Jurnal Dinamis (*Scientific Journal of Mechanical Engineering*)
Journal homepage: https://talenta.usu.ac.id/dinamis/

Retort Kiln Carbonization of Wet and Dry Young Coconut Wastes: Effects on Biochar Quality and Processing Efficiency

Rijalul Mufti[1], Adi Setiawan*[2], Abubakar Dabet[1], Alchalil[2], Munzir Absa[3], Muhammad Iqbal[3]

[1]*Mechanical Engineering Vocational Education Study Program, Faculty of Teacher Training and Education, Universitas Malikussaleh, Lhokseumawe, Indonesia*
[2]*Mechanical Engineering, Faculty of Engineering, Universitas Malikussaleh, Lhokseumawe, Indonesia*
[3]*Physics Education, Faculty of Teacher Training and Education, Universitas Malikussaleh, Lhokseumawe, Indonesia.*

*Corresponding Author: adis@unimal.ac.id

ARTICLE INFO

Article history:
Received January 10th 2025
Revised May 5th 2025
Accepted June 29th 2025
Available online June 30th 2025

E-ISSN: 2809-3410

How to cite:
Rijalul Mufti, Adi Setiawan, Abubakar, Alchalil, Munzir Absa, Muhammad Iqbal, "Retort Kiln Carbonization of Wet and Dry Young Coconut Wastes: Effects on Biochar Quality and Processing Efficiency", *Junal Dinamis (Scientific Journal of Mechanical Engineering)*, Vol. 13, No. 1, pp. 17-23, June 2025.

ABSTRACT

The increasing consumption of coconuts in Indonesia has led to the accumulation of young coconut waste, which remains underutilized despite its potential as a renewable energy source. This study aimed to develop an effective carbonization strategy using a retort kiln to produce high-quality biochar. An experimental method was applied with two set of feedstocks, *i.e.* wet and dry feedstocks, carbonized at 400°C in a pilot-scale retort kiln. An initial drying for wet feedstock was performed *in-situ* for 3 h followed by 5 h of carbonization. The results showed an increase in fixed carbon content from 56.25% to 62.32% and a calorific value from 5537 cal/g to 6376 cal/g when wet feedstock was dried in situ. On the other hand, the fuel consumption reached 1.636 L/kg for wet feedstock and 1.076 L/kg for dry feedstock. These findings demonstrate that *in-situ* drying of wet young coconut waste prior to carbonization process significantly accelerates biochar production and improves its quality, supporting the more efficient and sustainable use of agricultural biomass waste through retort kiln technology.

Keywords: *retort kiln, carbonization, young coconut waste, calorific value, proximate analysis*

ABSTRAK

Peningkatan konsumsi kelapa di Indonesia telah menyebabkan akumulasi limbah tempurung kelapa muda yang masih belum dimanfaatkan secara optimal, padahal memiliki potensi sebagai sumber energi terbarukan. Penelitian ini bertujuan mengembangkan strategi karbonisasi yang efektif menggunakan retort kiln untuk menghasilkan bioarang berkualitas tinggi. Metode eksperimen dilakukan dengan dua perlakuan kadar kelembapan bahan baku (basah dan kering), dikarbonisasi pada suhu 400°C menggunakan reaktor retort kiln skala pilot, dengan pengeringan awal pada bahan basah selama 3 jam kemudian dilanjutkan pemanasan selama 5 jam. Hasil penelitian menunjukkan peningkatan kandungan karbon tetap dari 56,25% menjadi 62,32% dan nilai kalor dari 5537 cal/g menjadi 6376 cal/g ketika bahan baku basah dikeringkan di reaktor sebelum proses karbonisasi, sementara konsumsi bahan bakar tercatat sebesar 1,636 L/kg untuk bahan baku basah dan 1,076 L/kg untuk bahan baku kering. Temuan ini membuktikan bahwa pengeringan awal pada proses karbonisasi limbah kelapa muda basah secara signifikan mempercepat produksi bioarang dan meningkatkan kualitas produk, sehingga mendukung pemanfaatan limbah biomassa pertanian melalui teknologi retort kiln secara lebih efisien dan berkelanjutan.

