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Fabrication of Biobriquettes from Mixture of Palm Fronds and Palm Shells with Varying Binders of Tapioca and Sago Flour

Dimas Frananta Simatupang[1]*, Merta Simbolon[2]
[1]Department of Chemical Engineering, Politeknik Teknologi Kimia Industri Medan, Indonesia
[2]Department of Physics Education, Universitas Musamus Merauke, Indonesia
Corresponding Author: Dimas Frananta Simatupang difratas@ptki.ac.id

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A B S T R A C T

Biobriquettes are products obtained from the compaction process of biomass residue used as fuel and formed by using a binding agent. In this study, the biomass used comprised palm fronds and palm shells. The objective was to determine the characteristics of biobriquettes. The research methodology adopted was quantitative experimentation. Results showed that the highest calorific value of biobriquettes was 6729.92 cal/g (1:3-sago 15%), the lowest moisture content was 1.1168% (1:3-tapioca 10%), the lowest ash content was 9.5232% (1:3-sago 10%) and the highest density was 0.9927 g/cm^3 (1:3-tapioca 20%). Based on the test results, it can be concluded that the optimal ratio of raw materials palm fronds to palm kernel shells for biobriquette fabrication is 1:3 with 10% tapioca flour and 10-15% sago flour as binders.

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INTRODUCTION

The increasing population growth leads to a rising demand for energy. One of the primary resources consumed by humans is derived from fossil fuels. These energy sources, formed millions of years ago, are gradually depleting, prompting the need for conservation and the search for alternative energy sources. Therefore, efforts are required to find alternative raw materials that can be renewed and easily obtained. One such example of energy is derived from biomass, known as bio-briquettes (Shafiyya et al., 2022).

One of the biomass sources suitable for making biobriquettes is derived from the fronds and palm shells. Palm fronds belong to the category of wet by-products because they contain approximately 75% water content, thus prone to quick spoilage if not promptly processed. The nutrient content of palm fronds and leaves includes dry matter 48.78%, crude protein 5.3%, hemicellulose 21.1%, cellulose 27.9%, crude fiber 31.09%, ash 4.48%, lignin 16.9%, and silica 0.6%. Palm shells possess a high calorific value, typically around 3,800 Kcal/kg. In the past, palm shells were primarily used as fuel for domestic and industrial purposes. The density of palm shells ranges between 1700 to 2050 kg/m^3 (Ardiansyah, 2014).

Several studies related to briquette production have been conducted. For instance, the utilization of plastic waste to produce biobriquettes has resulted in a calorific value of 8565.914 cal/g, a moisture content of 5.47%, and an ash content of 4.95%. These biobriquettes meet Indonesian national standards (Ningsih & Udyani, 2020). Additionally, biobriquettes made from corn cobs have been successfully characterized with a calorific value of 5666 cal/g, moisture content and ash content at 3.67% and 4.83%, respectively. These biobriquettes also meet Indonesian national standards (Aprilyanti et al., 2023). Moreover, biobriquettes produced from oil palm mesocarp fiber using tapioca flour as a binder showed characterization results with moisture and ash content reaching 7.6% and 22.52%, respectively (Rahardja et al., 2022).

The consumption rate of oil has increased by an average of 6% annually. It is anticipated that this trend will continue in the following years. This research aims to further develop the utilization of biomass waste such as palm fronds and shells to contribute to the effort in providing renewable alternative fuels. Palm fronds and shells, as biomass waste, are not optimally utilized. Hence, there is a need to explore and develop biomass from palm fronds and shells to create biobriquettes as one of the alternative fuel sources. This study is intended to produce biobriquettes derived from palm fronds and shells by varying the adhesive content using tapioca and sago flour to achieve desirable biobriquette characteristics.

LITERATURE REVIEW

Palm fronds and palm shells

Oil palm is a lignocellulosic material rich in carbohydrates in the form of starch and sugars. It contains cellulose, hemicellulose, and lignin components (Opuada Ameh et al., 2015). Oil palm is one of Indonesia's key plantation commodities contributing to the country's foreign exchange earnings every year. Currently, Indonesia ranks as the world's second-largest producer of palm oil after Malaysia, with an average annual production of around 9.9 million tons since 2003 (Haji, 2013). Traditionally, palm oil has been utilized solely for vegetable oil production without exploring its waste potential. Effectively managed, solid waste from oil palm could serve as an alternative energy source to replace coal. Indonesia holds significant potential in utilizing by-products of the oil palm industry for sustainable and renewable energy sources (Patisarana & Hazwi, 2012).

