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Pine-to-Bioenergy: Potential of pine sap as adhesive and pine flower biomass waste in the production of biobriquettes

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ABSTRACT

Pine-flower biomass waste is abundant, but its utilization is still lacking. This research converts pine-flower waste into biobriquettes by using pine resin adhesive. This study aims to identify the effect of pine resin adhesive concentration and the effect of grain size on the quality of the resulting biobriquettes. The production of biobriquettes begins by processing pine flower waste into biochar using the pyrolysis method at 400 °C. Biochar from pinecones was ground and sieved into sizes (250, 500, and 750 μm). Then proximate analysis (moisture content, ash content, volatile matter, fixed carbon), and heating value were performed. Making biobriquettes using pine resin adhesive with different concentrations (5, 10, and 15%) of the total mixture According to the results, the ideal grain size was 750 m, the adhesive concentration was 15%, and the moisture content, ash content, volatile matter content, fixed carbon content, and heating value were all respectively 2.23%, 4.51%, 30.23%, 70.04%, and 23.34 MJ/kg, and the longest flame was also determined to be 0.0250 g/sec. All of them comply with universally accepted biobriquette standards (Indonesian National Standard 01–6235–2000), Japanese, English, and ISO 17225. Biobriquettes have potential applications in bioenergy products. Investigation of the economic feasibility of biobriquette production seen from Profit on Sales is 26.43%, Rate on Investment is 34.00%, Pay Out Time is 2.47 years, and Break Event Point is 49.22%.

1. Introduction

The necessity of energy community is increasing while the availability of fossil energy raw materials such as coal, natural gas, and oil is decreasing. This trend of decreasing availability of fossil fuels, combined with their negative environmental impact, necessitates additional research into alternative energy sources that are not only renewable but also sustainable [14].

Biomass energy is one of the alternative energy sources that can be used. Lignocellulosic biomass is a sustainable resource for producing biofuels that are environmentally friendly, renewable, and worthless [30,67] and as a better alternative energy source [35], generally, they are disposed of or burned, causing significant environmental pollution. Lignocellulosic biomass is composed of three primary components: cellulose, hemicellulose, and lignin. This is absolutely essential in lignocellulosic biomass applications [42]. Pine flower is one of the biomasses with a high cellulose content. Biochar can be produced from biomass with a high lignocellulosic biomass content [36]. Biochar is a solid intermediate residue formed during the pyrolysis of most biomass [56]. Biochar in its natural state is a bulky material with a low bulk density, low heat release, and high smoke production [5]. One of the efforts to increase the added value of biomass is to convert biomass into solid fuel, namely biobriquettes. Torrefaction, slow and fast pyrolysis, hydrothermal carbonization, gasification, and microwave irradiation are all methods for converting biomass into biochar [2,34].

Pyrolysis is the thermochemical conversion of agricultural biomass in the absence of oxygen through the use of direct thermal decomposition [9]. Pyrolysis is the heating of organic materials in an inert

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atmosphere at a specific temperature (without the presence of oxygen) [25]. The main biomass components, hemicellulose, cellulose, and lignin, decompose gradually at temperatures of 220–315 °C, 280–400 °C, and 160–900 °C, respectively [11,44]. The pyrolysis process produces three products: solids (char), liquid (liquid pyrolysis), and gas [73].

Bio-briquette is a method of increasing biomass density through particle compaction. Bio-briquettes are renewable energy, unlimited resources, clean, cost-effective, and require less storage space than raw biomass [61]. Bio-briquettes are produced from agricultural waste that is environmentally friendly, healthy, and does not require the use of fossil fuels [48]. Bio-briquette processing may include biomass preparation (waste collection, cleaning, and storage), biomass drying, size reduction (crushing, milling, etc.), pyrolysis, binder addition, and biobriquette drying [33].

Bio-briquettes have been produced from a variety of agricultural and biomass wastes, including agricultural and forest waste [64], banana leaf [38], waste from agriculture and forestry [60], cotton dust[66], bagasse and corn starch waste [75], corn cob and rice husk [46], palm oil empty fruit bunches [39], rice husk and bran [74], solid waste from the textile industry [7], peat [23], wood, coconut shell, oil palm shell biochar, oil palm empty fruit bunches, banana peel, rice husk, peanut shell, jatropha curcas, durian skin, cocoa husk, corn cob [17], oil palm shell [1], cashew shell [58], bamboo fiber and sugarcane skin [10], cotton stick [72], cashew waste [29,41], carbon [43], rice husk [4], and jatropha seed shells [15]. Renewable energy is expected to play a significant role in future efforts to reduce carbon emissions and increase the global energy supply. Biofuels derived from renewable sources like lignocellulosic biomass have the potential to become one of the most important sources of clean, renewable, and sustainable energy, particularly for transportation and power generation [12,70].

Indonesia has a large amount of biomass that can be used as an energy source. All waste generated by animals and plants has the potential to be developed. Pine is a monocotyledonous plant with flattened needle-like leaves that grow in groups or the form of scales. Pine flowers are forest organic waste that has not been widely used. Due to their high cellulose content, pine flowers have the potential to be used as alternative energy sources, such as biobriquettes, which are simple to make and environmentally friendly [3,37,55].

The production of biobriquettes from pine needless using clay adhesives has been carried out by Pandey & Dhakal (2013) and Raj & Vaibhav (2017) [53,54], the best characteristics of the biobriquettes produced are the with a ratio of 80:20 [53]. Briquettes with clay adhesive with a ratio of four to six pine biochar have the best conditions [54]. So the researchers experimented with pine leaves and pine sap adhesive. According to the literature searches, the use of pine resin adhesive in the manufacture of biobriquettes has never been investigated.

One of the non-timber forest products obtained by tapping pine tree trunks is pine sap. Pine sap is insoluble in water and belongs to the pale yellow oleoresin group. Pine sap is hydrophobic (does not like water) and can be dissolved in neutral or non-polar organic solvents (ethyl ether, hexane, and oil solvents). Pine sap can be used in the production of gondorukem, soap, adhesives, paints, and cosmetics. Pine sap (colophony) is a clear, viscous substance with high adhesion. The high adhesive properties of pine resin are used as a biochar adhesive in this research to produce biobriquettes.

Biobriquettes from pine cones generally comply with the standards of several countries. Biobriquettes have potential applications in bioenergy products. Increased use of biobriquettes can help reduce dependence on forest wood for charcoal production. Biobriquettes from pine cones can be used to save fuel, especially for people who live around pine forest areas. Pine flowers, which are usually scattered on the forest floor to rot and are not used, can be used to produce biobriquettes. For small-scale daily use, pinecone charcoal briquettes have become a good alternative. Communities can make charcoal biobriquettes as a substitute for fossil fuels such as kerosene and natural gas in cooking. Besides being able to reduce environmental pollution, making the charcoal biobriquettes from pine cones will improve the economy of the local community.

The difference between the present study and previous studies is from the biomass. In this study, the biomass was originally from the same species, namely, combining pine-flower waste and pine-resin in the manufacture of biobriquette, while previous researchers used biomass waste the adhesive of which came from different biomass sources to produce biobriquettes. This research aimed to investigate the effect of pine resin adhesive concentration and the effect of grain size on the characteristics of the pine flower biobriquette charcoal produced. The economic analysis of pine flower biobriquettes can be observed from percentage of profit on sales, Rate on Investment, Pay Out Time, and Break Event Point.

2. Materials and methods

2.1. Research material

Pine flowers and pine sap (as an adhesive) were collected from Malino pine forest about 60 km from Makassar, South Sulawesi, Indonesia. Prior to pyrolysis, the material is directly sun-dried to reduce moisture content. The purpose of this process was to reduce the amount of energy used during pyrolysis [32,50] while compared to other mechanical drying processes commonly used during the rainy season [59].

