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Reseach Paper

Pyrolysis Effects of Coconut Shell and Wood Waste on Charcoal Characteristics as Biobriquette Raw

Dhifal Dui Rifaldy[1,*], Efri Mardawati[1], Yazid Bindar[2], Desy Nurliasari[1]

[1] *Agricultural Industrial Technology, Universitas Padjadjaran, Jl Raya Bandung-Sumedang KM.21, Sumedang, 45360, Indonesia*
[2] *Chemical Engineering, Institut Teknologi Bandung, Jl. Ganesa No.10, Lb. Siliwangi, Coblong, Bandung, 40132, Indonesia*

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Abstract: Coconut shell charcoal has been widely produced as a raw material for biobriquette production. This cause effect on an increase of coconut shell price as a raw material for charcoal production. Wood waste is one of the easier and cheaper biomass to be obtained than coconut shell. However, the quality of charcoal produced from wood waste need to be compared to be used as a substitute of coconut shell. This study aims to discover the effect of pyrolysis as a carbonisation process on coconut shell, wood waste, and a mixture of both biomass on the quality of charcoal produced including yield, proximate analysis, lignocellulose analysis, and calorific value. A completely randomized design was used in this study by taking into account two influencing factors, including the type of sample (biomass sample and charcoal sample) and the type of biomass (coconut shell, wood waste, and a mixture of both). Pyrolysis was carried out at 550℃ for 120 minutes. Pyrolysis of biomass and different types of biomass have giving effects on the characteristics of the biomass and charcoal produced. The results of the analysis showed that the type of coconut shell biomass and a mixture of the two biomasses produced charcoal that qualified on standards. The results of the analysis concluded that charcoal made from a mixture of coconut shell and wood waste could be a solution to substitute charcoal made from coconut shell only.

Keywords: Biobriquettes; charcoal; coconut shell; pyrolysis; wood waste.

1. Introduction

The global energy crisis is a widespread issue faced by societies around the world. According to the Indonesian Ministry of Energy and Mineral Resources (ESDM) [1], energy demand continues to rise year after year. This trend indicates the urgent need to increase energy production to meet future demands. Among the various forms of renewable energy, bioenergy stands out as a promising alternative. Bioenergy can be derived from both plant and animal biomass [2], and one notable form of bioenergy that has significant potential for development is biobriquettes. Biobriquettes are a type of charcoal briquette produced from biomass materials [3]. Traditionally, they are made from wood charcoal. However, recent innovations have introduced coconut shell charcoal biobriquettes, which are now being produced and exported to international markets.

Coconut shells are a by-product of coconut plantations and represent a valuable biomass resource. In Indonesia, coconut shells are abundantly available, with coconut plantations covering approximately 3.4 million hectares [4]. Coconut shells constitute around 40% of the coconut fruit, generating an estimated 8 million tons of coconut shell waste annually [5]. Compared to wood charcoal, coconut shell charcoal has a higher calorific value due to its lower ash content [6]. While the use of coconut shells for charcoal production offers great potential, it has also created a new challenge

* *Corresponding author: dhifal18001@mail.unpad.ac.id*

the price of coconut shells has been increasing yearly. This situation highlights the need to identify alternative biomass sources that can serve as substitutes in biobriquette production.

One such alternative is wood waste or sawdust, which is widely available. However, charcoal made from wood typically contains a high ash content [7], which negatively affects the burning duration and calorific value of sawdust-based biobriquettes [8]. Therefore, it is essential to carefully evaluate the quality of charcoal produced from this type of biomass.

While previous studies have explored the performance of biobriquettes made from various combinations of biomass-derived charcoal, there is limited research focusing specifically on the quality of the charcoal produced during pyrolysis. The desired charcoal characteristics must align with the Indonesian National Standard (SNI) 06-3730-1995 for sawdust charcoal and SNI 01-6235-2000 for biobriquette calorific value. Consequently, this study aims to investigate the charcoal quality resulting from the pyrolysis of coconut shells, wood waste, and their mixture.

