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The effect of microwave charcoal activation on the calorific value and burning rate of palm kernel shell charcoal briquettes

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Abstract: This experimental study aims to determine the effect of microwave charcoal activation parameters on the calorific value of palm kernel shell charcoal briquettes. The study was carried out in several stages, specifically collecting and drying the raw materials, carbonizing, grinding and sifting, activation, mixing adhesives, pressing, and drying. Palm kernel shell charcoal briquettes are made using sago as an adhesive with a mass ratio of 9:1. Charcoal granules are sieved using an 80-mesh size. The activation was performed using a microwave at 150 W with variations in activation time of 360, 480, and 600 seconds. The charcoal was also activated for 480 seconds at 70 watts, 150 watts, and 230 watts. The sample was compressed at a pressure of 9.31×10^6 N/m². The calorific value and burning rate of charcoal briquettes without activation are 6948.74 cal/g and 0.084 g/min. Microwave activation of charcoal can increase the calorific value of briquettes to 8015.14 cal/g and decrease the burning rate to 0.046 g/min at 230 watts of power and 480 seconds of time. The decrease in burning rate indicates that the briquettes are more efficient. SEM tests proved the change in diameter and number of pores, which are traces of volatile matter vaporized during charcoal activation, leading to an increase in calorific value and a decrease in combustion rate. The EDS test shows that the palm kernel shell charcoal briquettes do not contain sulfur, indicating that they are safe to use as fuel and environmentally friendly.
Keywords: *Activation, Burning rate, Calorific value, Microwave, Pore, Sulfur.*

1. Introduction

The increasing area of oil palm (Elaeis guineensis jacq.) plantations has implications for increasing the amount of biomass waste produced [1]. One of the solid waste from palm oil processing is palm shell, which is the part of the palm fruit that is located between the pulp and the palm kernel. Palm shell is difficult to decompose naturally in the environment, so it is necessary to find a solution for its use. The thermochemical characteristics of palm shells indicate that palm shells have high calorific value, low moisture content and ash content, as well as chemical components that support efficient combustion. The use of palm shells can reduce greenhouse gas emissions by about 78,647 metric tons per year [2]. Based on these characteristics, palm oil shells have great potential to be a solution in overcoming energy and environmental challenges in the future. One of the uses of palm shell is as a raw material for making briquettes as an alternative energy.

Charcoal briquettes are solid fuels made from charcoal powder and pressed adhesives [3]. Good quality briquettes are smooth textured, not easily broken, hard, and have good combustion properties [4]. The combustion characteristics of good quality briquettes have a short ignition time, a long burning time at maximum temperature, a low combustion rate, not generating soot and little smoke. One way to improve the combustion characteristics of charcoal briquettes is by activating charcoal to

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reduce the level of volatile matter so that the combustion rate is low (economical) and produces less smoke. Activation of charcoal with an electric kiln has been shown to increase the calorific value of the briquettes and improve the quality of combustion [5]. However, this method requires high energy.

In this study, the activation of charcoal was microwaved. The advantages of using a microwave are that it is more economical because the energy required is relatively small, heating faster and more evenly, and the level of safety is high [6]. In previous studies, microwave activation of palm shell charcoal resulted in a reduction in moisture content and volatile matter, resulting in an increase in carbon fix and calorific value. The activated charcoal has the potential to be a raw material for making briquettes [7].

The purpose of this study was to measure the calorific value of palm shell charcoal briquettes and the combustion rate of microwave-activated charcoal briquettes. In addition, changes in the diameter and number of charcoal pores will be tested. The elemental content of palm shell charcoal briquettes was tested to indicate the safety of using briquettes as fuel against the environment.

2. Method

2.1. Fabrication of Briquette

The palm kernel shell as a carbon source were taken from Lerehoma Village, Anggaberi District, Konawe Regency, Southeast Sulawesi. The sago was taken from the Abeko village, Ranomeeto, Konawe Selatan district. First, we dried the raw material in an electric oven at 110°C for 120 minutes, and then it was carbonated using carbonization reactor [7]. The resulting palm kernel shell charcoal was pulverized, obtaining a charcoal powder, which was subsequently sifted with an 80-mesh sieve to obtain a homogeneous charcoal powder [8]. The activation using a microwave at 150 W with variations in activation time of 360, 480, and 600 s. Activated charcoal powder was mixed with sago powder as an adhesive with a mass ratio of 9:1 and hot water and subsequently stirred, and Lestari, et al. [8]. The samples were compressed at a pressure 9.31×10^{6} N/m2, where the mixture material amassed into a cylindrical mold with an outer and inner diameter of 4 cm and 0.8 cm, respectively. Finally, it was dried for 48 hours in an electric oven at 60⁰C for 48 hours [8].

2.2. Characterization of Briquette

The briquettes characterization includes calorific value using Differential Scanning Calorimeter (DSC-60) from Shimadzu Scientific Instruments, and burning rate through combustion test, and Scanning Electron Microscope- Energy Dispersive X-Ray Spectroscopy (SEM_EDS) test. Determination of the flame time, the combustion rate, and the maximum temperature of the briquette were tested by burning in a chamber at room temperature 25⁰C, wind spreed of 0.25m/s, humidity 50%. The flame temperature was measured using an infrared thermometer [8].

3. Result and Discussion

Briquette parameter measurements were conducted on briquette samples made from microwave-activated charcoal at 150 watts for 360 seconds, 480 seconds, 600 seconds.; and the charcoal is activated for 480 seconds at 70 watts, 150 watts, and 230 watts.

3.1. Calorific Value

The calorific value is the maximum amount of heat energy generated by a fuel through a perfect combustion reaction per unit mass or volume of the fuel [9]. Activation of charcoal with a microwave causes a change in the calorific value of the briquettes. Calorific values are given in tables 1 and 2.

Table 1.
Calorific value of palm shell charcoal briquettes.

Charcoal	Processing time(s)	Calorific value (cal/g)
Without activation	-	6948.74
Activation (Power level 150 watts)	360	7718.53
	480	7809.44
	600	7912.27

Table 2.
Calorific value of palm shell charcoal briquettes.

Charcoal	Power level (watts)	Calorific value (cal/g)
Without activation	-	6948.74
Activation (Processing time 480 s)	70	7622.46
	150	7809.44
	230	8015.14

The calorific value of briquettes from activated palm kernel shell charcoal is higher than the calorific value of non-activated briquette. Giving microwave activation at 150 watts of power for 360 s, 480 s, and 600 s leads to an increase in the calorific value. The highest calorific value as much as 7912.27 cal/gr was obtained from activated charcoal of palm kernel shell for 600 s. This is in accordance with previous research, microwave-activated charcoal causes reduced moisture content and volatile matter, thereby increasing the carbon fix of charcoal and the calorific value of charcoal [7]. This can happen because during the combustion process carbon is needed to react with oxygen so that it will produce heat or heat. Another study stated that the smaller the moisture content of charcoal briquettes, the higher the calorific value produced by the charcoal briquettes [10].

3.2. Briquette Burning Parameters

The temperature change during the combustion of briquettes with a mass of 4.75 grams is depicted in the following graph:

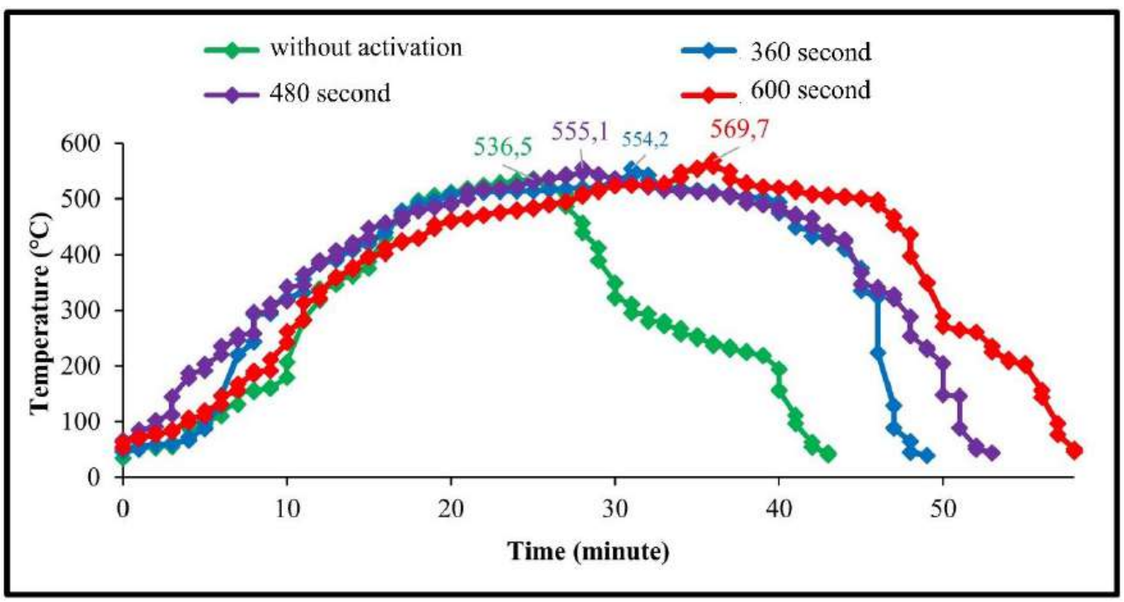

Figure 1.
Temperature changes during the burning of palm shell charcoal briquettes without activation and activated at a power of 150 watts.