2.2. Research tools

A set of pyrolysis reactors, a biobriquette mould, a biobriquette mixing container, an oven, a stirrer, a furnace, a sieve, a blender, and a bomb calorimeter was used in this research. The pyrolysis process employs a simple batch reactor that is externally heated by LPG. The reactor is cylindrical. It is possible to open the reactor's top side for raw material input. The biochar is easily removed at the end of the investigation. A thermocouple is placed vertically in the reactor measures the temperature. During the experiment, the upper side was tightly closed by the cover plate, which prevented atmospheric air from entering the reactor, in order to achieve the best pyrolysis conditions. The hot steam passes through the inner tube of the condenser and is condensed by circulating cold water around the line (Fig. 1) [6]. The pyrolysis reactor is made of stainless-steel plates with a height of 40 cm and a diameter of 27 cm. The condenser measures 1.07 m in length. In order to prevent heat loss, the reactor's outer wall is insulated to a thickness of 1.50 cm [28].

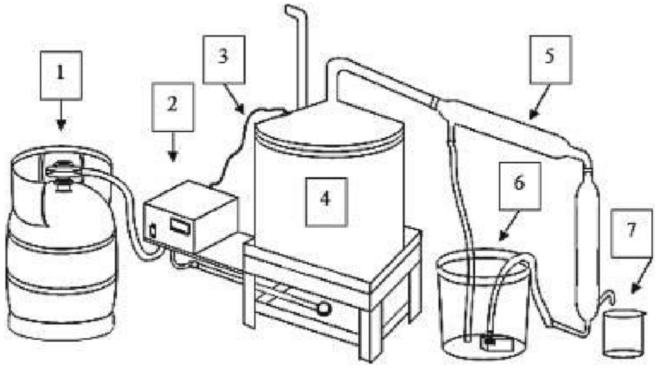

Fig. 1. A set of pyrolysis reactor (Information: 1-LPG; 2-Temperature indicator; 3-Thermocouple; 4-Pyrolysis reactor; 5-Condenser; 6-Condensate and pump; 7-Liquid Smoke Container) [28].

2.3. Research procedure

2.3.1. Pretreatment

The pine flowers are cleaned first, then cut into small pieces, and dried in the sun for five hours to reduce the water content [57].

2.3.2. Pyrolysis stage

Biochar was produced in this research using a pyrolysis device with a pyrolysis temperature of 400 °C for 3 h. The flow chart for the production of pine flower biobriquettes can be seen in Fig. 2. As shown in Fig. 1, the pyrolysis process was carried out by inserting 700 g of dried pine flowers into the pyrolysis reactor. The pyrolysis process yielded three products: liquid smoke, tar, and biochar. The resulting smoke is condensed into a liquid and poured into a filter funnel lined with paper. The biochar was ground and sieved in various sizes (250, 500, and 750 µm). Biochar particles that do not pass through the filter are ground once more. The biochar was then characterized using proximate analysis (moisture).

2.3.3. Bio-briquette production

The biochar is mixed with the adhesive before being compacted to each mesh size based on the material concentration (5, 10, and 15%). It is then fed into the mould of a hand press made locally. Sun drying is used to dry the finished biobriquettes. Biobriquettes are now ready for long-flame analysis.

2.4. Proximate analysis

2.4.1. Moisture content

Moisture content is defined as solid fuel's moisture-to-dry weight ratio. It was determined in this research by drying the sample in a calibrated free space oven from 105 °C to 110 °C, using a minimum free space oven (MFS oven) and a volume of 1.4 L. The gas flow rate is approximately 15 times per hour with a volume of 350 mL/min, and the mass lost after heating the charcoal briquettes using the 2017 ASTM D-3173 standard is as Equation (1) [15]:

$$\text{Moisture content}\,(\%) = \frac{W_0 - W}{W_{s0}} \times 100\% \tag{1}$$

where:

W_0 = Sample and saucer weight before drying (g).
W = Sample and saucer weight after drying (g).
W_{so} = initial sample weight (g).

2.4.2. Ash content

Ash is the material that remains when solid fuel is heated to a constant weight. The higher the ash content, the more difficult it is to burn. The test sample was heated to standard temperatures, and the ash content was calculated using the remaining residue. The ash content is calculated using Equation (2) and the ASTM D-3174 (2012) standards [28]:

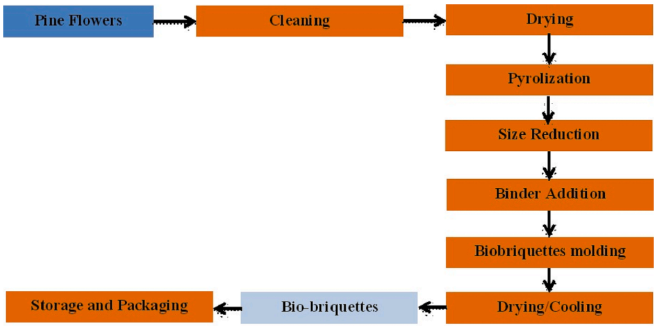

Fig. 2. Flow chart of bio-briquette production from pine flowers.

$$\text{Ash content}\,(\%) = 100\% - \frac{W_0 - W}{W_{s0}} \times 100\% \tag{2}$$

where:

W_0 = sample and saucer weight before ashing (g).
W = saucer weight + ash weight (g).
W_{so} = sample weight before ashing (g).

2.4.3. Volatile matter (VM)

The higher the volatile matter content in biobriquettes, the easier it is for the biobriquettes to burn and ignite, resulting in a faster combustion rate. The test sample was heated for 7 min at 900 °C. The percentage of volatile matter was calculated by subtracting the weight lost from the total weight. The amount of volatile substances is calculated using Equations (3) and (4) from the ASTM D-3175 2018 standard [28]:

$$\text{Lost weight}\,(\%) = A = \frac{W_0 - W}{W_{s0}} \times 100\% \tag{3}$$

$$\text{VM}\,(\%) = \text{lost weight} - \text{moisture content} \tag{4}$$

where:

W_0 = sample weight and initial cup (g).
W = cup weight + ash weight after heating (g).
W_{so} = initial sample weight (g).

2.4.4. Fixed carbon (FC)

A higher level of carbon bound leads to an increase in its calorific value. The Fixed carbon (FC) was determined using the data previously obtained in the proximate analysis. It is in line with the following Equation (5) [18,19,28,51]:

$$\text{FC}\,(\%) = 100 - (\text{moisture}\,(\%) + \text{Ash}(\%) + \text{VM}(\%)) \tag{5}$$

2.4.5. Calorific value

The calorific value represents the amount of energy in the biobriquettes. A PARR-bomb calorimeter was used to determine the calorific values of pine flower in accordance with the ASTM and D5865 2013 standard. The test sample used was an isoperibol calorimeter microprocessor which was calculated to determine the temperature rise and heat capacity in line with the standard procedure of the American Society for Testing and Materials (ASTM, 2013).

2.4.6. Flame lengfh

To determine how long the charcoal biobriquettes will burn, ignite the biochar biobriquettes until coals appear. The combustion rate test was performed by hand in a biobriquette furnace. When the flame duration of each biobriquette mixture is compared, which one is more flame resistant. Each sample was weighed before being subjected to the mass test. The samples are then burned to ash, and the combustion time is measured with a stopwatch. The timing begins when the coals in the biobriquettes begin to burn until they turn to ash. Equation (6) can be used to calculate flame length [54].

$$\text{Flame length}\left(\frac{g}{s}\right) = \frac{\text{Biobriquette weight}\,(g)}{\text{burning time}\,(s)} \tag{6}$$

3. Results and discussion

The effect of pine resin adhesive concentration on the characteristics of biobriquettes is presented in Tables 1 and 2 and Figs. 3 to 7.

3.1. Water content

Moisture analysis was used to determine the level of influence of biobriquette initial combustion because high water content reduces the

Table 1
The calorific value and approximate analysis of bio-briquettes produced from various raw materials.

