BIOMASS FUEL FROM OIL PALM EMPTY FRUIT BUNCH PELLET: POTENTIAL AND CHALLENGES

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BIOMASS FUEL FROM OIL PALM EMPTY FRUIT BUNCH PELLET: POTENTIAL AND CHALLENGES*

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Abstract

This study aims to determine the potential and challenges of oil palm empty fruit bunch (OPEFB) pellet as biomass fuel. The study was conducted by observing the process of commercial OPEFB pellets production and analysing some characteristics of the pellets. Proximate and ultimate analysis were carried out to determine the characteristics of pellets, namely mass specific, bulk density, water content, ash content, lignocellulose composition, and calorific value. In addition, XRF analysis was conducted to determine ash composition. Results showed that pressure applied during pellet production affected water content and density of the pellets. OPEFB pellets made with pressure of 90 MPa showed stronger characteristics than the pellet produced with 55 MPa. The pellets had a hexagonal cross section with diameter and mass density of 8.88 mm and 1.55 g/cm^3 for pellet produced at 90 MPa, and 9.65 mm and 1.39 g/cm^3 for pellet produced at 55 MPa. Calorific value of OPEFB pellet (15.82 MJ/kg) was still lower than the standard, while ash content was higher than the standard. High ash content and high mineral content are the main problems need to be addressed in order to savely use OPEFB pellet as fuel, especially for big industries or for generating electricity.

Keywords: biomass pellet, palm oil, renewable, sustainable

1. Introduction

Palm oil has become a leading commodity for Indonesia. Crude palm oil (CPO) exports generate significant amounts of foreign exchange. Good quality fruits harvested from large plantations can produce CPO up to 24% of fresh fruit bunch (FFB). Low quality oil palm fruits from smallholder plantations produce lower CPO yield. Generally, CPO yield is

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22% of milled FFB. Therefore, almost 80% of the processed raw material will end up as solid and liquid wastes. Expressed in units per ton of FFB, in general waste generated from the CPO extraction process consists of empty fruit bunches (OPEFB) of 22%, mesocarp fiber of 13%, shell of 6%, and liquid waste called palm oil mill effluent (POME) of 0.6-0.8 m^3 (Hasanudin et al., 2015). Thus, following oil extraction processes, around 40% of the oil palm fruit remains as solid residual material consists of the OPEFB, shells, and fibers. While oil palm shells and fibers are already used in oil palm mills to generate power and heat required for oil palm fruit processing, OPEFB is still underutilized.

OPEFB is resulted from the striping process that separates the oil palm nuts from its bunch. OPEFB is the largest solid biomass waste which is comparable to the amount of the produced CPO. This biomass is structured by very strong fibers consisting of main stalk around 20–25% and spikelets 75–80%. Therefore OPEFB biomass is difficult to decompose biologically. OPEFB has a such high moisture content up to 60% (Abdullah et al., 2011) due to the steam sterilisation process at the palm oil mill. High moisture content lowers energy value of OPEFB and reduces the combustion efficiency. OPEFB is also oily with oil content may reach 12% an average of 8.6% of dry OPEFB. Some palm oil mills are equipped with machine for tearing and pressing OPEFB to decrease water content and take the oil remnant that reduces oil content by 3.61% (Md Yunos et al., 2014). The water content, however, is still high at around 40%.

The most widely applied option in managing OPEFB is returning it to oil palm land as mulch, which is generally stacked between rows of plants. An integrated treatment for OPEFB and POME is beneficial in which POME is treated anaerobically to produce biogas, whereas OPEFB with addition of effluent from digested POME is composted to produce compost. The compost is returned to the palm oil plantation and the biogas is used as fuel to generate electricity and process steam. We recently reported that co-composting OPEFB and POME may reduce methane gas emissions by 35.92% and 53.22% for 30-day and 80-day composting period (Haryanto et al., 2019). The high investment in modern composting facilities makes this practice is difficult to find in the field.

In the long term, the OPEFB application to the plantation is expected to be a source of organic material for the soil and can save the use of chemical fertilizers. For palm oil mills that do not have their own plantations, however, this option is a problem. In 2006 the number of POM without plantation was 219, which is about 20% of around 1100 mills. Now, with 14.33 million ha oil palm plantations and CPO yield of 40.57 million tons, it is estimated the number of palm oil mills without plantation occupy around 2.87 million ha with OPEFB equivalent to nine million tons. Long distances and high transportation costs will become obstacles to return the OPEFB to the partnership farmers. Recently, OPEFB was reported as good growing media for cultivating rice straw mushroom (Triyono et al., 2019). Practicing this option, however, involves only little parts of the available OPEFB. Therefore it is necessary to find alternatives for better utilization of OPEFB. In dry conditions, OPEFB has a fairly high calorific value, so it has the potential to be developed as biomass fuel. Biomass from plants can serve as an alternative renewable and carbon-neutral raw material for the production of energy. But in the original condition, the biomass of OPEFB is difficult to handle, transport, store, and utilize.