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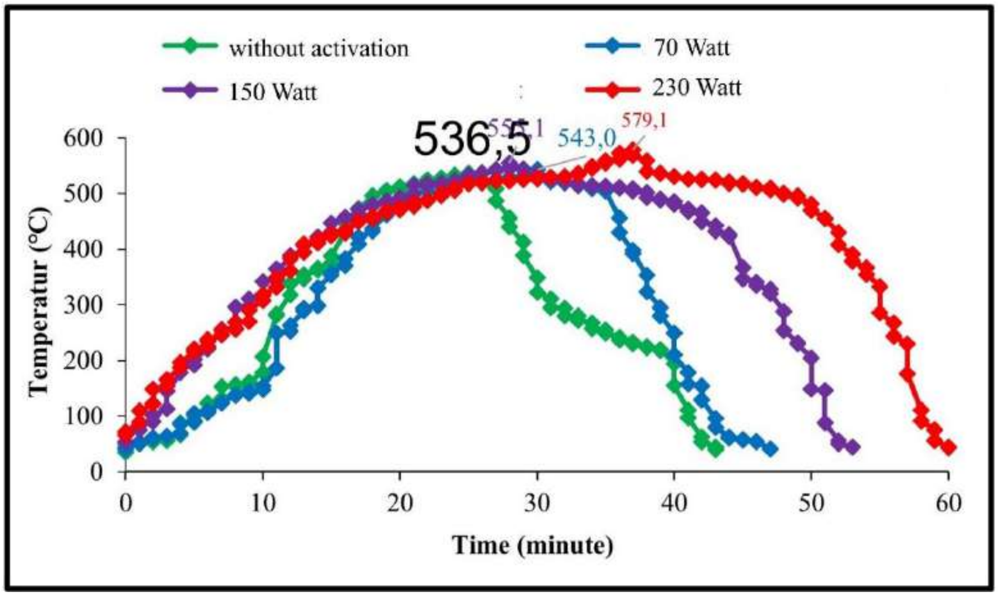

Figure 2.
Graph of the relationship between combustion time and temperature palm shell charcoal briquettes without activation and those activated at 480 seconds.

Based on the picture above, the burning of unactivated charcoal briquettes experiences the achievement of maximum temperature rapidly, and the temperature drops very quickly until the mass of charcoal briquettes is exhausted, seems less stable. Activation with a controlled microwave causes the burning of the briquettes to be more stable, although the maximum temperature of the activated charcoal briquettes is slower, depicted by a longer time interval around the maximum temperature. The temperature drop after the maximum temperature is reached becomes slower and not steep, the charcoal briquettes do not burn out quickly. This fact is related to the reduction of volatile matter during the activation process, the longer the duration of charcoal activation, the higher the activation temperature will be, causing more volatile substances contained in charcoal to decompose into gases and other compounds. The *low volatile matter* content of charcoal briquettes can result in a low combustion rate (economical) and reduce the smoke produced during the combustion of charcoal briquettes [7]. This is also related to the increase in the level of activation.

The achievement of the maximum temperature corresponds to the calorific value, it appears that the maximum temperature of the combustion of microwave-activated charcoal briquettes increased to 569.7°C, an increase of 33.2°C from unactivated charcoal briquettes.

Burning parameters such as ignition time, burning time, and maximum temperature is shown in Table 3 and Table 4.

Table 3.
The ignition time, burning rate, and the maximum temperature of briquettes activted at 150 watts of power.

Charcoal	Processing time (seconds)	Ignition time (seconds)	Burning rate (gr/min)	Maximum temperature (°C)	Time interval around the maximum temperature (minutes)
Without activation	-	8.8	0.084	536.5	11 (17 to 28 minutes)
Activation (Power Level 150 Watts)	360	9.8	0,066	554.2	24 (17 to 41 minutes)
	480	9.9	0,057	555.1	26 (16 to 42 minutes)
	600	10.6	0,051	569.7	28 (19.5 to 47.5 minutes)

Table 4.
The ignition time, burning rate, and the maximum temperature of briquettes activated for 480 seconds.

Charcoal	Power level (watts)	Ignition time (seconds)	Burning rate (gr/min)	Maximum temperature (°C)	Time interval around the maximum temperature (minutes)
Without activation	-	8.8	0.084	536.5	11 (17 to 28 minutes)
Activation (Processing time 480 seconds)	70	9.6	0.077	543,0	17 (Minutes 19-36)
	150	9.9	0.057	555,1	26 (Minutes 16-42)
	230	13.6	0.046	579,1	34 (17.5-51.5 minutes)

Ignition time is the time it takes for briquettes to appear, characterized by the presence of red on the surface of the briquettes. Factors that can affect the combustion of solid fuels include activation parameters, airflow velocity, fuel type and combustion air parameters [4]. The time test of North Sulawesi is carried out starting from the ignition of the briquettes until the briquettes start to burn. Ignition time is longer on activated charcoal briquettes than charcoal briquettes. This suggests that the reduction in volatility due to activation causes the briquettes to take longer to ignite.

Burning rate is the reduction in weight per unit of time during combustion. Good quality of briquettes if they have a low combustion rate. Good quality charcoal briquettes have a long flame time in the combustion process and a high calorific value. The combustion rate of charcoal briquettes is influenced by the structure of the material, density, moisture content, *volatile matter*, *fixed carbon* and calorific value. The burning rate of activated charcoal briquettes is smaller than charcoal, indicating that activation of charcoal results in frugal briquettes.

Scanning Electron Microscope- Energy Dispersive X-Ray Spectroscopy (SEM_EDS) test.

Scanning Electron Microscope (SEM) measurement results of microwave-activated charcoal briquettes at 150 watts for 360 seconds, 480 seconds, 600 seconds:

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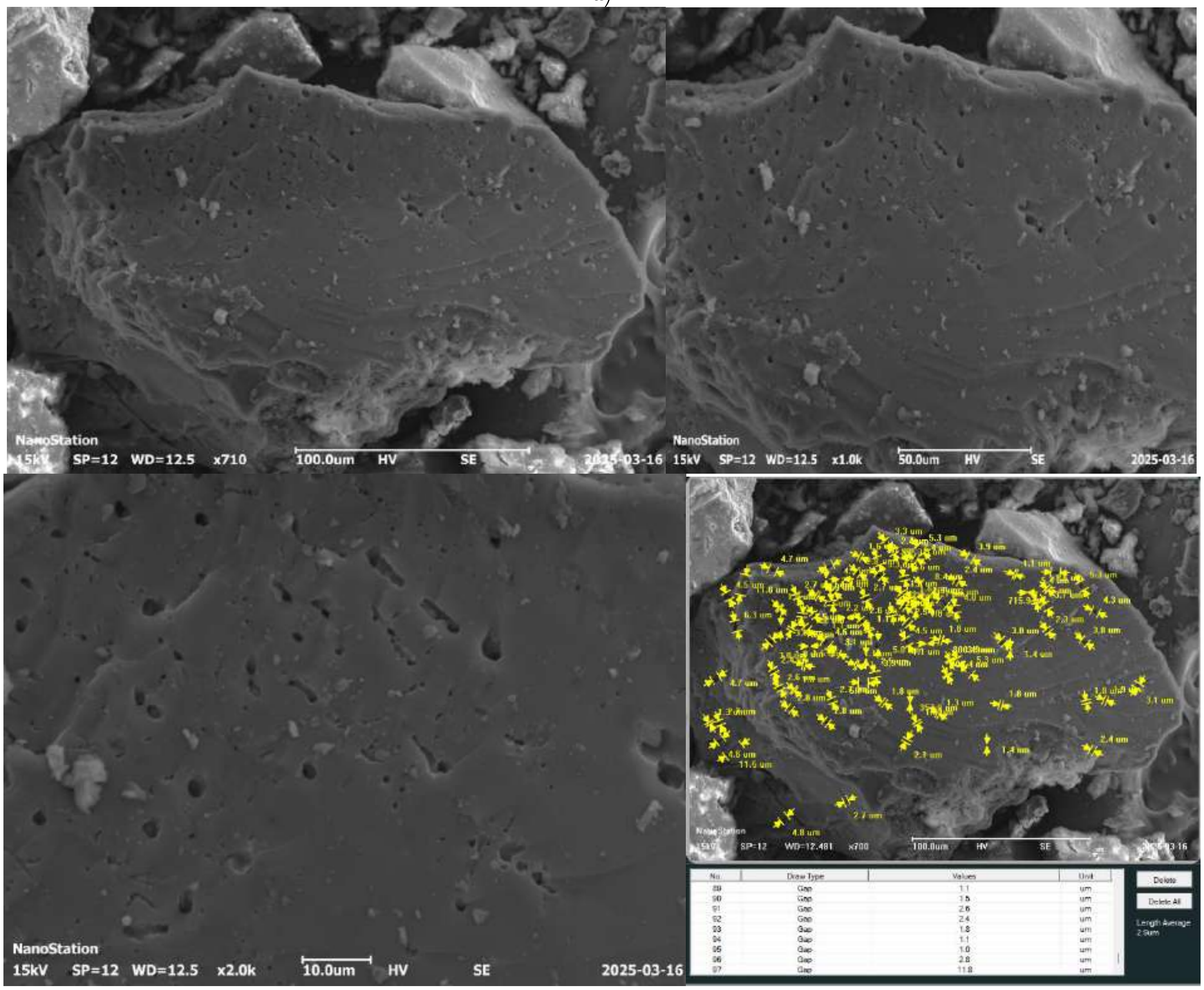