Materials	Moisture content (wt%)	Ash content (wt %)	Volatile matter (wt %)	Fixed carbon (wt %)	Calorific value (MJ/kg)	References
Cashew nutwaste	5.30	4.96	17.16	72.62	29.49	[29]
Blend of areca nut husk, simarouba seed shell, and black liquor	5.75	2.48	73.71	18.19	18.81	[69]
Cashew shell	–	5.80	29.65	64.55	27.73	[58]
Cotton stalk	4.50	7.30	60.30	39.70	27.90	[72]
Palm kernel shell	1.75	4.83	55.95	39.22	29.60	[1]
Banana peels, corn cobs and coal mixture	5.14	6.06	26.18	62.62	26.36	[17]
Wood	–	5.0–10	25–30	60–68	26.50	[8]
Textile industry solid waste	–	12.76	77.99	9.24	19.41	[7]
Bagasse and corn starchwaste	6.86	8.59	48.50	42.92	10.30	[75]
Cashew nut shell (CNS)	8.9	5.3	70.9	23.8	20.7	[41]
Sawdust charcoal	5.7	2.6	71	20.7	20.18	[5]
Agricultural and forest origin biomass	12.04	5.57	74.29	–	16.21	[64]
Banana leaves	7.17	10.70	75.3	14,00	17.70	[38]
Durian peel	0.01	18.18	3.94	77.87	26.27	[47]
Banana leaves	5.63	7.35	70.37	16.65	14.94	[66]
Bagase, sawdust and waste papper	5.96	13.58	63.65	22.16	20.42	[68]
Mixture of bagasse and coffee husk	4.40	12.00	24.00	64.00	11.13	[52]
Bagasse	4.10	36.4	27.20	36.40	18.38	[50]
Hazelnut shell	–	7.00	72.00	21.00	18.89	[27]
Pine needle	7.50	5.39	17.96	69.150	21.89	[53]
Palm oil empty fruit bunches	–	0.5–8	–	–	17.58–20.10	[39]
Rice husk	–	–	–	25.72	24.90	[4]
Pine flower	2.23–5.03	4.51–7.81	22.21–30.39	59.73–70.04	19.39–23.88	This research

Table 2
Comparison of Household Energy Consumption Costs (MJ = Mega Joule; 1 MJ equals 0.27778 kWh); 23.34 MJ/kg equals 6.48333 kWh/kg).

Item	Kerosene	LPG	Pine flowers bio-briquettes
Price (USD/kg)	0.60840	0.47179	0.28631
Calorific Value (MJ/kg)	42[a]	44[a]	23.34
Price/cal (USD/MJ)	0,01449	0,01072	0,01227
Consumption price: For example taking the price of LPG as the reference price (USD 0.01072/MJ)	0.821265	0.47718	0.32384

[a] [65].

calorific value of biobriquettes as the primary energy source of combustion. The quality of the biobriquettes is determined by the moisture content of biomass. Because of the high water content, the energy required for evaporation of water during combustion is also high and the calorific value of biobriquettes is low [16]. Because of the removal of volatile matter, the net calorific value per unit volume of biomass is increased [21,31]. The moisture content of the obtained biobriquettes is shown in Fig. 3 and the moisture content for several biobriquettes from different biomass is shown in Table 1.

Fig. 3 shows the water content of each treatment used in the production of biobriquettes. According to Fig. 3, the lowest water content was 2.23% at a grain size of 250 μm with an adhesive ratio of 5%. Meanwhile, the highest water content, 5.03%, was found at 500 μm grain size with a 10% adhesive ratio. The high water content in the 10% adhesive ratio was caused by the large amount of adhesive used as a mixture. The more adhesive added, the higher the water content contained in the briquettes. This occurs due to the water content contained in the adhesive so that when it is mixed with the biobriquettes, it will affect the moisture content of the biobriquettes. The adhesive concentration of 15% shows a decreasing trend in the water content of the biobriquettes. This shows that the higher the concentration of the adhesive given, the higher the density value of the biobriquettes. Increasing the adhesive concentration will increase the bonding power between particles so as to reduce the cavities in the biobriquettes. The small biobriquette cavity causes the absorbed water content to decrease. Biobriquettes with high water absorption have low energy content and

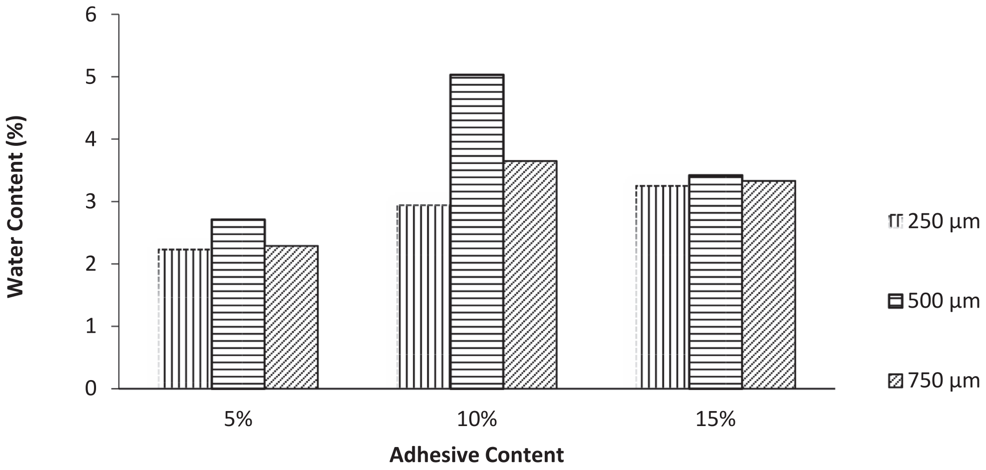

Fig. 3. Relationship between Adhesive Concentration and Grain Particle Size (250, 500, and 750 μm) in relation to Water Content.

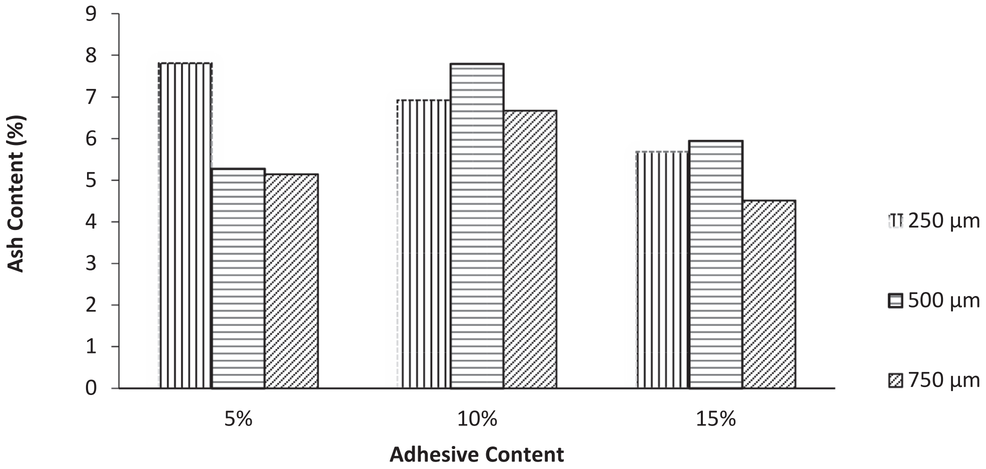

Fig. 4. Relationship between Adhesive Concentration and Grain Particle Size (250, 500, and 750 μm) in relation to Ash Content.

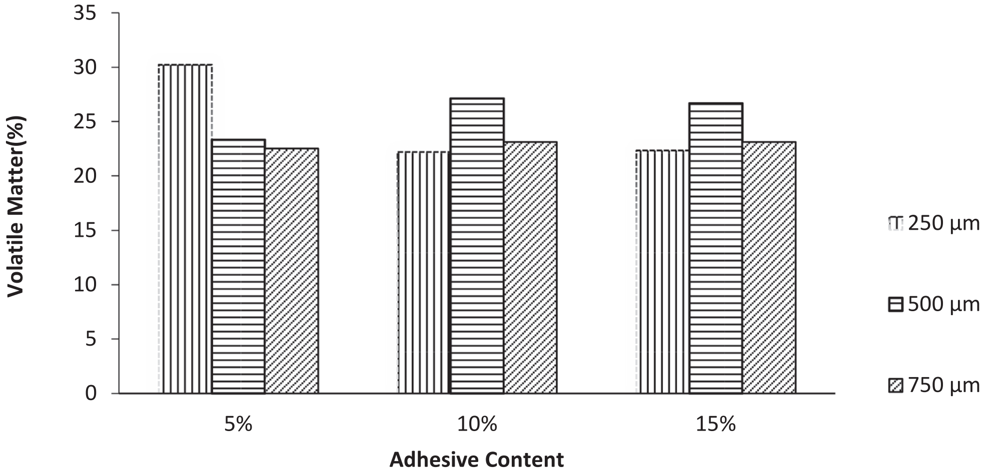

Fig. 5. Relationship between Adhesive Concentration and Grain Particle Size (250, 500, and 750 μm) in relation to Volatile Matter.