The major limitation of OPEFB for energy purposes is its low bulk density. One method to make easy transportation and decrease the costs is to reduce the volume of the OPEFB biomass by densification into pellet form. OPEFB pelletization can be one promising alternative, which fulfill not only the electricity and steam heating needs of the COP extraction process, but the excess can be connected to the national electricity grid (Salomon et al., 2013). The advantage of pellets, as compared to the original biomass, lies in their higher energy density, homogeneous quality, improved handling and storage properties, and better applicability for different end uses.

The purpose of this study is to evaluate the energy potential of biomass pellet from OPEFB and identify the technical problem of OPEFB pellet. The evaluation presented in this paper is focused only on the technical aspects regarding to the intrinsic properties of pellets.

This work is divided in three main parts, namely:

- Observation of case studies: A commercial OPEFB pellet industry located in District of Tebing Tinggi, North Sumatera Province;
- Testing and evaluation of sample of OPEFB pellet product;
- Discussion of results and drawing conclusion and recommendations for better future of OPEFB pellet fuel.

2. Materials and methods

OPEFB pellet production processes were observed at a commercial-scale pellet industry operating in North Sumatera, Indonesia. The factory operated three pelleting machines, namely two machines with working pressure of 55 MPa and capacity of 1.5 t/h (each) and one machine with working pressure of 90 MPa and a production capacity of 3 t/h.

OPEFB pellet was characterized to determine the important properties related to its utilization for fuel. Bulk density (g/cm^3) was determined by weighing sample of the OPEFB pellets filled in a container of known volume and calculating the ratio of the mass to the volume. Mass specific or true density (g/cm^3), was calculated from the ratio of mass of a single pellet to its volume. Flexural strength of pellet was measured by using a testing machine (MTS landmark 100 kN). Moisture (water) content (MC) was measured gravimetrically using an oven (Memmert UM 500) operated at 105°C for 24 h and was calculated as the following.

$$MC = \frac{M_f - M_d}{M_f} \times 100\% \qquad (1)$$

where M_f and M_d is wet and dry weight, respectively. Water absorption property of pellet was measured by leaving the pellet in an open container and measuring the water content every day until it reaches an equilibrium.

Oven-dried pellet was used to determine calorific value (MJ/kg) that was measured using a bomb calorimeter (Cal2k ECO). Ash content, was measured by burning oven-dried pellet in a furnace (Banrstead Thermolyne 1300) at 550°C for 2 h. Ash content is presented in percent of dry weight of pellet. Ash composition, was determined using XRF analysis. Lignocellulosic component (lignin, cellulose, hemicellulose) was determined using modified Chesson method as proposed by (Datta, 1981). One gram of ground pellet (a) was added with 150 mL of distilled water, refluxed at 100°C for 1 hour. The result was filtered and the residue was washed with hot water and then oven dried and weighed (b). The residue was added with 150 mL H_2SO_4 1 N and refluxed for 1 hour at 100°C. The result is filtered and washed with distilled water and then dried and weighed (c). Dry residue was added by 10 mL 72% H_2SO_4 and soaked at room temperature for 4 hours. Then, 150 mL of H_2SO_4 1 N was added and refluxed for 1 hour with the reverse cooling. The residue was filtered and washed with distilled water and then dried and weighed (d). The residue was finally burnt to ash and weighed (e). Lignocellulose components were calculated as the following:

$$Hemicellulose = \frac{b - c}{a} \times 100\% \qquad (2)$$

$$Cellulose = \frac{c - d}{a} \times 100\% \qquad (3)$$

$$Cellulose = \frac{d-e}{a} \times 100\% \quad (4)$$

3. Results and discussion

3.1. OPEFB pellet production process

The process of making commercial OPEFB pellets can be briefly explained through the flow diagram in Fig. 1. At first the shredded OPEFB is flown into a steam dryer which has a temperature of 116° through a screw conveyor. The dryer utilize the residual steam from the palm oil extraction process. Exiting from the steam dryer, OPEFB is dried again in a rotary dryer that works at 90°. Rotary dryers utilize flue gas from palm oil mills. The dried OPEFB is crushed (chopped) in a cutting mill into fine particles (passes 20 mesh sieve). The ground OPEFB was flowed into a vertical ring die type pellet machine that working at a pressure of 55 MPa. There are 2 machines with a capacity of 1.5 t/h each. The pellets produced from this machine are called single press (1X) pellets. If the consumers want harder pellets, the single press pellet is flowed into another pellet machine working at a pressure of 90 MPa with a capacity of 3 t/h. Pellets produced from this machine are called double press (2X) pellet. If the demand for pellets is high, the 90 MPa pellet machine can be operated also with feeding directly from cutting machine to produce 1X press so that the total capacity can reach 6 t/h (1X pellet). With this capacity, all OPEFB produced from POM with a capacity of 900 tons of FFB can be handled.

3.2. Pellet characteristics

The characteristics of the OPEFB pellet are very important to evaluate its quality as fuel. The OPEFB pellets have a hexagonal cross section. Visually the 2X pellet has a darker color, harder texture, and greater weight. But the 2X press pellet has a smaller size (diameter). Fig. 2 shows the visual differences of these two types of OPEFB pellets. The pellet is more easily damaged, especially if it is stored in an open space. It is well known that tropical regions such as Indonesia have high humidity environments. OPEFB pellet stored in a room without packaging will be damaged quickly. The pellet will become frangible and lose its consistency so that it breaks easily and eventually break down as shown in Fig. 3.

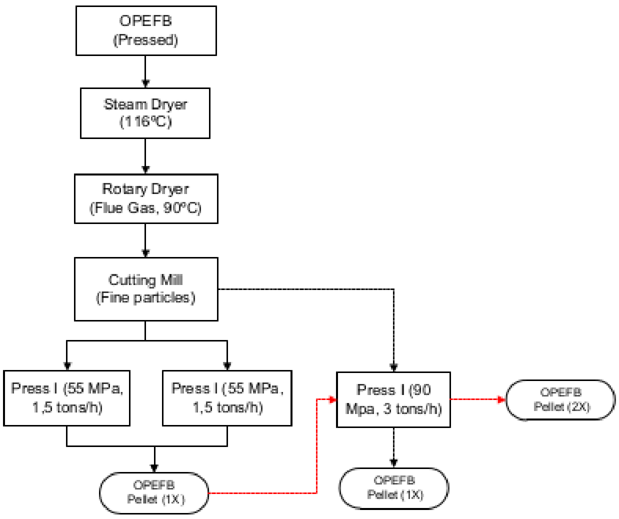


Fig. 1. Flow chart of OPEFB pellet production process (broken line is optional route)

Fig. 2. OPEFB pellet: 1X press (left) and 2X press (right)

Fig. 3. Rotten OPEFB pellets stored improperly in open space

The pellet has a hexagonal cross section with an average diameter of 9.65 mm and mass density of 1.39 g/cm^3 for 1X pellets (Table 1).

Table 1. Average size and densities of OPEFB pellets and wood pellet for comparison

Biomass pellets	***Diameter (mm)***	***Mass density (gr/cm^3)***	***Bulk density (gr/cm^3)***	***Reference***
OPEFB pellet 1X	9.65	1.39	0.580	This work
OPEFB pellet 2X	8.88	1.55	0.686	This work
Jabon pellet	8.50	0.91–1.05	NA	(Sulistio et al., 2020)

The diameter and mass density for 2X pellet is 8.88 mm and 1.55, respectively. OPEFB pellets have a heavier mass density than that wood pellets in general. For example, density of biomass pellet made of Jabon (*Anthocephalus macrophyllus*) is in the range of 0.91–1.05 g/cm^3 (Sulistio et al., 2020). The results also show that the density of pellets is influenced by the pressure applied during production process. The pressure exerting the biomass particles during pelletizing process is important factor influencing not only pellet density and durability, but also the energy consumption for pellet production. High pressure in the range of 50 to 90 MPa is enough to produce OPEFB pellet. Increasing pressure has improved mechanical properties of pellet, such as compressive strength and durability. It can be showed that the 1X OPEFB pellet has a larger diameter (almost 1 mm difference) than the

2X pellet. But the 2X pellet has a greater mass density than the 1X pellet. From the pellet samples, the single press pellets are more fragile than the double press pellets that can be observed from the amount of pellet debris during transportation.

