Wood Pellet Characteristics of Five Energy Species Grown in Post-Mining Reclamation Area in South Kalimantan

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Abstract. Biomass is one of the renewable sources of energy with prospective needs to be considered at a national or even global scale. Chemical components and physical properties of materials can be used as bioenergy in the form of pellets. Pellets made by compressing biomass using pressure-heat, resulting in higher calorific values than origin material. Reclamation forests can be seen as a potential source of energy. Considering the generally less-optimal environment, further research regarding the characteristic of species grown in such conditions required. Firstly, research aimed to determine pellets characteristics of five species grown at the post-coal-mining area at Tabalong Regency, i.e. laban (Vitex pinnata), sengon (Paraserianthes falcatoria), sungkai (Peronema canescens), trembesi (Samanea saman) and johar (Senna siamea). Secondly was to evaluate the potential of species as energy sources. Measurement focused on forest debris, followed procedures set on SNI 8021-2014. Characteristics measured were moisture-content, density, lignocellulose, extractive, calor, ash, igniting-time, and burning-rate. Statistical analysis indicates that characteristics of origin material positive correlated with a caloric value of pellets except for moisture and ash. Pellets made of laban had the highest calorific value. Five species grown on the post-mining area had calorific values of pellets fulfilling the standard, which means those all are potential to be developed as an energy source.

1. Introduction
Natural resources such as petroleum, coal, and natural gas are limited so that energy in the future tends to shift to renewable energy sources [1]. Biomass is one of the renewable energy sources, which is prospective at a national or even global scale. Forests can serve as a source of raw material for renewable energy in the form of wood biomass. Forests establishment part of post-mining reclamation potentially produces wood biomass for energy. Developing a post-mining area into energy forests will fulfill the need to rehabilitate the previously disturbed environment and at the same time to provide economic benefits [2].

Pellet made of wood is a form of biomass energy sources with many advantages in terms of having a uniform and high heating value. Converting plant biomass, mainly wood into pellets, will optimize their use as a source of energy due to the improvement in energy quality, consistency, and fuel efficiency. In this way, the use of pellets will eventually produce lower emissions compared to original raw material [3].

Some mining sites have been planted with tree species that can potentially be used as source energy or "energy species." One example, the ex-mining area planted with sengon and johar in Central Kalimantan and trembesi and sengon in South Kalimantan as energy species [4]. However, soil characteristics of rehabilitated post-mining areas are low nutrients availability, high bulk density, lack
of organic matter, and poor drainage) [5], and these conditions may affect the characteristics of vegetation growing on it [5]. Wood characteristics are also affected by the site characteristics, including climate, altitude, soil physical properties, nutrients as well as the age of the tree. Therefore energy species growing on rehabilitated soil may exhibit different wood characteristics compared with those growing on healthy soil.

This study aimed to examine the characteristics of wood as raw materials and wood pellets made of five tree species grown in rehabilitated coal-mining sites in South Kalimantan and evaluate their potency as energy wood. Those five species were locally known as laban (Vitex pinnata), sengon (Paraserianthes falcataria), johar (Senna siamea), trembesi (Samanea saman) and sungkai (Peronema canescens).

2. Method

2.1. Source of raw materials
A sampling of raw materials for making pellets conducted in February 2019. Raw materials used in this research were wood biomass taken from tree branches and twigs of five energy species, namely sengon, laban, sungkai, trembesi, and johar. Those five energy species grown in reclaimed sites of post-coal-mining located in Tanjung District, Tabalong Regency, South Kalimantan Province. Wood samples of laban, sungkai, and trembesi were taken from tree stands planted in 1997. However, wood samples of johar and sengon were taken from tree stand planted in 2015 and 2016, respectively. For each energy species, three to five individual trees selected, and their branches and twigs were cut off from the stems. Approximately seven-kilogram samples collected from each species. The sampled woods were subsequently cut into approximately 20 cm-long pieces. Their fresh weights were measured on the site using a spring balance. Some of the samples used for measuring physical properties and chemical components of raw materials (i.e. wood characteristics) and some others converted into pellets.