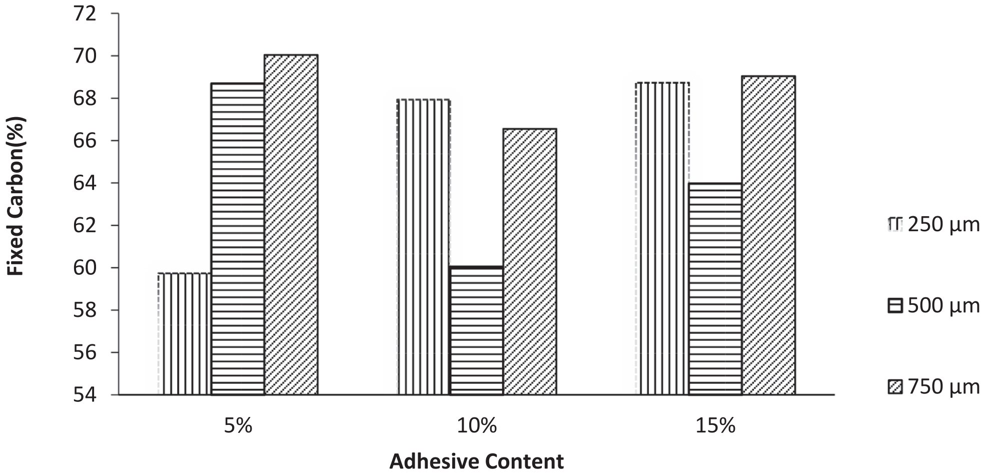

Fig. 6. Relationship between Adhesive Concentration and Grain Particle Size (250, 500, and 750 μm) in relation to Fixed Carbon.

are not economical for transportation [76]. The size of the biochar granules is 500 μm which is relatively smooth or has a large surface area, so it is easier to absorb water. Biochar particles are hygroscopic, which can cause a high yield of biobriquette water content. Water is trapped in the pores of the small biochar particles making it difficult to evaporate completely during drying [16]. When compared to other raw materials, pine flower biobriquette has a lower moisture content [5,17,29,41,64,66,68,69,75,15]. The water content obtained from each treatment exceeded the standards of the Indonesian National Standard 01–6235-2000, which has a maximum water content of 8%, and also the

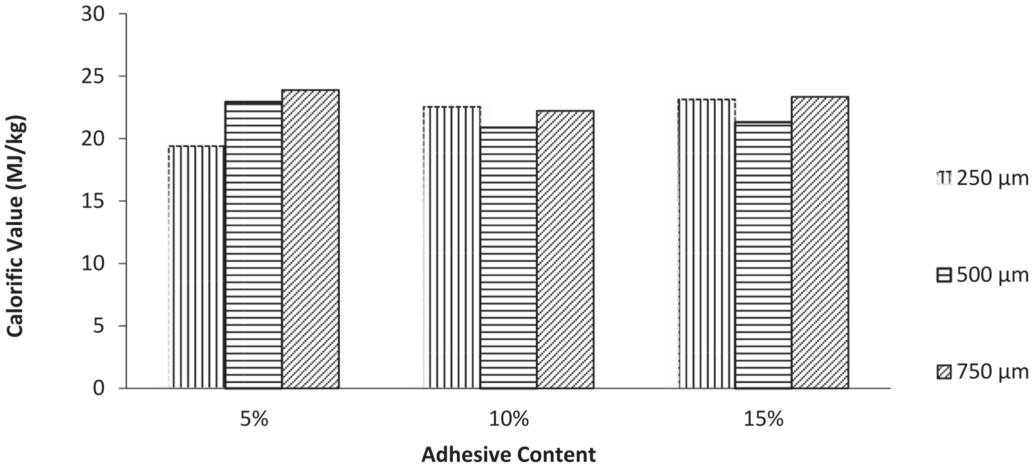

Fig. 7. Relationship between Adhesive Concentration and Grain particle Size (250, 500, and 750 µm) in relation to Calorific Value.

ISO 17225 bio-briquette standards (2.2–15.9%).

3.2. Ash content

Ash is the material that remains when solid fuel is heated to a constant weight. The higher the ash content, the more difficult it is to burn, and therefore, the lower the calorific value [20]. Fig. 4 shows the ash content of the obtained biobriquettes and Table 1 shows the ash content of several biobriquettes made from different biomass.

Fig. 4 shows the ash content of biobriquettes with different particle sizes and adhesive concentrations. The greater the adhesive concentration is and the larger the grain particle size is, the lower the ash content value is. This trend is in accordance with what was reported by Muraina et al. (2017) [45]. Slagging can occur when there is a high ash content [33]. Ash is essential in the production of biobriquettes because biobriquettes with a high ash content will form a crust. Higher ash content in fuel can cause higher dust emissions and affect combustion efficiency and produce low energy content [45]. The lower the ash content is, the higher the heating value. The lower the ash content is, there is a tendency for the calorific value to increase. When compared to other raw materials, pine flower biobriquettes have a lower ash content [5,7,47,52,68,75]. The ash content obtained from each treatment met the requirements of Indonesian National Standard 01–6235-2000, which calls for a maximum ash content of 8%.

3.3. Volatile matter

The content of flammable materials is defined as volatile matter. A disadvantage of high levels of volatile matter in agricultural waste is the low levels of fixed carbon. The volatile matter content refers to the amount of volatile substances lost in the charcoal. When the briquettes are lit, the high volatile substance content will produce more smoke. Fig. 5 shows the volatile matter levels of the biobriquettes obtained, and Table 1 shows the volatile matter levels of several biobriquettes derived from different biomass.

Fig. 5 shows that the smaller the granular particles is, the smaller the volatile matter. The volatile matter of pine flower biobriquettes is 22–30%, as shown in Fig. 5 and Table 1. The volatile matter content of this research is lower than that reported in the literature [1,5,7,38,27,47,64,66,68,69,72,75]. This is consistent with Suvunnapob et al. (2015) [66] research results that thick wood produces biobriquettes with higher volatile matter. The smoke produced by burning biobriquettes will be low because they contain few volatile substances. This makes pine flower biobriquette an environmentally friendly biobriquette because it can reduce the effects of global warming and has the potential to be a source of renewable solid fuel. The volatile material content meets Japanese bio-briquette standards (15–30%).

3.4. Fixed carbon

The calorific value is affected by the bound carbon content. The higher the calorific value, the higher the bound carbon content. Carbon is the most abundant element, but it also contains hydrogen, oxygen, sulfur, and nitrogen, which are not carried away by gases. Carbon (C) is bound in charcoal along with ash, water, and volatile fractions. Fig. 6 shows the mixed carbon biobriquette obtained, and Table 1 shows the fixed carbon content of several biobriquettes derived from various biomasses.

Fig. 6 shows that the smaller the particle size is, the higher the fixed carbon is. The greater the concentration of the adhesive used, the higher the fixed carbon is. This is due to the smaller the particle size is, the more carbon atoms will be, and the greater the adhesive concentration is, the more carbon atoms will be. The fixed carbon value is highly correlated to the calorific value of biofuels [40]. Because every oxidation reaction produces calories, the higher the fixed carbon content, the higher the calorific value. The fixed carbon content in this research is 60–70%, which is higher than the fixed carbon biobriquettes from various biomass sources [1,4,5,7,38,27,41,50,66,68,69,72,75]. The amount of carbon is approximately equal to the calorific value of biofuels [40]. Because heat energy is usually high, the higher the fixed carbon, the better the charcoal content produced. In this research, fixed carbon biobriquettes reached Japanese bio-briquette standards (60-80%) and British biobriquette standards (75.3%).

The fuel ratio is the proportion of fixed carbon to volatile matter [2,62]. The data can be used to analyse the co-combustibility of coal and biomass as an indicator of the ease with which solid fuels can be burned [62]. In this research, the biochar fuel ratio is 1.98–3.07. The bituminous coal fuel ratio used in coal-fired power plants ranges from 0.5 to 3.0 [62]. The results showed that it was in the range of the coal-to-fuel ratio. Thus, the raw materials used in this research can be considered for the production of biobriquettes.