Proximate analysis reveals that OPEFB pellet has lignocellulosic composition of hemicellulose (26%), cellulose (34%), and lignin (25%). The fibers (hemicellulose and cellulose) contained in the OPEFB pellet are very close to those of lignocellulosic content of pressed-shredded OPEFB reported by (Md Yunos et al., 2014). The lignin content, however is about twice. The OPEFB pellet has calorific value of 15.82 MJ/kg. This is little lower than that of Indonesian National Standard SNI 8675-2018 for biomass pellet which is 16.5 MJ/kg. The low energy value can be an obstacle in getting a good market for OPEFB pellet. In addition, OPEFB pellet samples also have a high ash content, reaching 12% of the dry matter. (Md Yunos et al., 2014) reported even higher ash content for OPEFB pellets, which is 18%. Although the ash content of our OPEFB pellet is not the highest value, it has far exceeded the 5% of national standard for biomass pellets, both for household and industrial applications. The high ash content also contributes in lowering the energy value (Haryanto et al., 2020). This means that pretreatment must be made on the raw material in order to produce better OPEFB pellets.

The bulk density of OPEFB pellet is 0.580 g/cm^3 for 1X pellet and 0.686 g/cm^3 for 2X pellet. Our pellet samples, however, is quite close to those reported by (Salomon et al., 2013) with 0.630 g/cm^3 for OPEFB pellet with 6 mm diameter and 0.580 g/cm^3 for pellet with 8 mm diameter. Bulk density is important property related to handling, packaging, and transportation.

The effect of pressure is also seen in the strength of the pellet, where the higher the pressure produces the stronger the pellet. The measurement results show that OPEFB 2X pellets have an average flexural force of 100.53 kgf, higher than 1X pellets (65.58 kgf). The applied pressure also affects the water content of the pellets. OPEFB pellet produced at compression of 55 MPa has water content of 8.6 (%wt) at air-dry condition. With compression of 55 MPa, OPEFB pellet has water content of 5.6 (%wt).

3.3. Water absorbtion

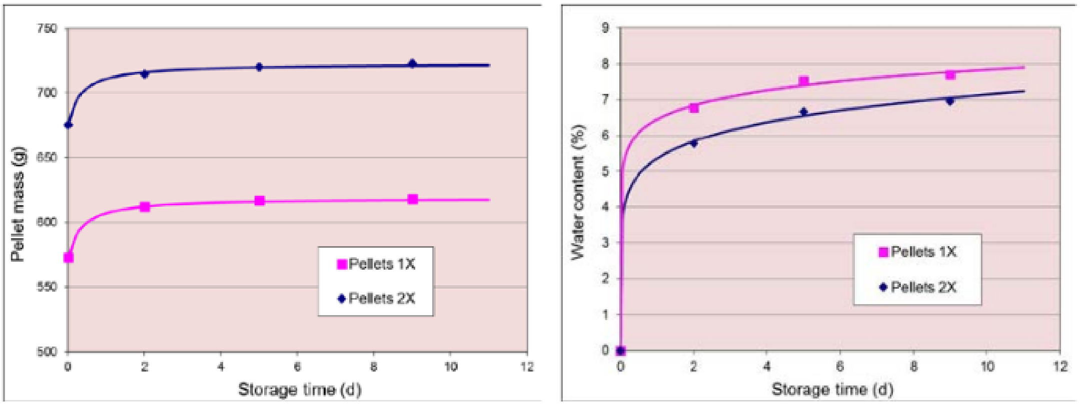
In order to evaluate the resistance of OPEFB pellet from ambient air, we have measured water adsorption capacity of the oven-dry pellet and presented the results in Fig. 4*a*. The pellets significantly gained weight as a result of water adsorption from the ambient air. This means that OPEFB pellet is so hygroscopic that should be stored in air tight containers, especially for Indonesia climate with very high air humidity. Although the rate of moisture adsorption is low after the second day, this pellet property needs to be watched for moisture adsorption by pellet can trigger other serious problems. Based on the data, a model to predict the pellet mass was developed by using power funtion in the Excell application as suggested by (Pinchuk and Kuzmin, 2019) with general form of:

$$y = A + B \cdot (x - C)^N \quad (5)$$

The mass of pellet m (g) as a function of storage time τ (days) is presented in Eq. (6) and (7), respectively for 1X and 2X pellets. Both models provide excellent approximation with very high R^2, namely 0.9966 for 1X pellet and 0.9997 for 2X pellet.