This research is designed to examine the influence of pyrolysis on the characteristics of coconut shell, wood waste, and their combination. It evaluates both the biomass quality and the resulting charcoal, comparing the outcomes with relevant SNI standards. The study involves conducting proximate and lignocellulosic analyses on the biomass before and after pyrolysis, as well as calculating charcoal yield and calorific value. The findings will provide essential data for future biobriquette production research.

2. Research and Methodology

2.1 Materials Preparation

The materials used in this study included coconut shells, mixed wood waste, and a combination of both. The coconut shells were obtained from traditional markets around Bandung Regency, collected from vendors selling mature coconuts used for coconut milk extraction. These coconut shells were then reduced in size using a hammer mill to obtain a particle size of approximately 3 cm or smaller.

The second material, mixed wood waste (non-specific types, including white teak, manglietia, and other available woods), was collected from local woodworking craftsmen in the Bandung area. The wood waste was carefully sorted to remove plastic, metal, or other non-biomass contaminants prior to the carbonization process.

The third sample was a blend of coconut shell and wood waste at a 50:50 mass ratio. Each biomass sample underwent two types of laboratory analysis: lignocellulosic analysis and proximate analysis.

Lignocellulosic analysis was performed based on the Van Soest method [9], which identifies the contents of cellulose, hemicellulose, and lignin in the biomass. The proximate analysis included determining the moisture content, ash content, volatile matter, and fixed carbon, following gravimetric procedures in accordance with Indonesian National Standard (SNI) 06-3730-1995 [1].

These analyses were conducted to assess the raw biomass characteristics prior to pyrolysis, which are essential in predicting the quality and yield of the resulting charcoal..

2.2 Pyrolisis Process

The pyrolysis process was conducted using a pyrolysis unit with a maximum capacity of 600 grams of biomass. The pyrolysis was carried out at a temperature of 550℃ for 120 minutes, measured from the point at which the fuel combustion reached a stable state. The fuel used to maintain the constant temperature ranged from 2 to 3 times the capacity of the pyrolysis unit. The types of fuel used included wood waste, coconut shells, and other available biomass residues to maintain a constant temperature of 550℃ during the process. The pyrolysis was repeated three times for each biomass type: coconut shells, wood waste, and a mixture of both materials [10].

2.3 Product characterization

The charcoal produced through the pyrolysis process was analyzed for lignocellulosic characteristics using the Van Soest et al. method [10]. Additionally, a proximate analysis was conducted to determine the ash content, moisture content, volatile matter, and fixed carbon content following the gravimetric procedure outlined in SNI 06-3730-1995 [1]. The yield of the charcoal produced was also measured to assess the efficiency of the pyrolysis process. Furthermore, the calorific value of the produced charcoal was tested to ensure it met the standards for briquette calorific value as specified by SNI 01-6235-2000.

For statistical analysis, the data was subjected to ANOVA (Analysis of Variance) for a Completely Randomized Design (CRD) and Factorial CRD to compare the variations between treatments. If significant differences were found, the Tukey HSD test was performed to identify which treatment groups were significantly different..

3. Results and Discussion

3.1 Lignocellulosic Characterization

The lignocellulosic content in the biomass samples and the charcoal samples is presented in Table 1. The ANOVA results indicate a significant effect on the lignin content based on the differences in samples and biomass types, but there was no significant effect on the hemicellulose and cellulose content. The lignin content in coconut shell is generally lower than that in wood waste, which can be attributed to the different fiber types in these two biomass materials. Lignin is a substance that contributes to the hardness of biomass, making wood much harder than coconut shells [26]. The mixture of these two biomasses produced a lignin content that falls between the lignin content of wood waste and coconut shell.

Table 1. Lignocellulosic Characterization Results

Sample Type	Biomass Ratio	Lignin	Hemicellulose	Cellulose
Biomass	TK	30,54%	25,82%	35,90%
	C	34,08%	27,28%	28,92%
	LK	36,81%	21,25%	33,69%
Charcoal	TK	25,29%	22,14%	38,20%
	C	28,28%	21,83%	36,96%
	LK	30,32%	21,33%	35,61%

Note : TK = Coconut Shell; C = Mixture (50%:50%); LK = Wood Waste

The pyrolysis process also affects the lignin content in the biomass used. Pyrolysis occurs at very high temperatures, causing many compounds to volatilize and convert into gas [22]. The research results indicate that significant changes only occurred in the lignin content, while hemicellulose and cellulose did not show significant changes. This is because lignin decomposes and evaporates at temperatures above 500°C, whereas cellulose and hemicellulose require chemical pretreatment for effective separation [25].

