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Utilization of *Indigofera tinctoria L.* Waste for the Production of Environmentally Friendly Biobriquettes

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ABSTRACT. Indigofera tinctoria L. is a natural source of blue dye widely used in various industries, particularly in the textile sector. One of the industries utilizing Indigofera tinctoria L. as a natural dye is CV Indigo Biru Baru, based in Puron Village, Bulu District, Sukoharjo. This company specializes in the production of batik fashion. The natural dye industry generates substantial organic waste from the processing of Indigofera tinctoria L., much of which remains underutilized and presents a potential environmental pollution risk. This study aims to optimize this waste by converting it into biobriquettes as an alternative fuel source. The production process involves pyrolyzing the waste at temperatures of 300–350°C for 2 hours, followed by binding with tapioca flour paste at a 10:1 ratio, molding, and quality testing based on SNI (Indonesian National Standard). The biobriquette characterization includes proximate analysis, calorific value measurement, drop test, and yield evaluation. The results showed a moisture content of 6.9665%, ash content of 7.2025%, volatile matter content of 33.522%, fixed carbon content of 52.309%, and a calorific value of 5438.902 cal/g. Meanwhile, the hardness test indicated that only 0.042% of the mass was lost during the drop test, demonstrating excellent physical durability. With its high calorific value and superior physical characteristics, this biobriquette exhibits great potential as a renewable fuel to support sustainable energy transition in Indonesia.

1. INTRODUCTION

Indigofera tinctoria L. is a plant that naturally produces blue dye. This plant produces indigo blue dye, which is widely used in industries, especially in the textile industry [1]. One industry that utilizes *Indigofera tinctoria* L. as a natural dye is CV Indigo Biru Baru, based in Puron Village, Sukoharjo. CV Indigo Biru Baru specializes in the batik fashion sector.

The processing of natural dyes from *Indigofera tinctoria* L. produces significant amounts of organic waste, as the dyes are derived mainly from the leaves, while the stems become waste materials. This waste is often not utilized optimally, so it has the potential to become a source of environmental pollution. To support sustainable waste management, it is important to find innovative solutions to utilize *Indigofera tinctoria* L. waste in products that have utility value.

Biobriquettes are solid fuels that are used as a substitute for fuel oil. It undergoes a carbonation process before being molded at specific pressure, whether it contains an adhesive or other additional components. [2]. Biobriquettes are produced from biomass charcoal derived from plant materials or agro-industrial waste. Various lignocellulosic wastes, such as rice husk and sawdust, have been widely studied as raw materials for biobriquette production. Previous studies report that briquettes made from rice husk and sawdust have relatively low calorific values (20,506–20,519 kJ/kg)[3]. This study investigates *Indigofera tinctoria* L. stem waste as a novel alternative biomass source. The stems have low moisture content and are classified as lignocellulosic waste, indicating strong potential for biobriquette production and a potentially high calorific value. Unlike commonly used materials such as rice husk and sawdust, the application of *Indigofera tinctoria* L. stems remains underexplored. Therefore, this study aims to evaluate their feasibility as a sustainable raw material for biobriquette development. The quality of biobriquettes is characterized by a smooth texture, high strength so that it is not easily broken, and properties that are safe for humans and environmentally friendly. Usually, biobriquettes are used in large-scale industries, home industries, restaurants, and household sector needs.

Utilization of *Indigofera tinctoria* L. waste for making biobriquettes is a strategic step that supports the transition to cleaner and more sustainable energy sources. Biobriquettes can be used as a substitute for fossil fuels. Energy use in Indonesia to date is still dominated by non-renewable energy derived from fossils, such as petroleum and coal [4]. The dominant use of fossil energy not only causes limited supply in the future but also hurts the environment such as increasing greenhouse gas emissions that contribute to climate change. Therefore, Indonesia must switch to more environmentally friendly renewable energy sources to ensure energy sustainability and reduce negative impacts on the environment. The use of renewable energy sources is expected to help the Indonesian government achieve its target of reducing emissions by 29% by 2030 and carbon neutrality by 2060 [5].

