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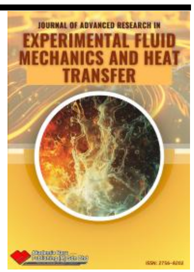
Journal of Advanced Research in Experimental Fluid Mechanics and Heat Transfer

Journal homepage: http://www.akademiabaru.com/submit/index.php/arefmht

ISSN: 2756-8202



Adiabatic Combustion Chamber Pyrolysis for Palm Kernel Shell Biochar Production

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ARTICLE INFO

Article history:
Received 20 April 2025
Received in revised form 10 May 2025
Accepted 10 June 2025
Available online 15 July 2025

Keywords:
Palm kernel shell (PKS); palm kernel shell charcoal; combustion chamber; pyrolysis; carbonization; temperature; resistance value; moisture content; calorific value

ABSTRACT

The rapid expansion of the palm oil industry has raised concerns about the increasing generation of waste, particularly Palm Kernel Shells (PKS). However, these byproducts present promising opportunities for conversion into valuable resources such as charcoal. To facilitate this process, a combustion chamber was designed and constructed to conduct pyrolysis for PKS charcoal production. This study aims to evaluate the performance of the combustion chamber in consistently reaching and maintaining a temperature of 600˚C using mangrove wood as fuel. Additionally, the quality of PKS charcoal was assessed by measuring its electrical resistance with an ohm meter, providing a quantitative indicator of carbonization. The calorific value of charcoal briquettes produced from powdered PKS charcoal was also analysed. Performance testing of the combustion chamber revealed that it achieved a maximum temperature of 795˚C at T1 and 671˚C at T2, confirming its capability to sustain the pyrolysis process. The measured electrical resistance of the PKS charcoal was 1.73Ω, indicating low resistance and, consequently, a high-quality charcoal product. The moisture content of the PKS charcoal was determined to be 4%, signifying a relatively low moisture level, which is crucial for maintaining high charcoal quality. Furthermore, the calorific value of the PKS charcoal was found to be 21.552 MJ/Kg, categorizing it as a moderate-to-high-quality fuel source. Charcoal with a higher calorific value releases more energy during combustion. In conclusion, this study demonstrates that palm kernel shell waste from the palm oil sector can be effectively converted into high-quality charcoal, highlighting its potential as a valuable and sustainable resource.

1. Introduction

The Malaysian palm oil industry is a significant player globally, ranking second in both production and export of palm oil, with Indonesia being the only country ahead [1]. The exponential growth of the palm oil sector has generated apprehensions regarding the concomitant escalation in waste generation, specifically palm kernel shells (PKS). The increase in worldwide palm oil demand is accompanied by a proportional rise in the quantity of waste produced during the production of palm oil. The number of palm kernel shells, which are a byproduct of oil production, has experienced a

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https://doi.org/10.37934/arefmht.21.1.19

proportional increase. If not efficiently handled, the increase in waste might provide environmental difficulties. Improper disposal of palm kernel shells (PKS) can give rise to environmental concerns such as land and air pollution, hence exerting adverse effects on ecosystems and local communities.

The waste produced from palm kernels, specifically palm kernel shells, indicates exciting possibilities for conversion into a valuable resource known as charcoal. Pyrolysis of palm kernel shells at specific temperatures results in the production of liquid smoke, tar and charcoal [2]. The sustainable utilization of resources not only covers the control of waste, but also presents a valuable opportunity for local communities to generate their own charcoal for diverse commercial applications. The utilization of charcoal, derived from palm kernel shells, as a viable and environmentally sustainable substitute for conventional charcoal. This charcoal production has the potential to provide significant benefits to various communities, particularly small-scale entrepreneurs such as satay and grilled chicken sellers.

Palm kernel shell charcoal has also been explored for its potential application in coal replacement, showcasing its versatility in energy production [3]. Through the use of this waste-to-resource approach, communities have the potential to make valuable contributions to both economic growth and environmental preservation. This strategy facilitates the establishment of an optimal balance between industry and local entrepreneurship, while simultaneously mitigating the environmental impact associated with the palm oil industry. The objectives of this study are to determine whether the combustion chamber can consistently attain and maintain a temperature of 600˚C using mangrove wood as fuel, to assess the quality of palm kernel shell charcoal by measuring its electrical resistance using an ohm meter, as a quantitative indicator of factor such as carbonization and to measure the calorific value of charcoal briquette from powered palm kernel shell charcoal.