In a study by Febriani & Lindawati [5], the lignin content in coconut shell was 23.28%. Meanwhile, research by Rulianah et al. [13] on mahogany wood waste showed lignin content of 42.72%, cellulose

42.61%, and hemicellulose 22.05%. In another study by Trisanti et al. [24], the lignocellulosic content of sengon wood sawdust was found to be 17.51% lignin, 41.1% cellulose, and 22.26% hemicellulose.

The lignocellulosic analysis in this study shows that the lignin content in wood waste significantly differs from the other biomasses and falls within the range observed in previous studies. Similarly, the hemicellulose and cellulose content in wood waste aligns with previous research findings. However, the lignin content in coconut shells in this study was higher than reported in previous studies. This difference is likely due to the geographic origin of the coconuts. Therefore, the biomass used in this study can result in different lignocellulosic content depending on the region from which the biomass is sourced.

3.2 Ash Content

The results of the ash content measurements in this study are shown in Table 2. The results indicate that the lowest ash content was found in the wood waste biomass sample, with an ash content of 2.08%, while the highest ash content was found in the coconut shell charcoal sample, with an ash content of 8.71%. The difference in ash content between the biomass and charcoal samples was quite significant, with the pyrolysis process generally increasing the ash content in the material. This occurs because of the conversion of biomass components into ash during the pyrolysis process. Ash forms when a material is heated above 500°C, and complete ash formation occurs when the temperature exceeds 800°C. Thus, the pyrolysis process in this study led to an increase in the ash content of the material [14].

The type of biomass used also affects the ash content produced, as the ash content of each material varies. The ash content in the wood waste biomass was lower than that of the coconut shell and mixture biomass in this study.

Table 2. Tables Ash Content Result

Biomass Ratio	**Ash Content (%w/w)**	
	Biomass	Charcoal
TK	$2,80 \pm 0,11^{b}$	$8,71 \pm 0,05^{e}$
C	$2,56 \pm 0,04^{b}$	$8,24 \pm 0,11^{d}$
LK	$2,08 \pm 0,16^{a}$	$7,02 \pm 0,13^{c}$

Note: TK = Coconut Shell; C = Mixture (50%:50%); LK = Wood Waste

The mixing of biomasses influences the ash content in the resulting charcoal, depending on the ratio of the biomass mixture. The results of this study show that the ash content of the biomass mixture is in the range between the ash content of wood waste biomass and coconut shell biomass. Therefore, the blending of materials can affect the quality of the ash content in the charcoal produced during the pyrolysis process.

The ash content in this study was then compared with several similar studies and with the quality standard of SNI 06-3730-1995. This comparison was made to determine whether this study meets the SNI standard and to see how it compares to other similar studies.

Based on Table 2, all the ash content data produced in this study meet the SNI 06-3730-1995 standard, which sets the maximum ash content value at 10%. In contrast, this study produced a range of ash content between 7% and 8.8%. In the study by Siahaan et al. [15], the pyrolysis of rice husks resulted in an ash content range of 29.4% to 46.7%. Furthermore, Surest et al. [20] demonstrated that pyrolysis of coconut shell increased the ash content of the coconut shell from 0.73% to 3.09%, while pyrolysis of sawdust increased the ash content from 0.96% to 6.93%.

The ash content in this study meets the SNI 06-3730-1995 standard, although it is higher compared to previous studies. This may be due to differences in the temperature and duration of the pyrolysis process. Further research is needed to identify the optimal conditions for pyrolysis. However, the ash content in this study still meets the SNI standard, making it suitable for use as a raw material for biobriquet production.

3.3 Moisture Content

The moisture content measurement results in this study are presented in Table 3. The findings indicate that the lowest moisture content was observed in the charcoal sample derived from mixed biomass, with a moisture content of 0.97%, while the highest moisture content was found in the wood waste biomass sample, at 13.21%. The significant difference in moisture content between the biomass and charcoal samples suggests that the carbonization process substantially reduces the moisture content in the material.

