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The Study on Utilization of Agricultural Waste as an Alternative Fuel for Bio-briquettes

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Abstract— The increase in fossil fuel consumption has led to the depletion of oil and natural gas reserves, necessitating the development of alternative energy sources from renewable biomass. Agricultural waste such as corn cob and banana stem, which are abundant in quantity, can be utilized as alternative bio-briquette fuel. This study aimed to synthesize bio-briquette using a mixture of corn cob and banana stem and investigate the influence of banana stem and corn cob composition on bio-briquettes' characteristics. The bio-briquette production process involved pyrolysis at a temperature of 350°C for corn cob and banana stem carbonization. The variations in banana stem composition with corn cob were 10%:90%, 30%:70%, and 50%:50%, respectively. The quality of the bio-briquettes was tested according to the SNI 01-6235-2000 standard. The research results showed that an increase in banana stem composition generally resulted in a decrease in moisture content, volatile matter, and calorific value but an increase in the ash content of the bio-briquettes. All variations of bio-briquette composition met the SNI 01-6235-2000 standard for moisture content, fixed carbon, and calorific value. The highest calorific value was obtained at a composition of 10% banana stem and 90% corn cob, which measured 8929 cal/g. The emission test results for bio-briquettes with a composition of 10% banana stem and 90% corn cob indicated concentrations of SO_2, NO_x, and CO parameters at 65,67 mg/Nm^3, 0 mg/Nm^3, and 307,3 mg/Nm^3, respectively.

Keywords: agricultural waste, Corn Cob, Bio-briquettes, Banana Stem, Pyrolysis.

I. INTRODUCTION

The rapid development of technology has led to increasing demand and use of fossil fuels. This has resulted in negative impacts on the rise of greenhouse gas (GHG) emissions, contributing to global warming and climate change [1]. The finite nature of fossil fuels has spurred the utilization of renewable energy sources, such as solar energy, biomass, wind power, geothermal energy, and tidal energy, in order to reduce reliance on fossil fuels [2]. Biomass is the third-largest alternative energy source worldwide, derived from plants and organic matter, with great potential for utilization as an alternative energy source. Various types of materials can be classified as biomass, including solid waste from agricultural, domestic, and forestry activities [3]. The primary advantage of utilizing biomass as an energy source is its ability to reduce greenhouse gas emissions, such as carbon dioxide, when compared to fossil fuels. Additionally, it is estimated to enhance a nation's energy resilience [4].

The direct combustion of biomass materials for heating and cooking purposes can negatively impact human health due to the indoor air pollution generated [5]. The synthesis of bio-briquettes is one method of utilizing biomass. Research findings have shown that biomass conversion into bio-briquettes can improve biomass combustion efficiency by up to 20% compared to direct combustion. Bio-briquettes offer several advantages, including abundant raw material sources, simple technology, easy operation, low cost, and ease of handling, making them suitable for large-scale utilization [1].

Biomass is a relatively abundant energy source in Indonesia, but its utilization has not been optimized. According to data from the Ministry of Energy and Mineral Resources (ESDM), the biomass energy potential in Indonesia is estimated to be nearly 443000 MW, with only around 1.9% being utilized for electricity generation. Data from the Central Statistics Agency (BPS) in 2021 reported that the fuel usage percentage for cooking purposes in Indonesia includes gas/LPG (83.36%), wood (11.76%), kerosene (2.78%), and charcoal/briquettes (0.08%) [6]. Developing countries like Indonesia are rich in agricultural commodities, resulting in a significant potential for generating agricultural residues or waste. Utilizing solid agricultural waste with low economic value is an alternative that should be considered to produce affordable bio-briquette products.

