using the following formula

$$RC = \frac{m_2}{t}$$

Description:

R : Carbonization rate (kg/h)

m_2 : Mass of charcoal (kg)

t : Duration of carbonization (hour)

Material Requirement Rate Calculation

The material requirement rate can be calculated using the following formula:

$$RMR = \frac{m_1}{t}$$

Description:

RMR : The rate of material requirements (kg/hour)

m_1 : Mass of biomass (kg)

t : Length of time for active charcoal formation (hours)

Grinding and Sieving

The steps taken in the grinding and sieving stage are:

a. Grinding the dried charcoal using a mortar and pestle.
b. Store the charcoal in a dry container before sifting it.
c. Set up a 70 mesh and 80 mesh sieve, with the 70 mesh sieve on top.

d. Sifting charcoal.
e. Take the charcoal that lies between the 70 mesh and 80 mesh sieves. Then store the charcoal in a dry and closed container.

Charcoal Activation

The activation process of swit shell charcoal in this study was carried out using a microwave, namely by placing the charcoal in a cup and putting it in the microwave. Activating the charcoal with a microwave with a certain power and time. Storing the activated charcoal in a dry and closed container.

Calculation of Moisture Content

This procedure is based on (ULFI, 2016) and American Society of Testing and Materials (ASTM) D 2866-70 as follows:

a. Weighing activated charcoal samples
b. Place the cup in the oven and heat at 105˚C for 3 hours.
c. Remove the cup from the oven and store in a desiccator and then weigh until constant weight.

The moisture content of activated charcoal can be measured using the following formula:

$$\text{M (\%)} = \left(\frac{m2-m3}{m2-m1}\right)\times 100\%$$

Description:

M(%) : Moisture (water content) (%)
m_1 : Mass of empty cup (grams)
m_2 : Mass of empty cup + mass of sample (grams)
m_3 : Mass of sample after heating at 105˚C (grams) (ULFI, 2016).

Ash Content

The steps in measuring ash content are based on (ULFI, 2016) and American Society of Testing and Materials (ASTM) D 2866-70 as follows:

a. Weighing activated charcoal samples
b. Place the cup in a furnace at 700˚C for 3 hours.
c. Remove the cup from the furnace and cool in a desiccator and then weigh it.

The ash content analysis of activated charcoal can be measured using the following formula:

$$\text{AC (\%)} = \left(\frac{m3-m1}{m2-m1}\right)\times 100\%$$

Description:

AC (%) : Ash Content (%)
m_1 : Mass of empty cup (grams)
m_2 : Mass of empty cup + mass of sample (grams)
m_3 : Mass of sample after heating at 700˚C for 3 hours (grams) (ULFI, 2016).

a. Volatile Matter

The steps of volatile matter characterization are as follows:

1) Weighing activated charcoal samples
2) Cover the cup with aluminum foil and put it in the furnace at 900˚C for 7 minutes.
3) Remove the cup from the furnace and cool in a desiccator.

Volatile matter analysis of activated charcoal can be measured using the following formula:

$$\text{KHZ (\%)} = \left(\frac{[MS-(MC+SP(750^{\circ}C))-MCK]}{MS} \times 100\%\right)$$

Volatile Matter = KZH (750˚C) - moisture content

Description:
KZH : Substance Loss Rate
RESTROOMS : Empty Cup Mass (gram)
MS : Sample Mass (gram)
MC+SP(750˚C) : Mass of cup + mass of the sample after heating at 750˚C (grams) (Hasan et al., 2017).

b. Fixed Carbon

The procedure for determining the bound carbon content refers to the ASTM D.2172-12 standard. The fixed carbon content test is determined by subtracting 100% from the sum of the percentages of water content, volatile matter content and ash content. (Hasan et al., 2017).