As a lignocellulosic waste, the utilization of solid waste such as trunks and fronds of oil palm requires attention (Ridwansyah et al., 2007). Oil palm fronds fall into the category of wet by-products because they contain a moisture content of about 75%, making them susceptible to rapid decay if not processed promptly. The nutritional content of oil palm fronds and leaves comprises dry matter of 48.78%, crude protein 5.3%, hemicellulose 21.1%, cellulose 27.9%, crude fiber 31.09%, ash 4.48%, lignin 16.9%, and silica 0.6% (Ardiansyah, 2014).

Palm shells are biomass with a high calorific value, typically around 3,800 Kcal/kg. In the past, palm kernel shells were primarily used as fuel for households and industries. The density of palm kernel shell ranges between 1700 to 2050 kg/m^3. Palm kernel shells consist of 33% charcoal, 45% pyroligneous liquor, and 21% easily combustible gas (Baffour-Awuah et al., 2021). Waste from oil palm fronds (OPF) and palm kernel shells from oil palm plantations are considered biomass waste that can be maximally utilized as a renewable energy source (Hassan et al., 2013).

Biomass and biobriquette

Biomass is a complex mixture of organic materials, usually comprising carbohydrates, fats, proteins, and some trace minerals such as sodium, phosphorus, calcium, and iron. Carbohydrates are the primary component of biomass from plants (dry weight is approximately up to 75%), followed by lignin (up to 25%), although the composition may vary among different plants. The advantage of using biomass is its status as a sustainable fuel source. The potential of biomass energy is an alternative energy source that should be prioritized, given that Indonesia, as an agrarian country, produces a substantial amount of agricultural waste that is underutilized. Agricultural waste can be processed into a solid fuel used as a substitute for fossil fuels. The benefits of biomass energy utilization include its recyclability for sustainable use, minimal air pollution compared to fossil fuels due to its relatively low sulfur content, and its potential to enhance agricultural waste efficiency, thereby reducing environmental pollution (Arni et al., 2014; Erfanti, 2013).

Biobriquettes are solid fuels produced through a process of compacting and applying pressure, which, when burned, produce minimal smoke. Processed as biochar or biobriquettes by using a pressing system and binding agents, they take the form of biobriquettes usable for daily purposes (Arni et al., 2014). Generally, biobriquette fuel materials exhibit favorable energy parameters, higher density, higher calorific value, and lower moisture content compared to unprocessed biomass. Biobriquettes can be made from various combinations of agricultural waste or biomass. Factors influencing charcoal briquette properties include fuel density or charcoal powder density, powder fineness, carbonization temperature, and pressure during molding. Additionally, the mixing formula in briquette preparation affects its characteristics. The criteria for good briquettes include having a smooth surface and not leaving black marks on hands. Furthermore, as fuel, briquettes should meet consumer requirements such as being easy to ignite, having appropriate size and shape for usage, emitting no smoke, producing combustion gas emissions that are non-toxic and free from hazardous gases, being water-resistant and resistant to mold during long-term storage, and exhibiting burning properties suitable for specific needs (burning time, speed, temperature, ease of ignition, energy efficiency, and stable combustion) (Sinurat, 2011).

Binding agents

Binding agents are substances or materials capable of binding two objects through surface adhesion. Some other terms for binding agents with specific properties include glue, mucilage, paste, and cement. Each type of binder has its own advantages and disadvantages. The primary requirement for a binding material is that it must be combustible and able to increase calorific value (M. Tarigan et al., 2023).

Based on previous research, the best type of binding agents ever used in the production of various types of briquettes is tapioca flour. Binding agents made from tapioca flour have several properties, including (1) water absorption capacity, (2) good adhesive strength, (3) easy availability without health hazards, and (4) easy mixing with other raw materials, in this case, charcoal powder (Sarjono). Tapioca flour is a material with high viscosity that works well as a binding agent when mixed with powder, so that the particles of powder are attracted to each other due to adhesive and cohesive forces. Adhesive forces occur in the interfacial area between particles, while cohesive forces exist between particles. Water molecules (H_2O) used as a solvent for the adhesive material form a thin layer on the particle surface, enhancing the contact between particles. Determining the ratio between the adhesive material and powder is crucial as it significantly affects the resulting briquettes, particularly their calorific value (Budi, 2011; Kurniati & Suprihatin, 2009).

