Coconut Shell Carbonization to Produce Biochar Using a Cylinder Retort Kiln

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Abstract. Biomass is an alternative energy source derived from organic materials such as wood and coconut shells. Biomass is used by communities as an alternative fuel for cooking through direct combustion. One way to improve the quality of biomass is through carbonization. Carbonization is a combustion method with limited air to produce charcoal with high calorific value. One commonly used carbonization method is the drum retort kiln, which involves external heating of the kiln drum. The heat generated from this combustion process is convected into the drum to heat the raw materials inside. This study aims to analyze the effect of carbonization time and temperature on the quality of charcoal, evaluated by yield, proximate test values, fuel energy values, and specific fuel consumption during the carbonization process. The optimal results from this carbonization process were achieved at a temperature of 400˚C for 135 minutes with four kilograms raw materials, 2.80% water content, 2.80% ash content, 25.65% volatile matter, and 71.55% fixed carbon with the yield produced was 60.75% or 2.43 kg and spesific fuel consumption value of 0.4038kkal/kg. These scores meet the SNI 1-1683-1996 standards for water and ash content, while the volatile matter content approaches the applicable standards.

Keywords: Coconut shell, carbonization, biochar, cylinder retort kiln.

1 Introduction

The utilization of renewable energy has been steadily increasing in line with the growing number of industries and the global population. This utilization is part of efforts to mitigate the global energy crisis issue. One of the renewable energy sources that can be prioritized for long-term utilization is biomass [1]. Biomass contributed for approximately 14% of the world's total energy consumption, surpassing coal, which constitutes 12% of the global energy supply [2]. Biomass is an alternative energy source derived from organic materials and organic waste, which are by-products of a process [3]. The application of biomass in South Sumatra has significant potential, considering the abundant availability of biomass from the plantation sector, reaching 2,552,440 tons in 2021 [4]. There are two types of biomass raw material sources: woody biomass, which includes various types of wood, branches, and tree trunks, and non-woody

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biomass, which consists of fruit and vegetable residues, straw, and animal manure [5]. Commonly, biomass is an alternative solid fuel for rural households, often utilized through direct combustion without any prior processing.

Carbonization, or charring, is one approach to converting biomass into an alternative energy product. Carbonization is a process to enrich carbon content by eliminating non-carbon elements using thermal decomposition, reducing the volatile matter content of raw materials, and converting charcoal to have a higher fixed carbon content [6]. Charcoal resulting from carbonization is a product that has undergone heating and has a high calorific value with minimal water content. The higher the temperature during the carbonization process, the lower the water content, ash content, and volatile matter, resulting in a higher calorific value [7].

There are several types of carbonization kilns commonly used depending on their application [8]. The earth kiln is the simplest type of carbonization kiln and has long-term durability, making it frequently used for carbonizing organic waste. There is also the Drum Retort kiln, which is a cylindrical kiln designed to rotate to evenly distribute external heating. The kiln design will affect the carbonization process [3]. On of the most frequent biomass raw materials used in the carbonizaiton process are coconut shells. These hard shells serve as protective layers for coconuts and are commonly employed as fuel in combustion processes. Typically, coconut shells are burned directly when used as fuel. However, through carbonization, their economic value can be enhanced by converting them into smokeless charcoal with a high calorific value.

Based on research conducted by Qistina, the characteristics of ash content in coconut shell briquettes reached 11.99% and moisture content 4.34% with a carbonization time of 50 minutes at a temperature of 75°C. These ash content levels are still far from the standards set by SNI 01-6235-2000 for charcoal briquette quality. This is because ash, the by-product of combustion, contains no carbon or calorific value. The amount of ash is a crucial factor in evaluating charcoal quality, as ash-free fuels like oil and gas have superior combustion characteristics [9]. Research by Surono on the quality of alternative fuels produced through carbonization showed an ash content of 4.14% and a high volatile content of 32.71% on the resulting product, which indicate in considerable CO emissions [10]. Based on the description above, the author aims to conduct research involve carbonization with different temperature and combustion time variations, utilizing the cylinder retort kiln method and using coconut shell as the raw material

2 Material and Methods

2.1. Tools and Materials

In this study, the raw materials used is coconut shells obtained from coconut farmers around the Palembang City area. The equipment used in this research is a set of carbonization tools using the cylinder retort kiln method. The retort column in the center of the carbonization chamber, which directly penetrates from the combustion chamber, will conduct heat from the combustion chamber to the center of the carbonization tube. A design of the equipment used in the experiment is presented in figure 1.