RESULTS AND DISCUSSION

Carbonization Result

The carbonization process is carried out using a carbonization reactor, as shown in Figure 1, which is designed using tools made of drums as the reactor body, iron cylinders as chimneys, and iron plates as covers. The limited air supply aims to prevent further combustion so that a high charcoal yield is obtained due to the formation of charcoal perfectly.

During the carbonization process, the combustion temperature is continuously observed by using an infrared thermometer, and the measurement results are recorded at an interval of 2 minutes. The stability of the combustion temperature must be maintained by adding an igniter so that the carbonization process takes place quickly. This process will continue until thick to clear smoke comes out of the chimney, indicating that the palm kernel shell material has been carbonized completely. The expected result of carbonization is to create black charcoal, not ash, which can be visually identified by looking at the color of the charcoal. The carbonized charcoal is sprinkled with water to stop the process and and then dried in the sun.

The following calculates the carbonization reactor's carbonization efficiency, charcoal formation rate, and material requirement rate.

Table 1. Charcoal formation efficiency, charcoal formation rate, and palm kernel shell carbonization demand rate

Mass Of Biomass (Kg)	Charcoal Masks (Kg)	Length Of Carbonization Time (Hours)	Carbonization Efficiency (%)	Carbonization Rate (Kg/H)	Material Requirement Rate (Kg/H)
45	28	6.3	62.2222	4.4444	7.1429

The carbonization efficiency is 62.2222%, meaning that the reactor can produce charcoal, where the mass of charcoal formed is 62.2% of the mass of the palm kernel shell. This reduction in mass is due to the fact that in this process, water evaporates at temperatures up to 200˚C. At 200-500˚C, the cellulose, hemicellulose, and lignin components are decomposed into a liquid fraction and a gas fraction containing CO and CO_2 as its main components. Each biomass component undergoes dehydration and depolymerization processes in this region, with repeated intramolecular binding, resulting in low molecular weight fragments breaking down into liquid and gaseous products. The high molecular weight fragments formed by condensation are equal to the burnt part and the undecomposed part. The mass loss of the material decreases at temperatures above 500˚C, but polycondensed aromatic carbon increases with the formation of H_2 in the charcoal range of 80˚C to 700˚C (Gunawan, S., Banu N., 2022).

The carbonization rate of the reactor is 4.4444 kg/hour, meaning that the reactor can produce a mass of 4.4444 kg of charcoal for one hour. The material requirement Moreover,e of 7.1429 kg/hour means that the reactor can produce a mass of 7.1429 kg of palm kernel shells for one hour. If you look at the description by Gunawan et al., 2017 above, this figure is related to temperature changes during carbonization as in the following figure:

