Characteristics of wood pellets from over-dry sawdust waste

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Abstract. Wood pellets are renewable fuels from biomass which can be an alternative substitute for petroleum fuels. One of the raw materials for making wood pellets is sawdust from the sawmill industry or other wood craftsmen. Sawdust waste that dumped for a long time will reduce its moisture content (over-dry) and will be difficult to form into pellets. In this paper, we studied the effect of adding liquid solution ie. water, tapioca starch solution, pure molasses solution and dilute molasses solution on over-dry sawdust to the characteristic properties of wood pellet torrefaction. The sawdust material was collected from the wood sawmill in the Bogor District. There were five treatments i.e sawdust (control), sawdust + 10% water, sawdust + 10% tapioca starch solution, sawdust + 10% pure molasses solution, sawdust + 10% diluted molasses solution. The wood pellet torrefaction properties were investigated using a manual hot press at the temperature of 210°C. The results showed that the addition of pure molasses solution produced better pellets than other treatments, with properties i.e water content of 2.65%, the ash content of 1.45%, volatile matter 76.72%, fixed carbon 19.18%, the calorific value of 19.56 MJkg⁻¹, density 0.84 gcm⁻³, and compressive strength 52.22 kgcm⁻².

1. Introduction

Energy is one of the essential human’s need in their activities for food, travel, production, and activities in the house [1]. Unfortunately, until today the major energy resources is supplied from fossil fuel. Therefore, it is important to develop an innovation in alternative energy. One of the valuable renewable energy resources is wood pellet from biomass. In the future, it is expected to be one of the promising alternative energy in replacing fossil fuels and contributing to greenhouse gas emissions mitigation [2].

Wood pellets are usually made from wood processing waste such as cutter shavings, dust from wood mill and sawdust [3]. Sawdust is a waste of small particles in the form of wood powder from wood cutting in sawmill and wood processing industries [4]. Based on BPS data in 2018, sawn wood production in Indonesia was 2,078,551 m³. According to Maharani et al. 2010 [5], the total volume of sawdust produced in sawmilling process was about 10-13%. Therefore, it is estimated there is about 207,855.1-270,211.63 m³ sawdust waste from sawmill industries.
Wood pellets are generally made by densification of wood or biomass powder. According to Yang et al. [3], the sawdust was pressed by a roller that rotates on a die surface and compacting sawdust through the holes of a die or uses hydraulic press equipment. The strength that binds or locks wood particles during the pelleting process, will determine the strength and the resistance of wood pellets. Kaliyan & Morey [6], has classified the binding forces of wood pellet namely the attraction power in solid particles, the forces of adhesion, cohesion or interfacial, and pressure of capillary. All binding forces were affected by sawdust size, moisture, type of the raw material, and pelleting process such as pellet machine type, the addition of binder and type of binder, etc [3].

One of the important factors that affect pellet properties was the moisture content [7]. The proper moisture content can assist in the formation of internal adhesives from lignocellulosic materials. The water content in the raw material together with heat produced from pellet machines or steam will assist the physical and mechanical changes of the material such as biomass softening, protein denaturation, starch gelatination, and sugar crystallization [6]. The problem of sawdust from the sawmill that not directly use as another product, but just abandon as waste, was becomes decomposed or over-drying (in a sheltered place). The over-dry sawdust (<10%) will increase emission significantly [8], and difficult to pelletize because it will slide in a die hole and it will seriously damage the pellet machine [9].

The previous research show there was a significant effect that adding water to increasing the water content of the raw material to some extent can improve the quality of the pellets and can act as a binder and also a lubricant [6]. According to Grover and Mishra [7], the range of moisture content for raw material pelleting was 10-15%. Based on this, it is very important to find technology regarding the type of solution that can improve the quality of wood pellets. For this reason, this study was conducted to determine the effect of adding water, molasses and tapioca starch to the quality of wood pellets made from overdrying sawdust, compared to the quality standards of wood pellets (SNI 8021:2014).

2. Materials and Methods
The materials used for the production of wood pellets are sawdust waste, tapioca starch, molasses, and water. The devices used in this study were a sieve, digital scales, bomb calorimeter, oven, furnace, and hydraulic pelleting press, etc. The sawdust was collected from a wood sawmill in Bogor District. The no-bark sawdust with a moisture content of 7.2±0.31% was then milled for a uniform shape as well as pass-through in a 40-mesh sieve and was stored in a plastic bag before pelleting process. Furthermore, four liquid solutions i.e water, pure molasses, tapioca starch solution, and dilute molasses (ratio of pure molasses:water was 1:1) were prepared as moisture content enhancers and organic binder. There were five treatments applied i.e A. sawdust (control), B. sawdust + 10% water, C. sawdust + 10% tapioca starch solution, D. sawdust + 10% pure molasses and E. sawdust + 10% dilute molasses. The pellets were produced in a laboratory-scale process with a hydraulic pelleting press that equipped 20 die holes in diameter of 10 mm and a length of 250 mm as well as temperature control. The hydraulic press set on 210°C, then sawdust fed into the die hole and press for 10 minutes. Each treatment used 3000 mg of sawdust. The Pellets were cooled and stored in a plastic bag for further analysis i.e moisture content, ash content, volatile matter, calorific value, fixed carbon, density (SNI 8021:2014), and compressive strength [13].