The sago palm, scientifically known as Metroxylon sagu, is a native Indonesian plant introduced from Maluku, Irian Jaya (Papua). This plant thrives in coastal areas and freshwater swamps. Its trunk grows to about 10 meters in height and multiplies through root shoots, resulting in clustered growth resembling a fan shape, much like a coconut palm. The main product obtained from this tree is sago, which can be harvested after about 12 years. It's estimated that each sago palm can yield around 250 kilograms of sago flour. The starch is extracted from the pith of the trunk. Sago flour is produced from processing the sago palm. It has a relatively fine texture, pale white in color, and feels compact when held—grainy and sandy—and when cooked with water, it thickens to form a paste (Jamaludin et al., 2014).

METHODOLOGY

Tools and materials

Several tools used in this research include a digital scale, bucket, stirrer, bomb calorimeter, oven, furnace, briquette compression tool, briquette mold, sieve, tensile test equipment, porcelain crucible, and standard glassware. Various materials used include palm fronds, palm shells, tapioca flour, sago flour, and distilled water.

Biobriquette manufacturing procedure

The raw materials, such as palm fronds and palm shells, were chopped into smaller sizes and dried using sunlight. Once dried, the raw materials were carbonized for 20 minutes in a furnace to produce biochar (Simatupang et al., 2020) The biochar was then ground to finer particles and sieved to achieve uniform particle sizes. The composition of the biobriquette was varied between palm fronds and palm shells in ratios of 1:1, 1:2, and 1:3. Tapioca flour and sago flour, used as binders, were individually mixed with distilled water and heated to 70°C until the mixture reaches a paste-like consistency. The mixture was stirred until all components are evenly blended and then molded into shape. The molded biobriquettes were subsequently dried under sunlight (Lusyiani et al., 2023; Rahmatullah et al., 2022).

Calorific value analysis

The procedure to determine the calorific value of biobriquettes involvesedthe use of a bomb calorimeter. The instrument was turned on, and the calorimeter operation menu was selected with the heater pump activated. Subsequently, the determination method in the operation menu was chosen, and the cooler system was turned on. A sample weighing 1 gram was placed into the bomb head. Then, a string was attached to the wire above the sample until the string touches the sample. The bomb head was assembled with the bomb cylinder. The air outlet in the bomb head was closed. Next, the oxygen valve was connected to the bomb calorimeter, and the O_2 fill option was selected to fill it completely. Water was filled from the cooler system into a 2-liter volumetric flask until it was full. Then, the water from the volumetric flask was poured into a bucket. The bucket was placed inside the bomb calorimeter, and the measured calorific value was recorded (Bazenet et al., 2021; Firdaus & Octavianus, 2021).

Moisture content analysis

The procedure involved weighing an empty porcelain crucible and then placing a 5-gram sample of the biobriquette into it. The sample was leveled and put into an oven at 105°C for 3 hours. Afterward, the crucible was removed from the oven, cooled in a desiccator, and weighed to determine its weight. The moisture content was calculated using the formula:

$$\text{Moisture Content (\%)} = \frac{w_0 - w_1}{w_0} \times 100\ \% \quad \text{.................(1)}$$

whereas W_0 = Weight of the empty crucible + weight of the sample before heating (grams) and W_1 = Weight of the empty crucible + weight of the sample after heating (grams) (Simatupang, Saragih, et al., 2021; J. Tarigan & Simatupang, 2019).

Ash content analysis

The porcelain crucible was dried in a furnace at a temperature of 600°C for 3-5 minutes. The crucible was cooled in a desiccator for 30 minutes and then weighed to obtain its empty weight. A sample weighing 1 gram was placed into the crucible and then put into the furnace at a temperature of 850°C for 4 hours until the sample turns to ash. The crucible was removed, cooled in a desiccator, and then weighed to determine the weight of the ash. The formula used to calculate the ash content as follows :

$$\text{Ash Content } (\%) = (A/B) \times 100\% \text{............(2)}$$

whereas A was weight of ash (gram) and B was weight of sample (gram) (Nanda, 2016).