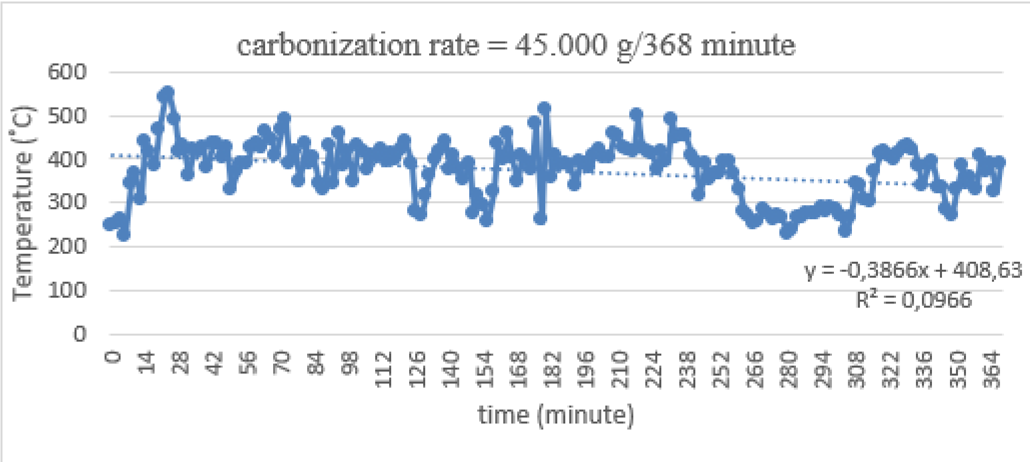

Figure 2. Graph of carbonization rate

The highest temperature of the carbonization reactor measured during the carbonization process was 548.7℃, and the lowest temperature of the carbonization reactor was 225.2℃. A mass of 45kg of palm kernel shells produced 28kg of charcoal. The duration of carbonization is influenced by the hard texture of palm kernel shell biomass. The 7cm chopped palm kernel shell causes the biomass to be quite dense in the reactor, so it takes a long time for the chimney to emit clear smoke. Visually, the charcoal produced was black and lacked visible ash.

Microwave Activation, Proximate Test, and Calorific Value

Activation of palm kernel shell charcoal with a particle size of 70 mesh-80 mesh was tested at 150 watts of power. Observing the temperature changes and physical changes of the charcoal, activation can be done in 2 minutes to 4 minutes. If it exceeds 4 minutes, the charcoal will smolder, and ash will form. Furthermore, activation was carried out for 2 minutes, 3 minutes, and 4 minutes, respectively, and the moisture content, ash content, volatile matter, and calorific value were measured.

The following is a characterization of moisture content, ash content, volatile matter, fixed carbon, and calorific value of microwave-activated palm kernel shell charcoal at 150 watts.

Table 2. Proximate analysis and calorific value of palm kernel shell-activated charcoal

No.	Activation Time (Minutes)	Moisture Content (%)	Ash Content (%)	Volatile Matter (%)	Fixed Carbon (%)	Calorific Value (Cal/Gr)
1	Without activation	5.900	6.1234	19.1357	68.8409	5400.00
2	2	5.6530	6.9721	17.7388	69.6361	5634.23
3	3	5.1661	7.1813	15.4982	72.1545	6634.12
4	4	4.4834	7.5697	14.4250	73.5219	7532.27

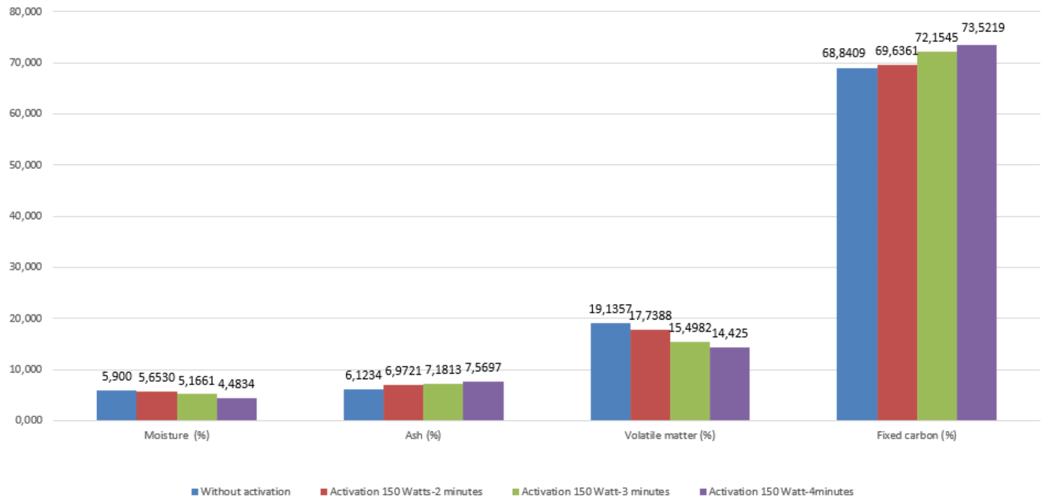

Figure 3. Graph of proximate test of palm kernel shell charcoal

The decrease in moisture content due to activation is due to the evaporation of water contained in the charcoal. Although the water content of charcoal without activation has met the quality as a raw material for briquette making, of course this decrease in water content can improve its quality. The moisture content of activated charcoal meets the quality of briquetted charcoal according to the SNI 01-6235-2000 standard, which is less than 8% (National, 2000).