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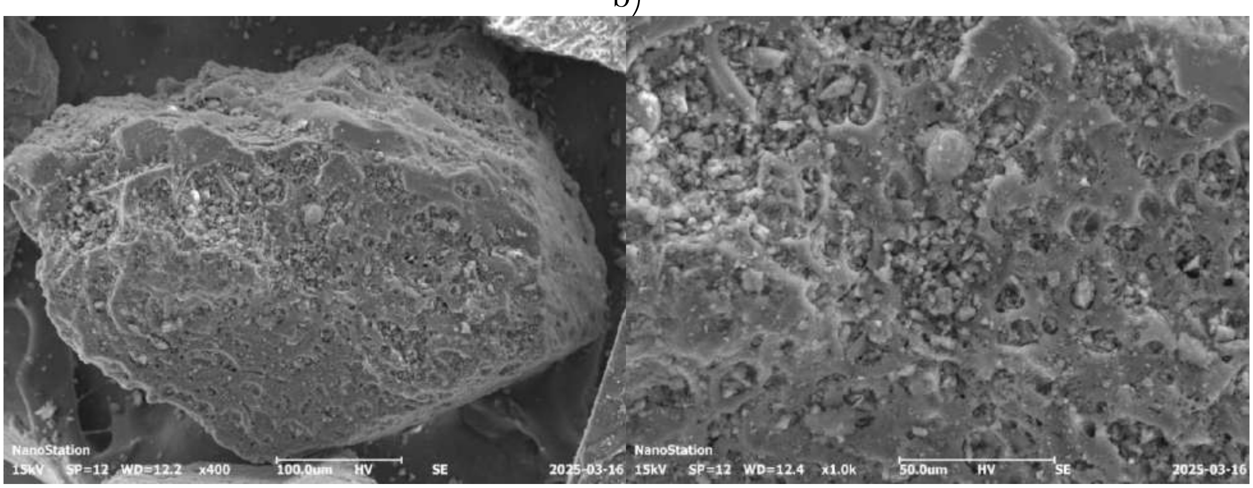

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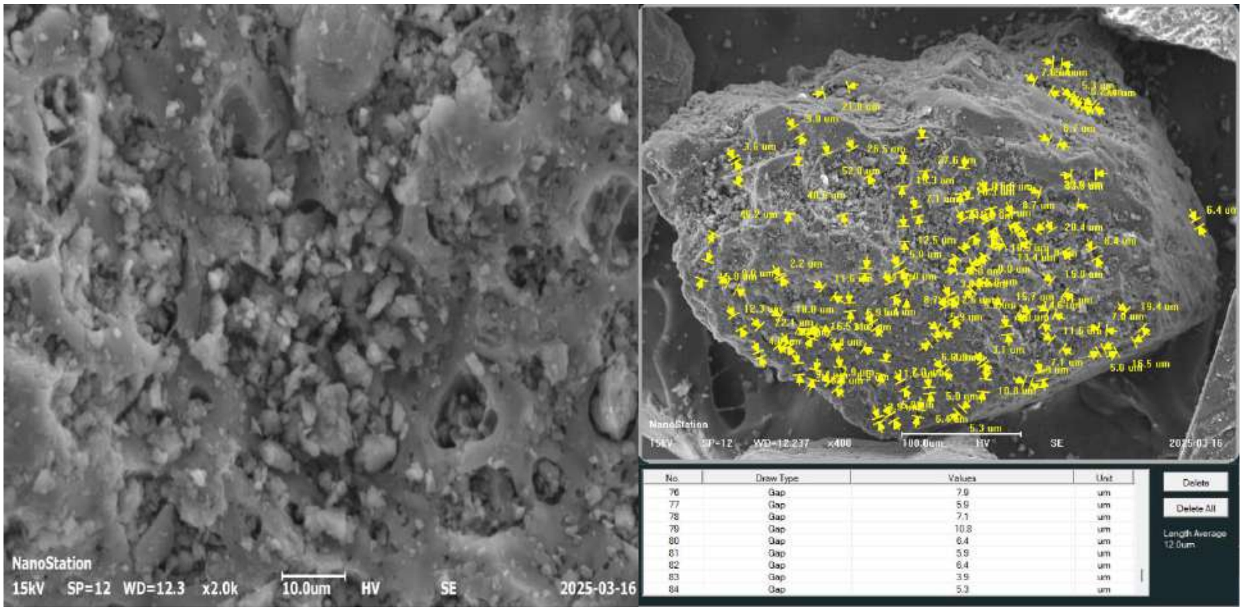
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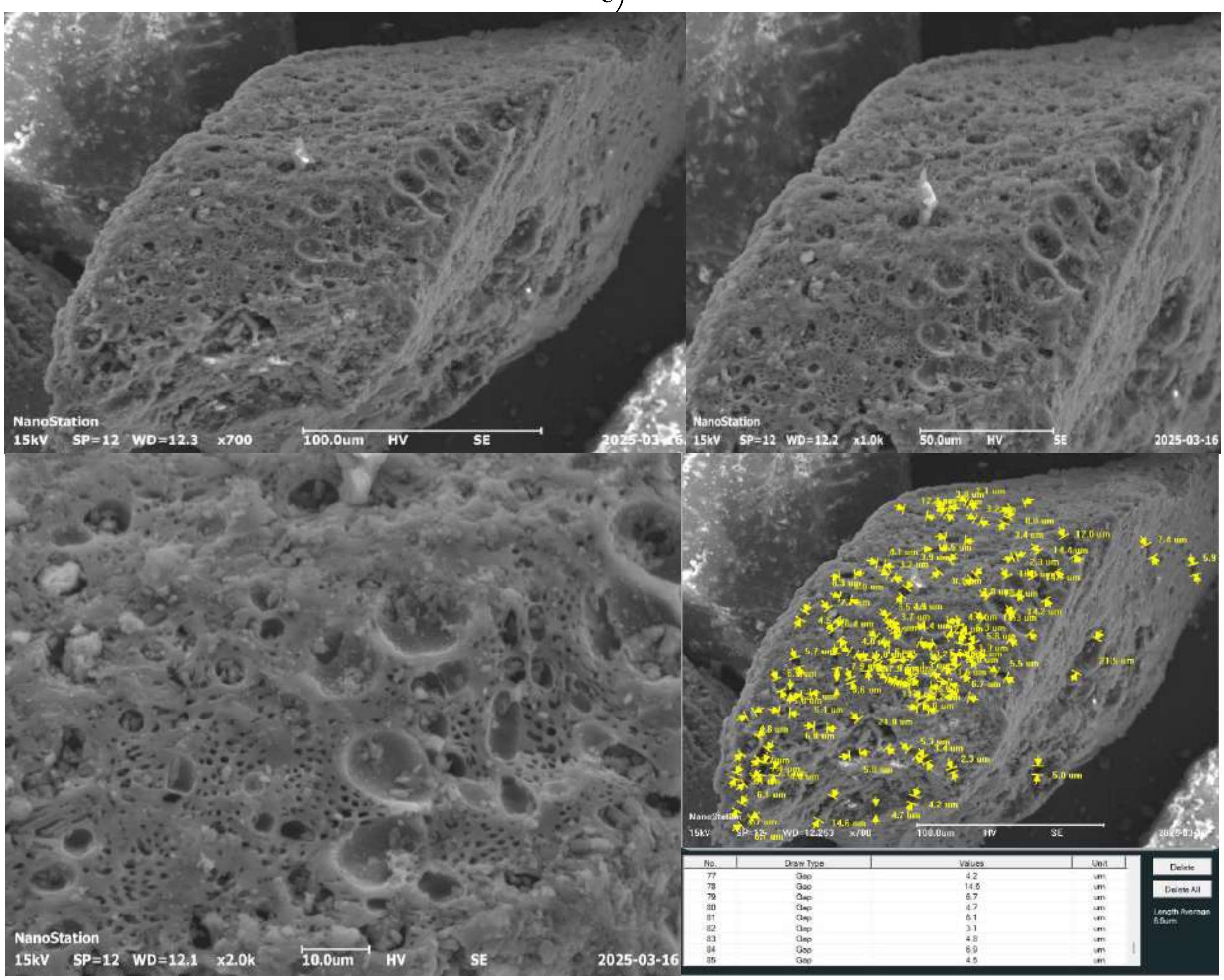
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d)