2. Adiabatic Combustion Chamber Pyrolysis

2.1 Working Principle

The adiabatic combustion chamber as shown in Figure 1 operates by burning fuel in a well-insulated environment to minimize heat loss, ensuring maximum energy efficiency. The process begins as air enters through the intake, supplying the necessary oxygen for combustion. Inside the combustion kiln, fuel burns, generating high temperatures, with heat retained due to the insulation. The burner chimney facilitates the removal of combustion gases, while the vapour gas outlet at the top allows the escape of hot gases and byproducts. Because the chamber is adiabatic, it prevents heat dissipation to the surroundings, maximizing combustion efficiency and maintaining high temperatures for prolonged thermal processes. This setup is commonly used in pyrolysis, gasification and high-temperature industrial applications.

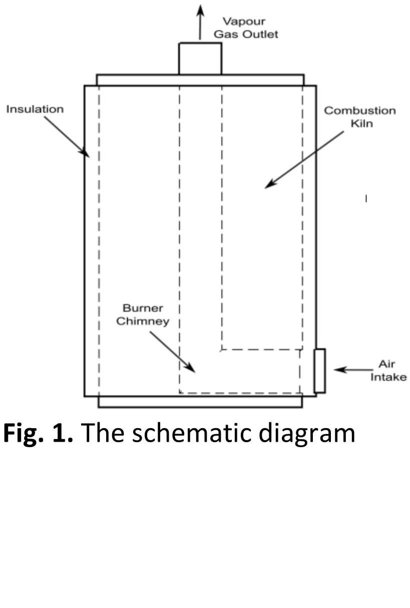

Fig. 1. The schematic diagram

2.2 Pyrolysis

A Fixed Bed Pyrolysis Reactor functions by thermally breaking down biomass, such as palm kernel shells, in the absence of oxygen. This process generates biochar, bio-oil and syngas. The biomass is positioned in a stationary bed within the reactor, where it is heated in a controlled manner, typically between 300°C and 800°C, using an external heat source. As the temperature increases, the biomass goes through several pyrolysis stages: drying (removal of moisture), primary pyrolysis (release of volatile gases and bio-oil vapours) and secondary pyrolysis (further decomposition of volatiles into syngas) [4] . The solid biochar remains in the reactor, while the gaseous products are sent to a cooling system. Here, bio-oil vapours condense into liquid and non-condensable gases are either used as fuel or safely released. The absence of oxygen prevents combustion and allows for the production of valuable byproducts such as bio-oils, char and gases [5].

2.3 Factor Affecting Pyrolysis Performance

Firstly, charcoal production and quality are significantly affected by the pyrolysis temperature. Higher temperatures correlate with increased charcoal production. Secondly, the rate of heating of palm kernel shells has a direct impact on both the quantity and quality of the resulting charcoal. Faster rates of heating can lead to incomplete pyrolysis and less production of charcoal. The pyrolysis temperature, heating rate and residence time play critical roles in determining the yield and properties of the pyrolysis products [6]. Besides, charcoal that is generated without the presence of oxygen, known as black charcoal, possesses a greater amount of fixed carbon and is better suited for industrial use

3. Methodology

3.1 Design and Fabrication of the Combustion Chamber

The combustion chamber was designed and fabricated according to specifications that have been set. The specifications such as the combustion chamber must be able to achieve 600˚C temperature. The materials to construct the combustion chamber must withstand high temperature such as using steel oil drum and hollow structural steel for the burner chamber as shown in Figure 2. The combustion chamber is also wrapped with glass mineral wool insulation for preventing heat loss. Lastly, the combustion chamber was installed with wheels to make it portable and easy transportation from one place to another.