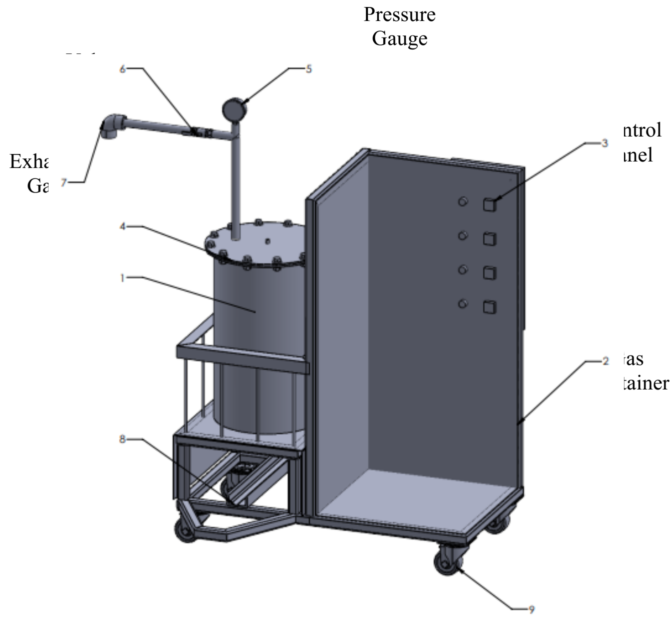


Fig. 1. SEQ Figure * ARABIC 1. Carbonization Unit

2.2. Methods

This research conducted from February until July 2024 at the Energy Engineering Laboratory and the product analyzed at Chemical Engineering Laboratory of Politeknik Negeri Sriwijaya. The variables used in this study consists of variations in the different of carbonization time (75 minutes, 90 minutes, 105 minutes, 120 minutes, and 135 minutes), carbonization temperature (300˚C and 400˚C), and raw materials mass (4 kg and 5 kg).

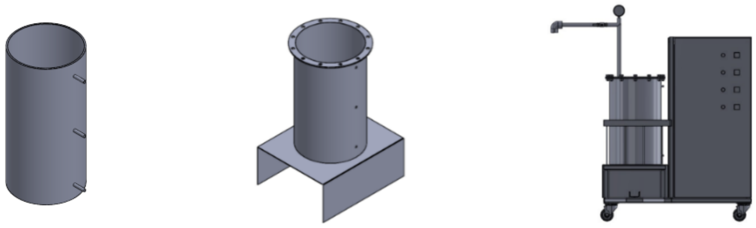
Equipment Design

Structurally, the design of this equipment is divided into three main sections: the Carbonization Chamber, the Combustion Chamber, and the Control Panel.

The Carbonization Chamber is a cylinder where the carbonization of raw materials placed. Carbonization chamber located inside the combustion chamber and has a diameter of 23.2 cm and a height of 50 cm. Inside this chamber, there is a retort tube with a diameter of six cm and a height of 49.2 cm, positioned in the center of the carbonization chamber. The carbonization chamber has characteristic to isolate the raw material from external circumstances, optimally utilize the gas by collecting and recovering the gas, and evenly distribute the heat through the retort pipe.

Surrounding the carbonization chamber, the Combustion Chamber is the outer cylinder that encloses the carbonization tube and combustion area in one unified space. The combustion chamber has a length of 45 cm, a height of 22 cm, and a width of 40 cm, with a five cm gap between the combustion chamber and the sides of the carbonization chamber on both the right and left. At the top of the combustion chamber, there are thermocouples and a pressure gauge. Inside the combustion area, there is a gas burner with a diameter of eight cm and a height of 11 cm, connected to a 0.5-inch gas pipe that is 41 cm length.

The third part is the Control Panel. The control panel functions to turn the equipment on and off. In addition, the control panel is used to display the temperature in the four combustion zones.



(a) (b) (c)

Material Preparations

The coconut shells used as raw material are initially cleaned of residual fibers and then reduced in size to approximately 2 to 4 cm.