$$\text{Pellets 1X } (R^2 = 0.9966)\text{: } m = 619 - \frac{15.87}{\tau + 0.33} \quad (6)$$

$$\text{Pellets 2X } (R^2 = 0.9997)\text{: } m = 723 - \frac{15.87}{\tau + 0.33} \quad (7)$$



(a) (b)

Fig. 4. The change of mass (*a*) and water content (*b*) of OPEFB pellets during storage in open room

The increase of pellets water content as a result of moisture adsorption is presented in Fig. 4*b*. Water content of the pellet increases sharply up to the second day, and then slowly sloping. Based on the collected data, we developed a model to predict water content w (%wt) of the pellet during open storage as a function of storage time τ (days) as following:

Pellets 1X (R^2 = 0.9993): $w = 0.0645 \cdot \tau^{0.085}$ (8)

Pellets 2X (R^2 = 0.9992): $w = 0.0535 \cdot \tau^{0.125}$ (9)

Again, these model give excellent prediction with very high R^2, namely 0.9993 for 1X pellet and 0.9992 for 2X pellet.

3.4. Calorific value

The relative energy value of pellets is calculated by using oven dry materials. The increase in water content during storage will definitely decrease calorific value of the pellets by two reasons. At first, due to increasing in pellets mass because of water absorbing. The organic mass (flammable components) remains constant, but its content in the mass unit decreases. Since calorific value is the relative energy per one kg of the fuel, the less flammable fraction per mass unit causes the less heat generation. Second, since the increase in mass is due to water adsorption, during the combustion the heat energy is spent for the heating of the water to boiling point, and then to vaporization of that water. Thus, the part of the heat of the wet pellets combustion is spent to water heating and vaporization. This part does not produce useful heat therefore it must be subtracted from the initial calorific value. Based on the water adsorption characteristics in Fig. 4*b*, we have predicted the calorific value of the pellet based on as presented in Figure 5. Equation (10) and (11) represent the decrease of pellet calorific value q (MJ/kg) as a function of storage time τ (days). We can predict that for nine day storage period the calorific value of the OPEFB pellets decrease to 14.61 MJ/kg for 1X pellets and 14.48 MJ/kg for 2X pellets. This means a reduction of 7.6% and 8.5% of the initial value (15.82 MJ/kg), respectively for 1X pellets and 2X pellets.

Pellets 1X (R^2 = 0.999997): $q = 14.43 + \dfrac{0.49}{\tau + 0.35}$ (10)

Pellets 2X (R^2 = 0.999999): $q = 14.54 + \dfrac{0.68}{\tau + 0.53}$ (11)

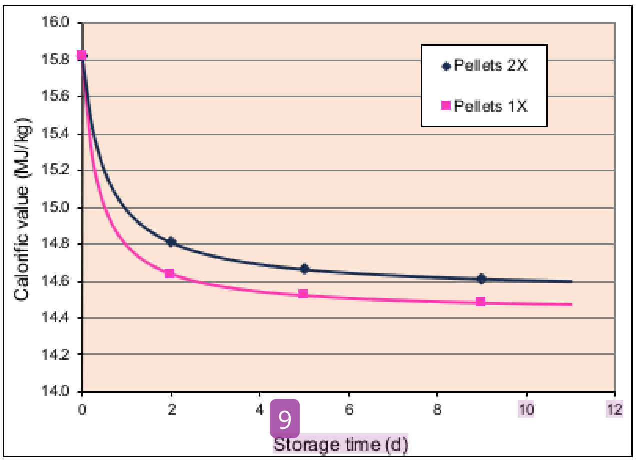


Fig. 5. The decrease of pellet calorific value during storage in open room

3.5. Environmental impact

Another issue for OPEFB pellet is its mineral content.

Our results showed that OPEFB pellets still have high potassium in the range of 26.57 to 46.46 percent of ash. Other minerals with significant content include Fe, Ca, Si, Al, and Cl. Table 2 and Table 3 summarize some properties of OPEFB pellet in comparison with the national standard SNI 8675-2018. Physically, the pellets pass the standard, but fail in view of energy properties like energy value, ash content, and mineral content.

3.6. Market Potential

Based on the characteristics of OPEFB pellets as discussed above, the potential use of OPEFB pellets for fuel is still limited for small industries and households such as tofu, brown sugar, and other home industries. This potential is quite large because of the increasing number of small industries that move.