Moisture begins to evaporate when the material is heated above 100°C, corresponding to the phase transition temperature. In this study, the high temperature during the carbonization process caused most of the moisture to evaporate, resulting in a drastic reduction in moisture content after pyrolysis [19].

Table 3. Tables Moisture Content Result

Biomass Ratio	**Mositure Content (%w/w)**	
	Biomass	Charcoal
TK	11,75±0,07^{c}	1,18±0,27^{a}
C	11,35±0,25^{c}	0,97±0,1^{a}
LK	13,21±0,32^{d}	2,69±0,26^{b}

Note: TK = Coconut shell; C = Mixed biomass (50%:50%); LK = Wood waste

Different types of biomass result in varying moisture content depending on the structure and water activity present in the material [3]. Wood waste initially exhibited the highest moisture content at 13.21% and also demonstrated higher water activity, resulting in the highest charcoal moisture content at 2.69%. Coconut shell biomass tends to have lower moisture content. However, mixing coconut shell and wood waste did not result in a statistically significant difference in moisture content compared to using coconut shell alone, as indicated by the same notation in the Tukey HSD post-hoc analysis.

The moisture content in this study was then compared with similar studies as well as the quality standards specified in SNI 06-3730-1995. This comparison was made to determine whether the results comply with the SNI standard and to evaluate the relative quality of this study's outcome compared to previous research.

According to Table 3, all charcoal moisture content results in this study meet the SNI 06-3730-1995 standard, which allows a maximum moisture content of 15%. The results of this study showed a range between 0.8% and 3%. In a study by Siahaan et al. [15], the pyrolysis of rice husks produced moisture contents ranging from 5.2% to 9.2%. Meanwhile, the study by Surest et al. [20] demonstrated that pyrolysis reduced the moisture content of coconut shells from 10.71% to 7.82%, and that of sawdust from 11.62% to 9.85%.

The moisture content achieved in this study not only meets the SNI 06-3730-1995 standard but is also lower than that reported in previous studies. This indicates that the charcoal produced in this research possesses good quality and is suitable for use as raw material in biobriquette production.

3.4 Volatile Matter Content

The measurement results of volatile matter content in this study are presented in Table 4. The findings indicate that the lowest volatile matter content was observed in the charcoal sample derived from coconut shell biomass, with a value of 22.34%, while the highest was found in the wood waste biomass sample, reaching 83.96%. A substantial difference was observed between the biomass and the charcoal samples, indicating that the pyrolysis process significantly reduces the volatile matter content in the material.

This reduction is attributed to the high-temperature pyrolysis, which causes many organic components in the biomass to be converted into vapor and gas [22]. In general, volatile matter components in biomass can evaporate completely at temperatures around 950°C, but some components begin to volatilize at much lower temperatures, typically between 200°C and 500°C. As a result, biomass combustion tends to produce more smoke compared to charcoal combustion, which has undergone prior thermal decomposition.

Table 4. Volatile Matter Content

Biomass Ratio	Volatile Matter Content (%w/w)	
	Biomass	Charcoal
TK	79,73±0,55^{c}	22,34±0,42^{a}
C	81,78±0,49^{d}	23,49±0,17^{a}
LK	83,96±0,3^{e}	28,08±0,64^{b}

The type of biomass used also affects the resulting volatile matter content, as each material has different intrinsic levels of volatile compounds. Combustion of coconut shell generally produces less smoke compared to wood waste combustion. Therefore, blending wood waste with coconut shell can reduce the amount of smoke produced during the combustion of the resulting charcoal [8]. This is supported by the results of this study, which showed that the volatile matter content of the mixed biomass charcoal was similar to that of coconut shell charcoal, as indicated by the same notation in the Tukey HSD post-hoc analysis.

The volatile matter content observed in this study was then compared with similar studies and with the quality standard SNI 06-3730-1995. This comparison was conducted to assess whether the results comply with the SNI standard and to evaluate whether the performance is better or worse than that of previous studies.

Based on Table 4, several volatile matter values obtained in this study met the requirements of SNI 06-3730-1995, which specifies a maximum volatile matter content of 25%. Charcoal made from coconut shell and the mixed biomass charcoal yielded volatile matter contents of 22.34% and 23.49%, respectively—both of which meet the SNI standard. However, charcoal derived from wood waste did not meet the standard, as it exhibited a volatile matter content of 28.08%.