Kata kunci: *retort kiln, karbonisasi, limbah kelapa muda, nilai kalor, analisis proksimat*

http://doi.org/10.32734/dinamis.v13i1.19748

1. Introduction

Indonesia has significant biomass potential, reaching approximately 146.7 million tons annually, with an estimated 53.7 million tons recorded in 2020. Coconut production is one of the largest contributors to this biomass, supported by a plantation area of 3,731,565 hectares producing 3,098,539 tons of coconuts in 2003. As coconut consumption grows by approximately 4.5% each year, the accumulation of coconut waste, especially young coconut shell and fiber, has become a critical environmental concern due to its large size, hard structure, and resistance to decomposition. In Aceh, the popularity of young coconut beverages has surged, contributing to a significant increase in coconut waste that is usually discarded without further utilization. This young coconut waste represents an organic material with high lignocellulosic content, making it suitable for conversion into high-value products such as biochar, activated carbon, or alternative fuels.

Biomass utilization as a renewable energy source is a strategic issue in supporting energy transition efforts. However, traditional carbonization methods using conventional kilns often face inefficiencies, including prolonged carbonization times, high fuel consumption, and negative environmental impacts. Retort kiln technology has been introduced to address these limitations by offering better temperature control, improved energy efficiency, and reduced harmful gas emissions.

Previous studies have explored retort kilns for coconut-based biomass carbonization. However, only limited research has examined how variations in feedstock moisture content—specifically comparing wet and dry young coconut waste—affect retort kiln performance, biochar yield, and quality. This research gap is crucial since feedstock moisture directly influences the heat transfer, process efficiency, and the fixed carbon and calorific value of the produced biochar.

The novelty of this study lies in investigating the integration of a direct drying stage inside the retort kiln during the carbonization of wet young coconut waste, compared to pre-dried feedstock, to evaluate whether this approach can reduce process time and improve product quality.

The objective of this study is to analyze the effect of young coconut waste moisture content on the performance of the retort kiln, particularly in terms of biochar yield, fixed carbon content, calorific value, fuel consumption, and carbonization time efficiency.

1.1. Tables

Table 1. Potential and Utilization of Young Coconut Waste in Indonesia

Aspect	Description
Biomass potential in Indonesia	146.7 million tons/year
Estimated biomass potential in 2020	53.7 million tons
Coconut plantation area (2003)	3,731,565 hectares
Coconut production (2003)	3,098,539 tons
Young coconut consumption growth	Increased 4.5% per year
Challenges of coconut waste	Difficult to decompose; large and hard structure; environmental accumulation
Utilization opportunities	Alternative energy, biochar, activated carbon, furniture
Research gap	Effect of feedstock moisture on retort kiln performance still rarely studied

1.2. Construction of References

Several studies have explored the utilization of coconut biomass as a raw material for charcoal production due to its high lignocellulosic content and energy potential. Tumbel et al. (2019) highlighted the high cellulose and lignin content in coconut shells, which makes them ideal for charcoal production while contributing to waste reduction. Ramadhani et al. (2020) emphasized that coconut shell-based biochar can act as an environmentally friendly fuel alternative and help manage organic waste.

Previous research has examined various kiln designs to improve the carbonization process. Padakan (2019) reported that retort kilns offer better thermal control and efficiency compared to traditional kilns, reducing greenhouse gas emissions and improving product quality. Furthermore, El-Sheikha and Hegazy (2020) described the importance of thermal insulation and mass transfer optimization in kiln design to achieve higher carbonization efficiency.

However, limited studies have analyzed how variations in the initial moisture content of young coconut waste influence the performance of retort kilns. Wahyuni et al. (2022) and Afrianah et al. (2023) suggested that feedstock moisture critically affects heat transfer, carbonization time, and final biochar properties, but did not specifically evaluate wet versus dry young coconut shells in retort kilns.

Therefore, this study is designed to fill this research gap by experimentally analyzing the effect of feedstock moisture variations on the retort kiln's performance, including its impact on fuel consumption, carbonization time, fixed carbon content, and calorific value of the produced biochar. This research aims to contribute to the improvement of retort kiln technology for better biomass utilization, higher energy efficiency, and environmental sustainability.