Fig. 3. Raw Material Preparations

Carbonization Process

The carbonization process is conducted by loading four kg of pre-treated raw material into the carbonization chamber. The chamber is then sealed, and the operating parameters are adjusted according to the operating conditions. After the carbonization complete, the product are permitted to cool in ambient air, and the yield of the resulting charcoal is weighed. Then the carbonization process repeated for another operating conditions with different variable.

Moisture Content

The moisture content refers to the amount of water present in the sample under field conditions. Typically, the moisture content in charcoal ranges from 6-8% of the total material composition. A lower moisture content indicates a higher quality of charcoal.

To determine the moisture content, combustion is carried out at a temperature of 105-110°C for two hours using a burner.

Ash Content

Ash content decreases the quality of charcoal by reducing the calorific value. This reduction occurs because the heat released during combustion is used to decompose the mineral matter present. The resulting ash consists of compounds that were not burned during the combustion process. Ash can include minerals that are not combustible or oxidizable by oxygen, such as SiO_2, Al_2O_3, Fe_2O_3, and CaO [7]. Additionally, ash content reflects the inorganic fraction within the material [11]. To determine the ash content, combustion is carried out at a temperature of 650°C for two hours using burner.

Volatille Matters

Volatile matter content is used to measure the amount of compounds that yet not evaporated during the carbonization process but do vaporize at the higher temperature of carbonization. Volatile substances typically include combustible gases such as H_2, CO, and CH_4 [12]. The higher volatile matter content results in increased smoke production [13]. To determine the moisture content, combustion is carried out at a temperature of 950°C for seven minutes using burner.

Table 1. Indonesia National Standard for Biochar from Coconut Shell

No	Type of test	Unit	Requirement
1.	Volatille Matters	%	Max. 15
2.	Moisture Content	%	Max. 6
3.	Ash Content	%	Max. 3

Fixed Carbon

Fixed carbon refers to the percentage of carbon in charcoal after all volatile substances have been removed. A higher fixed carbon content results in a higher calorific value, which improves the overall fuel efficiency [13]. To calculate the fixed carbon value, the following formula is used:

$$FC = 100 - (A + VM)\ \% \tag{1}$$

Specific Fuel Consumption (SFC)

Specific Fuel Consumption (SFC) is the ratio of total fuel consumption to the amount of charcoal produced. To calculate the specific fuel consumption, the following calculation is used:

$$SFC = \frac{Q_{bb}}{W} \tag{2}$$

3. RESULTS AND DISCUSSIONS

3.1 The Effect of Carbonization on Charcoal Yield

Based on figure 3, the percentage yield of charcoal is significantly influenced by both the temperature and duration of the carbonization process. The highest charcoal yield was observed at 300˚C for 75 minutes with four kilograms raw materials, achieving

72.25%. Conversely, the lowest yield was recorded at 400˚C for 135 minutes with four kilograms raw materials, which resulted in a yield of 60.75%.

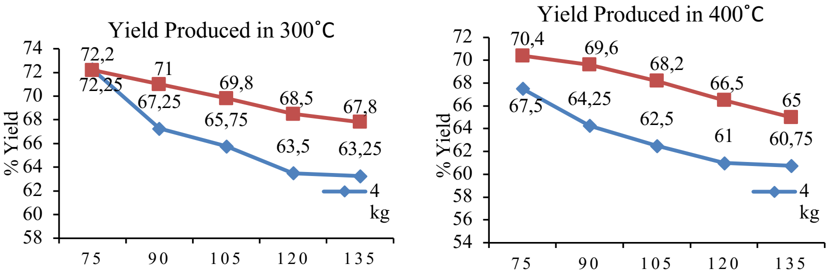


Fig. 4. SEQ Figure * ARABIC 3**.** Percentage of yield of charcoal produced : (a) at 300°C, (b) at 400 °C

From figure 4, it can be observed that as both the temperature and duration of carbonization increase, the yield of the produced charcoal decreases. While an increase in the amount of raw material will lead to a higher percentage of the resulting product. However, the quality of the resulting charcoal, in terms of its appearance and texture, improves. This trend is due to the enhanced reaction between carbon and steam at higher temperatures and longer carbonization times, leading to a greater formation of CO_2 and a reduction in the amount of residual carbon [14]. Data from figure 4 further indicate that with increased carbonization time and temperature, the proportion of charcoal exhibiting a uniform black color and brittle texture increases, while the total yield of charcoal decreases. This observation aligns with the findings of Jaya and Khai, who reported similar results in their study of palm oil stem carbonization. They found that the lowest yield occurred at a temperature of 350˚C with a carbonization duration of 150 minutes [15].