2. MATERIALS AND METHODS

2.1 Materials

The materials utilized in this study included *Indigofera tinctoria* L. plant waste obtained from CV Indigo Biru Baru, water, tapioca flour, kerosene, and firewood.

Figure 1. *Indigofera tinctoria* L. waste

2.2 Tools

The equipment used in this study includes a pyrolysis reactor with the design shown in Figure 2. The dimensions of this pyrolysis reactor are 30 cm in diameter and 40 cm in height. The first, larger pipe has a diameter of 8 cm, while the smaller pipe is square-shaped with a side length of 4 cm. Additionally, the combustion chamber has dimensions of 15 x 18 x 19 cm. Other equipment used includes an electric grinder, a 50 mesh sieve, and a hydraulic press equipped with a block-shaped mold with dimensions of 4 × 3 × 3 , as shown in Figure 3.

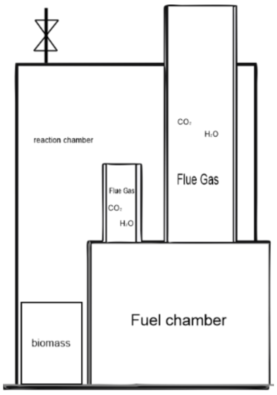

Figure 2. Pyrolysis Reactor Design

Figure 3. Hydraulic Press

2.3 Methods

The waste stems of *Indigofera tinctoria* L. were sun-dried for one day to remove moisture content. The waste was then cleaned to separate the leaves and cut into pieces measuring 3–4 cm. 400 g of the waste were carbonized over 2 hours at 300–350°C in a pyrolysis reactor. A grinder was used to grind the resultant charcoal, which was then sieved through a 50-mesh screen.

The first step in biobriquette production involves preparing an adhesive mixture by boiling water and mixing it with tapioca flour at a ratio of 10:1 (volume of water in mL to mass of flour in g) until a homogeneous mixture is achieved. Next, the charcoal is combined with the adhesive mixture at a ratio of 10:1 (charcoal mass to adhesive mass) and stirred until evenly blended. The blended charcoal mixture is then shaped using a hydraulic press at a pressure of 3.5 tons for 10 minutes and dried under sunlight for 24 hours.

2.4 Briquettes Characterization

The characterization of the briquettes included proximate analysis, calorific value analysis, and drop test. Proximate analysis was carried out in accordance with ASTM D 5142 – 90, which includes tests for moisture content, volatile matter, ash content, and fixed carbon content. Calorific value and proximate analysis were conducted at the UGM Center for Food and Nutrition Studies.

2.4.1 Moisture Content

The moisture content test was conducted by drying a pre-weighed sample in a crucible using an oven at a temperature of 104–110°C for 1 hour. The sample was then placed in a desiccator and subsequently weighed [6]. To determine the moisture content, the following formula was used:

$$M = \left[\frac{(W-B)}{W}\right] \times 100\% \quad (1)$$

with:
M = percentage of water content
W = initial sample weight (g)
B = sample weight after drying (g)

2.4.2 Volatile Matter

A furnace was used to heat the sample from the moisture content analysis to 950 ± 20°C for 7 minutes. Afterward, the sample was placed in a desiccator and weighed [7]. The volatile matter content was calculated using the following equation:

$$V = \left[\frac{(B-C)}{W}\right] \times 100\% \quad (2)$$

with:
V = percentage of fly matter
B = sample weight of moisture content analysis results (g)
C = sample weight after heating in the furnace (g)

2.4.3 Ash Content

The sample was heated in a furnace for 2–4 hours at a temperature of 700–750°C to start the test. After that, the sample was taken out, put in a desiccator, and weighed [6]. The ash content was calculated using the following equation:

$$A = \left[\frac{(F-G)}{W}\right] \times 100\% \quad (3)$$

with:
A = percentage of ash
F = weight of crucible and ash residue (g)
G = weight of empty crucible (g)

2.4.4 Fixed Carbon

To calculate the fixed carbon content, the following formula was used [6].

