Characterization of Coconut Jelly Pellets Made from Solid Waste of Ready-to-drink Industry

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Coconut jelly, the solid waste from ready-to-drink industry, was used to produce solid fuel pellets. Pelletization was done by a single 10-ton hydraulic press unit without any binders. The characteristics of the pelletized fuel including pellet dimensions, bulk density, pellet density, proximate analysis, higher heating value, energy density, combustion rate, heat release rate, compressive strength and durability were investigated. The pellets had an average diameter and length of 10 mm. Pelletization significantly increased the bulk density from 30 kg/m³ of the original coconut jelly and 70 kg/m³ of ground dried coconut jelly to 659 kg/m³ of the pellets. Proximate analysis values of pellets (moisture 8.05 wt%, ash 2.06 wt%, volatile matter 77.04 wt% and fixed carbon 12.85 wt%) indicated good combustion parameters. The higher heating value of the pellets was 15.995 MJ/kg, which increased by 19.05% from its original form. The fuel pellets also increased the combustion rate and heat release rate from 0.05 to 0.17 g/min and 672 to 2,719 J/min, respectively, when compared with the original form. The pellets had a high durability (98 wt%) and high compressive strength in horizontal direction (4.84 MPa). Overall, the properties of coconut jelly pellets meet the requirements of Thai and European standards of the pellet properties for non-woody materials. Thus, coconut jelly waste could be considered as a potential raw material to manufacture pellets as an alternative energy source.

Key Words
Pellet, Coconut jelly, Higher heating value, Bulk density, Solid waste

1. Introduction

Due to the growing energy consumption and environment concerns it is important to develop new energy sources to replace fossil fuels. Biomass is a sustainable alternative energy source because it is renewable, clean, inexpensive and widely available. However, the direct use of biomass has several disadvantages such as the relatively low heating value per unit volume and large volume or area required for storage and transportation due to low bulk density 1. The densification of biomass into pellets can eliminate these disadvantages. Pelletization is the process of compacting material to form a densified and homogeneous product. The resulting product exhibits a high energy density and convenience in transportation. Frequently, binders are added in the pelletization process to improve the pellet quality. However, this increases the process cost, and no negative impact on the environment should be considered when selecting the binder.

There are many types of biomass wastes such as agricultural residues, forestry residues, farm slurries, municipal solid waste and industrial wastes. In recent years, various biomass sources have been studied for densification into solid fuel pellets, for example wood 2,3, rice straw 4, wheat straw 5, corn stover 5, spent coffee grounds 6, tea waste 7 and animal manure 8.

In Thailand, coconut jelly is mixed into various ready-to-drink beverages such as fruit juice, coconut juice, palm juice, and herbal drinks, and after the production process
some coconut jelly remains as solid waste. Coconut jelly is prepared by adding sugar to the coconut water followed by heating at medium temperature and stirring in sliced coconut flesh. The mixture is cooled to room temperature for about 15 to 20 minutes, and finally refrigerated for about 30 minutes until gel formation. The waste from the coconut jelly consists of the material that remains in the pipe after bottling as well as the coconut jelly in the rejected bottles that do not pass the quality control. The data from a major ready-to-drink company in Thailand reported that from the coconut jelly that is added to the production process, approximately 20% ends up as coconut jelly waste. One ready-to-drink beverage company located in central Thailand produces coconut jelly waste of approximately 1 ton per year. To the best of our knowledge, there are no reports in the literature on the production of solid fuel pellets from coconut jelly. Hence, this study examined the potential of coconut jelly solid waste as an energy source in the form of pellets. The pellet quality is characterized by physical and thermal properties including pellet diameter and length, bulk density, pellet density, proximate analysis, higher heating value, compressive strength and durability. The energy density, combustion rate and heat release rate were also calculated.

2. Experiments

2.1 Preparation of the raw material

Coconut jelly waste was obtained from ICHITAN Group Public Company Limited. The sample was sun-dried and then crushed and sieved into particles smaller than 4 mm (mesh no. 5). The image of coconut jelly waste in its original form after being sun-dried and after crushing and sieving are shown in Fig. 1.

2.2 Production of solid fuel pellets

The pellets were produced by using a hydraulic press (Fig. 2 (a)) with single compression channel diameter of 10 mm and length of 40 mm (Fig. 2 (b)), without adding any binder. After loading the sample into the channel, the pressure was manually applied at 5 ton by pumping the lever for 5 times. Then, the pressure was released for 5 seconds and the pellet sample was removed from the channel. The process was conducted at room temperature.

![Fig. 1](image1.png) Coconut jelly waste (a) original form after being sun-dried and (b) after crushing and sieving

![Fig. 2](image2.png) (a) Hydraulic press used to compress sample into pellet and (b) block for placing the sample
2.3 Characterization of solid fuel pellets

The pellet diameter and length were measured with a vernier caliper. The pellet density was determined by the ratio of pellet mass to pellet volume. All reported values were the average of 10 samples. The bulk density was determined by pouring the pellets into a container (30.5 cm \( \times \) 30.5 cm \( \times \) 30.5 cm) and the total mass of pellets was divided by the container volume.