Corn cob and banana stem are agricultural waste products that have the potential to be utilized as alternative energy sources for bio-briquettes [7]. The banana plant (Musa paradisiaca) is a fruit-bearing plant commonly found in Southeast Asia, including Indonesia. Bananas are one of the largest fruit commodities in Indonesia, with a production of 8,74 million tons per year in 2021 [6]. The post-harvest process of banana trees often generates underutilized banana stem waste. Banana stem waste has a composition that consists of approximately 5%-10% lignin, 6%-8% hemicellulose, 60%-65% cellulose, and 10%-15% water content [8]. Corn (Zea mays) is a major agricultural commodity in Indonesia, with a production volume reaching 19.61 million tons in 2021. The large-scale production of corn leads to an increase in corn cob waste, which has the potential to cause environmental pollution if not properly managed. Corn cob waste is an organic waste that has not been widely utilized as an alternative fuel source. The general characteristics of corn cobs consist of approximately 16-18% lignin, 31-33% hemicellulose, 40-44% cellulose, and 3-5% ash content [9]. Research findings report that corn cob waste has a calorific value of 4.6 kcal/kg, nitrogen content of 0.41-0.57%, and sulfur content of 0.03-0.05% [10].

Pyrolysis is a process of decomposing materials through heating in the absence of external air. The pyrolysis process produces several products, including solid char, liquid oil, and gaseous fuel. Research findings have shown that bio-briquette production using the pyrolysis process yields higher calorific values compared to carbonization. This is evidenced by the study conducted by Ridhuan and Suranto. (2016) [11], which reported the calorific analysis of bio-briquettes produced from durian peel using pyrolysis and regular carbonization. The pyrolysis process of durian peel resulted in a calorific value of 5726 cal/g, while the carbonization process yielded a calorific value of 3418 cal/g for the bio-briquettes. Several previous studies have been conducted to synthesize bio-briquettes using the pyrolysis method. Sari (2017) [12] reported on the influence of bio-briquette dimensions resulting from the pyrolysis of empty fruit bunches of oil palm (EFB). That research reported that the hollow cylinder dimension had the highest calorific value at 5122 kcal/kg. Ayuningtyas and Aridito (2019) [13] reported that briquettes synthesized from wood charcoal using the pyrolysis process can achieve calorific values ranging from 6913 to 7039 kcal/kg. Previous studies have shown that biomass synthesis through pyrolysis is still limited to a single type of biomass, and detailed information regarding emission test results from the combustion of such biomass is lacking. This study aimed to synthesize bio-briquettes using a mixture of corn cob and banana stem and investigate the effect of corn cob and banana stem composition on the characteristics of the bio-briquettes. The bio-briquettes with the highest calorific value in this study were subjected to emission testing to determine the levels of SO_2, NO_x, and CO emissions produced.

II. Material and Methods

2.1. Materials and Equipment

The equipment used in this study included a pyrolysis reactor, an analytical balance (Shimadzu AY 220), a 60-mesh sieve, an oven (Binder ED 53), bio-briquette molds, and a mortar. The materials used in this study included corn cob (CC), banana stem (BS), and tapioca flour. Figure 1 shows the raw materials of banana stem and corn cob before the pyrolysis process.

Figure 1. Raw Materials for Bio-briquettes (a) Banana Stem and (b) Corn Cob, After Drying Process

2.2. Method

i. Bio-briquette Production Procedure

The bio-briquette production procedure consisted of biomass waste preparation, material pyrolysis, charcoal grinding, and bio-briquette molding. The preparation process of biomass waste involved collecting the raw materials, corn cob, and banana stem. The raw materials were cleaned and cut into approximately 2 cm sizes, followed by a drying process under sunlight for 5 days. The dried biomass waste of banana stem and corn cob then underwent a 90-minute pyrolysis process at an operating temperature of 350°C. The pyrolysis process of banana stem and corn cob was conducted in batches, as shown in Figure 2.