Fig. 2. The combustion chamber

3.2 Testing Combustion Chamber Performance and Making Palm Kernel Shell Charcoal

The designed combustion chamber is tested using mangrove wood as a fuel to heat up the combustion chamber. The fuel is placed inside the burner chamber where it was placed in the centre of the combustion chamber. The combustion chamber was filled with palm kernel shell as to help in burning process and making charcoal. The burner chamber will distribute heat inside the combustion chamber. Thermocouple was used to measure the temperature inside the combustion chamber. Two temperature areas were recorded, which is T1 on the centre of the combustion chamber while T2 was placed on the tip of the combustion chamber. The duration of the testing is 2 hours and 25 minutes. If the combustion chamber can attain and maintain 600˚C of temperature, the production of palm kernel shell charcoal through pyrolysis can be done.

3.3 Measurements
3.3.1 Quality measurement for palm kernel shell charcoal

The produced palm kernel shell charcoal undergoes quality control using an ohmmeter, measuring its electrical resistance as a quantitative indicator of factors such as carbonization. The test probe was inserted into the charcoal sample and the resistance value was recorded from the digital multimetre display. Calorific Value Measurement of Charcoal Briquettes from Pulverized Palm Kernel Shell Charcoal can be taken as a Secondary Quality Control. For calorific value (CV), the analysis was carried out using Bomb Calorimeter based on British Standard EN 14918 [7].

3.3.2 Moisture content experiment for produced palm kernel shell charcoal

Moisture content experiment was carried out using an oven. Weigh 1 gram of palm kernel shell charcoal powder in crucible. The crucible was placed inside the oven maintained at 105 degrees Celsius for 1 hour. Find the difference between the starting weight and the final weight of charcoal powder sample which represents as moisture is evaporated during heating.

3.3.3 Palm kernel shell charcoal briquette making process

The produced palm kernel shell charcoal was placed inside the mortar for crushing process for it to becomes charcoal powder. The charcoal powder was mixed with corn starch with ratio 300 gram of charcoal powder and 75-gram corn starch. A starch content of 8% has been found to be effective in the production of charcoal briquettes [8]. This mixed then poured with water and stirred until it became lump. The lump was moulded using PVC pipe shape to form cylindrical charcoal briquette.

The formula to determine moisture content of PKS charcoal [9]:

$$\%\ of\ Moisture\ Content = \left(\frac{Weight\ of\ Moisture\ Removed}{Weight\ of\ Sample\ Charcoal}\right)\ X\ 100\% \tag{1}$$

4. Results and Discussions
4.1 Performance of the Combustion Chamber

The result for the testing of combustion chamber was shown in Figure 3 above. From the result, it can be observed that the highest temperature that the combustion chamber achieved was 795˚C at T1 and 671˚C at T2. This shows the combustion chamber able to reach 600˚C of temperature. The step that has been done to make the combustion chamber able to reach 600˚C is from the usage of blower. This blower helps in forcing air (oxygen) to flow inside the burner chamber. Besides, the methane gas release from the palm kernel shell also helps in this burning process. Research on the methane adsorption capabilities of activated carbon generated from palm kernel shells, revealing the material's potential for methane adsorption [10]. With this temperature, pyrolysis process occurred and palm kernel shell charcoal was produced successfully.

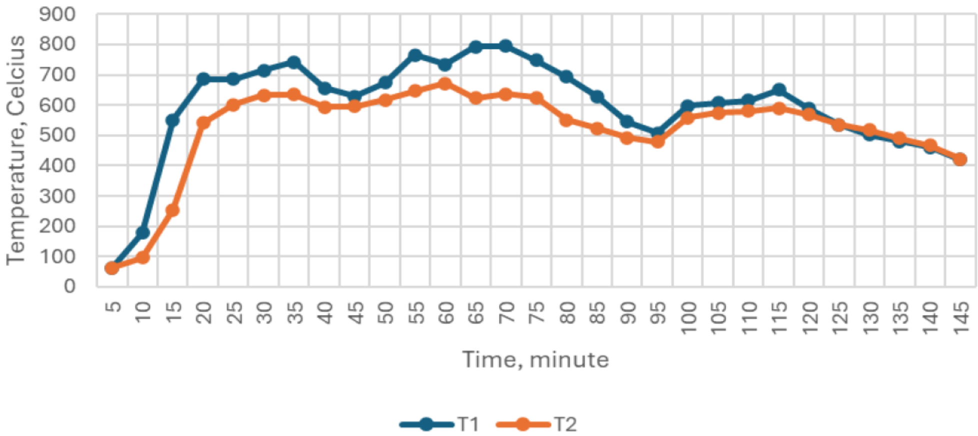

Fig. 3. Graph time vs temperature where T1 is Internal temperature and T2 is external temperature of the chamber

Figure 4 shows the product after 2hours 25 minutes of combustion.