Controlling the activation time up to 4 minutes caused the ash content to increase, not exceeding the threshold of charcoal quality as briquette-making material, which is a maximum of 8%, according to SNI 01-6235-2000 standard (National, 2000). From the measurement of ash content, although activation causes ash content to increase, this increase is still controlled during activation by observing changes in temperature and charcoal color.

Volatile matter of activated charcoal decreased from 19.1357% to 14.4250%. According to the SNI 01-6235-2000 standard (National, 2000), the maximum volatile matter recommended for the quality of briquette material is 15%, which is fulfilled from the charcoal activated for 4 minutes.

The data shows that the fixed carbon of activated charcoal is higher than that of charcoal without activation. Fix carbon increases with an increase in activation time due to the reduction of water content and volatile matter. This is as expected, given that fix carbon affects the heating value.

From the above experiments, microwave activation has a higher economic value than conventional heating. Activation with a furnace has been carried out at a temperature of 650oC for 5 minutes, showing quality that also meets the standards. (Lestari et al., 2020). However, it requires much energy. The very real advantage of microwaves over other methods is the time coefficient, which is easily controlled and energy efficient. Microwaves have the fastest heating capability of all ovens. The heat distribution is greater even as the material absorbs the microwaves and converts them into heat. The main difference between conventional and microwave processes is that the heating element supplies heat to the sample, and some of the heat is concentrated along the surface. In contrast, in a microwave furnace, the material will absorb microwave energy and convert it into heat (Sudiana et al., 2017).

Charcoal without activation has a heating value of 5400 cal/gram. Although this calorific value meets the quality requirements as briquettes, the significant increase in calorific value due to microwave activation for 2 minutes, 3 minutes, and 4 minutes to produce 5634.23 cal/gr, 6634.12 cal/gr, 7532.27 cal/gr, respectively certainly provides very important information in the repertoire of charcoal material science as a raw material for briquetting. During controlled activation, although more ash is formed, water and volatile matter evaporate in greater quantities so that the fixed carbon increases, which results in the calorific value increasing significantly.

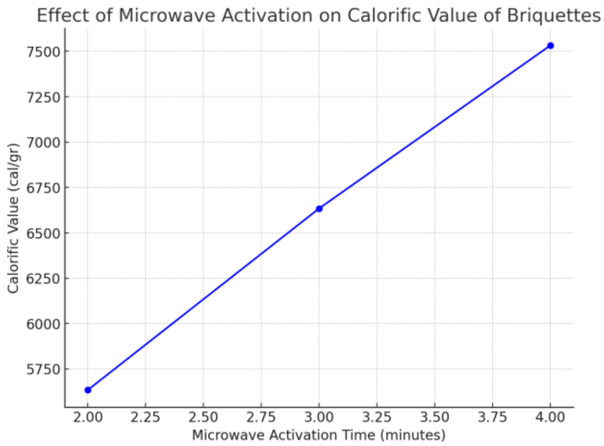

Figure 4. the effect of microwave activation time on the calorific value of briquettes

CONCLUSION

Palm kernel shell charcoal can be produced with a carbonization reactor with an efficiency of 62.2222%, a carbonization rate of 4.4444 kg/hour, and a material requirement rate of 7.1429 kg/hour. Microwave-activated charcoal has better characteristics as a raw material for briquetting than charcoal without activation. Activation time of 4 minutes on charcoal sieved with 70 mesh and 80 mesh sieves in stages gave the highest calorific value of 7532.27 cal/gr with the lowest moisture content of 4.4834%, ash content of 7.5697%, and volatile matter of 14.4250%, fixed carbon of 73.5219%.

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