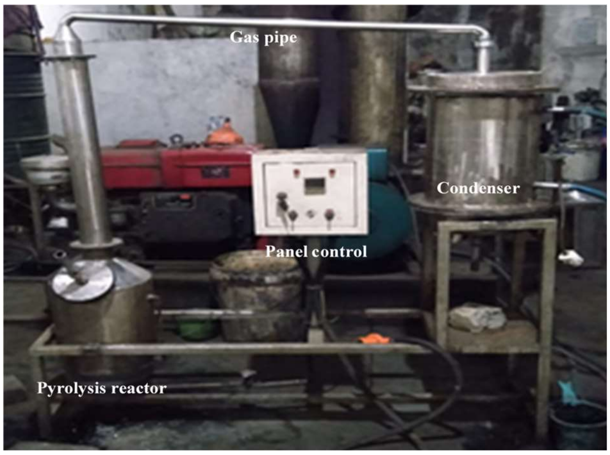

Figure 2. Pyrolysis Reactor

The resulting charcoal from the pyrolysis of banana stem and corn cob was then ground using a mortar and sieved through a 60-mesh sieve. The next step involved mixing the charcoal from the banana stem, charcoal from the corn cob, and the binder. The binder used was tapioca flour, comprising 10% of the mixture. The biomass composition variations used were 10% BS: 90% CC; 30% BS: 70% CC; and 50% BS: 50% CC. The next stage involved molding the thoroughly mixed materials, including charcoal powder, binder, and water.

Figure 3. Dried Bio-briquettes

The molding process involved shaping the bio-briquette material into cylindrical forms and manually compressing them to obtain dense, compact, and durable briquettes. The molded bio-briquettes then underwent drying in an oven at a temperature of 110°C for 8 hours, as shown in Figure 3. The heating process in the oven aimed to reduce the moisture content of the bio-briquettes.

ii. Characteristic Testing of Corn Cob and Banana Stem Raw Materials

The characteristic parameters tested on the raw materials included moisture content, ash content, volatile matter, fixed carbon, and calorific value. The data from the characteristic tests are presented in Table 1 and Table 2.

Table 1. Characteristics Testing of Corn Cob

Parameters	Unit	Test results
Moisture content	%	14.0
Ash content	%	1.48
Volatile matter	%	82.3
Fixed carbon	%	2.22
Calorific value	cal/g	3716.5

Table 2. Characteristics Testing of Banana Stem

Parameter	Satuan	Hasil Uji
Moisture content	%	12.5
Ash content	%	20..2
Volatile matter	%	67
Fixed carbon	%	0.31
Calorific value	cal/g	3138

iii. Quality and Emission Testing of Bio-Briquettes

The quality testing of bio-briquettes was conducted to determine the moisture content, ash content, volatile matter, fixed carbon, and calorific value present in the bio-briquettes. The quality testing of bio-briquettes was carried out according to the SNI 01-6235-2000 quality standard. The emission testing of bio-briquettes was performed to determine the emissions content during combustion. The emission testing was conducted on the bio-briquette samples with the highest calorific value. The gas emission parameters tested included the concentration of SO_2, NO_x, and CO. These parameters were tested following the SNI 19-7117.2-2005 standard on exhaust gas emissions.

III. Result and Discussion

3.1. Characteristics of Bio-briquettes

The moisture content testing of bio-briquettes aimed to determine the water content present in the bio-briquettes. Moisture content has a significant impact on the quality and value of the briquettes. The higher the moisture content, the lower the quality of the bio-briquettes, as it has the potential to reduce the calorific value of the bio-briquettes [14]. The results of the moisture content testing of bio-briquettes in Figure 4 show that bio-briquettes with all variations of banana stem (BS) and corn cob (CC) composition have met the SNI 01-6235-2000 standard. The maximum moisture content allowed for bio-briquettes in the standard is 8% by weight (wt). An increase in the banana stem composition in the bio-briquettes tends to increase the moisture content of the bio-briquettes.