2. Method

This research uses the experimental method which is a quantitative approach that is generally used in solving problems in the field of engineering. The experiment aims to find out the effect of the independent variable (treatment) on the dependent variable (outcome) under controlled conditions. The independent variable in this study is the condition of the raw materials, *i.e.* sun-dried young coconut waste and wet young coconut waste (fresh). While the dependent variables in this study are the characteristics of biochar such as moisture, ash, vollatile matter, and fixed carbon contents which analysed under proximate analysis. The calorific value of resulting biochar was quantified using bomb calorymeter. During experiment, some parameters were measured including temperature changes as a function of time, total time of carbonization process and fuel consumption.

The materials used in this research are young coconut waste and used oil, while the tools used in this research include:

(1) Retort Kiln: used to convert organic materials such as biomass into biochar through pyrolysis process under oxygen-reduced conditions.
(2) Thermocouple: used to measure temperature in this study. For this research, the thermocouple used is the type that can withstand heat up to 1250°C.
(3) Crusher: used to crush the biochar into smaller particles to facilitate further processing.
(4) Mesh: used to screen biochar particles according to the desired particle size. In this study the sieve used was mesh size 60.
(5) Digital scales: used to measure the weight of the pulverized biofuel.
(6) Furnance: used to heat bio charcoal for proximate analysis testing. In this study, the temperature used was 850 °C for ash content and volatille metter test.
(7) Oven: used for testing the moisture content of the biochar.
(8) Calorimeter Bomb: used for testing the calorific value of Bioarang.
(9) Moisture Meter: used to measure the moisture content of a material.

2.1. Preparation of feedstock materials

Young coconut waste was obtained from a coconut agro-industry in Krueng Geukuh, North Aceh, Aceh Province, Indonesia. The initial process involved cleaning the impurities attached to the raw material. The cleaned coconut waste was then chopped into eight sections from the coconut fruit. Some of chopped young coconut waste was dried under the sun for 15 days in hot and sunny weather conditions, later denoted as KLP K. The indicator of drying was determined when the weight of the raw material has decreased by about 60% of the initial weight of the fresh raw material. Previous research showed that the drying method with drying resulted in a reduction in water content of 61.3% before the carbonization process was carried out [9]. The other chopped young coconut waste was directly fed into reactor for in-situ drying, later denoted as KLP B.

2.2. Carbonization experiment

Fig. 1 shows the arrangement of the carbonization experiment, which mainly consists of furnace, carbonization vessel, heating pipe/chimney, retort kiln cover, condenser, fuel tank, liquid smoke separation chamber, and syngas outlet pipe. To reduce heat loss, the carbonization reactor was insulated with cement. The total volume of the reactor was 160 L. The carbonization experiment of young coconut waste of each raw material variation was put about 10 kg in the reactor and then closed it tightly. Carbonization was carried out with two different processes, (i) wet young coconut waste drying in-situ at the beginning of the carbonization process for 3 hours and then the temperature was set 400 °C for 5 hours; (ii) dry young coconut waste, the temperature was directly set to 400 ° C for 5 hours. Heat was regulated using a valve on the fuel tank. During the experiment, temperature changes in the reactor and heating pipes were recorded automatically. When the temperature of the carbonization reactor reached higher than 400°C, the fuel tank valve was adjusted to maintain the temperature at 400°C. The carbonization process was stopped after 5 h at a temperature of 400°C. The burner was then turned off, allowing the reactor to cool down to carefully collect and measure the products. The products of each experiment are denoted as shown in Table 1.