3.5. Calorific value

The higher the calorific value of the biobriquettes, the higher the quality of the biobriquettes due to their high combustion efficiency. Fig. 7 shows the calorific value of the obtained biobriquettes, and Table 1 shows the calorific value of several biobriquettes derived from various biomasses.

Grain size affects the calorific value of biobriquettes. As shown in Fig. 7, the smaller the particle size, the greater the calorific value. The smaller the particle size, the more particles or carbon there are, and the denser the pores of the biobriquettes, the less water vapor is absorbed. As a result, the calorific value of the biobriquettes is high. Biomass fuel's calorific value is determined by its chemical composition and moisture content [5]. A high calorific value indicates that combustion can produce greater heat energy [16]. Fig. 7 shows that high adhesive content tends to reduce the calorific value of briquettes [45]. This is because the adhesive material has thermoplastic properties and is difficult to burn and carries and easily binds water so that the heat energy generated works first to evaporate the water in the biobriquettes.

Fig. 7 and Table 1 show that the heat qualities of the biobriquettes produced in this research indicate that the pine flower is suitable for the production of biobriquettes. Biobriquettes produced from pine flowers have a calorific value of 23.34 MJ/kg, which is higher than the 20.42 MJ/kg of biobriquettes produced from bagasse, sawdust, and waste paper [68]; blend of areca nut husk, simarouba seed shell, and black liquor of 18,81 MJ/kg [69]; sawdust charcoal of 20.18 MJ/kg [5]; textile industry solid waste of 19.41 MJ/kg [7]; bagasse and corn starchwaste of 10.30 MJ/kg [75]; agricultural and forest origin biomass of 16.21 MJ/kg [64]; banana leaves of 14.94 MJ/kg [66]; mixture of bagasse and coffee husk of 11.13 MJ/kg [52]; bagasse of 18.38 MJ/kg [50]; hazelnut shell of 18.89 MJ/kg [27]; palm oil empty fruit bunches of 17.58–20.10 MJ/kg [39]; bamboo fiber of 16.92 MJ/kg; and sugarcane skin of 17.23 MJ/kg [10]. The yield of this pine flower biobriquette is relatively higher that that of low-rank coal (12–25 MJ/kg) [18]. The calorific value of the pine cone biobriquettes was significantly higher than or comparable to that of various raw materials reported in the literature (Table 1). The heating value is also higher than that reported in the literature for biochar Yatagan coal (raw) of 18.17 MJ/kg [22]. These findings are also in accordance with what was reported by Egbosiuba (2022) [13] with a temperature of 400 °C, a calorific value of biochar of 22.70 MJ/kg (heating rate of 10 °C/min), 23.26 MJ/kg (heating rate of 20 °C/min), and 23.52 MJ/kg (heating rate of 30 °C/min). The results obtained indicate that biochar is very suitable for usage as a solid fuel [13]. The resulting biobriquettes have properties that make them suitable for use as an energy source. The obtained value is said to be in the sub-bituminous coal calorific value range (20.51–28.47 MJ/kg). The value has reached the minimal amount for household fuel [57]. This calorific value (>20.93 MJ/kg) satisfies Indonesian National Standard 01–6235–2000. The results of this research indicate that biobriquettes produced from pine flowers can compete profitably with coal, providing a renewable energy source. The calorific value obtained in this research is higher than the minimum value set by the Wood Pellet Association of Canada (calorific value of 16.0 MJ/kg) [4]. Of all these parameters, the calorific value is considered as an important property of solid biofuels and the pinecone showed a comparable value of 23.34 MJ/kg (Table 1) and was the highest found for various types of biomass.

3.6. Comparison of household energy consumption costs

Pine flower biobriquettes are made from waste which is easy to obtain, is abundantly available, has affordable prices, and is relatively easy to manufacture. To determine the efficiency/fuel savings can also be carried out by comparing the calorific value per unit price. Comparison of fuel efficiency data in Table 2 shows that the price per MJ of pine flower biobriquettes is cheaper than the price per MJ of kerosene and LPG gas.

For example, a household needs 1 kg of LPG/day, where the calorific value of LPG is 44.00 MJ/kg, and the calorific value of kerosene is 42.00 MJ [65]. For example, the price of LPG for cooking is the reference price (USD 0.01072/MJ), and household energy costs for LPG are USD 0.47718/day. If the current price of kerosene is USD 0.60840/kg, one family needs energy costs of USD 0.81265/day. Comparison of the energy consumption of this fuel can be seen in Table 2. In contrast, with pinecone waste biobriquettes, the cost of energy consumption to meet household energy needs is USD 0.32384/kg. The price of biobriquette pine flower USD 0.01227/MJ (Table 2) is higher than that reported in the literature [40]. According to the results of the energy consumption cost ratio, it is evident that the efficiency produced when using pinecone biobriquettes. The use of bio-briquettes can also be a low-cost alternative energy, especially for the economy of rural communities. In this biobriquette research, it has been shown that there is a potential future market for biobriquettes in addition to household needs as well as to replace the use of coal for electricity generation. This biobriquette can also be used for burning in brick kilns, in the cement industry and as fuel for boilers.

3.7. Length flame

The ratio of the amount of material burned to the time required to burn that amount of material is identified as combustion power. The length of time influences the quality and efficiency of combustion. The longer it burns continuously, the better. The data on the relationship between the size of the biobriquette charcoal granules with each ratio of the adhesive with the length of the flame was obtained from the flame length test as as can be seen in Table 3.

Table 3 shows the relationship between flame duration and adhesive concentration. The highest flame duration was found in the grain size of 500 μm at 5% adhesive concentration, namely 0.0186 g/s; at 10% adhesive concentration, the highest flame duration was found in the grain size of 250 μm, namely 0.0180 g/s. At a 15% adhesive concentration, the highest flame duration value, 0.0250 g/s, was found in the grain size of 750 μm.

According to Table 3, the relatively short flame duration was 0.0147 g/s at a grain size of 250 μm with a 5% adhesive concentration. Meanwhile, the highest value of flame duration is 0.0250 g/s at 750 μm grain size with a 15% adhesive ratio. The length of the flame has an effect on the quality of the biobriquettes. The higher the value of the flame duration, the higher the quality of the biobriquettes produced. This result is lower than the durian peel biobriquette result of 0.0398 g/s [26], pine needle of 2–7 g/s [54].

3.8. Economic analysis

The cost of production is obtained by adding up all costs incurred by the company for one year which include fixed capital investment (FCI), working capacity investment (WCI) and total production cost (TPC). Annual production capacity is 20,000 kg. The next step is to estimate the profit (Table 4).

If briquettes are sold per kilogram at USD 0.28, this price is much cheaper than the price of kerosene at USD 0.61. The profitability of the pine flower biobriquettes is viewed from several indicators.

3.8.1. Percentage of profit on sales

Equations (7) and (8) are mathematical expression for determining the percentage return on sales.

Table 3
Grain size of biobriquettes, adhesive concentration, and length flame.

Biobriquette Material (μm)	Adhesive Concentration (%)	Length Flame (g/s)
250	5	0.0147
	10	0.0180
	15	0.0199
500	5	0.0186
	10	0.0171
	15	0.0165
750	5	0.0154
	10	0.0150
	15	0.0250

Table 4
Estimated profit.

Item	Unit cost, USD	Total, USD
Sales	5,517.24	
Total production cost	3,896.55	
Profit before taxes		1,620.69
Income taxes (10%)	162.07	
Profit after taxes		1,458.62

$$\text{Psb} = \frac{\text{Pb}}{\text{S}} \tag{7}$$

$$\text{Psa} = \frac{\text{Pa}}{\text{S}} \tag{8}$$

where:

Psa = percentage of profit on sales after tax, expressed in decimal.
Psb = percentage of profit on sales before tax, expressed in decimal.
S = selling price per production unit.
Pb = profit before tax per unit of production = 29.38%.
Pa = profit after tax per unit of production = 26.43%.