Fig. 4. Palm kernel shell charcoal after completion from the pyrolysis process

4.2 Resistance Value of Produced Palm Kernel Shell Charcoal

Measuring the resistance value of produced palm kernel shell charcoal is one of the methods used to determine the quality of the palm kernel shell charcoal. Lower resistance usually indicates higher quality because it implies better conductivity and higher carbon purity. The resistance value for the palm kernel shell charcoal is 1.73Ω (ohms). A resistance value of 1.73 ohms in palm kernel shell charcoal indicates a low level of resistance, which is indicative of a high-quality product. A resistance value of 1.73 ohms signifies that the PKS charcoal has undergone successful carbonization, leading to a significant amount of carbon concentration.

4.3 Moisture Content of Palm Kernel Shell Charcoal

Moisture content in charcoal refers to the amount of water present in the charcoal after production. It is a crucial determinant impacting the quality and efficacy of charcoal as a fuel. A low moisture content is a crucial indicator of high-quality charcoal. Charcoal that has a low moisture level typically has a higher calorific value and is more easily ignited [11]. After completing the experiment procedure and analysing the data for calculation, the moisture content of the palm kernel shell charcoal is 4% as listed in Table 1. A moisture content of 4% indicates that the PKS charcoal sample has a relatively low moisture level. Ensuring a suitable moisture level is essential for maintaining high-quality charcoal. Typically, moisture levels below 10% are considered acceptable prior to selling [12].

Table 1
Result of moisture content experiment

		Weight (gram)
1	Weight of empty crucible (W1)	63.406
2	Weight of crucible and PKS charcoal powder sample before heating (W2)	64.406
3	Weight of PKS charcoal powder taken (W3=W2-W1)	1
4	Weight of crucible and PKS charcoal powder sample after heating (W4)	64.366
5	Weight of moisture removed (W5=W2-W4)	0.04
6	Percentage of Moisture Content	4%

A low moisture content is a crucial indicator of high-quality charcoal. Charcoal that has a low moisture level typically has a higher calorific value and is more easily ignited [11]. After completing the experiment procedure and analysing the data for calculation, the moisture content of the palm kernel shell charcoal is 4%. A moisture content of 4% indicates that the PKS charcoal sample has a relatively low moisture level. Ensuring a suitable moisture level is essential for maintaining high-quality charcoal. Typically, moisture levels below 10% are considered acceptable prior to selling [12].

4.4 Palm Kernel Shell Charcoal Briquette

The process of pyrolysis involves transforming organic waste materials into high-density, energy-efficient fuel sources, resulting in the successful production of palm kernel shell charcoal briquettes. Figure 5 below shows the successful palm kernel shell charcoal briquettes making. The selection of the briquette shape to cylindrical is already considered to several factors or advantages. Cylindrical briquettes offer advantages in terms of higher energy density and practical designs, which enhance their ease of handling and storage [13]. Besides, cylindrical form enhances airflow among the briquettes, a critical factor for optimizing combustion efficiency, the uniform cylindrical shape of briquettes allows for consistent burning characteristics, the cylindrical shape of the briquettes contributes to their structural integrity by distributing stress concentrations and cylindrical shapes are more convenient to produce and transport.