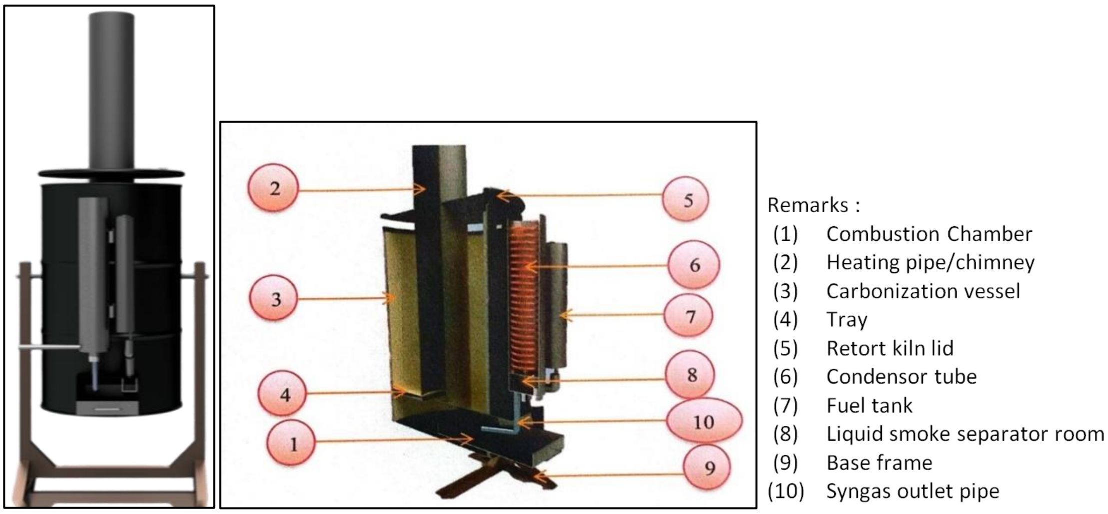

Figure 1. Carbonization Experiment Setup

Table 2. Sample Identification

No	Sample Name	Description
1	KLP B	Carbonization of wet young coconut waste
2	KLP K	Carbonization of dried young coconut waste

2.3. Product characterization

The thermophysical properties of the product were characterized by several techniques, including proximate analysis and bomb calorimeter. Furthermore, the contents of water, ash, volatile substances, and fixed carbon were analyzed by proximate analysis using the procedures of the Indonesian National Standard SNI No. 1683:2021. Meanwhile, bomb calorimeter type automatic calorimeter IKA-2000 was used to analyze the calorific value of young coconut waste products.

3. Result and Discussion

3.1. Carbonization experiment

During the carbonization experiments, temperature changes in the reactor and chimney were observed and recorded every 10 minutes from the beginning to the end of the process. Figures 2 and 3 show plots of the reactor and chimney temperatures, which act as a function of time recorded for the carbonization experiments of KLP B and KLP K. Based on the temperature rise achieved by these setup furnaces, the process can be classified as a low temperature carbonization process [10].

The difference in temperature profiles of wet young coconut waste is shown in Figure 2, while for dry young coconut waste in Figure 3. The KLP B experiment took an average drying time of 170 minutes at an ambient temperature of 120-130°C and at an average carbonization temperature of 260 minutes at 400°C with a total time of 480 minutes used to complete the process. Meanwhile, KLP K took an average drying time of 20 minutes and at an average carbonization temperature of 220 minutes with a total time of 300 minutes.