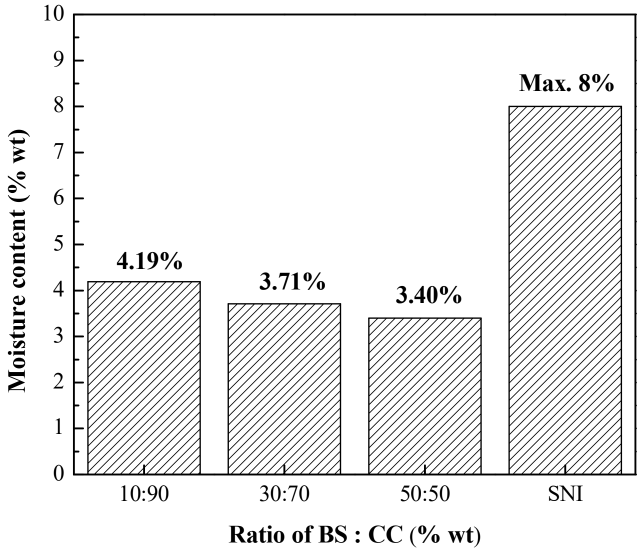

Figure 4. Moisture Content Testing Results of Bio-briquettes

The minimum moisture content value was obtained for the composition of banana stem and corn cob at a ratio of 10:90, with a value of 4,19%. This can be supported by the results of the characteristic testing of the raw materials, which showed that the moisture content of corn cob was higher than that of banana stem. Banana stem charcoal tends to have larger and more numerous pores compared to coconut shell charcoal, making it easier to absorb moisture from the surrounding air, thus resulting in increased moisture content in the bio-briquettes [7].

The ash content testing of the bio-briquettes was conducted to determine the amount of ash present. Ash content in bio-briquettes generally consists of residues from inorganic materials. Figure 5 shows the results of the ash content testing of the bio-briquette samples.

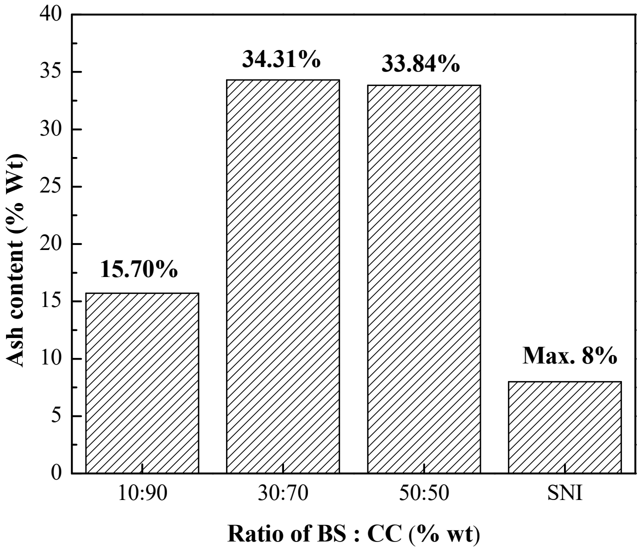

Figure 5. Ash Content Testing Results of Bio-briquettes

The testing results showed that the ash content in all bio-briquette variations did not meet the SNI 01-6235-2000 standard, as it exceeded 8% by weight (wt). An increase in the banana stem composition generally led to higher ash content in the bio-briquettes. The minimum ash content value was obtained for the composition of the banana stem (BS) and corn cob (CC) at a ratio of 10:90, which was 15.70%. This is because the ash content of the banana stem material is higher (20.2%) compared to the ash content of the corn cob material (1.48%), as indicated in the data from the characteristic testing of the raw materials in Table 1 and Table 2.

The testing of volatile matter content was used to determine the amount of easily evaporated compounds produced during the combustion process of the bio-briquettes. The volatile matter content was determined by the weight loss when the briquettes were heated without contact with air at a temperature of around 950°C at a specific heating rate. A high volatile matter content in the bio-briquettes could generate significant smoke when the bio-briquettes were ignited [15]. Figure 6 shows the results of the volatile matter content testing of the bio-briquettes.