In the study conducted by Siahaan et al. [15], the pyrolysis of rice husk resulted in a volatile matter range of 19.2–26.4%. Meanwhile, research by Surest et al. [20] showed that pyrolysis reduced the volatile matter content of coconut shell from 75.51% to 26.21%, and that of sawdust from 81.1% to 39.21%.

The results of this study indicate that the volatile matter content in both coconut shell charcoal and mixed biomass charcoal complied with the SNI 06-3730-1995 standard and were even better than the outcomes reported in several previous studies. This suggests that charcoal made from a mixture of biomass materials can meet the quality requirements for briquette production and may offer a viable alternative to using only coconut shell as the feedstock for bio-briquettes.

3.5 Fixed Carbon Content.

The fixed carbon content measured in this study is presented in Table 5. The results showed that the lowest fixed carbon content was found in the biomass sample made from wood waste, at 0.74%, while the highest was observed in the charcoal sample made from coconut shell, at 67.77%. The significant difference in fixed carbon content between biomass and charcoal samples indicates that the carbonization process considerably increases the fixed carbon in the material. This is due to the conversion of many compounds into carbon under high temperatures during pyrolysis. In addition, the carbonization process reduces other components such as moisture, volatile matter, and other non-carbon substances, thereby increasing the proportion of fixed carbon in the final product [2].

The type of biomass also influences the fixed carbon content, as each raw material has different initial compositions of moisture, ash, and volatile matter [4]. Coconut shell tends to have lower moisture, ash, and volatile matter contents compared to wood waste, resulting in a higher yield of fixed carbon after the carbonization process.

Table 5. Volatile Matter Content

Biomass Ratio	**Fixed Carbon Content (%w/w)**	
	Biomass	Charcoal
TK	5,72±0,44^{c}	67,77±0,2^{e}
C	4,31±0,63^{b}	67,30±0,19^{e}
LK	0,74±0,69^{a}	62,21±0,54^{d}

Note: TK = Coconut Shell; C = Mixed Biomass (50%:50%); LK = Wood Waste

The addition of coconut shell to wood waste produced charcoal with a high fixed carbon content. This is evidenced by the results of this study, where the fixed carbon content in the mixed biomass charcoal was comparable to that of coconut shell charcoal, as indicated by the same notations according to the Tukey HSD post-hoc test.

Based on Table 5, several fixed carbon content values obtained in this study meet the SNI 06-3730-1995 quality standard, which requires a minimum fixed carbon content of 65%. Both coconut shell charcoal and mixed biomass charcoal fulfilled this requirement, with fixed carbon contents of 67.77% and 67.3%, respectively. However, wood waste charcoal did not meet the standard, with a fixed carbon content of 62.21%.

In a study by Siahaan et al. [15], carbonization of rice husk produced charcoal with fixed carbon contents ranging from 26.06% to 41.3%. Similarly, in research conducted by Surest et al. [20], the carbonization of coconut shell increased its fixed carbon content from 13.05% to 62.48%, while sawdust increased from 6.32% to 44.01% after carbonization.

The fixed carbon content obtained in this study—particularly from coconut shell and mixed biomass—successfully meets the SNI 06-3730-1995 standards and demonstrates superior quality compared to previous studies. This suggests that mixed biomass charcoal can serve as a viable alternative to coconut shell charcoal, offering comparable quality and performance as a raw material for biobriquette production.

3.6 Charcoal Yeald.

The charcoal yield data from this study are presented in Table 6. The yield ranged between 26% and 30%. The carbonization process is influenced by the temperature and duration of carbonization.

Generally, higher temperatures and longer carbonization durations result in lower yields, as more of the biomass content is oxidized and released as gas [15].

Table 6. Charcoal Yield Results.