2.2 Measuring physical properties and chemical components of raw materials
Measurement of physical properties and chemical components conducted at LABTEK I, School of Life Sciences, and Technology (SITH) ITB at Jatinangor campus. The process of manufacturing and testing of the pellet heat value carried out at the Physical Chemistry Laboratory of the Faculty of Mathematics and Natural Sciences (FMIPA) ITB.

2.3 Pelletizing process
There were six steps in making pellets in sequence, i.e. a) particle production, b) particle drying, c) mixing particles with starch, d) printing and drying, e) conditioning and sorting, and f) pellet testing. Particles made using a crusher, then dried up to ± 2-3% moisture content, mixed with starch as an adhesive and printed using a pellet press tool. Pellet molding was done using particles inserted into a cylindrical hole, then pressed and compacted with a manual pellet press tool, and drying at 200°C in the oven for 120 minutes. Furthermore, conditioning, sorting, and testing were carried out.

2.4 Sample testing
Determination of the value of water content was done by the gravimetric method, which compared the weight of water contained in raw materials or pellets to the dry weight of the furnace and stated in percentage. Testing the moisture content of raw materials was done on solid wood with a size of 2 cm x 2 cm x 2 cm, while for pellets carried out on a cylindrical pellet printing results [7]. Samples of raw materials and pellets placed on aluminum foil whose weights are known. Then the raw material or pellet was put into the oven at 103 ± 2°C until the dry weight of the furnace reached. Then the sample cooled in a desiccator and then weighed. The determination of density counted by the result of a comparison between weight and volume. The test sample for determining the density of raw materials
was in the form of solid wood with a size of 2 cm x 2 cm x 2 cm, while pellets were in a cylindrical shape with a diameter of 1.1 cm and a length of 3 cm [7].

Determination of the value of ash content done by weighing five grams of sample powder and placed on a porcelain cup of known weight. Then, the cup containing the sample was put into the furnace at 550°C for six hours. After that, the sample was taken and cooled in desiccators then weighed [8]. The determination of lignin content is done using the Klason method. Firstly, preparing a sample powder of 1 ± 0.1 g equivalent to the dry weight of the furnace, then extracted with alcohol and benzene solvent in sequence in Soxhlet at 100°C until six circulations occur every hour. The result of soxhlet added with H₂SO₄ solution and left for two hours, then stored in a water bath until boiling and left for four hours. After deposition occurs, the solution containing lignin was then poured hot water so that the lignin deposits are free of acid [9]. The determination of cellulose content done through the gradual addition of NaOH to three grams of powder. After that, the addition of acetic acid and wash it with hot water. Then, the solution is filtered to form cellulose deposits on filter paper. The precipitate dried in the oven to a constant weight [10]. The determination of extractive content was done with a neutral with a hot water solvent. Two grams of powder put in 100 ml of hot water. The extraction of the powder was carried out for four hours in a soaking tub at 20°C. Extractive levels determined by removing the solvent, then the substrate dried in an oven at 103 ± 2°C until it reached the weight of the dry weight of the furnace and compared with the weight of the powder at the dry condition of the furnace [11].

The determination of the heat value of the pellet was done using a bomb calorimeter and refers to the SNI 8021-2014 standard. Determination of the heating value was done by weighing a sample of pellets weighing one gram, and then the pellets are placed on an iron cup. The metal cup connected by an igniter. The steel rod contained in the bomb calorimeter and the ignition wire section touched to the sample in the form of wood dust contained in an iron cup. After that, the heat gauge (bomb) contained in the calorimeter bomb was tightly closed, then slowly filled with oxygen at a pressure of 35 atmospheres. The bomb put into a calorimeter that has been filled with water as much as 1,350 ml, then closed. Measurements made until the system temperature reaches a maximum (200°C), and the heating value calculated based on the amount of heat released equal to the amount of heat absorbed. The determination of pellet ignition is done by using a syngas stove, as much as one gram of wood pellets are burned using fire through the stove gap. The length of time since the fire is lit to ignite until the pellet lit calculated using a stopwatch, whereas the measurement of the combustion rate is carried out through as much as one gram of wood pellets weighed in an air-dried state. The weighed pellets then burned in the syngas stove. The length of time for combustion calculated using a stopwatch since the pellets start burning until they burned. A comparison was made between the mass of the pellet before it burned with the length of time required for combustion.