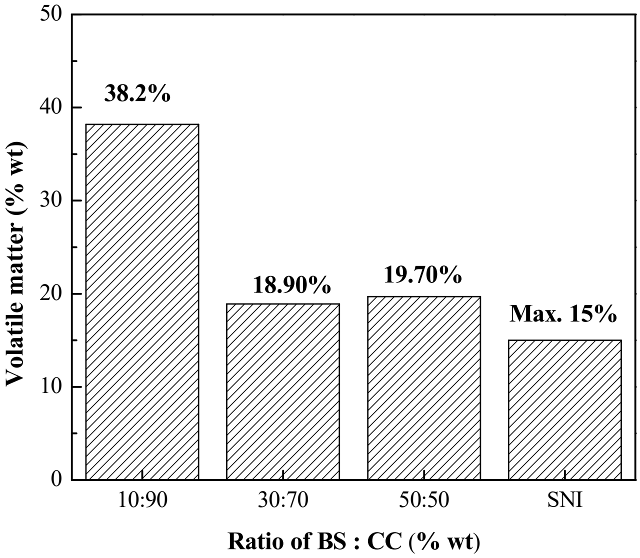

Figure 6. Volatile Matter Testing Results of the Bio-briquettes

The test results in Figure 6 indicated that all variations of the bio-briquettes did not meet the SNI 01-6235-2000 standard. The maximum allowable volatile matter content was 15%. Bio-briquettes with low volatile matter content are preferable to those with high volatile matter content, as bio-briquettes with high volatile matter content tend to produce excessive smoke when ignited or burned. The research findings showed that an increase in the banana stem composition tended to decrease the volatile matter content. Based on the data in Table 2, the volatile matter content of the banana stem was lower compared to the volatile matter content of the corn cob. Therefore, an increase in the banana stem composition would reduce the bio-briquettes' volatile matter content.

The testing of fixed carbon content in the bio-briquettes was conducted to determine the amount of bound carbon present in the bio-briquettes. Fixed carbon is an important parameter in bio-briquettes, as a higher fixed carbon value indicates less smoke produced by the bio-briquettes. The results of the fixed carbon content testing can be seen in Figure 7.

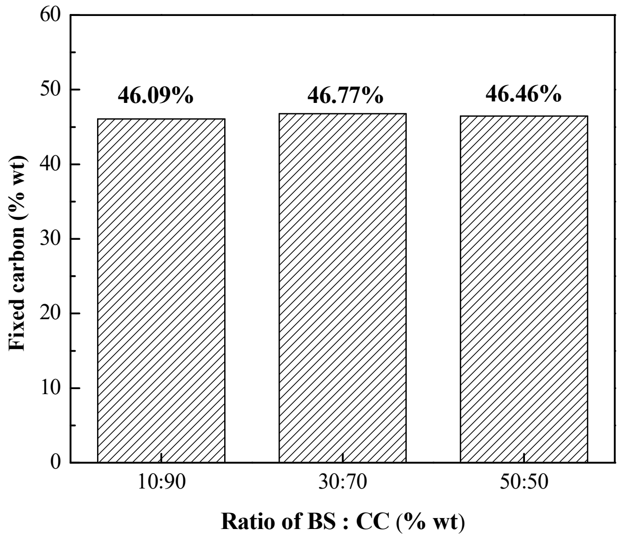

Figure 7. Fixed Carbon Testing Results of the Bio-briquettes

The data in Figure 7 shows that all bio-briquette variations met the SNI 01-6235-2000 standard, as the standard does not provide detailed specifications for fixed carbon content in bio-briquettes. The calorific value is influenced by the carbon content in the briquettes, as a higher carbon content leads to a higher calorific value. Therefore, a higher carbon content indicates that the material is more suitable for use as fuel [16].

The calorific value was tested to determine the bio-briquettes' heat value. Calorific value is the most important parameter in bio-briquettes, as a higher calorific value indicates a higher quality of the briquettes produced. The results of the calorific value testing are shown in Figure 8.