Biomass Ratio	Sample Image	Yield (%b/b)
Coconut Shell	 (Personal Dokument)	30,28±0,35^{c}
Wood Waste	 (Personal Dokument)	26,17±0,33^{a}
Mixed (50%:50%)	 (Personal Dokument)	28,28±0,25^{b}

In addition, the yield is also influenced by the type of biomass used, due to the variations in biomass composition. Each biomass type has different contents such as moisture, ash, and volatile matter [4]. These factors contribute to the amount of carbon retained after carbonization, leading to differences in charcoal yield. The results of this study show that coconut shell produced the highest yield. When mixed with wood waste, the resulting pyrolysis yield also increased significantly, as indicated by the different notations observed in the Tukey HSD post-hoc test.

In a study by Siahaan et al. [15], carbonization of rice husk at 400–600°C for 30–120 minutes resulted in charcoal yields ranging from 38.91% to 54.7%. Another study by Tirono & Sabit [23], which performed carbonization at 200–550°C for 1.5 hours, reported the highest yield at 89% at the lowest temperature and the lowest yield at 30.6% at the highest temperature.

From these references, it can be concluded that the charcoal yield in this study is still within the range reported by previous studies.

The findings clearly demonstrate that different biomass types produce different yields, which is attributed to the varying proportions of material converted to gas. In this study, wood waste showed the lowest yield, while coconut shell produced the highest. Consequently, the yield from the mixed biomass lies between the two, forming a balanced outcome between both feedstocks.

3.7 Calorific Value of Charcoal.

The calorific value results of the charcoal samples are presented in Table 7. The lowest calorific value was recorded in wood waste charcoal at 6653 cal/g, while the highest was found in coconut shell charcoal at 7873.7 cal/g. The type of biomass used greatly influences the calorific value, as it correlates directly with the fixed carbon content, which varies depending on the material [9].

Coconut shell, having a higher fixed carbon content compared to wood waste, results in a higher calorific value. Therefore, the addition of coconut shell to wood waste enhances the calorific value of the resulting charcoal. This is evident in the current study, where the calorific value of the mixed biomass charcoal lies between that of coconut shell and wood waste, though it tends to be closer to coconut shell charcoal, suggesting its dominant effect on energy value.

Table 7. Calorific Value of Charcoal

Ratio Biomass	Calorific Value of Charcoal (kal/g)
TK	7873,7±14,5^{c}
C	7561±11^{b}
LK	6653±6^{a}

Note: TK = Coconut Shell; C = Mixed Biomass (50% Coconut Shell : 50% Wood Waste); LK = Wood Waste

The calorific values obtained in this study were then compared with those from previous research and the Indonesian National Standard (SNI) 01-6235-2000. This comparison aims to evaluate whether the charcoal produced in this study meets the SNI standard and to assess whether the results are superior or inferior to other similar studies.

Based on Table 7, all charcoal samples in this study exhibited calorific values ranging from 6600 to 7900 cal/g, thereby meeting the minimum requirement of 5000 cal/g as stipulated in SNI 01-6235-2000.

Research by Tirono & Sabit [23] showed that the calorific value of coconut shell charcoal ranged from 5238 to 8142.7 cal/g, while Surest et al. [20] found that the carbonization process increased the calorific value of coconut shells from 4411 cal/g to 6655 cal/g, and that of sawdust from 4289 cal/g to 5970 cal/g.

These comparisons indicate that the calorific values obtained in the current study not only meet SNI standards but also surpass the results of several previous studies. This demonstrates that the charcoal produced from this biomass, especially the mixed biomass, has good quality and is highly suitable as a raw material for biobriquette production.

4. Conclusion

Based on the results of this study, pyrolysis significantly alters the physical and chemical characteristics of biomass, including changes in ash content, moisture content, volatile matter, fixed carbon content, and lignocellulosic composition. Furthermore, the type of biomass used has a significant effect on the charcoal yield, ash content, moisture content, volatile matter, fixed carbon, lignocellulosic components, and calorific value. The combination of coconut shell and wood waste biomass for charcoal production proves to be a viable alternative to using coconut shell alone. The resulting charcoal quality not only exceeds the SNI standard but also closely approaches the quality of charcoal derived from 100% coconut shell, making it suitable as a raw material for biobriquette production. Future studies are recommended to further analyze the quality and performance of biobriquettes produced from the combination of wood waste and coconut shell, particularly in terms of combustion efficiency, emission characteristics, and mechanical properties.

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