3.8.2. *Percentage of return on investment (ROI)*

One of the most common ways to analyze the profitability of a new factory is the percentage of return on investment, which is the annual rate at which profits will return investment (capital). Equation (9) is the equation for the per cent return on investment [71]:

$$\text{ROI} = \frac{\text{Profit}}{\text{FCI}} \times 100\% \tag{9}$$

Based on Equation (9), the ROI price was 34.00% per year, after the collection of taxes. This result was greater than that of Soetaredjo et al. (2021) [63], at 25.77%. The interest price obtained is greater than the interest price for capital loans to banks (5.5%). The ROI value obtained is greater than the ROI reported by Hakizimana & Kim (2016) [23] of 24.94% and Vlysidis et al. (2011) of 18.2% [71]. This shows that this biobriquette is feasible to be passed on to the next stage.

3.8.3. *Pay out time (POT)*

POT is the annual period of return, the investment of profits calculated before deducting depreciation. Based on Equation (10) obtained POT of 2.47 years. This is shorter than the POT reported by Soetaredjo et al. (2021) [63], namely 2 years and 10 months and longer than reported by Okolie et al. (2021) [49], ranging from 3.2 to 5.4 years.

$$\text{POT} = \frac{\text{FCI}}{(\text{Pb} \times \text{ra} + 0.1 \times \text{FCI})} \tag{10}$$

where:

Pb = profit before paying tax per unit of production
ra = annual production rate

In other studies, the POT for bio-briquette from cashew nut shell waste was 3.42 years [28], while peat briquettes production was between 5 and 6 years [23], and for the production of rubber seed kernel (RSK) and palm oil shell (POS) briquettes was 2 years [24]. According to Okolie et al. (2021) [49] that a profitable POT must always be smaller than the estimated life of the project. The smaller the number of years to recover the investment, the better it is for the project [33]. The POT of this study is less than the age of the project (5 years), indicating that the pine flower biobriquette factory is a prospect.

3.8.4. *Break event points (BEP)*

Break Even Point is a point that shows at what level costs and income are the same. Break Even Points can be used to determine what level the selling price is and the minimum number of units sold and what price and sales units must be achieved in order to make a profit. A good Break Even Point value for chemical factories generally ranges from 40 to 60%.

$$\text{BEP} = \frac{Fa + 0.3 \times Ra}{Sa - Va - 0.7 \times Ra} \times 100\% \tag{11}$$

where:

FC = Fa = Fixed Charge.
SVC = Ra = Semi Variable Cost.
VC = Va = Variable Cost.
Sa = Sale.

Based on Equation (11) obtained BEP value of 49.22%, it means that at a capacity of 49.22% × production capacity (20,000 kg/year) or at a capacity of 9,844 kg/years, the pine blossom biobriquettes make no profit and no loss (break even). The BEP value of this study is better than the BEP value of Hakizimana & Kim (2016) [23] and Soetaredjo et al. (2021) [63], at 38.02% and 21.5%, respectively.

4. Conclusion

The highest heating value was obtained in pine flower biobriquettes charcoal at a ratio of 15% with a grain size of 750 μm which is equal to 23.34 MJ/kg. The resulting biobriquettes have properties suitable for use as an energy source. The value obtained is considered within the range of the calorific value of sub-bituminous coal (20.51–28.47 MJ/kg). Hence, the value has reached the standard fuel for households. The results of research show that bio-briquettes produced from pine flowers can compete profitably with coal, a non-renewable energy source, which adhere to widely accepted bio-briquette standards (Indonesian National Standard 01–6235–2000), Japan, the United Kingdom, and ISO 17225. Biobriquette products have a high potential for converting biomass into solid fuels and can be used as energy sources. Increased use of bio-briquettes can help reduce reliance on forest wood for charcoal production as well as harmful emissions to the environment. The product of this research will help rural residents who are economically impossible to switch from firewood to liquified petroleum gas (LPG) to the use of processed agricultural waste fuels such as biobriquettes.

Charcoal biobriquettes from pine cones can be used to save fuel, especially for people who live around pine forest areas. Pine flowers which are usually scattered on the forest floor, then rot and are not used can be used to make biobriquettes. Communities can make charcoal biobriquettes as a substitute for fossil fuels such as kerosene and natural gas in cooking. Besides being able to reduce environmental pollution, making charcoal biobriquettes from pine cones will improve the economy of the local community. Therefore, charcoal biobriquettes from pine cones is used as an alternative that can be taken to save fuel use, especially fossil fuels, which are increasingly scarce and non-renewable.

The advantages of this research are pine flower briquettes using the pyrolysis method to manufacture is simple, the costs used are economical, and the calorific value is relatively high. In this biobriquette research, it has been shown that there is a potential future market for biobriquettes as an addition to meet the household needs as well as to replace the use of coal for electricity generation.

CRediT authorship contribution statement

Lenny Andar Ningsih: Investigation, Visualization. **Imam Setiawan:** Investigation, Visualization. **Takdir Syarif:** Methodology, Writing – original draft. **Nurdjannah Nurdjannah:** Conceptualization, Investigation, Methodology, Writing – original draft. **La Ifa:** Conceptualization, Investigation, Methodology, Writing – original draft. **Irma Nur Afiah:** Methodology, Visualization. **Heri Septya Kusuma:** Validation, Writing – review & editing, Supervision.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this article.

Data availability

No data was used for the research described in the article.

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References

[1] Abdullahi N, Sulaiman F, Safana AA. Bio-oil and biochar derived from the pyrolysis of palm kernel shell for briquette. Sains Malaysiana 2017;46(12):2441–5. https://doi.org/10.17576/jsm-2017-4612-20.

[2] Agu OS, Tabil LG, Mupondwa E, Emadi B, Dumonceaux T. Impact of biochar addition in microwave torrefaction of camelina straw and switchgrass for biofuel production. Fuels 2022;3(4):588–606.

[3] Aisiyah MM, Masruri M, Srihardyastutie A. Crystallinity of nanocellulose isolated from the flower waste of pine tree (Pinus merkusii). IOP Conference Series: Materials Science and Engineering 2020;833(1):012003. https://doi.org/10.1088/1757-899X/833/1/012003.

[4] Akolgo GA, Awafo EA, Essandoh EO, Owusu PA, Uba F, Adu-poku KA. Assessment of the potential of charred briquettes of sawdust, rice and coconut husks: using water boiling and user acceptability tests. Scientific African 2021;12:e00789. https://doi.org/10.1016/j.sciaf.2021.e00789.

[5] Akowuah JO, Kemausuor F, Mitchual SJ. Physico-chemical characteristics and market potential of sawdust charcoal briquette. Int J Energy Environ Eng 2012;3(20):1–6. https://doi.org/10.1186/2251-6832-3-20.

[6] Aladin A, Alwi RS, Syarif T. Design of pyrolysis reactor for production of bio-oil and bio-char simultaneously. AIP Conference Proceedings 2017;1840. https://doi.org/10.1063/1.4982340.

[7] Avelar NV, Rezende AAP, de C. O. Carneiro A, Silva CM. Evaluation of briquettes made from textile industry solid waste. Renewable Energy Journal 2016;91:417–24. https://doi.org/10.1016/j.renene.2016.01.075.

[8] Borowski G, Stępniewski W, Wójcik-Oliveira K. Effect of starch binder on charcoal briquette properties. Int Agrophys 2017;31:571–4. https://doi.org/10.1515/intag-2016-0077.

[9] Bridgwater AV. Review of fast pyrolysis of biomass and product upgrading. Biomass Bioenergy 2012;38:68–94. https://doi.org/10.1016/j.biombioe.2011.01.048.

[10] Brunerová A, Roubík H, Brožek M. Bamboo fiber and sugarcane skin as a bio-briquette fuel. Energies 2018;11(2186). https://doi.org/10.3390/en11092186.

[11] Carrier M, Auret L, Bridgwater A, Knoetze JH. Using apparent activation energy as a reactivity criterion for biomass pyrolysis. Energy Fuel 2016;30(10):7834–41.

[12] del Río JI, Pérez W, Cardeño F, Marín J, Rios LA. Pre-hydrogenation stage as a strategy to improve the continuous production of a diesel-like biofuel from palm oil. Renew Energy 2021;168:505–15. https://doi.org/10.1016/j.renene.2020.12.086.