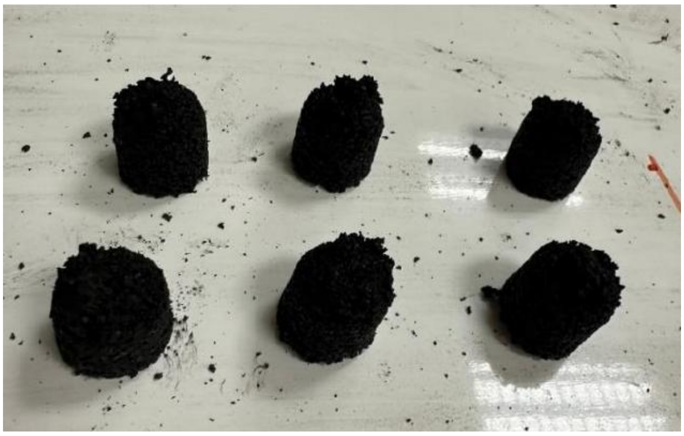

Fig. 5. Palm kernel shell charcoal briquettes

4.5 Calorific Value of Palm Kernel Shell Charcoal

The calorific value of a substance refers to the precise quantity of energy that is released when the substance undergoes full combustion. The measurement is typically expressed in joules per kilogram (J/kg) or megajoules per kilogram (MJ/kg). This parameter represents the fuel's energy efficiency, which is essential for assessing its performance:

$$Average\ Calorific\ Value = \frac{21.56+21.54+21.56}{3} = 21.55\,\frac{MJ}{kg} \quad (2)$$

From the result above, the calorific value for PKS charcoal is 21.552 MJ/Kg. This calorific value is considered moderate and it also indicates that PKS charcoal is a good quality of charcoal. Charcoal having higher calorific value emits a greater amount of energy as it experiences combustion. This implies that for every kilogram of charcoal combusted, a greater quantity of heat is generated in comparison to charcoal with a lower calorific value. Charcoal with a high calorific value produces a higher energy output per unit weight when ignited, making it a highly efficient and efficient fuel for a wide range of uses [14].

Table 2 provides a comparison of the calorific values of various types of biomass charcoal, measured in megajoules per kilogram (MJ/Kg). The values provided represent the energy content of each type of charcoal, which is essential for assessing its efficiency and suitability for various uses, including cooking and heating applications. The table encompasses many forms of biomass charcoal, such palm kernel shell, bamboo, wood, coconut shell, sawdust, bagasse and mangrove.

Table 2
Type of biomass charcoal and its calorific values

	Biomass Charcoal	Calorific Valor	References
1	Mangrove	29.8	[15]
2	Wood	28	[16]
3	Bamboo	24.4-29.2	[17]
4	Coconut Shell	20.8	[18]
5	Sawdust	16.3	[19]
6	Bagasse	16.87.18.64	[20]
7	Palm Kernel Shell	21.55	Current Study

From the table, mangrove charcoal has the highest calorific value at 29.8 MJ/Kg [15]. Wood and bamboo charcoals also have high calorific values, at 28 MJ/Kg [16] and 24.4-29.2 MJ/Kg [17] respectively. Palm kernel shell and coconut shell charcoals have moderate calorific values of 21.55 MJ/Kg and 20.8 MJ/Kg [18], respectively. Bagasse and sawdust charcoals, with lower calorific values of 16.87-18.64 MJ/Kg [19] and 16.3 MJ/Kg [20] respectively, are valuable for their role in waste recycling and are ideal for applications requiring less intense heat. The higher the calorific value, it will indicate it's had a good quality of charcoal.

5. Conclusions

The result obtained from the testing shows the first objective was achieved. In this testing, the combustion chamber was filled with palm kernel shell. As from the results, the maximum temperature that the combustion chamber reach is 795˚C at T1 and 671˚C at T2. With this temperature, palm kernel shell charcoal was produced successfully. Moreover, the resistance value for the palm kernel shell charcoal is 1.73Ω (ohms). A resistance value of 1.73 ohms in palm kernel shell charcoal indicates a low level of resistance, which is indicative of a high-quality product. Besides, the moisture content of the palm kernel shell charcoal is 4%. A moisture content of 4% indicates that the palm kernel shell charcoal sample has a relatively low moisture level. Ensuring a suitable moisture level is essential for maintaining high-quality charcoal. Furthermore, the calorific value for palm kernel shell charcoal is 21.552 MJ/Kg. This calorific value is considered moderate and it also indicates that palm kernel shell charcoal has a good quality of charcoal. Overall, the combustion chamber delivered a successful pyrolysis process on making palm kernel shell charcoal. The palm kernel shell charcoal produced has good quality charcoal characteristics.

Acknowledgement
This research was not funded by any grant.

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