3.2 The Effect of Carbonization on Charcoal Quality Based on Proximate Analysis

The proximate analysis aims to determine the moisture content, ash content, volatile matter, and fixed carbon of the charcoal produced from carbonization. Table 2 show the result of proximate analysis in charcoal product

Table 2. Result of Proximate Analysis

Raw Materials Mass (kilograms)	**Carbonzation Temperature (˚C)**	**Carbonization Time (minutes)**	**Moisture Content (%)**	**Ash Content (%)**	**Volatille Matter (%)**	**Fixed Carbon (%)**
SNI 1-1683-1996			**<6**	**<3**	**<15**	
4	300	75	5.04	1.63	35.58	62.78
		90	4.81	1.87	33.12	65.00

		105	4.53	1.94	31.55	66.51
		120	4.29	2.24	29.79	67.96
		135	3.83	2.53	26.75	70.72
	400	75	4.35	1.87	31.84	66.29
		90	3.84	2.37	29.93	67.70
		105	3.39	2.51	26.39	71.09
		120	3.17	2.74	26.53	70.72
		135	2.80	2.80	25.65	71.55
5	300	75	5.41	1.75	38.08	60.17
		90	5.26	1.99	35.42	62.59
		105	5.19	2.01	32.36	65.63
		120	5.11	2.20	30.86	66.94
		135	4.22	2.35	30.46	67.19
	400	75	4.76	1.92	34.53	63.55
		90	4.32	2.15	31.78	66.07
		105	3.96	2.37	29.35	68.28
		120	3.48	2.63	28.56	68.81
		135	3.08	2.82	27.96	69.22

Moisture content in coconut shell charcoal represents the -OH compounds remaining from the carbonization process. The moisture content decreases with increasing temperature and duration of carbonization. lower moisture content indicates the efficiency of the carbonization apparatus in heating and evaporating the water from the raw material, thus improving the quality of the resulting charcoal. The highest moisture content, 5.41%, was observed in the experiment conducted at 300˚C for 75 minutes with five kilograms raw materials, while the lowest value, 2.80%, was observed at 400˚C for 135 minutes with four kilograms raw materials. According to Indonesia National Standard/*Standard Nasional Indonesia* (SNI) No 1-1683-1996, the maximum allowable moisture content is 6%, and all the carbonized charcoals produced meet this standard.

Ash content represents the residue left after the combustible material has burned during the ashing process. The remaining ash may include minerals such as silica, alumina, iron oxide, magnesium, and calcium. The highest ash content, 2.82%, was recorded in the experiment at 400˚C for 135 minutes with five kilograms raw materials, while the lowest, 1.63%, was at 300˚C for 75 minutes with four kilograms raw materials. Increased ash content correlates with higher temperature and longer combustion time, indicating more material decomposing into ash. According to SNI No 1-1683-1996, the maximum ash content for coconut shell charcoal is 3%, and all produced charcoals meet this standard. Besides temperature and combustion time, ash content also depends on the type of raw material used [16].

Volatile matter content is determined by heating the charcoal product at 950˚C for seven minutes. This test indicates the completeness of the carbonization process. Higher temperature and longer carbonization times result in more volatile substances being expelled, thus reducing the volatile matter content [17]. The lowest volatile matter content, 25.65%, was found in the experiment at 400˚C for 135 minutes with four kilograms raw materials, while the highest, 38.08%, was at 300˚C for 75 minutes with five kilograms raw materials. According to SNI No 1-1683-1996, the maximum allowable volatile matter content is 15%, and all produced charcoals do not meet this standard. Volatile matter content can also serve as an indicator of smoke production during combustion. Higher volatile matter results in more smoke and makes the charcoal easier to ignite, potentially increasing the burn rate and making fuel consumption more inefficient [18].