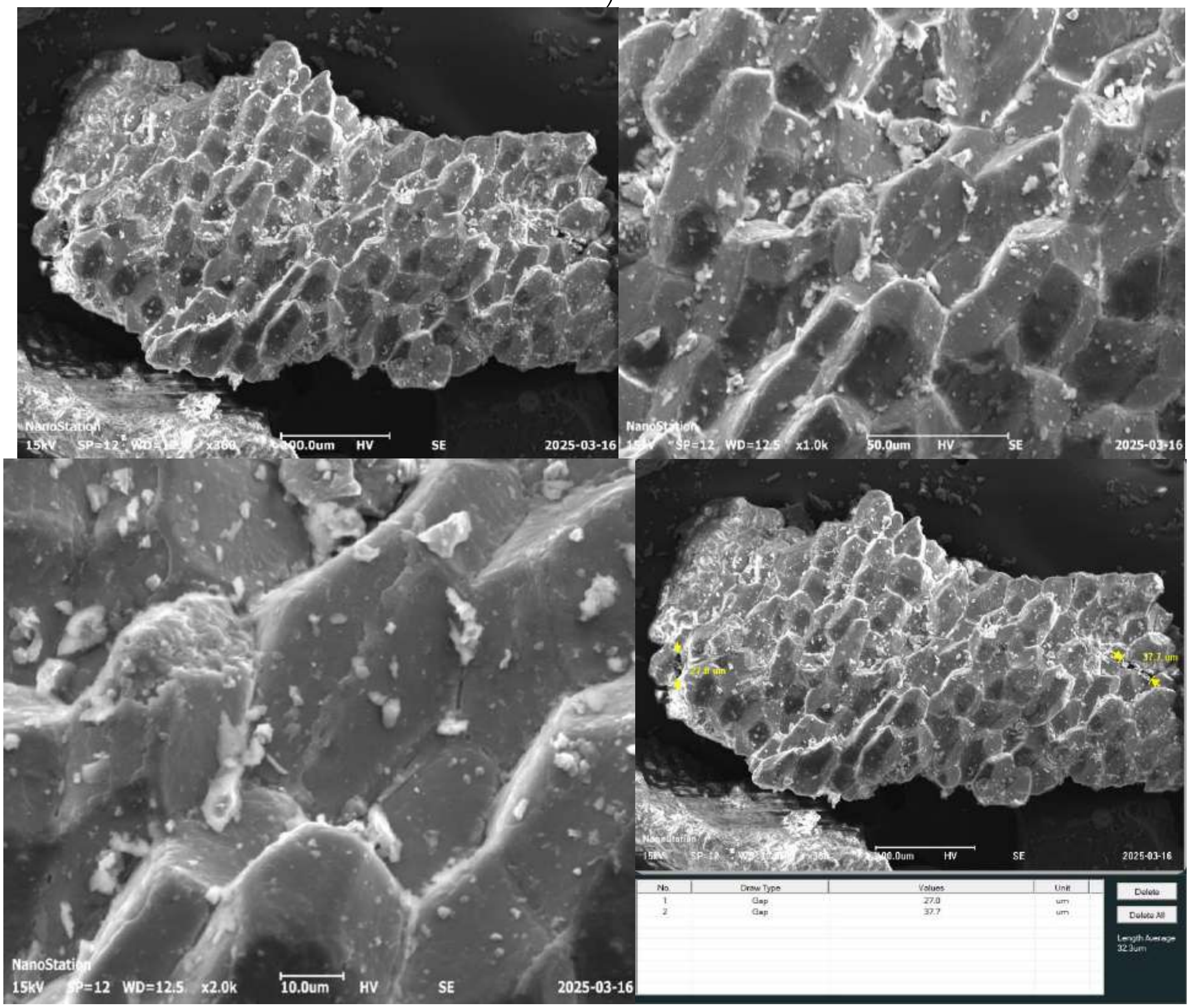


Figure 2.
Morphology and pores of palm shell charcoal briquettes (a) without activation (b) activated with 150 watts of power for 360 seconds, (c) activated with 150 watts of power for 480 seconds (d) activated with 150 watts of power for 600 seconds.

Observations using Scanning Electron Microscope (SEM) on palm shell charcoal briquette samples showed significant differences in the number and size of pores between the unactivated charcoal and those activated using a microwave with a power of 150 watts at various activation durations. The pore structure is highly influential in the combustion process because it affects the distribution of oxygen and the rate of combustion reactions, so the distribution, number, and size of the pores formed can affect the combustion performance of charcoal briquettes.

In the unactivated palm shell charcoal briquette sample, SEM results showed that the number of pores formed was 97 with an average pore diameter of 2.9 micrometers. These pores are evenly distributed, but with a relatively small size, which limits the efficiency of combustion. This pore structure suggests that although the number of pores is quite large, the small size reduces the surface area that can react with oxygen, making combustion less efficient. Research by He, et al. [11] shows that unactivated charcoal tends to have smaller pores with less even distribution, which leads to low combustion efficiency and shorter burn times [11].

In samples activated at 150 watts for 6 minutes, the microwave activation process produced pores with a number of 84 and an average diameter of 12.0 micrometers. Although the number of pores is slightly reduced, the larger pore size and better distribution provide increased combustion efficiency. The larger pore structure increases the surface area of the charcoal, allowing oxygen to react more quickly with the surface of the charcoal, which speeds up combustion despite a slightly shorter burning time. Research by Zhang, et al. [12] confirms that a shorter duration of activation with a microwave at low power can result in larger pores, albeit in small numbers, and this can improve combustion efficiency [13].

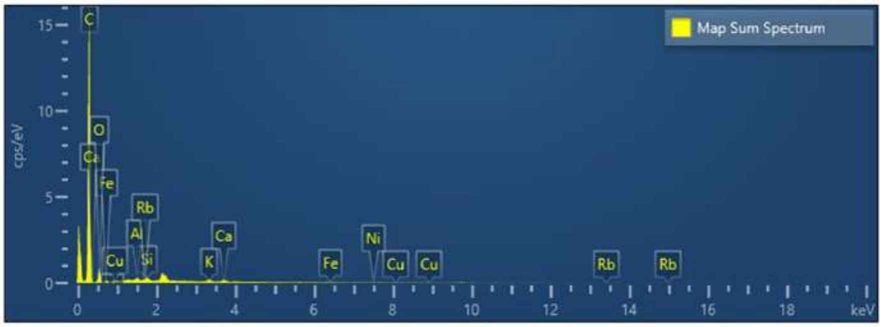
In samples activated at 150 watts for 8 minutes, the number of pores formed slightly increased to 85 with an average diameter of 6.6 micrometers. Longer activation duration results in more controlled pore size and more even distribution, which supports more stable and efficient combustion. Smaller pores with better distribution allow oxygen to react more effectively with charcoal, resulting in more controlled and efficient combustion. Research by Villota, et al. [14] states that increasing the duration of activation with a microwave can result in a more even distribution of pores, which contributes to a more stable burn [14].

In samples activated at 150 watts of power for 10 minutes, although the number of pores decreased significantly to only 2, the size of the pores formed was enormous, with an average diameter of 32.3 micrometers. Although the number of pores is very small, the large pore size allows oxygen to react more efficiently with the surface of charcoal. Larger pores slow down the rate of combustion and extend the duration of combustion because oxygen takes longer to spread over the entire surface of the charcoal. Research by Li, et al. [15] shows that although the number of pores is reduced, a larger pore size can slow down the rate of combustion and increase the duration of combustion, providing better stability in the combustion process [15].

The process of activating palm shell charcoal briquettes using microwave has been proven to be effective in reducing volatile levels, which has an effect on improving the quality of charcoal briquettes. Research by Li, et al. [16] suggests that heating with a microwave can lead to the release of volatile compounds and pore restructuring, where small pores merge to form larger pores. This contributes to an increase in the specific surface area and pore volume, which in turn improves the quality of the charcoal briquettes. The results of the SEM test shown in Figure 2 show that the best volatile level reduction occurs at the 10-minute activation time. Significant pore structural changes are seen, where small pores merge to form larger pores. These conditions contribute to the increased calorific value and burning time of charcoal briquettes, making them an excellent choice for energy-efficient applications. Thus, the right activation time is essential to produce palm shell charcoal briquettes with low volatility levels and ideal pore structure, according to the results of the research and microscopic observations carried out.

Overall, the SEM results showed that the duration of microwave activation had a significant effect on the pore structure of palm shell charcoal briquettes. Samples activated at 150 watts of power for 10 minutes showed an optimal balance between pore size and count, resulting in a controlled rate of combustion and a longer burn time. Although the number of pores decreases, the larger pore size allows for better control of the combustion rate and stability of the combustion process. These findings are in line with research by Ma, et al. [13] and Villota, et al. [14] which confirms that control of pore structure, especially through the duration of microwave activation, can produce charcoal briquettes with better efficiency and combustion resistance.