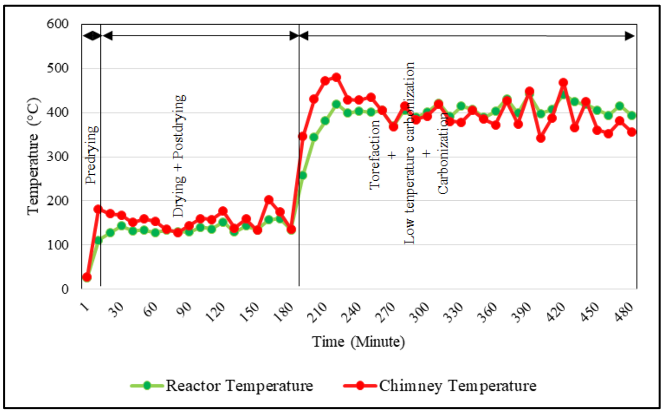

Figure 2 Temperature Profile of the KLP B Experiment

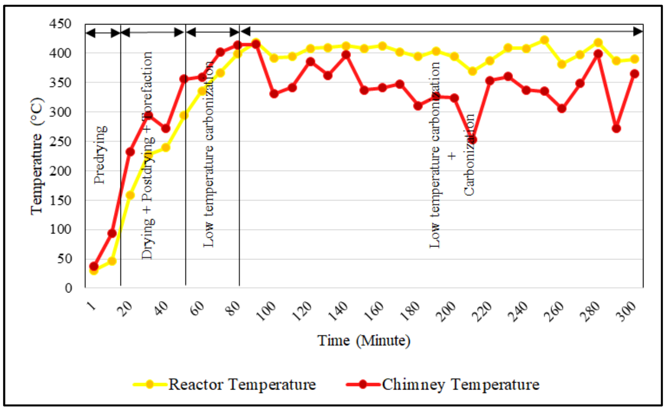

Figure 3. Temperature Profile of the KLP K Experiment

In terms of residence time, the greater the moisture content of the processed feedstock, the longer the drying process time required to complete the carbonization process [13]. The longest carbonization process during this study was 480 minutes, which is from the KLP B experiment, and this shows that wet young coconut feedstock waste requires longer processing time than dry feedstock waste [14].

Figure 4. Fuel Consumption of Carbonization Experiments

The calculation of used oil fuel consumption for the carbonization process was carried out using a measuring cup during the carbonization process. Figure 4 shows the overall plot of fuel consumption per 1 kilogram of carbonized feedstock during each process. In general, there is not much difference in the decrease of fuel consumption between dry and wet feedstock [15].

The carbonization process of KLP K only requires 1.076 L of used oil per kg of feedstock. Meanwhile, carbonization of undried young coconut waste (KLP B) required 1.636 L of used oil per kg of feedstock. The benefit of drying the feedstock at the beginning of the carbonization process is that it allows simultaneous processing fifteen times faster than the feedstock that goes through the drying process using sunlight. The faster the biochar production process, the more time it takes.

3.2. Product characterization

The results of proximate data analysis and heating value of all biochar products are listed in Table 3. Based on the data, it was found that no significant changes were observed in terms of moisture and ash content due to differences in the moisture content of the raw materials. The parameters that changed the most were fixed carbon and volatile matter. Due to the devolatilization reaction and thermal breakdown in the presence of drying at the beginning of the carbonization process, the carbon content in the wet young coconut waste biochar slightly increased from 56.25% to 62.32%. Furthermore, the drying at the beginning of the carbonization process helped to increase the heating value of the product reaching 6376 cal/g, where the percentage of fixed carbon is directly correlated with the hemicellulose and cellulose being completely devolatilized, while the lignin starts to degrade which has a positive impact on the heating value.

Table 3. Proximate Analysis Results and Calorific Value of Biochar Products

Parameters	KLP B	KLP K
Proximate analysis		
Moisture content (%)	2.69	3.99
Ash content (%)	11.12	11.51
Volatile matter (%)	23.86	28.25
Fixed carbon (%)	62.32	56.25
Caloric value (cal/g)	6376	5537

Different values were obtained from the analysis of the moisture content of biochar products. For example, the moisture content of KLP K is greater than KLP B due to the absence of drying at the beginning of the carbonization process. Meanwhile, the residence time at the KLP K drying temperature is relatively short at only 20 minutes, while KLP B has a long residence time at the drying temperature which reaches 170 minutes [10].

Testing of volatile substances KLP B and KLP K obtained different values of 23.86% and 28.25%. KLP K has the highest volatile matter content because the carbonization time is faster than the KLP B raw material. The longer the time in the charring process, the more volatile substances are wasted, so the level of volatility is lower [11]. The volatile matter content is largely influenced by the process parameters used during carbonization.

By testing the water, ash, volatile matter and fixed carbon content of the resulting biochar can be calculated. Table 2 shows the highest fixed carbon content was observed from the KLP B sample. This is largely because the wet young coconut waste feedstock goes through drying at the beginning of carbonization and has a longer residence time compared to the KLP K sample. KLP B has a higher heating value than KLP K because the feedstock goes through drying at the beginning of the carbonization process. This is in line with research [12] which states that the lower the moisture content in briquettes, the better the heating value produced.

4. Conclusion

This study has successfully examined the feasibility of fresh/ wet coconut waste carbonization using a pilot-scale reactor. Drying the fresh feedstock in-situ at the beginning of the carbonization process was performed to speed-up the biochar production time. As comparison, the carbonization process of sun-dried young coconut waste which took 15 days to dry the feedstock under the sun was also carried out. The fuel consumption data indicates that the wet coconut waste experiment requires a longer residence time compared to sun-dried coconut waste carbonization, leading to a higher fuel consumption. Product characterization results showed that the biochar produced by in-situ drying process has better properties with a fixed carbon content of 62.32% and heating value of 6376 cal/g.