3. Results and discussions
The lignin content of the raw materials varied, as shown in Table 1. According to the classification of chemical components of hardwood [11], the lignin content of those five energy species was in the medium to high range. The lignin content of laban (Vitex pinnata) was the highest, and it was significantly different from the four others. Higher lignin in raw materials results in higher calorific value [3]. Lignin constitutes the second most significant portion of chemicals in the wood after cellulose, but it has a more significant effect in increasing heating value than cellulose [12].

The percentage of lignin in softwood trees is around 25-35%, and in hard-wood trees is around 18-25% [13]. All species used in this research are hard-wood trees, and their average lignin content was higher (25.7-34.6%) than those reported by Dumanaw. A study reported that the lignin content of laban grown in whole land (not affected by mining) was 21.13% [14]. This study found a higher lignin content of laban (34.6%). This finding confirms that the level of lignin influenced by several factors, such as plant type, place of growth, climate, and geographical location [15]. Higher lignin level indicates that the wood has matured; it means that the wood has thickening and hardening of cell walls more thoroughly [16].
The cellulose content of the raw materials (Table 1) suggests that the five energy species studied as having low to high cellulose content, according to Koesoema [11]. We found three groups of species that were significantly different in terms of their level of cellulose content. Species with low cellulose levels were sengon (Paraserianthes falcataria) and trembesi (Samanea saman). Sungkai (Peronema canescens) belonged to medium level, whereas johar (Senna siamea) and laban (Vitex pinnata) belonged to a high level. Higher cellulose level in raw materials results in higher heating value [12]. Similar to the finding on the lignin content, this study also found that the cellulose content of laban (Vitex pinnata) growing in post-mining soil (46%) was higher than that of finding in healthy soil (43%) [14]. The higher cellulose content of laban growing in post-mining reclamation land may indicate a higher accumulation of chemical components in the cell walls. In addition, the age of trees may affect the level of cellulose; the older tree will have higher cellulose content, which is marked by the extensive hardening of wood [16].

In terms of extractive substances of the raw materials (Tabel 1), all five species belonged to a high level according to classification by Koesoema in ‘Panduan Kehutanan Indonesia” book [11]. Their values ranged from 16.5% to 22%. This study used hot water as the extracting solvent. Extraction using hot water allows the level of starch (complex sugar groups) to be determined along with other chemical substances like tannins, gums, and carbohydrates [10]. Laban (Vitex pinnata) had the highest extractive substances compared to other species. The extractive substance has an important role for a material to be able to produce energy. The higher the extractive substances, the higher the energy that can be produced [12]. Levels of extractive substances in raw materials in the temperate region range from 4-10%, whereas in the tropics it can reach up to 20% [17].

Raw material density and pellet density (Table 1) varied each other. The density of the five species energy after being turned into wood pellets is higher than the density of the original raw materials. This caused by the wood through a compaction process [18] till the density fulfilled the required. The results of the significant difference test showed that the pellets were from raw materials of sengon (Paraserianthes falcataria) significantly different from the other four species. Wood pellets from three different types of raw materials, namely trembesi (Samanea saman), laban (Vitex pinnata), and sungkai (Peronema canescens) have no significant difference, whereas wood pellets are made from raw materials of johar (Senna siamea) shows a higher value than other wood pellets. There is a positive correlation between the density value and the heating value [19]. The higher the density of wood pellets, the higher the heating value. This is caused by the high density will reduce the voids contained or porosity in pellets. This is evidenced by the high of Pearson correlation value, which is 0.86 between the density of wood pellets with the heating value, as shown in Figure 4.