Discussion of Energy Dispersive X-Ray Spectroscopy (EDS) test results: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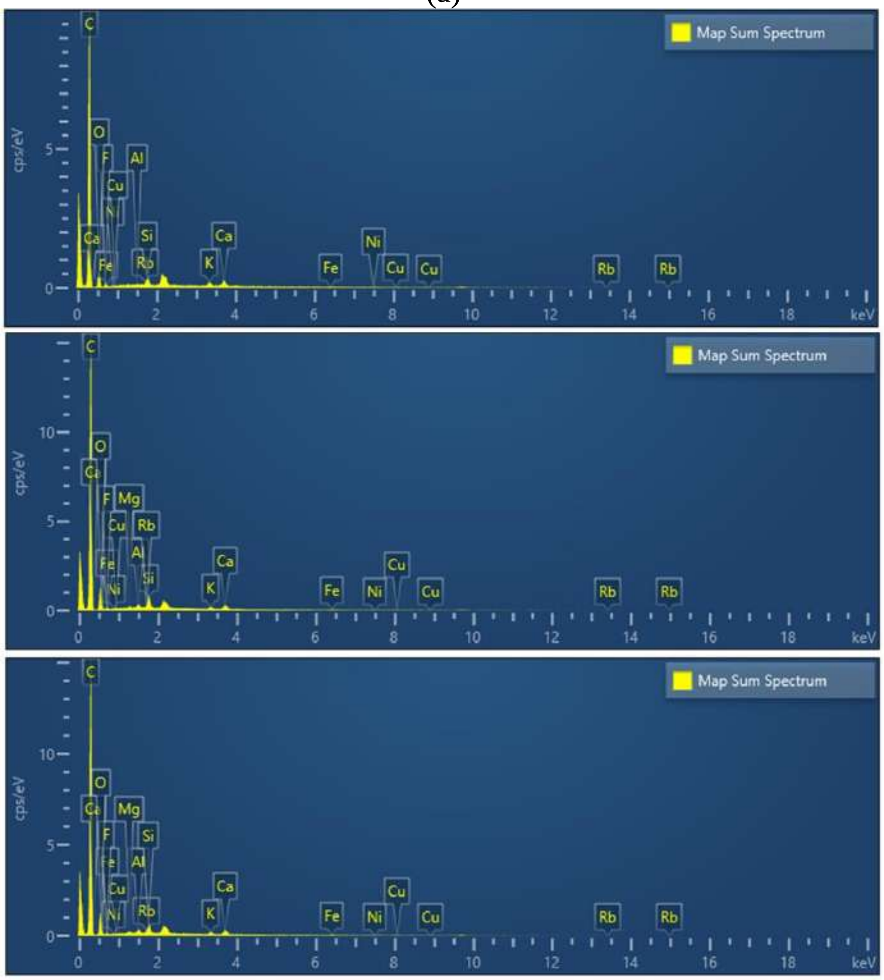
(a)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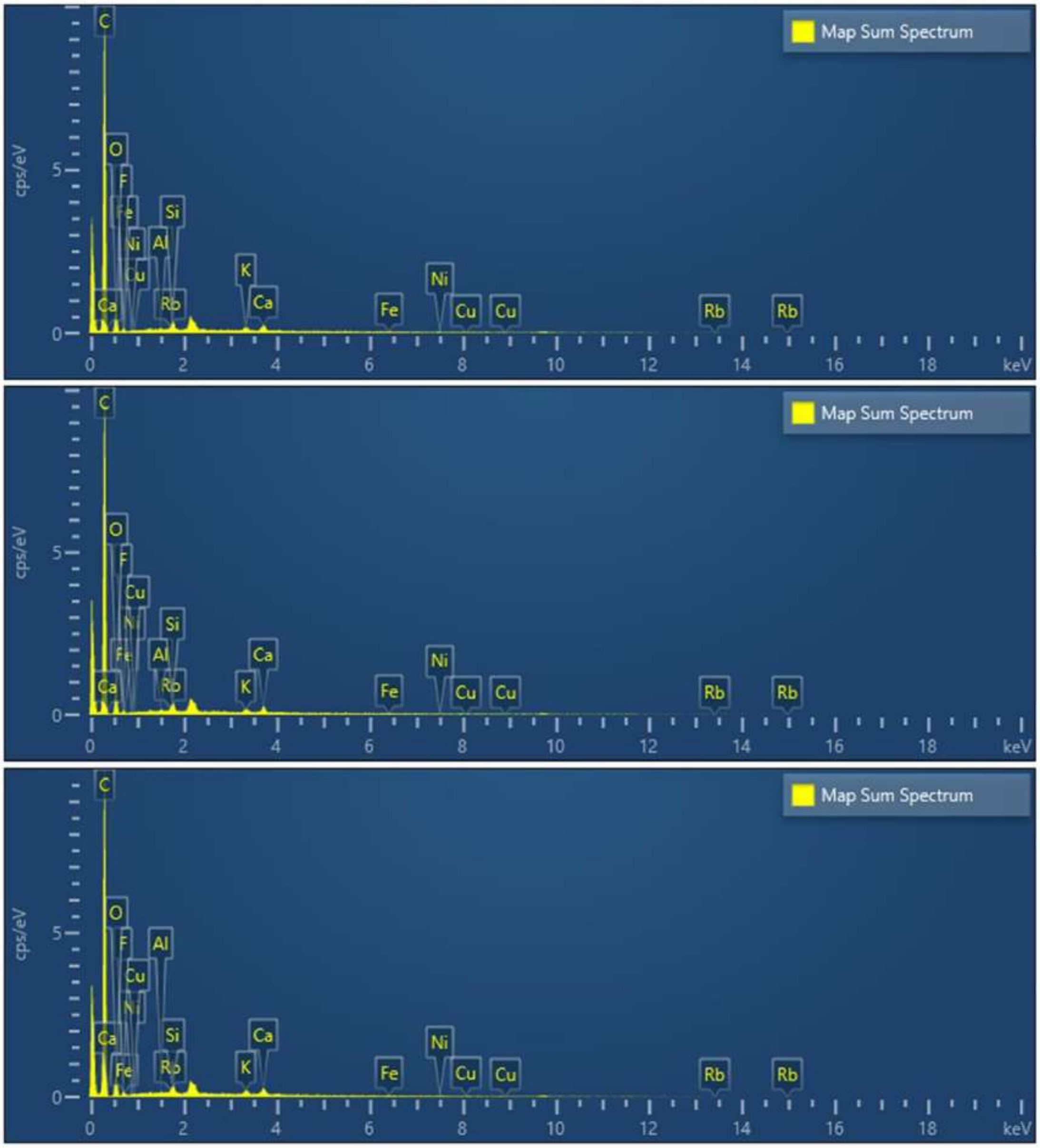

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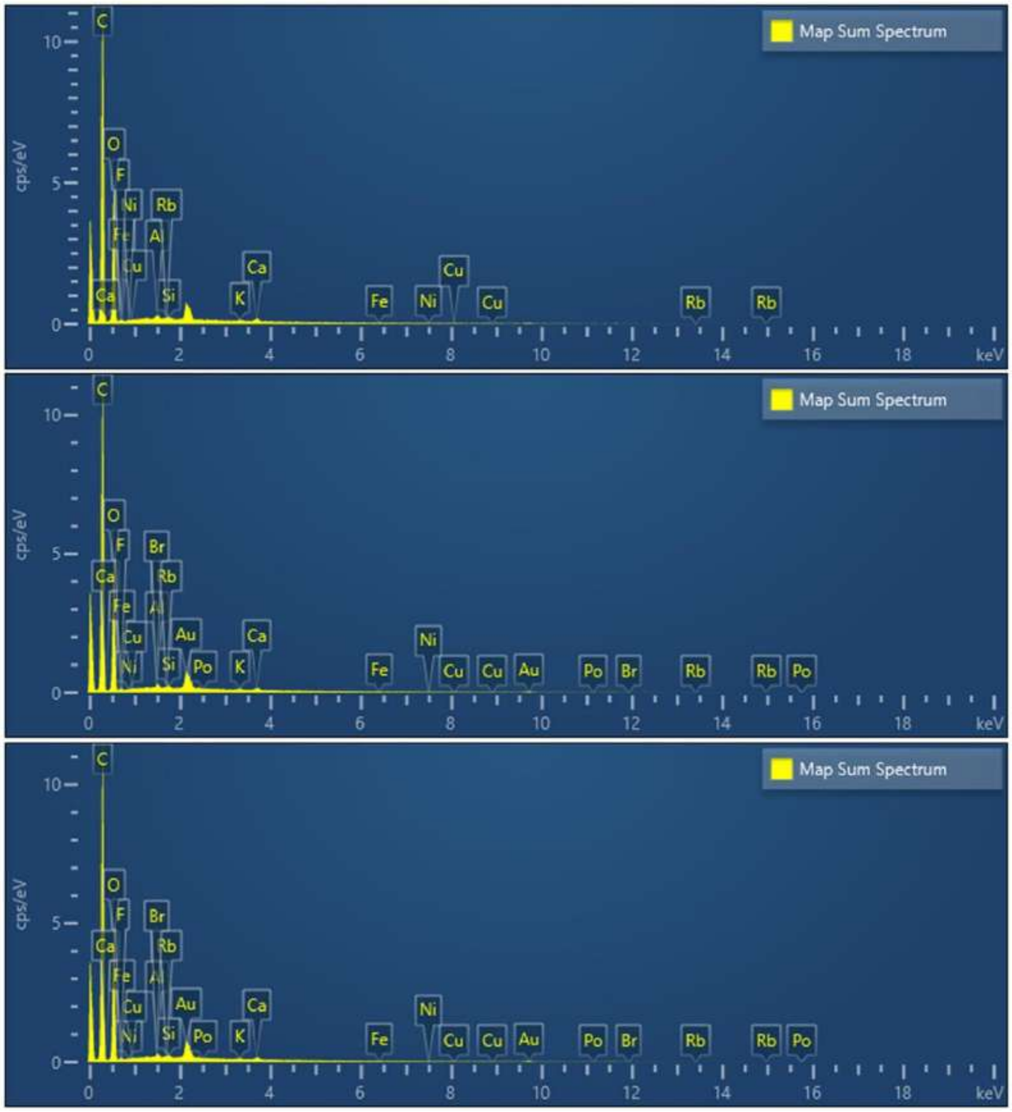

(d)

Figure 3.
EDS test of palm shell charcoal briquettes (a) without activation (b) activated with 150 watts of power for 360 seconds, (c) activated with 150 watts of power for 480 seconds (d) activated with 150 watts of power for 600 seconds.