[13] Egbosiuba TC. Biochar and bio-oil fuel properties from nickel nanoparticles assisted pyrolysis of cassava peel. Heliyon 2022;8(8):e10114. https://doi.org/10.1016/j.heliyon.2022.e10114.

[14] Esposito D, Antonietti M. Redefining biorefinery: the search for unconventional building blocks for materials. Chem Soc Rev 2015;44(16):5821–35. https://doi.org/10.1039/c4cs00368c.

[15] Fadele OK, Amusan TO, Afolabi AO, Ogunlade CA. Characterisation of briquettes from forest wastes: Optimisation approach. Res Agric Eng 2021;67(3). https://doi.org/10.17221/6/2021-RAE.

[16] Mohd AN, Faizal, Shaid MSHM, Zaini MAA. Solid fuel briquette from biomass: recent trends. Ovidius University Annals of Chemistry 2022;33(2):150–5. https://doi.org/10.2478/auoc-2022-0022.

[17] Faizal M. Utilization biomass and coal mixture to produce alternative solid fuel for reducing emission of green house gas. International Journal on Advanced Science Engineering Information Technology 2017;7(3):950–6.

[18] Farobie O, Amrullah A, Bayu A, Syaftika N, Anis LA, Hartulistiyoso E. In-depth study of bio-oil and biochar production from macroalgae Sargassum sp. via slow pyrolysis. RSC Adv 2022;12:9567–78. https://doi.org/10.1039/d2ra00702a.

[19] García R, Pizarro C, Lavín AG, Bueno JL. Bioresource technology characterization of spanish biomass wastes for energy use. Bioresour Technol 2012;103(1):249–58. https://doi.org/10.1016/j.biortech.2011.10.004.

[20] Güleç F, Williams O, Kostas ET, Samson A, Lester E. A comprehensive comparative study on the energy application of chars produced from different biomass feedstocks via hydrothermal conversion, pyrolysis, and torrefaction. Energ Conver Manage 2022;270:116260. https://doi.org/10.1016/j.enconman.2022.116260.

[21] Gürdil GAK, Demirel B. Effect of particle size on surface smoothness of bio-briquettes produced from agricultural residues. Manufacturing Technology 2018;18(5):742–6. https://doi.org/10.21062/ujep/180.2018/a/1213-2489/MT/18/5/742.

[22] Gwenzi W, Ncube RS, Rukuni T. Development, properties and potential applications of high-energy fuel briquettes incorporating coal dust, biowastes and post-consumer plastics. SN Appl Sci 2020;2(6). https://doi.org/10.1007/s42452-020-2799-8.

[23] de D. K. Hakizimana J, Kim H. Peat briquette as an alternative to cooking fuel: a techno-economic viability assessment in Rwanda. Energy 2016;102:453–64. https://doi.org/10.1016/j.energy.2016.02.073.

[24] Hamid MF, Idroas MY, Ishak MZ, Zainal Alauddin ZA, Miskam MA, Abdullah MK. An experimental study of briquetting process of torrefied rubber seed kernel and palm oil shell. Biomed Res Int 2016;2016:3–5. https://doi.org/10.1155/2016/1679734.

[25] Harris K, Gaskin J, Cabrera M, Miller W, Das KC. Characterization and mineralization rates of low temperature peanut hull and pine chip biochars. Agronomy 2013;3:294–312. https://doi.org/10.3390/agronomy3020294.

[26] Haryati S, Rahmatullah R, Putri RW. Torrefaction of Durian peel and bagasse for bio-briquette as an alternative solid fuel. IOP Conference Series: Materials Science and Engineering 2018;334(012008). https://doi.org/10.1088/1757-899X/334/1/012008.

[27] Haykiri-Acma, H., & Yaman, S. (2010). Production of Smokeless Bio-briquettes from Hazelnut Shell. *Proceedings of the World Congress on Engineering and Computer Science, WCECS 2010*, *2*.

[28] Ifa La, Yani S, Nurjannah N, Darnengsih D, Rusnaenah A, Mel M, et al. Techno-economic analysis of bio-briquette from cashew nut shell waste. Heliyon 2020;6(9):e05009. https://doi.org/10.1016/j.heliyon.2020.e05009.

[29] Ifa L, Yani S, Nurjannah N, Sabara Z, Yuliana Y, Kusuma HS, et al. Production of bio-briquette from biochar derived from pyrolysis of cashew nut waste. Ecology, Environment and Conservation 2019;25(Suppl. Issue):S125–31.

[30] Isikgor FH, Becer CR. Lignocellulosic biomass: a sustainable platform for the production of bio-based chemicals and polymers. Polym Chem 2015;6(25):4497–559. https://doi.org/10.1039/c5py00263j.

[31] Kaur A, Roy M, Kundu K. Densification of Biomass by Briquetting: A Review. International Journal of Recent Scientific Research 2017;8(10):20561–8. https://doi.org/10.24327/IJRSR.

[32] Kers J, Kulu P, Aruniit A, Laurmaa V, Križan P, Soos L, et al. Determination of physical, mechanical and burning characteristics of polymeric waste material briquettes. Est J Eng 2010;16(4):307–16. https://doi.org/10.3176/eng.2010.4.06.

[33] Kpalo SY, Zainuddin MF, Manaf LA, Roslan AM. A review of technical and economic aspects of biomass briquetting. Sustainability 2020;12(4609). https://doi.org/10.3390/su12114609.

[34] Lian F, Xing B. Black carbon (biochar) in water/soil environments: molecular structure, sorption, stability, and potential risk. Environ Sci Tech 2017;51:13517–32. https://doi.org/10.1021/acs.est.7b02528.

[35] Ling CK, San HP, Kyin EH, Hua LS, Chen LW, Yee CY. Yield and calorific value of bio oil pyrolysed from oil palm biomass and its relation with solid residence time and process temperature. Asian J Sci Res 2015;8, 8(3):351–8. https://doi.org/10.3923/ajsr.2015.351.358.

[36] Liu WJ, Jiang H, Yu HQ. Development of biochar-based functional materials: toward a sustainable platform carbon material. Chem Rev 2015;115:12251–85. https://doi.org/10.1021/acs.chemrev.5b00195.

[37] Lusiana SE, Srihardyastutie A, Masruri M. Cellulose nanocrystal (CNC) produced from the sulphuric acid hydrolysis of the pine cone flower waste (Pinus merkusii Jungh Et De Vriese). J Phys: Conf Ser 2019;1374(1):012023.

[38] de Maia BG, Souza O, Marangoni C, Hotza D, De Oliveira APN, Sellin N. Production and characterization of fuel briquettes from banana leaves waste. Chem Eng Trans 2014;37:439–44. https://doi.org/10.3303/CET1437074.

[39] Maitah M, Prochazka P, Pachmann A, Šrédl K, Řezbová H. Economics of palm oil empty fruit bunches bio briquettes in Indonesia. Int J Energy Econ Policy 2016;6(1).

[40] Mardoyan A, Braun P. Analysis of Czech Subsidies for Solid Biofuels. Int J Green Energy 2015;12(4):405–8. https://doi.org/10.1080/15435075.2013.841163.

[41] Moreira R, dos Reis Orsini R, Vaz JM, Penteado JC, Spinacé EV. Production of Biochar, Bio-Oil and Synthesis Gas from Cashew Nut Shell by Slow Pyrolysis. Waste Biomass Valoriz 2017;8(1):217–24.

[42] Morgan HM, Bu Q, Liang J, Liu Y, Mao H, Shi A, et al. A review of catalytic microwave pyrolysis of lignocellulosic biomass for value-added fuel and chemicals. Bioresour Technol 2017;230:112–21. https://doi.org/10.1016/j.biortech.2017.01.059.

[43] Mousa E, Kazemi M, Larsson M, Karlsson G, Persson E. Potential for developing biocarbon briquettes for foundry industry. Appl Sci 2019;9(5288). https://doi.org/10.3390/app9245288.

[44] Mukherjee A, Okolie JA, Niu C, Dalai AK. Experimental and modeling studies of torrefaction of spent coffee grounds and coffee husk: effects on surface chemistry and carbon dioxide capture performance. ACS Omega 2022;7(1):638–53. https://doi.org/10.1021/acsomega.1c05270.