Like the others, moisture content of raw materials and pellets shows the variation from one to another (Table 1). The moisture content of pellets from different raw materials fulfilled the specified standards (SNI 8021, 2014), except for pellets made by sengon raw materials (Paraserianthes falcataria) [6]. Moisture content of pellets from laban raw materials (Vitex pinnata) has a significantly different value from other pellets, while pellets from four types of raw materials, like johar (Senna siamea), sungkai (Peronema canescens), trembesi (Samanea saman), and sengon (Paraserianthes falcataria) not show any significant difference each other. There is a significant change between the moisture content of raw materials (before pelletizing) and the moisture content after pelletizing. This is due to the raw material, which has a higher moisture content will absorb more heat when the pellets dried up [20]. So, it can decrease the moisture content. The higher the moisture content of raw materials will cause more heat needed to remove the water in the pellet to become steam. This has an impact on the heating value that the remaining energy becomes smaller [21]. Thus, the heating value of pellets will decrease with increasing water content. This is evidenced by the Pearson correlation, which shows a very strong negative linear relationship (-0.96), which means the relationship between the two is very opposite, as shown in Figure 3.

The heating value (calorie) of pellets from the five energy species varied in value, as shown in Figure 1. Consequently, the highest heating value obtained in pellets with laban raw materials (Vitex pinnata) followed by sungkai (Penorema canescens), trembesi (Samanea saman), johar (Senna
siamea), and sengon (Paraserianthes falcataria). All pellets with different raw materials fulfilled the required heating value, as stated on the SNI 8021, which is > 4,000 calories / gram [6]. Pellets own the most significant calorific value with laban raw material (Vitex pinnata), that's 4,455.5 calories / gram. Pellets from laban raw materials have the highest heating value because based on the results of raw material testing, laban has high levels of lignin, cellulose, and extractives substances (Table 1) so that significantly affects to the heat of the pellet. The results of previous studies the average calorific value of pellets made from laban species cultivated in normal land is 4,600 calories / gram at a density of 0.88 gr / cm³ in equilibrium temperature [22]. This is different from the calorific value of wood pellets from the branches and twigs of laban that grow in post mining reclamation area, specifically the Tabalong Regency, which is 4,455.5 calories / gram. This shows that plants grown on reclamation area have potential as energy plant, although the heating value is slightly lower. The results of the statistical significant difference test through simple-T-test showed an increase for the heating value, that is an increase 3-4% after being made into wood pellets compared to the original raw materials. This proves that the compaction process in making pellets can increase the calorific value compared to conventional wood that is burned [1].

Ash content of raw material is higher than ash content of pellets (Figure 2). Based on the classification of chemical components of hardwood by Koesoema [11], ash content of pellets from four species, namely laban (Vitex pinnata), trembesi (Samanea saman), sungkai (Peronema canescens), and sengon (Paraserianthes falcataria) classified as medium, while the ash content of pellets from johar (Senna siamea) classified as high. Based on the statistical test, ash content owned by johar pellets was significantly different than other pellets. High ash content of raw materials can reduce the heating value of pellets. This is due to the high ash content which can increase the smoke produced during combustion in the furnace [20]. Figure 2 showed that in addition to johar, the ash content of raw materials or pellets of the other four species has a relatively low. This is related to the condition of post-mining reclamation land which has lower organic and inorganic material content compared to normal land [23]. Therefore, inorganic minerals such as the ash have a smaller amount.

Pellets from five energy species have varied value on ignition time (Table 1). Based on the results of the statistical test, the mechanical strength of pellets from trembesi (Samanea saman), sungkai (Peronema canescens), and johar (Senna siamea) does not show any significant difference, but it is significantly different from the mechanical strength of pellets from laban (Vitex pinnata) and sengon (Paraserianthes falcataria). Ignition time indicates the speed of pellets to burn. The faster it burns, the better the wood pellet will be. Pellets with high ignition speed indicate that the heat produced by pellets can be used immediately [24]. Ignition time is caused by several factor, such as moisture content of wood pellet. If the water content of the pellet is high, ignition time is low. It mean that the time needed to burn the pellet will be longer [24].