References

[1] L. Parinduri and T. Parinduri, “Biomass conversion as a renewable energy source” *Journal of Electrical Technology*, vol. 5, no. 2, pp. 88–92, 2020.

[2] G. Mardiatmoko and M. Ariyanti, *Coconut Plant Production (Cocos nusifera L.)*. Ambon: BPFP-UNPATTI.

[3] S. Cho and J. Kim, “Multi-site and multi-period optimization model for strategic planning of a renewable hydrogen energy network from biomass waste and energy crops,” *Energy*, vol. 185, pp. 527–540, Oct. 2019, doi: 10.1016/j.energy.2019.07.053.

[4] C. G. G. T. Sibarani, S. A. Silahi, N. Armayanti, T. Sriwedari, and J. Suharianto, "Shell and young coconut shell waste as an alternative to polybags and environmentally friendly charcoal briquettes" *Amaliah: Jurnal Pengabdian Kepada Masyarakat*, vol. 5, no. 2, pp. 146–149, 2021.

[5] N. Tumbel and A. K. Makalalag, "Processing of coconut shell charcoal using a modified kiln," *Journal of Industrial Technology Research,* vol. 11, no. 2, pp. 83–92, 2019, doi: 10.33749/jpti.v11i2.5744.

[6] L. F. Ramadhani, I. M. Nurjannah, R. Yulistiani, and E. A. Saputro, "Review: physical activation technology in the preparation of activated carbon from coconut shell waste," Journal of Chemical Engineering, vol. 26, no. 2, pp. 42–53, Jul. 2020, doi: 10.36706/jtk.v26i2.518.

[7] R. Padakan, "Effect of the flue of charcoal Retort Kilns on production charcoal using drum Kilns for households," *International Journal of Engineering and Technology*, vol. 11, no. 4, pp. 245–248, Aug. 2019, doi: 10.7763/IJET.2019.V11.1155.

[8] A. El-Sheikha and R. Hegazy, "Designing and evaluating biochar pyrolysis kiln," *Journal of Soil Sciences and Agricultural Engineering*, vol. 11, no. 12, pp. 701–707, Dec. 2020, doi: 10.21608/jssae.2020.159761.

[9] F. V. L. Koly, H. Manimoy, and M. Lonapadara, "Quality analysis of young coconut shell charcoal briquettes as an alternative energy solution in the marine tourism area," Wahana Pendidikan Scientific Journal, vol. 10, no. 10, pp. 286-291, 2024.

[10] M. Amer and A. Elwardany, "Biomass carbonization," in *Renewable Energy - Resources, Challenges and Applications*, IntechOpen, 2020. doi: 10.5772/intechopen.90480.

[11] L. Rumiyanti, A. Irnanda, and Y. Hendronursito, "Proximate analysis of agricultural waste charcoal briquettes," Spektra: Journal of Physics and its Applications, vol. 3, no. 1, pp. 15-22, Apr. 2018, doi: 10.21009/SPEKTRA.031.03.

[12] I. Ardiansyah, A. Yandra Putra, and Y. Sari, "Calorific value analysis of various types of biomass briquettes by calorimeter," Journal of Research and Education Chemistry, vol. 4, no. 2, p. 120, Dec. 2022, doi: 10.25299/jrec.2022.vol4(2).10735.

[13] S. Mansyur and E. Apriani, "Analysis of the effect of temperature and raw material mixes on the pyrolysis process with single retort-rocket stove technology on the characteristics of sawdust charcoal briquettes," *International Journal of Industrial Optimization*, pp. 38–46, Mar. 2023, doi: 10.12928/ijio.v4i1.6688.

[14] W. A. Akinfiresoye and J. A. Ogidan, "Discovering the Macro-Elements Presence in Biochar Produced Indigenously," *ABUAD Journal of Engineering Research and Development*, 2024, doi: 10.53982/ajerd.

[15] S. Ntandoyenko, S. Laishi, and N. K. Singh, "Softening of Hard Water Using Activated Charcoal Derived Coconut Shells," *Mawardi University*, 2025.