Moisture content was calculated by using the formula as follow:

\[
\text{Moisture content, } \% = \frac{A - B}{A} \times 100
\]

where: \( A = \) weight of the sample used (g), \( B = \) weight of the sample after heating of 105°C (g)
Ash content was calculated by using the equation as follow:

\[
\text{Ash content, } \% = \frac{C}{A} \times 100
\]

(2)

where: \(A\) = the initial weight of the sample used (g), \(C\) = the final weight of the sample after heating to 750°C (g)

Volatile matter was calculated by using the formula as follow:

\[
\text{Volatile matter, } \% = \frac{B-D}{A} \times 100
\]

(3)

where: \(B\) = weight of the sample after heating of 105°C, \(D\) = weight of the sample heating at 950°C, \(A\) = weight of the sample (g)

Density was calculated by using the formula as follow:

\[
\text{Density, g/cm}^3 = \frac{A}{V}
\]

(4)

where: \(A\) = weight of the sample used (g), \(V\) = volume of the sample (cm³)

Fixed carbon was calculated by subtracting from the sum of the moisture, ash content and volatile matter from 100

\[
\text{Fixed carbon} = 100 - (M + Ac + Vm)
\]

(5)

where: \(M\) = moisture content, \(Ac\) = Ash content, \(Vm\) = volatile matter

Calorific value was calculated by using bomb calorimetry (Parr Calorimeter model 6400). Meanwhile the compressive strength test was calculated by using universal testing machine (Alb. von Tarnogrocki).

3. Results and Discussion

The results showed that the addition of liquid materials (water, pure molasses, liquid tapioca, and molasses + water) had increased the water content of the initial raw materials from 7.2±0.31% to 13.5±0.3%, 11.6±0.2%, 13.2±0.26%, 13.3±0.2% respectively. After the pelletizing process, the moisture content of all the pellets produced from the treatment was 2.65±0.58 to 3.53±0.50% with lower moisture content in adding 10% molasses (2.65±0.58%), and highest moisture content in adding 10% water (3.53±0.50%) as presented in Table 1.

The lower moisture content of the pellets in this study is influenced by the heating process (torrefaction) in the pressing process of the pellets. The pressing process at 210°C for 10 minutes will evaporate the moisture contained in the pellet product. The moisture content of the pellets produced meets the SNI 8021:2014 and European Standard (En plus).

The moisture content of the raw material is a significant characteristic because it impacts the calorific value and during storage of wood pellet (microbe attack). The high moisture content can make the sawdust slick and slide across the die holes, resulting in poor pellet quality. However, when the raw material is over dry, it may also slide across the die holes, especially when using a hydraulic press, or it may plug the die hole because of the compression force of the roller [2]. The suitable moisture content of sawdust for good quality biofuel is in the range of 11-16%, below 11% will result in a low density and easy to break [10].
Table 1. The pellet characteristic from sawdust.

| Source | Moisture content (%) | Ash content (%) | Calorific value (MJkg⁻¹) | Density (gcm⁻³) | Volatile matter (%) | Fixed carbon (%) | Compressive strength (kgcm⁻²) |
|--------|----------------------|-----------------|---------------------------|-----------------|--------------------|-----------------|-----------------------------|
| A      | 3.49±0.48            | 1.13±0.25       | 17.81±0.10                | 0.67±0.10       | 79.89±0.22         | 15.49±0.44      | 30.91±1.93                 |
| B      | 3.53±0.50            | 1.17±0.10       | 17.64±0.12                | 0.85±0.14       | 79.00±0.23         | 16.31±0.66      | 67.56±1.66                 |
| C      | 2.73±0.45            | 1.47±0.08       | 18.64±0.09                | 0.81±0.13       | 79.54±0.75         | 16.26±1.19      | 38.74±1.68                 |
| D      | 2.65±0.58            | 1.45±0.08       | 19.56±0.12                | 0.84±0.12       | 76.72±1.05         | 19.18±1.04      | 52.22±1.70                 |
| E      | 2.80±0.68            | 1.48±0.05       | 18.83±0.10                | 0.86±0.13       | 77.23±0.38         | 18.49±0.75      | 65.96±1.82                 |

**En plus A1** ≤10 ≤0.7 ≥16.5 ≥0.6 - - -

**En plus A2** ≤10 ≤1.2 ≥16.5 ≥0.6 - - -

**En plus B** ≤10 ≤2.0 ≥16.5 ≥0.6 - - -

**SNI 8021:2014** ≤12 ≤1.5 ≥16.75 ≥0.8 Max 80 Min 14 -

Remarks: A: Sawdust (control), B: Sawdust + water, C: Sawdust + water + starch, D: Sawdust + molasses, E: Sawdust + molasses + water, En plus A1, A2, B [11] Indonesian Standard (SNI 8021 : 2014)[12]