Table 5.
Elemental Compositions of palm shell charcoal briquettes.

Elements	Without Activation (%)	Activation with 150 Watts for 360 s (%)	Activation with 150 Watts for 480 s (%)	Activation with 150 Watts for 600 s (%)
C	86.76	83.94	82.99	66.64
O	11.51	13.6	14.81	32.14
F	0.56	0.46	0.81	0.57
Al	0.13	0.03	0.07	0.04
Si	0.15	0.91	0.6	0.04
K	0.26	0.42	0.18	0.06
Ca	0.42	0.17	0.41	0.18
Fe	0.12	0.38	0.04	0.03
Ni	0	0.01	0.01	0.03
Cu	0.04	0.01	0.01	0.06
Br	0.01	0.03	0.01	0.14
Rb	0	0	0.02	0.03
Po	0	0.03	0	0

The results of the Energy Dispersive X-ray Spectroscopy (EDS) test showed significant differences in carbon and oxygen levels in microwave-activated charcoal samples at 150 watts with variations in activation duration, as well as unactivated samples. This composition has a direct effect on the combustion efficiency and calorific value of charcoal, which plays an important role in the performance of palm shell charcoal briquettes. In the inactivated sample, the average carbon content detected was 86.76%, while the average oxygen level was recorded at 11.51%. Although high carbon levels support good combustion potential, relatively low oxygen levels limit charcoal's ability to react optimally with oxygen. This results in faster combustion, but with a lower calorific value as oxidation reactions do not occur efficiently. Inefficient combustion produces less energy, which is reflected in lower calorific values and shorter burn times.

In the activated sample with a power of 150 watts for 6 minutes, the average detected carbon level was 83.94%, while the average oxygen level was 13.6%. This increase in oxygen levels compared to samples without activation favors a more efficient combustion process. The pore structure formed in this sample allows for better distribution of oxygen to react with carbon. Although the carbon levels were slightly lower compared to the non-activated sample, the significant increase in oxygen levels helped improve the combustion rate and calorific value. However, despite the improvement in combustion efficiency, the resulting calorific value is still lower compared to samples that are activated for longer.

In the samples activated for 8 minutes, the detected carbon content averaged 82.99%, and the oxygen content was recorded at 14.81%. Higher oxygen levels compared to the 6-minute activated sample resulted in an increased oxidation reaction with carbon. Combustion in these samples takes place more stable and more efficiently. A more controlled combustion process results in higher calorific values and longer burning times. These findings suggest that longer activation durations result in better compositional combinations for optimal combustion.

In the sample activated for 10 minutes, the detected carbon level was 66.64%, while the oxygen level increased significantly to 32.14%. Although the carbon levels decreased slightly compared to the rest of the sample, the very high increase in oxygen levels allowed for more efficient and controlled combustion. The high oxygen content accelerates the oxidation reaction, resulting in more stable combustion and higher calorific values. Although the amount of carbon decreases slightly, the high oxygen levels contribute to more efficient combustion, resulting in more energy and longer burn times. This shows that oxygen plays a crucial role in optimizing combustion, which contributes to the best performance of charcoal briquettes.

The higher calorific values and more efficient combustion rate in samples activated for 10 minutes at 150 watts of power can be explained by a combination of two main factors: large pore diameter and very high oxygen levels. Larger pores allow for a more even distribution of oxygen throughout the surface of the charcoal, accelerating the oxidation process, and increasing the rate of combustion. At the same time, high oxygen levels accelerate oxidation reactions, produce more energy in the form of heat, and favor more controlled combustion, which results in higher calorific values. In this case, the sample activated at 150 watts for 10 minutes showed the most optimal conditions for the burning of palm shell charcoal briquettes, with a combination of fairly high carbon levels and excellent oxygen levels. These results suggest that in addition to large pore diameters, high oxygen content is a key factor that allows for more efficient combustion and results in higher calorific values He, et al. [11] and Ma, et al. [13].

Overall, the longer activation duration at 150 watts of power, especially for 10 minutes, results in the most optimal conditions for palm shell charcoal briquettes. Although the carbon content decreased slightly, the significant increase in oxygen levels in these samples allowed for more efficient combustion and resulted in higher calorific values. The combination of a fairly high carbon content and excellent oxygen makes this sample ideal for more efficient and more durable combustion applications.

In addition, based on the results of EDS measurements, no harmful elements that have the potential to become pollution, such as sulfur and nitrogen, were found in either charcoal briquettes produced without activation or those through microwave activation. According to Gao, et al. [17] the carbonation process of palm oil shells has been shown to be effective in reducing sulfur and nitrogen gas emissions. In addition, the microwave activation process can further lower the sulfur and nitrogen content in biochar, potentially making it more environmentally friendly. Caroko, et al. [18] It was also revealed that microwave activation could further reduce sulfur and nitrogen content, making charcoal briquettes cleaner, more stable, and safer to use as fuel in the long run.

SEM measurement results of microwave activated charcoal for 480 seconds at a power of 70 watts, 150 watts, 230 watts:

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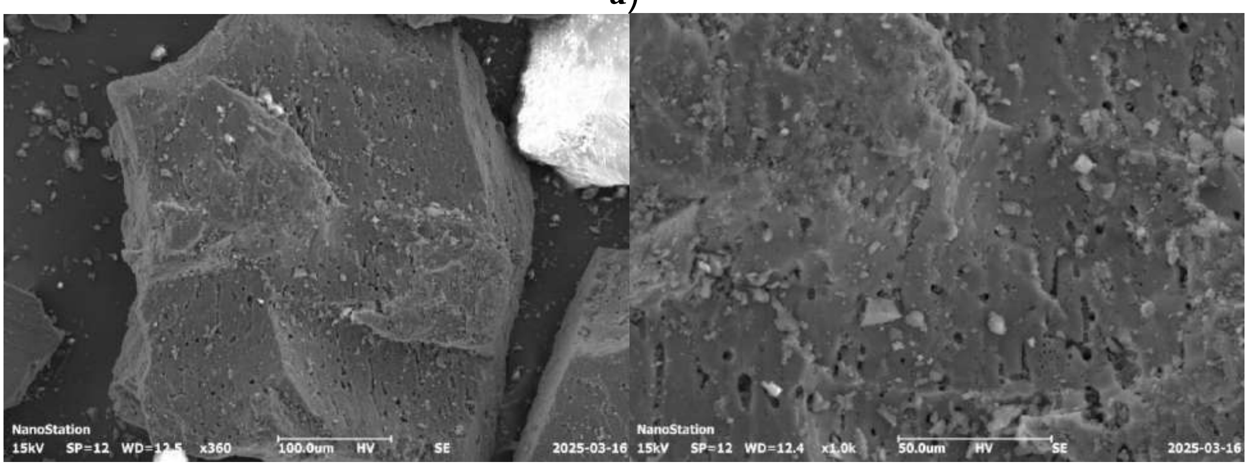