Density analysis

The sample biobriquette is weighed and its height as well as radius are measured. The density of the biobriquette can be calculated using the formula:

$$\rho = \frac{m}{v_{tot}} \text{..............(3)}$$

with volume of biobriquette was determined by following formula :

$$V_{tot} = \pi r^2 t \text{ ....(4)}$$

whereas ρ was density (g/cm^3), m was final weight of sample (g), V_{tot} was volume (cm^3), t was height (cm) and r was radius (cm) (Simatupang, Tarigan, et al., 2021).

RESEARCH RESULT

Table 1. Biobriquette Calorific Value

No	Palm Fronds : Shells	Tapioca Binder (%)	Calorific Value (cal/g)	Sago Binder (%)	Calorific Value (cal/g)
1	1 : 1	10	5800.71	10	6210.03
2	1 : 2	10	6005.23	10	6305.95
3	1 : 3	10	6089.64	10	6410.89
4	1 : 1	15	5858.08	15	6524.48
5	1 : 2	15	6067.83	15	6630.38
6	1 : 3	15	6141.22	15	6729.92
7	1 : 1	20	5816.75	20	6424.39
8	1 : 2	20	6021.43	20	6430.38
9	1 : 3	20	6102.51	20	6329.92

Table 2. Biobriquette Moisture Content

No	Palm Fronds : Shells	Tapioca Binder (%)	Moisture Content (%)	Sago Binder (%)	Moisture Content (%)
1	1 : 1	10	1.5291	10	3.7501
2	1 : 2	10	1.4217	10	3.3212
3	1 : 3	10	1.1686	10	3.2123
4	1 : 1	15	1.6871	15	3.6453
5	1 : 2	15	1.4912	15	3.5321
6	1 : 3	15	1.3875	15	3.4315
7	1 : 1	20	1.8067	20	3.8124
8	1 : 2	20	1.5215	20	3.2313
9	1 : 3	20	1.3134	20	3.1223

Table 3. Biobriquette Ash Content

No	Palm Fronds : Shells	Tapioca Binder (%)	Ash Content (%)	Sago Binder (%)	Ash Content (%)
1	1 : 1	10	17.4107	10	9.8952
2	1 : 2	10	13.8321	10	10.7953
3	1 : 3	10	11.4218	10	9.5232
4	1 : 1	15	18.2387	15	9.7232
5	1 : 2	15	15.9866	15	9.7132
6	1 : 3	15	13.0984	15	9.7122
7	1 : 1	20	20.0455	20	11.6990
8	1 : 2	20	14.9321	20	9.6955
9	1 : 3	20	13.4570	20	9.8441

Table 4. Biobriquette Density

No	Palm Fronds : Shells	Tapioca Binder (%)	Density (g/cm^3)	Sago Binder (%)	Density (g/cm^3)
1	1 : 1	10	0.8443	10	0.6112
2	1 : 2	10	0.8571	10	0.6234
3	1 : 3	10	0.8704	10	0.6349
4	1 : 1	15	0.8953	15	0.6499
5	1 : 2	15	0.9033	15	0.6567
6	1 : 3	15	0.9193	15	0.6667
7	1 : 1	20	0.9843	20	0.6789
8	1 : 2	20	0.9896	20	0.6885
9	1 : 3	20	0.9927	20	0.6992

DISCUSSION

The calorific value in briquette production needs to be known to obtain the combustion heat value that can be produced by the briquette as a fuel. The higher the calorific value produced by the briquette, the better its quality. The calorific value of briquettes at various ratios of palm fronds and palm shell, as well as adhesive content, can be seen in Table 1. Table 1 showed that the heat generated using tapioca flour adhesive ranged from 5800.71-6141.22 cal/g, and with sago flour adhesive ranged from 6210.03-6729.92 cal/g. The highest calorific value is achieved in the biobriquette mixture of palm fronds and palm shell with a ratio of 1:3 using 15% sago flour adhesive, reaching 6729.92 cal/g. This calorific value met the Indonesian National Standards (SNI 01-6235-2000) with a minimum criterion of 5000 cal/g. From the research results, it can be concluded that the higher the amount of palm fronds and palm shells added to the briquette, the higher the calorific value generated. Increasing the adhesive content can also affect the rise in calorific value, but if the adhesive content added increases, it can raise the moisture and ash content of the briquette. Research that produced briquettes from palm fronds using tapioca flour adhesive reported biobriquette characteristics with a calorific value reaching 5,863 kkal/kg for dry weight (Saputra et al., 2021).