Proximate analysis including moisture content (wt%), volatile matter (wt%) and ash content (wt%) were determined according to the standards EN 14774-1 Solid biofuels – Determination of moisture content – Oven dry method, EN 15148 Solid biofuels – Determination of the content of volatile matter and EN 14775 Solid biofuels – Determination of ash content, respectively 9). Briefly, the moisture content was determined by heating the sample at 105 °C for 24 h in an oven using open crucibles. The volatile matter was determined by combusting the sample at 700 °C for 7 min in lid-covered crucibles in a muffle furnace. The ash content was determined by combusting the sample at 550 °C for 1 h in open crucibles in a muffle furnace. The fixed carbon content was calculated as 100% minus the sum of moisture content, volatile matter and ash content.

The apparatus used to test the higher heating value was an automatic bomb calorimeter (GALLENKAMP). A certain length of wire was coiled around the sample, which was fixed in the oxygen bomb. After filling with oxygen, the oxygen bomb was installed into the calorimeter to measure the heating value (kJ/kg). The time for complete combustion was also recorded and was used to calculate the combustion rate (g/min) as the pellet mass divided by the combustion time 11). By knowing the higher heating value and combustion rate, the heat release rate (J/min) could be calculated by multiplication of both values 11). The energy density (MJ/m³) was found by multiplying the higher heating value with the pellet density 10).

The compression resistance in horizontal direction was determined for 3 samples using a universal testing machine (EZ-LX, Shimadzu). The pellet was placed in the machine and a load was applied at a rate of 10 mm/min until the pellet failed. The compressive strength was calculated according to the Newton equation 6). Pellet durability was determined by placing 10 pellets with known total initial mass into a vibrating sieve at 80 rpm with screen size of 2.08 mm (mesh no. 10) 11). After 10 min, the pellets were weighted again and the total final mass was recorded. Pellet durability (wt%) was calculated by dividing the total final mass by the total initial mass.

3. Results and Discussion

Coconut jelly pellets developed without any binding material are shown in Fig. 3. It is observed that the pellets had a smooth texture without any cracks. The average length, diameter and density of the pellets are given in Table 1. The pellet length and diameter are in accordance with Thailand Standard TIS 2772-2560 (2017) and European Standard EN 14961-6:2012 for solid biofuel pellets (non-woody), which require the length and diameter of the pellets to be in the range of 3.15–40 mm and 6–25 mm, respectively. Consequently, the ratio of length to diameter is 0.99. Obernberger and Thek 12) reported that this ratio should be less than 5. This parameter is important if pneumatic feeding systems are used, due to the fact that even a single long pellet is able to block the transport pipe.

The coconut jelly pellet density of 1,100 kg/m³ meets the guiding value of pellet density, which should be greater than 1,000 kg/m³ according to the Austrian standard 12). In previous studies, some bio-fuel pellets had a density lower than 1,000 kg/m³ such as Malaysia tea waste pellets.

Table 1 Physical properties of feedstock and pellets

| Properties          | Coconut jelly | Crushed coconut jelly | Coconut jelly pellets |
|---------------------|---------------|------------------------|-----------------------|
| Length (mm)         | –             | –                      | 10.13                 |
| Diameter (mm)       | –             | –                      | 10.23                 |
| Pellet density (kg/m³) | –            | –                      | 1,100                 |
| Bulk density (kg/m³) | 30           | 70                     | 659                   |
| Durability (wt%)    | –             | –                      | 98                    |
| Compressive strength (MPa) | –         | –                      | 4.84                  |

Fig. 3 Pellets made from coconut jelly waste
(933 kg/m$^3$)\(^7\), palm empty fruit bunch pellets (981 kg/m$^3$)\(^7\), or wood saw dust pellets (609–922 kg/m$^3$)\(^8\). On the contrary, some biomass-derived pellets had a density higher than 1,000 kg/m$^3$, for example, lodgepole pine (1,037 kg/m$^3$)\(^9\), bagasse (1,049 kg/m$^3$)\(^10\), corn stover (1,133 kg/m$^3$)\(^10\) and miscanthus (1,247 kg/m$^3$)\(^11\). The high pellet density results in a high mechanical strength due to the close packing.

The bulk density of coconut jelly in its original form is 30 kg/m$^3$ while the crushed sample has a bulk density of 70 kg/m$^3$. Pelletizing of the coconut jelly significantly increases the bulk density to 659 kg/m$^3$. This represents an increase of approximately 22 times compared to the original form. According to the literature, the pellets of wheat straw\(^17\), lodgepole pine\(^14\), corn stover\(^14\), bagasse\(^15\) and miscanthus\(^16\) had bulk density of 469, 568, 580, 590 and 625 kg/m$^3$, respectively. A guiding value for the bulk density of non-woody pellet is greater than 600 kg/m$^3$ according to Thai and European Standards. A low bulk density has a negative effect on the energy density and also on transportation cost and storage capacity.