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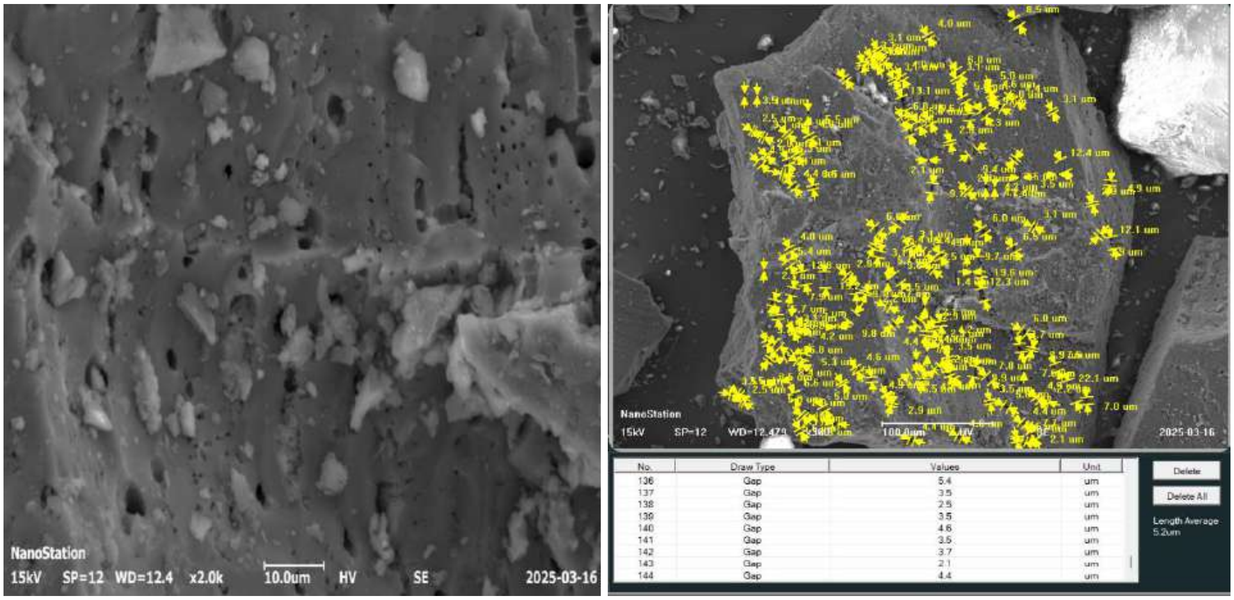
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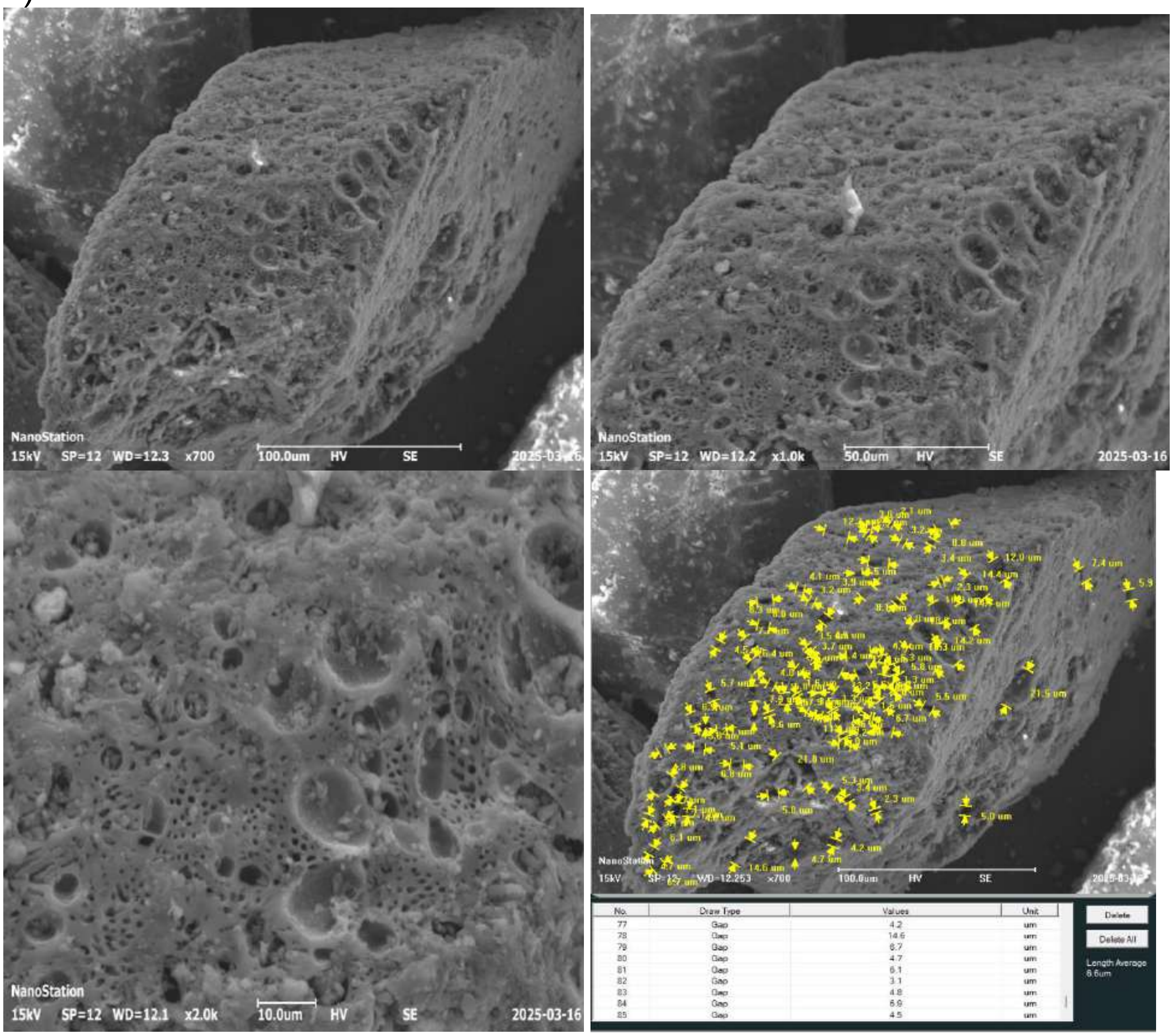
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Length Average 6.6um

c)

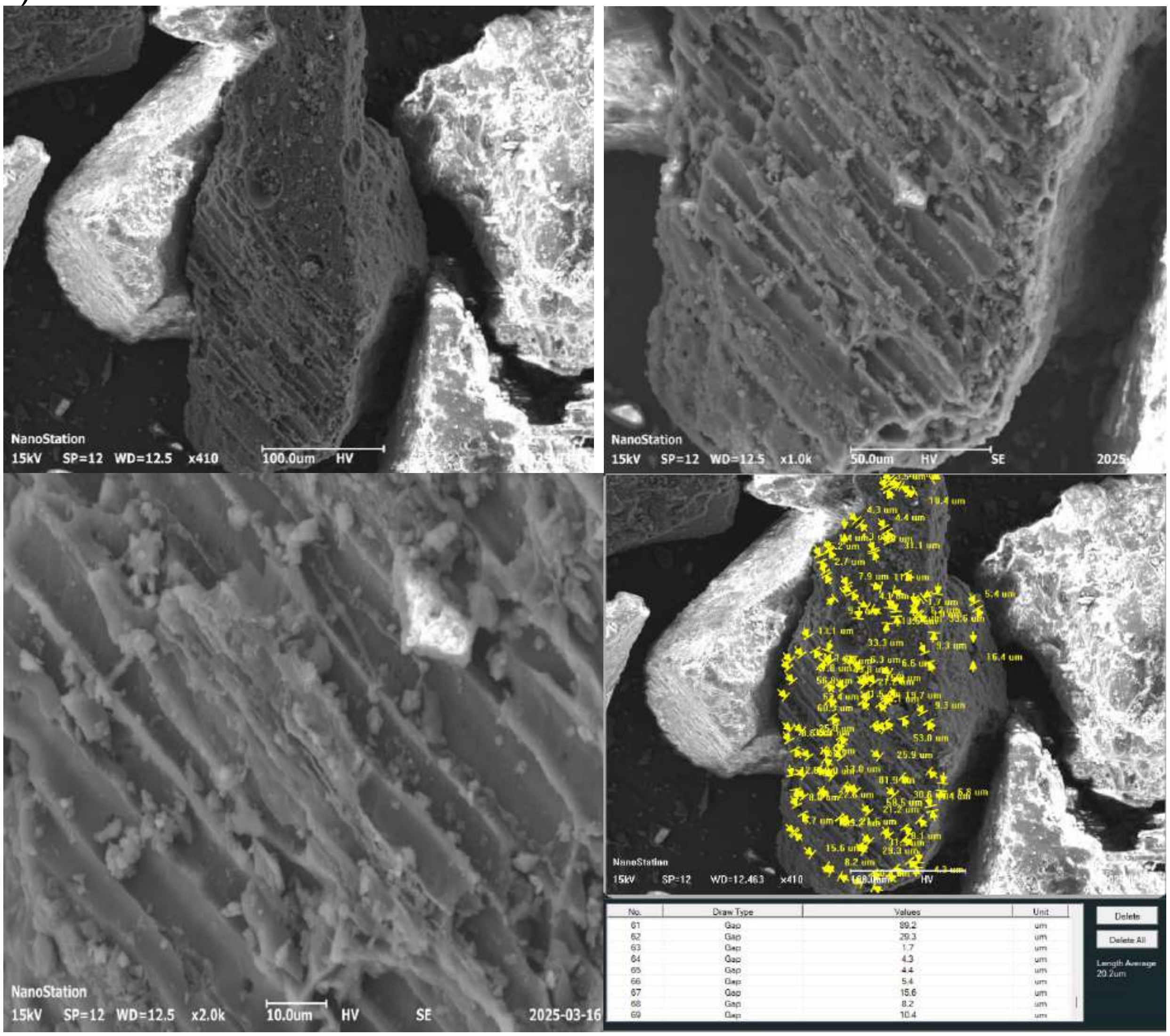

Figure 4.
Morphology and pores of charcoal briquettes from palm shells activated for 480 seconds at (a) 70 watt power, (b) 150 watts and (c) 230 watts.