The moisture content in biobriquettes refers to the amount of water remaining within the biobriquette after heating. Moisture content significantly affects the quality of the resulting biobriquette. If the moisture content in the biobriquette is higher, its combustion ability becomes lower, and vice versa. This is due to the heat provided to the briquette being initially used to evaporate the water present in the biobriquette. As a result, the biobriquette becomes difficult to ignite. The moisture content value in biobriquettes is influenced by the raw material type, adhesive type, and the testing method employed. The moisture content of biobriquettes at various ratios of palm fronds and palm shell, as well as adhesive content, can be seen in Table 2. Based on Table 2, it can be observed that the moisture content in biobriquettes using tapioca flour adhesive ranged from 1.3134-1.8067%, while with sago flour adhesive, it ranged from 3.1223-3.8124%. This moisture content value also complied with the Indonesian National Standards (SNI 01-6235-2000) with a maximum criterion of 8%. The lowest moisture content was found in the biobriquette with a ratio of 1:3 using 10% tapioca flour adhesive, reaching 1.1686%. The lower the amount of palm shell in the biobriquette and the higher the tapioca adhesive content, the higher the moisture content. The adhesive content used also affects the moisture content because the water contained in the adhesive will enter and bind within the charcoal pores. Biobriquettes containing high moisture content are prone to fungal growth and are difficult to ignite. Related research on briquette production from salak seed waste using tapioca and sago flour adhesive variations reported a moisture content characteristic of 5.17% (Sari Harahap & Jumiati, 2023).

The determination of ash content aimed to identify the unburned portion that no longer contains carbon after the biobriquette has been burned. The ash content of biobriquettes at various ratios of palm fronds and palm shell, as well as adhesive content, can be seen in Table 3. Based on Table 3, the ash content resulting from this research using tapioca flour adhesive ranges from 11.4218-20.0455%, and with sago flour adhesive ranges from 9.5232-11.6990%. The lowest ash content was obtained in the biobriquette with a 1:3 ratio using 10%

sago flour adhesive, reaching 9.5232. This ash content value did not met the Indonesian National Standards (SNI 01-6235-2000) with a maximum criterion of 8%. The ash content will increase with a decrease in palm fronds and palm shell and an increase in tapioca adhesive content. Moreover, a higher tapioca adhesive content can lead to an increase in ash content due to the inorganic content in tapioca flour. Although adhesive materials contribute to an increase in ash content in briquettes, they must still be used. Biobriquettes without adhesive materials have low density, making them easily breakable and unsuitable as fuel. High ash content can create slag and reduce the quality of the produced briquette. Research related to briquettes made from palm shell using tapioca and rice flour adhesive resulted in an ash content of 5.50% (Milya et al., 2023).

Density in biobriquettes relates to their compactness, observed by weight per unit volume. Higher-density biobriquettes will be more compact than those with lower density. Density in briquettes can determine their combustion value. Density values at various ratios of palm fronds and palm shell, along with adhesive content, can be seen in Table 4. Table 4 showed that the density of briquettes produced with tapioca flour adhesive ranged from 0.8443-0.9927 g/cm^3, and with sago flour adhesive, it ranged from 0.6112-0.6992 g/cm^3. The highest density value was achieved with a 1:3 ratio of palm fronds and palm shell with 20% tapioca flour adhesive. Density is influenced by the uniformity of charcoal and adhesive mixture. High density affects the calorific value of the briquette. However, excessively high density can lead to difficult combustion, while those with lower density are more easily burned due to larger air gaps allowing oxygen flow during combustion. Briquettes with lower density are consumed faster due to excessive air gaps. Increasing the amount of palm shell in the briquette can strengthen the bond between particles, enhancing density because the charcoal particles' bonding becomes more compact. Higher adhesive content leads to higher density as it enters the briquette's pores.

CONCLUSIONS AND RECOMMENDATIONS

Based on the research findings, it can be concluded that the optimal composition for biobriquette fabrication was a ratio of palm fronds to palm shell at 1:3 with an ideal adhesive content using 10% tapioca flour and 10-15% sago flour. As a recommendation, exploring other types of adhesives that could yield higher calorific values while maintaining moisture and ash content below the maximum value of 8% is suggested.

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