Table 2. Mineral components (% ash) in the ash of OPEFB pellet

	MgO	***Al_2O_3***	***SiO_2***	***P_2O_5***	***SO_3***	***Cl***	***K_2O***	***CaO***	***MnO***	***Fe_2O_3***
1X	1.31	6.15	23.94	1.27	2.65	6.45	46.46	17.07	0.67	16.34
2X	1.34	11.55	29.35	1.49	2.42	4.53	26.57	9.14	0.465	11.770

Table 3. Characteristic of OPEFB pellets in comparison to standards.

Parameter	***OPEFB pellet (this work)***	***SNI 8675 (2018)***	***Remark***
Diameter (mm)	8.88–9.65	-	passed
Density (g/cm^3)	1.39–1.55	> 1.0	passed
Water content (%)	5.6–8.6	< 12	passed
Energy value (MJ/kg)	15.82	> 16.5	failed
Ash content (%)	4–12	< 5	failed
K_2O (% ash)	26.57–46.46	< 20	failed
Chlor (% ash)	4.52–6.45	< 0.1	failed
Na_2O (% ash)	NA	< 5	-
Sulfur (% ash)	2.42–2.65	< 0.1	failed

One of the small industries that has the potential to use OPEFB fuel pellets is the tofu industry. Tofu is the main and favorite food of Indonesian people with high consumption. Tofu is a rich nutrient food at an affordable price so that huge number of micro, small and medium scale tofu industries are widely spreaded in Indonesia. Tofu industries are generally classified as a small-medium industry with high fuel consumption. For example, a tofu industry in the city of Bandar Lampung, Indonesia with a daily capacity of 500-1000 kg of soybeans requires wood pellets of around 1 t/d. Whereas the smaller tofu industry with daily capacity of 200 kg of soybeans consumes one truck of firewood in 3 days plus 13 sacks of rice husk per day. Therefore, OPEFB pellets are very potential to be used as fuel in the tofu industry. Other potential industries include the red brick and tile industry. The use of OPEFB pellets for power generation needs to be further evaluated mainly because of the high ash content with a high mineral composition.

3.7. Challenges

OPEFB pellet contains high ash and minerals. Some of these minerals are a problem in high temperature combustion because they may melt and build a blockage for combustion air. The chemical composition of OPEFB pellet ash which is rich in minerals (Si, Ca, Mg, Cl, and K) will result in various undesirable reactions in the combustion system. It is well known that high concentrations of ash and silica and alkali metals can trigger agglomeration, fouling, slagging in boiler components which results in decreased combustion system efficiency and failure of most furnaces and boiler. Washing is able to significantly decrease minerals content. According to (Abdullah et al., 2011), washing OPEFB may reduce ash content by 81% from 5.43% (db) to 1.03% (db). However, its application in the pellet production need further studies because it makes a longer route in pellet production processes.

In addition to the intrinsic problems, another OPEFB pellet constraint is price. At the time of observation (2018), a pellet factory in Medan, North Sumatra, could receive a pellet price of 500 IDR/kg (0.036 USD/kg). This price was quite low because the pellet mill is operated near the palm oil mill, so that the operating costs of raw materials, drying, and transportation are practically free. The price of pellets purchased by the small-scale tofu industry in Bandar Lampung (south part of Sumatra) was 1,500 IDR/kg (0.107 USD/kg). However, the transportation cost from the North to the South of Sumatera will take no less than 2,000 IDR/kg making a total price higher than that can be accepted. Nowadays, OPEFB pellets that satisfy national standard are offered in some online shops at the higher price of 1,500 IDR/kg (0.107 USD/kg). This is a good opportunity and a challenge at the same time, to produce good quality OPEFB pellets and develop market close to the palm oil mill operating areas.

4. Conclusions

Commercial biomass pellet fuel made from OPEFB is produced with pressure of 55 MPa and 90 MPa. The pressure influence pellet properties, namely water content, mass density and bulk density. The higher the pressure, the lower the moisture content and the higher the densities. The OPEFB pellets showed good physical characteristics and passed standards for water content and mass density, but failed for energy value and ash content and mineral content. The pellets easilly adsorp moisture from surrounding air within first two days storage in open container. Excellent models to predict water content and calorific value as a function of storage time have been developed based on power function of Excell. The OPEFB pellet has energy value of 15.82 MJ/kg and is potentialy accepted for fuel in small scale applications. For large industrial applications, there are some issues need to be solved to increase energy value and to reduce ash content as well as its mineral composition.

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