This study aims to evaluate the effect of microwave activation on the pore structure of activated palm shell charcoal briquettes at three different power levels, namely 70W, 150W, and 230W, with a duration of 8 minutes. Based on the morphology results of Figure 4, it is shown that the change in microwave power has a significant effect on the number and size of pores formed in the material. At 70W power, the number of pores formed is the most, which is 144 pores, with an average pore diameter of 5.2 micrometers. This indicates that at low power, the activation process produces more pores, but with a relatively small pore size. This is in line with findings in the study [16] which states that at low power, a more even distribution of heat allows for the formation of larger numbers, albeit with smaller sizes.

When the power is increased to 150W, the number of pores decreases to 85, but the average diameter of the pores increases to 6.6 micrometers. This suggests that at medium power, the activation process reduces the number of pores formed, but results in slightly larger pores. Research Ahmad, et al.

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[19] also shows that at medium power, the microwave activation process results in a larger pore size even though the number of pores decreases. The increased power causes the movement of molecules in the material faster, resulting in the formation of larger pores with fewer volumes.

At 230W power, the number of pores is further reduced to 69, while the average diameter of the pores increases significantly to 20.2 micrometers. This shows that at high power, even though the number of pores decreases drastically, the pore size becomes much larger compared to the previous two power levels. This is in line with research Thue, et al. [20] which states that at high power, even though the number of pores decreases, the pore size can increase significantly due to a more aggressive and rapid heating process, which leads to greater expansion of the formed pores.

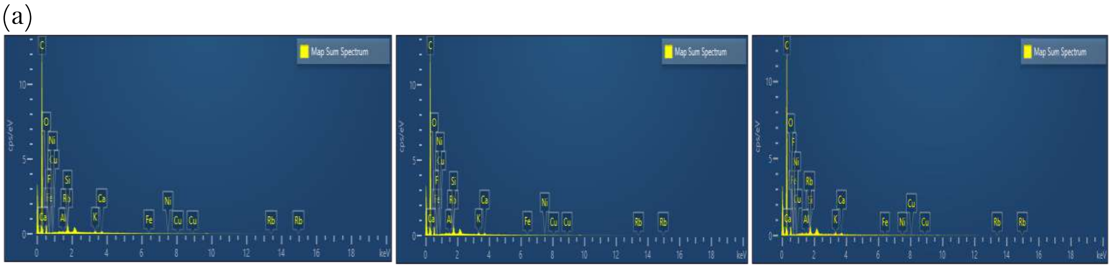
These results suggest that there is an inverse relationship between pore count and pore size: the higher the microwave power used, the less pore number is formed, but the larger the pore size produced. At low power (70W), more pores are formed as the heating process takes place more slowly, giving the material more opportunity to develop into small pores. In contrast, at high power (230W), more intense heating causes the material to decompose more quickly and leads to the formation of larger pores, albeit in fewer amounts. Research [21] also shows that the higher the microwave power, the less number of pores form, but the pore size increases due to the faster and more intense heating process.

This significant increase in pore size at high power (230W) can be interpreted as a result of a faster and more aggressive heating process, which leads to greater pore expansion but reduces the total number of pores. Thus, it can be concluded that the change in microwave power has a direct impact on the structure of the formed pores, with low power producing many small pores and high power producing few large pores. Research by Wang, et al. [22] also noted that at high power, although the number of pores decreases, larger pore sizes can improve the structural properties of the material.

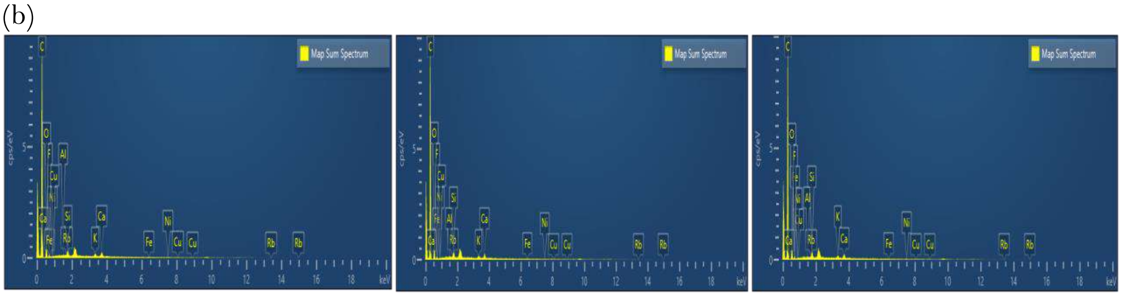
The 480 seconds duration used in this study seems to be sufficient to allow for significant structural changes to the material, so that comparisons between power variations can be made clearly without causing too drastic changes to the material. Research by Chakraborty, et al. [21] showed that sufficient activation duration provides a balance between efficient heating and optimal pore formation without causing excessive material damage, allowing for clearer comparisons between power variations.

EDS test results of microwave activated charcoal for 480 seconds at a power of 70 watts, 150 watts, 230 watts:

(a)



(b)



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(c)

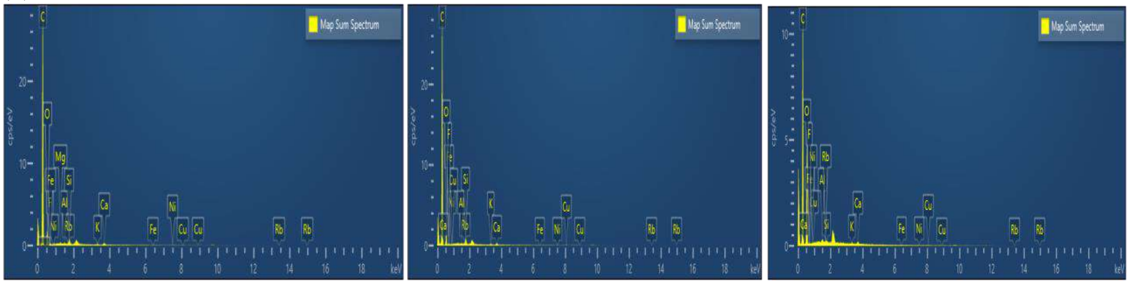

Figure 5.
EDS test of briquettes from activated palm shell charcoal for 480 seconds at (a) 70 watt of power (b) 150 watt of power and (c) 230 watts of power.

Table 6.
Elemental Compositions of palm shell charcoal briquettes activated for 480 seconds.

Elements	70 Watts of power (%)	150 Watts of power (%)	230 Watts of power (%)
C	84.83	82.99	81.10
O	13.67	14.81	16.91
F	0.52	0.81	0.71
Al	0.03	0.07	0.06
Si	0.36	0.6	0.07
K	0.2	0.18	0.28
Ca	0.21	0.41	0.13
Fe	0.03	0.04	0.45
Ni	0.01	0.01	0.11
Cu	0.05	0.01	0.01
Br	0	0.01	0.02
Rb	0.04	0.02	0.03
Po	0	0	0.08

The process of activating palm shell charcoal briquettes using a microwave with a power variation of 70, 150, and 230 watts for the same duration, i.e. 8 minutes, affects the chemical composition produced, especially on the elements carbon and oxygen as shown by the results of the EDS test in Figure 5 and Table 4. At 70 watts, the carbon content reaches 84.83% and oxygen is 13.67%. When the power increases to 150 watts, the carbon content decreases slightly to 82.99%, while the oxygen increases to 14.81%. This decline continued at 230 watts of power, with 81.10% carbon and 16.91% oxygen. This increase in oxygen levels indicates a chemical change in the surface of the charcoal due to higher power treatments, which is likely related to more intense oxidation processes.

From the data, it can be seen that despite the variation, the levels of carbon and oxygen produced at the three power levels are in a range that is not much different. This shows that the treatment for 8 minutes can be categorized as a moderate activation time, since it is able to produce relatively similar elemental characteristics, albeit with different power levels. The similarity of these elemental levels suggests that the duration of time plays an important role in the stability of the composition of the activated charcoal that is formed.

In addition, the results of the EDS test did not show the presence of nitrogen or sulfur elements in the three samples. The absence of these two elements indicates that there are no residues that can cause harmful emissions during the use of briquettes. This is also in line with findings [5] which reported similar results in activated charcoal made from palm oil shells activated using microwaves. Research by He, et al. [11] also reinforces that activation with a microwave in a short period of time can trigger changes in the surface of charcoal, mainly through the formation of oxygen groups, without sacrificing too much carbon structure.

Thus, it can be concluded that an activation time of 8 minutes in microwave power variations produces activated charcoal with carbon and oxygen levels that exhibit moderate and consistent patterns, and does not contain elements that have the potential to pollute the environment.

4. Conclusion

Microwave activation of charcoal can increase the calorific value of briquettes to 8015.14 cal/gr, and decrease the burning rate to 0.046 g/min, at 230 watts of power and 480 seconds of time. There is a change in the morphology and pore diameter of charcoal due to the activation process with a microwave. Briquettes do not contain Nitrogen and Sulfur, so they are safe to use as fuel.

Transparency:

The authors confirm that the manuscript is an honest, accurate, and transparent account of the study; that no vital features of the study have been omitted; and that any discrepancies from the study as planned have been explained. This study followed all ethical practices during writing.

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