$$H = 100\% - (M + A + W) \quad (4)$$

with:
H = percentage of solid carbon

2.4.5 Calorific Value

To assess the calorific value, a bomb calorimeter was used. In the bomb calorimeter, a thread and wire were attached after a 1 g sample was weighed. After that, the sample and 1 mL of distilled water were added to the instrument and set up. Oxygen gas was introduced at a pressure of 20–30 bar. The bomb calorimeter unit was placed in a chamber containing 2.1 kg of water, and the stirrer was activated. The initial temperature was recorded as shown by the thermometer. An electric current was then passed through for approximately 5 seconds, and the final stabilized temperature after the rise was recorded [7]. The calorific value was calculated using the following equation:

$$Q = \frac{(\varepsilon \times \Delta T) - Qk - Qb}{m} \tag{5}$$

with:
Q = calorific value of the sample (cal/g)
ε = heat capacity of the calorimeter (cal/°C)
ΔT = temperature change (°C)
Qk = heat released from wire combustion (cal/g)
Qb = heat released from burning the yarn (cal/g)
m = sample weight (g)

2.4.6 Drop Test

The drop test was conducted to evaluate the breakage strength of biobriquettes when dropped from a height and to determine their size stability. This test followed the ASTM D 440 – 86 procedure, which involves dropping the biobriquette from a height of 1.8 meters. After the drop, the intact biobriquettes were weighed [8]. The calculation for this test was performed using the following equation:

$$\%\ \text{Friability} = 100 - \left[\frac{(100 \times s)}{S}\right] \tag{6}$$

with:
S = weight before drop test (g)
s = weight after drop test (g)

2.4.7 Yield

The yield calculation was performed to determine the amount of charcoal produced from the pyrolysis process. A higher yield value indicates that more raw material can be converted into the final product, and vice versa. The yield was calculated using the following equation:

$$\text{Yield} = \frac{\text{product mass}}{\text{raw material mass}} \times 100\% \tag{7}$$

3. RESULTS AND DISCUSSION

Raw materials in the form of *Indigofera tinctoria* L. waste weighing 400 g were fed into the pyrolysis reactor, resulting in an output product of 154 g of charcoal. This occurs due to the loss of volatile components during the pyrolysis heating process. In the first conversion stage, components such as CH_2, CO_2, CO, and CH_4 are removed. Then, in the second conversion stage, the biomass transforms into heavy chemicals, which are divided into charcoal and pyrolysis gas [9]. The heating rate during the pyrolysis process can influence the composition and output yield [10]. The resulting charcoal from pyrolysis was then mixed with an adhesive made of tapioca flour, with a composition of 154 mL water and 15.4 g tapioca flour for 154 g of powdered charcoal. This mixture was molded into blocks measuring 4 × 3 × 3 cm. Based on this composition, the biobriquettes demonstrated excellent hardness and breakage resistance.

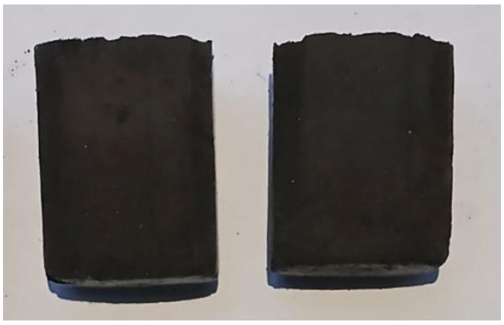

Figure 4. *Indigofera tinctoria* L. Stems Waste Biobriquettes

Several tests were carried out to evaluate the biobriquettes quality; the outcomes are shown in Table 1.

Table 1. Test Results of *Indigofera tinctoria* L. Biobriquettes

Testing	Result	SNI 01-6235-2000
Moisture Content (%)	6.9665	≤8
Ash Content (%)	7.2025	≤8
Volatile Matter (%)	33.522	≤15
Fixed Carbon (%)	52.309	-
Calorific Value (cal/g)	5438.902	≥5000

3.1 Moisture Content

A high moisture level decreases combustion efficiency, as additional energy is needed to evaporate the water before the biobriquettes can ignite, leading to an unstable heat output. As shown in table 1, the moisture content in the biobriquette is 6.9665%, respectively. According to SNI 01-6235-2000, high-quality briquettes should have a moisture content less than 8%. Briquettes with moisture content above 8% are more susceptible to mold growth and degradation during storage and are generally more prone to physical disintegration.