Based on the results of statistical significant difference test, the rate of burning of pellets from five types of energy plant has a value that is not significantly different (Table 1). The rate of combustion is affected by the density of pellets. The high density of pellets causes the heat generated to spread more slowly on all particles in the pellets, thus slowing the rate of pellet combustion [24]. Previous studies have shown that sengon pellets have a burning rate of 0.0005082 gram/second or 0.03 gram/minute [24]. This value is higher when compared to the rate of burning of sengon pellets obtained in this study which is equal to 0.001 gram/minute.

Based on the characteristics of the energy species, especially raw materials and pellets, the five species energy studied are not only suitable for planting on post mining reclamation land (marginal land), it is also feasible to be developed as bioenergy raw material in the form of pellets. The development of pellets as bioenergy have a good prospects. This is in line with the strategy of accelerating the development of new and renewable energy from the Ministry of Energy and Mineral Resources. The development of pellets as bioenergy will have the effect of creating new markets and an environmentally friendly business climate and creating new economic value.
Table 1. Physical properties and chemical components of five energy plant species

| Pellet Properties          | Laban | Sengon | Trembesi | Johar | Sungkai | Criteria                  |
|----------------------------|-------|--------|----------|-------|---------|---------------------------|
| Moisture content (%)       | 3.96<sup>a</sup> | 12.82<sup>b</sup> | 11.92<sup>b</sup> | 10.85<sup>b</sup> | 11.11<sup>b</sup> | SNI: MC≤12%            |
| Density (g/cm<sup>3</sup>)  | 0.855<sup>b</sup> | 0.837<sup>ab</sup> | 0.845<sup>b</sup> | 0.860<sup>b</sup> | 0.859<sup>b</sup> | SNI: Density≥0.8 gr/cm<sup>3</sup> |
| Ignition time (second)     | 5.5<sup>b</sup> | 6.14<sup>c</sup> | 5.4<sup>a</sup> | 5.5<sup>a</sup> | 5.34<sup>b</sup> |
| Burning rate (g/menit)     | 0.03<sup>a</sup> | 0.1<sup>a</sup> | 0.1<sup>a</sup> | 0.06<sup>a</sup> | 0.05<sup>a</sup> |

| Characteristic of Raw Materials | Laban | Sengon | Trembesi | Johar | Sungkai | Category         |
|--------------------------------|-------|--------|----------|-------|---------|-----------------|
| Cellulose content (%)         | 45<sup>c</sup> | 39.3<sup>b</sup> | 40<sup>b</sup> | 45<sup>c</sup> | 42.9<sup>c</sup> | low-high         |
| Lignin content (%)            | 34.6<sup>c</sup> | 29.5<sup>b</sup> | 29.7<sup>b</sup> | 25.7<sup>c</sup> | 31<sup>b</sup> | medium-high      |
| Extractive Substances (%)     | 22<sup>c</sup> | 16.5<sup>a</sup> | 17<sup>a</sup> | 20.5<sup>b</sup> | 19<sup>b</sup> | High             |

Note: * Tukey HSD significant difference test results (p<0.05)

Figure 1. The heating value of five energy species
4. Conclusion
The result from characteristics of raw materials consisting of water content, density, cellulose content, lignin content, extractive substances, and ash content, the five energy species studied have significant differences. The same thing when viewed from the characteristics of pellets consisting of water content, density, ash content, calorific value, and mechanical properties. Burning rates of the five species are not significantly different from each other. Sequentially, species that have the potential to be used as reclamation plants at the Tabalong Regency and at the same time have a high heating value are laban (*Vitex pinnata*), sungkai (*Peronema canescens*), trembesi (*Samanea saman*), johar (*Senna siamea*), and sengon (*Paraserianthes falcataria*), respectively.

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