The increase of temperature and durations of carbonization indicate a better value of moisture content, ash content, and volatile matter. This occurs because the longer the duration and the higher the carbonization temperature, the greater the intensity of combustion. Increased time and temperature allow for a more complete breakdown of biomass, leading to a higher degree of carbonization. The mass of the raw material affects the heating process. The larger the mass of the raw material, the longer it takes for complete heating to occur. Therefore, using smaller amounts of raw material will result in better product outcomes.

Fixed carbon content indicates the quality of the charcoal; a higher fixed carbon content correlates with better quality. The highest fixed carbon content, 71.55%, was found in the experiment at 400˚C for 135 minutes with four kilograms raw materials, with moisture content of 2.80%, ash content of 2.80%, and volatile matter of 25.65%. Fixed carbon content is inversely related to moisture content, ash content, and volatile matter. Fixed carbon represents the carbon fraction in the charcoal other than ash. Consequently, the extractive substances in the biomass affect the fixed carbon content and are a determinant of charcoal quality due to their relationship with calorific value [16].

3.3. The Effect of Carbonization on Specific Fuel Consumption

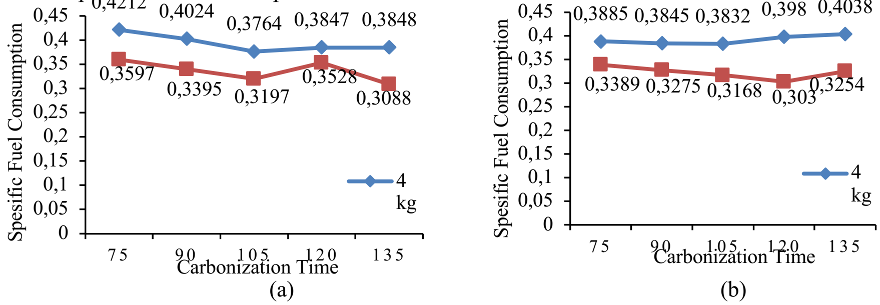


Fig. 5. SEQ Figure * ARABIC 4. Specific Fuel Consumption Value : (a) at 300ºC, (b) at 400ºC

The value of specific fuel consumption is the amount of energy required to produce charcoal per kilogram of product. Specific fuel consumption indicates the ability of the equipment to carry out carbonization to produce charcoal. A lower specific fuel consumption value indicates a good combustion process, as it means that the equipment uses less fuel to produce the product.

From Figure 5, it is known that the lowest specific fuel consumption value was observed in the experiment at a temperature of 400°C for 120 minutes with five kilograms raw materials, with a value of 0.3030 kcal/kg. The highest fuel energy value was obtained in the experiment at a temperature of 300°C for 75 minutes with four kilograms raw materials, with a value of 0.4212 kcal/kg. The fluctuating fuel energy values are caused by several conditions, such as the influence of wind and ambient heat, which affect the airflow speed in the combustion chamber and lead to differences in speed and load adjustments required for the equipment to reach operational conditions. This occurs because the combustion chamber has an open gap at the bottom of the burner (Fig. 2 (c)), allowing outside air to flow into the chamber, even under limited conditions. The airflow around the combustion chamber can cause turbulence. The higher the intensity of turbulence in the combustion chamber, the more it will affect the specific fuel consumption value [19]. Therefore, airflow in the combustion chamber must be maintained to optimize the specific fuel consumption value in the carbonization process.

4. CONCLUSIONS

The coconut shell carbonization process in a Cylinder Retort Kiln has proven to be effective in producing biochar with good physical and chemical characteristics. Based on research conducted, optimal proximate analysis results were achieved by carbonization for 135 minutes at a temperature of 400˚C with four kilograms of raw material. The resulting values are 2.80% water content, 2.80% ash content, 25.65% volatile substances and 71.55% fixed carbon with a charcoal production yield of 60.75% or 2.43 kg . The best specific fuel consumption value was achieved at a carbonization temperature of 400°C for 120 minutes with five kilograms of raw material, with a value of 0.3030 kcal/kg. The analysis results show that the biochar produced has water content, ash content, low volatile substances and high carbon content. In addition, the use of a Cylinder Retort Kiln allows better control of the carbonization process, reduces greenhouse gas emissions and minimizes waste. Therefore, coconut shell carbonization is a sustainable solution for managing coconut shells for biochar development.

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