The durability of the pellets is 98 wt% which meets the minimum requirement of Thai and European Standards (> 96 wt%). Tumuluru\(^14\) recorded that wheat straw pellets and corn stover pellets had a durability of approximately 98 % while lodgepole pine pellet and pinion juniper pellet had durability greater than 96 %. The wheat straw\(^17\) and pine wood\(^18\) pellets also had durability values of 97 and 99 wt%, respectively. Williams et al.\(^19\) suggest that optimization of the pelletizing process is to ensure that the pellets are durable during transportation and also easy to disintegrate during pellet milling. They claimed that pellets with a low durability are unsuitable for transportation and comminution. The requirement of durability is also related to the end use of the product\(^20\). The same pellets would probably give different results when using a different type of heating machine.

The coconut jelly pellets also show a high compressive strength of 4.84 MPa. Lisowski et al.\(^6\) also reported that spent coffee grounds pellets had a high strength (> 1 MPa). Pellets with a low compression resistance are associated with problems such as difficulty in storage and transportation.

As shown in Table 2, the moisture content of the pellets is approximately 8 wt% which is in conformity with Thai and European Standards, which stipulate that the moisture content should be lower than 15 and 10 wt%, respectively. The low moisture content indicates that the pellets can be stored for longer times with minimal loss in quality\(^16\).

The amount of volatile matter of the coconut jelly pellet is 77.04 wt% which is high. The amount of volatile matter influences the behavior during the combustion of solid fuels. A high volatile matter content implies that the feedstock is suitable as fuel for thermal conversion. However, high levels of volatile matter produce a fast burning that is a disadvantage to fuels\(^5\).

The ash content of the coconut jelly pellet is considerably low (206 wt%). Furthermore, the ash content of the pellets in this study also meets the requirements of the standards (lower than 10 wt%). Pellets with a low ash content are suitable for thermal conversion. A higher ash content in solid fuel results in a lower heating value and increases emissions to the environment, causing problems with the handling and management of large quantities of ash produced and slagging or corrosion in the boiler\(^2\). The coconut jelly pellets contain 12.85 wt% fixed carbon. Fixed carbon has been reported to influence the heating value; materials with a high fixed carbon concentration have a higher heating value.

The higher heating value of the coconut jelly pellets is 15.995 MJ/kg, which is 19.05% higher than the heating value of the original coconut jelly (13.435 MJ/kg). This may be due to the lower moisture content of the pellets compared to the original form. After moisture removal, biomass particles rearrange to fill this space. This is in agreement with the heating value and moisture content of the crushed coconut jelly that was not significantly different from the original form. According to Thai and European

| Properties          | Coconut jelly | Crushed coconut jelly | Coconut jelly pellets |
|---------------------|---------------|------------------------|-----------------------|
| Moisture content (wt%) | 9.06          | 9.24                   | 8.05                  |
| Volatile matter (wt%) | 78.28         | 78.37                  | 77.04                 |
| Ash (wt%)           | 2.46          | 2.04                   | 2.06                  |
| Fixed carbon (wt%)  | 10.20         | 10.35                  | 12.85                 |
| Higher heating value (MJ/kg) | 13.435   | 13.920                  | 15.995                |
| Energy density (GJ/m$^3$) | –             | –                      | 17.59                 |
| Combustion rate (g/min) | 0.05          | 0.07                   | 0.17                  |
| Heat release rate (J/min) | 672           | 974                    | 2719                  |
Standards, the heating value of non-woody pellets should be higher than 14,500 MJ/kg. Pua et al. 7) also found that the heating value of bio-fuel increased after pelletization of Malaysian tea waste and oil palm empty fruit bunch.

The high pellet density (1,100 kg/m³) resulted in a high energy density of 17.59 GJ/m³ and a decrease in transportation and storage costs. Manouchehrinejad and Mani 20) reported that yellow pine and sawmill residue pellets (16.020 MJ/kg) 8), miscanthus Malaysian tea waste and oil palm empty fruit bunch.

Mani 20) reported that yellow pine and sawmill residue pellets (15.995 MJ/kg) was comparable to coconut jelly pellets (15.995 MJ/kg) was also comparable to other biomass pellets such as wheat straw (15.430 MJ/kg) 17), apple pomace waste pellets (16.020 MJ/kg) 9), miscanthus pellets (16.200 MJ/kg) 7), horse manure pellets (16.550 MJ/kg) 16), or oil palm empty fruit bunch pellets (16.736 MJ/kg) 7).

4. Conclusions

The coconut jelly waste from ready-to-drink industry is suitable for the production of pellets that meet Thai and European standards. Pelletization increased the bulk density of coconut jelly waste from 30 to 659 kg/m³. The higher heating value of the pellets (15.995 MJ/kg) also met the minimum requirement of the standards (≥14.500 MJ/kg). The pellet had a low moisture content of 8.05 wt%, low ash content of 2.06 wt% and high volatile matter of 77.04 wt% that result in a high flammability. Moreover, the coconut jelly pellets exhibited a higher combustion rate and heat release rate than its original form. The pellets exhibited good mechanical properties including high compressive strength of 4.84 MPa and high durability of 98 wt%. This research represents an initial stage in the study of coconut jelly pellets and could act as a guideline for further study.

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