3.2 Ash Content

The ash content impacts the amount of residue generated after combustion. Higher ash content results in more residue, which can complicate the cleaning and maintenance of combustion equipment. As shown in table 1, the ash content in the biobriquette is 7.2025%, respectively. According to SNI 01-6235-2000, briquettes of good quality should have an ash content lower than 8%. Briquettes with lower ash content tend to be more efficient, as they burn more effectively, producing less residue.

3.3 Volatile Matter

The volatile matter content in biobriquettes can influence various aspects, including the amount of smoke released during ignition, ease of burning, combustion stability, and more. Based on table 1, it can be stated that the volatile matter content in the biobriquette is 33.522%. According to SNI 01-6235-2000, the recommended parameter for a good briquette is a maximum loss of material during heating of 15%. In this study, the higher volatile matter value compared to the SNI standard was attributed to the addition of an adhesive material, namely tapioca flour, which is consistent with previous studies reporting that volatile matter content increases with higher adhesive composition [11]. Furthermore, the volatile matter content is also influenced by other variables including temperature and carbonization duration. The percentage of volatile matters in the charcoal decreases with increasing temperature and carbonization time.

3.4 Fixed Carbon

The fixed carbon content is an important factor in assessing biobriquette quality. A higher fixed carbon value indicates better quality, as it is linked to the amount of smoke produced during ignition. Biobriquettes with higher fixed carbon content tend to produce less smoke. The experiment showed that the fixed carbon content of biobriquettes is 52.309%. SNI 01-6235-2000 does not specify criteria for fixed carbon content. The fixed carbon value of the biobriquettes can be decreased by adding an adhesive. This happens because the adhesive raises the volatile matter content and the fixed carbon content decreases as the volatile matter level increases. Consequently, adding an adhesive to the biobriquettes introduces more volatile substances, which ideally should have been removed during the pyrolysis process.

3.5 Calorific Value

The calorific value of a biobriquette determines its quality. The grade of the briquette increases with its calorific value. This is due to the fact that a higher calorific value leads to more effective heating, which enhances the temperature and burn time. The experiment showed that the calorific value is 5438.902 cal/g. The calorific value of the biobriquettes in this experiment satisfies the SNI requirement because the minimum standard for briquettes is 5000 cal/g, as stated in SNI 01-6235-2000. The calorific value of the biobriquettes can be influenced by a number of variables, including the pyrolysis process, the fixed carbon content, and the volatile matter content.

3.6 Drop Test

In addition to proximate analysis, the quality of biobriquettes is determined by their strength or hardness. Testing was conducted by dropping the biobriquettes from a height of 1.8 meters and weighing the intact portion. Based on this test, it was found that the biobriquette weight decreased by only 0.0126 g from its total weight of 30 g, equivalent to just 0.042%. This result indicates that the biobriquettes passed the drop test, according to ASTM D 440 – 86, which states that the maximum allowable weight loss is 1%. Thus, the biobriquettes produced demonstrated excellent durability.

3.7 Yield

Yield is the amount of product produced from a process relative to the amount of raw material used. In this biobriquette production, the yield refers to the total weight of raw material (*Indigofera tinctoria* L. waste stems) after the pyrolysis process. Based on the experiment, 154 g of charcoal was obtained from 400 g of raw material, resulting in a yield of 38.5%.

4. CONCLUSION

Biobriquettes made from *Indigofera tinctoria* L. waste, produced using a pyrolysis reactor at a temperature of 300–350°C for 2 hours with an adhesive made from tapioca flour paste (10:1 ratio), demonstrated good quality. The results of the tests for calorific value, ash content, and moisture content satisfied SNI 01-6235-2000 requirements. Hardness testing also showed excellent durability, with a weight loss of only 0.0126 g or 0.042% of the total biobriquette weight after a drop test. However, the volatile matter content did not satisfy the standard, possibly due to the adhesive ratio used and result in a suboptimal calorific value. Therefore, future research can explore varying adhesive ratios to observe their impact on volatile matter content. Nonetheless, with its high calorific value and strong physical properties, this biobriquette shows potential as an alternative fuel source.

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