The ash content of the pellets in this study was between 1.13±0.25 to 1.48±0.05% (Table 1). The lowest ash content was found in the control pellets which was 1.13±0.25%. The highest value of ash content was found in pellets with the addition of 10% dilute molasses, namely 1.48±0.05%. This condition affected by molasses that contains inorganic ash of 7.88% [13]. Nevertheless, the ash content still meets the standards SNI 8021:2014 and En plus B, but the control treatment and sawdust+water have meets the En plus A2, also. According to Qayim et al. [14], ash deposits from biomass can cause corrosion trouble to the stove or boiler, and lack of heat transfer. The high ash content will degrade the pellet quality, reduce the calorific value of the pellet and increase the particle's emission to the atmosphere [15].

The calorific values obtained in this study ranged from 17.64±0.12 to 19.56±0.12 MJkg⁻¹. The lowest calorific value is found in pellets with the addition of 10% water, which is 17.64±0.12 MJkg⁻¹, while the highest calorific value is in pellets with the addition of 10% molasses which is 19.56±0.12 MJkg⁻¹. This resulting calorific value meets SNI and En plus standard as shown in (Table 1). Not only acts as an adhesive, but molasses also contains a low heating value of 11.07 MJkg⁻¹. So that the torrefaction process which reduces the water content of the pellets plays a role in increasing the calorific value. According to [16], high calorific values enable the biofuel, for example, wood pellet, to result in a high amount of energy in low fuel volume.

The volatile matter produced ranged from 76.72±1.05% to 79.89±0.22% The highest level of the volatile matter was in the sawdust without any adding additives, which was 79.89±0.22% and the lowest level of the volatile matter was in sawdust with the addition of 10% molasses, namely 76.72±1.05%. This volatile matter value meets the SNI 8021-2014 standard, namely the maximum flight substance level value of 80%. Data in Table 1 figured up the level of volatile matter in the addition of molasses is lower than other treatments, due to a relatively high reducing sugar content in molasses (59.14%) [13]. Besides that, molasses also benefits as a binder of raw materials, and accelerates the release of the volatile matter of raw materials during torrefaction. The high rates of volatile matters on biomass will produce a solid fuel burn faster, that trouble as fuel [17].

According to Speight [18], the determination of the fixed carbon content serves to determine the amount of solid material that can burn after a volatile matter has been removed from its raw material. Fixed carbon content in this study was ranged from 15.49±0.44% to 19.18±1.04%. The highest value of fixed carbon content was found in pellets with the addition of 10% molasses, i.e 19.18±1.04%. This result is consistent with the results of Manyuchi [19], that the fixed carbon content increased with addition to molasses as an organic binder. The lowest fixed carbon content was found in pellets without any adding additives, i.e 15.49±0.44%. A high level of fixed carbon content is an indication of a high calorific value.
of the solid fuel [20]. The fixed carbon content in this study meets the SNI 8021-2014 standard which requires at least 14%.

The density values of pellet obtained ranged 0.67±0.10 to 0.86±0.13 gcm$^{-3}$. The lowest density value was found in pellets without the addition of other ingredients, namely 0.67±0.10 gcm$^{-3}$, while the highest was found in pellets with the addition of water and molasses (10% w/w), namely 0.86±0.13 gcm$^{-3}$. Presumably, the light molasses (molasses + water) can enter deep into the area of the raw material particles and binder them together to narrow the space between the pellet particles. Alvarez et al. [21], is ascertain that a good way to improve the density is a pelletization process. Low-density values can cause high transportation and cost of storage [16]. The density of all pellets in this study meets En plus standards and SNI 8021-2014 (except control treatment) which require density values $\geq 0.6$ gcm$^{-3}$ and $\geq 0.8$ gcm$^{-3}$, respectively (Table 1).

According to Artemio et al. [16], the compression resistance property of wood pellet was an important factor in industry and trade, especially in transportation, storage, and health issues, because pellets were easy to break when friction occurred particularly in low compression resistance pellet. In this study, the value of the compressive strength of wood pellets ranged from 30.91±1.93 to 67.56±1.6 kgcm$^{-2}$. The highest value of compressive strength was found in pellets with the addition of 10% water, which was 67.56±1.6 kgcm$^{-2}$, while the lowest was found in pellets without any adding additives, namely 30.91±1.93 kg/cm$^2$. We found that the addition of tapioca starch solution resulted in a slightly higher compressive strength than the control treatment, namely 38.74±1.68 kgcm$^{-2}$, but lower than the addition of water and molasses treatment. This is thought to be due to the nature of tapioca starch which undergoes a gelatinization process that occurs when starch and water are heated together at 62-80°C [22], but the torrefaction process causes the gelatinization to become dry and brittle.

4. Conclusion
Wood pellets were successfully produced from over-drying sawdust waste using the method of increasing moisture content. The optimal treatment was the addition of 10% pure molasses which can improve the quality of the wood pellet because it increases the calorific value and bound carbon and reduces the moisture content and the volatile matter, so it is good to be used as alternative energy material.

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