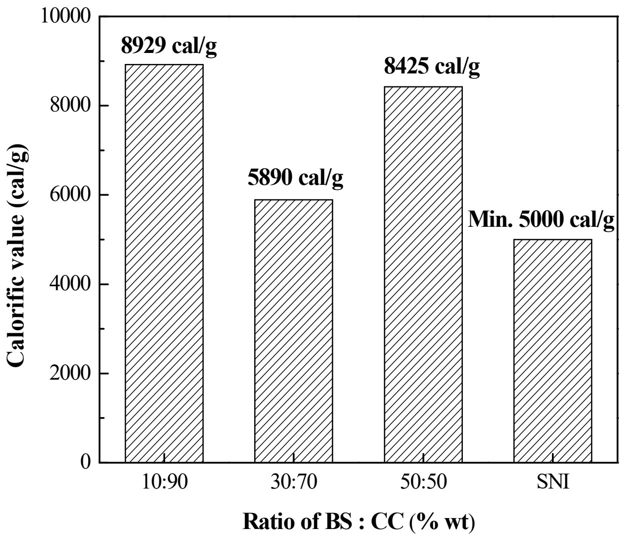

Figure 8. Calorific Value Testing Results of the Bio-briquettes

The data in Figure 8 indicated that all bio-briquette variations met the SNI 01-6235-2000 standard, which required a minimum calorific value of 5000 cal/g. Therefore, the higher the calorific value produced, the better the quality of the bio-briquettes. Figure 8 showed that the calorific value produced in the 10% banana stem: 90% corn cob variation was generally higher compared to the other variations, at 8929 cal/g. This was because the bio-briquettes had a higher content of corn cob, resulting in a higher calorific value. However, in the variation with a composition of 30% banana stem: and 70% corn cob, there was a decrease in calorific value due to the differences in the composition percentages used. Each material had different moisture content, ash content, volatile matter, and fixed carbon content, which resulted in variations in the calorific value produced [17].

3.2. Analysis of Bio-briquette Combustion Emissions

The emission testing of the bio-briquettes was conducted on the composition of the bio-briquettes with the highest calorific value (BS : CC = 10 : 90). The emission testing aimed to determine the emission content produced when the briquettes were ignited. The results of the emission testing are presented in Table 3. The testing data reported a sulfur dioxide (SO_2) content of 65.67 mg/Nm^3, a nitrogen oxide (NO_x) content of 0 mg/Nm^3, and a carbon monoxide (CO) content of 307.3 mg/Nm^3. The measurement of the SO_2 content was performed to determine the sulfur dioxide content during the combustion of the briquettes. The tested values of sulfur dioxide content met the quality standards. The results of the emission test of biobriquettes obtained from banana fronds and cobs (10 : 90) had lower NO_x and CO emission values compared to fish bone and bagasse biobriquettes (50 : 50) with molasses binder. This shows that the biobriquettes of banana stems and corncobs in this composition have better combustion quality than the biobriquettes of fish bones and bagasse.

Table 3. Results of Briquette Emission Testing

Parameters	**Quality standars (mg/Nm^3)**	**Concentration (mg/Nm^3)**	
		(This study)	**Fishbone-bagasse biobriquettes** [18]
SO_2	*800	65,67	0
NO_x	*1.000	0	43.77
CO	**30.000	307,3	1566.67

*East Java Governor Regulation No. 10 of 2009 on Ambient Air Quality and Emission Standards for Non-Mobile Sources in East Java

**Government Regulation of the Republic of Indonesia No. 41 of 1999 on National Ambient Air Quality Standards

Haryanti et al. (2018) [19] reported in their study that the lower the levels of SO_2, NO_x, and CO emitted from the combustion of bio-briquettes, the better the quality of the briquettes.

IV. Conclusion

Based on the research findings, it can be concluded that banana stem and corn cob waste can be effectively utilized as bio-briquette fuel through the pyrolysis process at a temperature of 350°C. Increasing the composition of banana stems generally led to a decrease in moisture content, volatile matter, and calorific value but an increase in the ash content of the bio-briquettes. All variations of bio-briquette composition met the SNI 01-6235-2000 standards for moisture content, fixed carbon, and calorific value. The best quality bio-briquette was obtained with a composition of 10% banana stem and 90% corn cob. The parameters for this composition were as follows: moisture content of 4.19%, ash content of 15.7%, volatile matter of 38.2%, fixed carbon of 46.9%, and calorific value of 8928 cal/g. The emission testing conducted on this composition resulted in concentrations of SO_2, NO_x, and CO parameters at 65.67 mg/Nm^3, 0 mg/Nm^3, and 307,3 mg/Nm^3, respectively.

V. Acknowledgement

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