[45] Muraina H, Odusote J, Adeleke A. Physical properties of biomass fuel briquette from oil palm residues. J Appl Sci Environ Manag 2017;21(4):777–82. https://doi.org/10.4314/jasem.v21i4.19.

[46] Nurhayati AY, Hariadi YC, Hasanah W. Endeavoring to food sustainability by promoting corn cob and rice husk briquetting to fuel energy for small scale industries and household communities. Agric Agric Sci Procedia 2016;9:386–95. https://doi.org/10.1016/j.aaspro.2016.02.154.

[47] Nuriana W, Anisa N, Martana. Synthesis preliminary studies durian peel bio briquettes as an alternative fuels. Energy Procedia 2014;47:295–302. https://doi.org/10.1016/j.egypro.2014.01.228.

[48] Obeng GY, Amoah DY, Opoku R, Sekyere CK, Adjei EA, Mensah E. Coconut wastes as bioresource for sustainable energy: quantifying wastes, calorific values and emissions in Ghana. Energies 2020;13(2178). https://doi.org/10.3390/en13092178.

[49] Okolie JA, Nanda S, Dalai AK, Kozinski JA. Techno-economic evaluation and sensitivity analysis of a conceptual design for. Bioresour Technol 2021;331:125005. https://doi.org/10.1016/j.biortech.2021.125005.

[50] Onchieku JM, Chikamai BN, Rao MS. Optimum parameters for the formulation of charcoal briquettes using bagasse and clay as binder. European Journal of Sustainable Development 2012;1(3):477–92. https://doi.org/10.14207/ejsd.2012.v1n3p477.

[51] Onwumelu DC. A Comparative Analysis of Activated Carbons from African Teak (IROKO) Wood and Coconut Shell in Palm Oil Bleaching. AIJR Preprints 2021;350(2). https://doi.org/10.21467/preprints.350.

[52] Pallavi HV, Srikantaswamy S, Kiran BM, Vyshnavi DR, Ashwin CA. Briquetting Agricultural Waste as an Energy Source. Journal of Environmental Science, Computer Science and Engineering & Technology 2013;2(1):160–72.

[53] Pandey S, Dhakal RP. Pine needle briquettes: a renewable source of energy. International Journal of Energy Science 2013;3(3):254–60.

[54] Raj D, Vaibhav S. Design and thermal analysis of pine needle charcoal briquette. Asian Journal of Advamced Basic Sciences 2017;5(2):14–8.

[55] Rambabu N, Panthapulakkal S, Sain M, Dalai AK. Production of nanocellulose fibers from pinecone biomass: Evaluation and optimization of chemical and mechanical treatment conditions on mechanical properties of nanocellulose films. Ind Crop Prod 2015;83(May):746–54. https://doi.org/10.1016/j.indcrop.2015.11.083.

[56] Rapheala IA, Mokia EC, Muhammad A, Mohammed G, Murtala M, A.. Production and characterization of bio-briquettes from production and characterization of bio-briquettes from biochar. Acta Chemica Malaysia (ACMY) 2022;6(2):52–7. https://doi.org/10.26480/acmy.02.2022.52.57.

[57] Sanchez PDC, Aspe MMT, Sindol KN. An Overview on the Production of Bio-briquettes from Agricultural Wastes: Methods, Processes, and Quality. Journal of Agricultural and Food Engineering 2022;1:0036. https://doi.org/10.37865/jafe.2022.0036.

[58] Sawadogo M, Tanoh ST, Sidib S, Kpai N, Tankoana I. Cleaner production in Burkina Faso: case study of fuel briquettes made from cashew industry waste. J Clean Prod 2018;195:1047–56. https://doi.org/10.1016/j.jclepro.2018.05.261.

[59] Sen R, Wiwatpanyaporn S, Annachhatre AP. Influence of binders on physical properties of fuel briquettes produced from cassava rhizome waste. Int J Environ Waste Manag 2016;17(2):158–75. https://doi.org/10.1504/IJEWM.2016.076750.

[60] Sharma MK, Priyank G, Sharma N. Biomass briquette production: a propagation of non-convention technology and future of pollution free thermal energy sources. American Journal of Engineering Research 2015;4(02):44–50.

[61] Shuma R, Madyira DM. Production of loose biomass briquettes from agricultural and forestry residues. Procedia Manuf 2017;7:98–105. https://doi.org/10.1016/j.promfg.2016.12.026.

[62] Singh S, Chakraborty JP, Mondal MK. Torrefaction of woody biomass (Acacia nilotica): Investigation of fuel and flow properties to study its suitability as a good quality solid fuel. Renew Energy 2020;153:711–24.

[63] Soetaredjo FE, Laysandra L, Putro JN, Santoso SP, Angkawijaya AE, Yuliana M, et al. Ecological-safe and low-cost activated-bleaching earth: preparation, characteristics, bleaching performance, and scale-up production. J Clean Prod 2021;279(2021):123793. https://doi.org/10.1016/j.jclepro.2020.123793.

[64] Stolarski MJ, Szczukowski S, Tworkowski J, Krzyzaniak M, Gulczynski P, Mileczek M. Comparison of quality and production cost of briquettes made from agricultural and forest origin biomass. Renew Energy 2013;57:20–6. https://doi.org/10.1016/j.renene.2013.01.005.

[65] Surange JR, Patil NK, Rajput AV. Performance analysis of burners used in LPG cooking stove-a review. International Journal of Innovative Research in Science Eng Technol 2014;3(4):87–97. www.ijirset.com.

[66] Suvunnapob S, Ayudhya BIN, Kusuktham B. A study of cotton dust mixed with wood dust for bio-briquette fuel. Engineering Journal 2015;19(4):57–70. https://doi.org/10.4186/ej.2015.19.4.57.

[67] Takkellapati S, Li T, Gonzalez MA. An overview of biorefinery-derived platform chemicals from a cellulose and hemicellulose biorefinery. Clean Techn Environ Policy 2018;20(7):1615–30. https://doi.org/10.1007/s10098-018-1568-5.

[68] Tamilvanan A. Preparation of biomass briquettes using various agro- residues and waste papers. Journal of Biofuels 2013;4(2):47–55. https://doi.org/10.5958/j.0976-4763.4.2.006.

[69] Ujjinappa S, Sreepathi LK. Evaluation of physico-mechanical-combustion characteristics of fuel briquettes made from blends of areca nut husk, simarouba seed shell and black liquor. International Journal of Renewable Energy Development 2018;7(2):131–7. https://doi.org/10.14710/ijred.7.2.131-137.

[70] Vaez E, Zilouei H. Towards the development of biofuel production from paper mill effluent. Renew Energy 2020;146:1408–15. https://doi.org/10.1016/j.renene.2019.07.059.

[71] Vlysidis A, Binns M, Webb C, Theodoropoulos C. A techno-economic analysis of biodiesel biore fineries: assessment of integrated designs for the co-production of fuels and chemicals. Energy 2011;36(2011):4671–83. https://doi.org/10.1016/j.energy.2011.04.046.

[72] Wu S, Zhang S, Wang C, Mu C, Huang X. High-strength charcoal briquette preparation from hydrothermal pretreated biomass wastes. Fuel Process Technol 2018;171:293–300. https://doi.org/10.1016/j.fuproc.2017.11.025.

[73] Yani S, Zhang Z, Zhu M, Zhou W, Yang H, Zhang D. Effect of Activated Carbon in the Cracking of Volatiles from the Pyrolysis of a Pine Sawdust in a Fixed Bed Reactor. Proceedings of the Australian Combustion Symposium. 2013.

[74] Yank A, Ngadi M, Kok R. Physical properties of rice husk and bran briquettes under low pressure densification for rural applications. Biomass Bioenergy 2016;84:22–30. https://doi.org/10.1016/j.biombioe.2015.09.015.

[75] Zanella K, Gonçalves JL, Taranto OP. Charcoal Briquette Production Using Orange Bagasse and Corn Starch. Chem Eng Trans 2016;49:313–8. https://doi.org/10.3303/CET1649053.

[76] Araújo S, Boas MAV, Neiva DM, Carneiro AC, Vital B, Breguez M, et al. Effect of a mild torrefaction for production of eucalypt wood briquettes under different compression pressures. Biomass Bioenergy 2016;90:181–6. https://doi.org/10.1016/j.biombioe.2016.04.007.