Development of De-Oiled Cashew Nut Shell as Fuel Briquettes

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Converting the de-oiled cashew nut shell into usable products (e.g., briquettes) will address the problem of waste disposal. The study was conducted to develop an environment-friendly fuel briquette sufficient to resist impact during handling and transport and produce the required heat for domestic cooking and also for industrial application. Piston-type and screw-type briquetting machines and three levels of binding agent were used in the production of de-oiled spent cashew shell-based fuel briquettes. The produced briquettes were subject for physico-chemical, mechanical and thermal properties tests. Results showed that the best formulation that is required to produce a good quality de-oiled cashew nut shell fuel briquettes using both piston-type and screw type briquetting machines is 10% binding agent with briquette density, shatter resistance and compressive strength of 0.87 g/cm³ and 0.83 g/cm³, 99.54 and 99.89 % and 43.97 and 101.82 kPa, respectively. The total electricity consumption is 150.91 kWh per ton of briquettes while LPG consumption is 1.32 kg. It is concluded that the energy values and combustion qualities of the briquettes produced in this study are sufficient enough to produce the required heat for domestic cooking and a potential for industrial application.

Key Words
De-oiled cashew nut shell, Fuel briquettes, Binding agent, Physico-mechanical properties, Heating value

1. Introduction

In recent years, the cashew fruit (Anacardium occidentale L.) has increased in value, especially in the tropical countries where it is grown extensively such as the Philippines. In 2011, the Philippines ranked sixth among the top 10 cashew producers in the world with a total production of 133,388 metric tons¹.

Cashew fruit has two major food products, namely: the peduncle or pseudo-fruit (cashew apple), and the nut. The nut is considered more important due to its widespread acceptance and demand in the international market². It is kidney shaped with 3.5 mm thick soft leathery outer skin (epicarp) and thin hard inner skin (endocarp) where kernel is extracted through shelling. The roasted or dried kernels are utilized for making ice cream, confectionaries, pastries and hardener for chocolates.

In practice, the spent cashew nut shells are dumped in open spaces and allowed to decompose³. These cashew nut shells have not been fully utilized and most of them are still in a form of wastes. Cashew nut shell contains high lignocellulosic material that is difficult to hydrolyze, thus, takes a very long time to decompose naturally⁴. Moreover, it contains cashew nut shell liquid (CNSL). Dela Cruz et al.⁵ reported that CNSL has several medicinal uses; including treatment of leprosy, elephantiasis, psoriasis, ringworm, warts, corns and cracks in the soles of feet. It is also used in the manufacture of industrial products such as preservative and water proofing agent in insulating varnishes and paints and adhesives; oil- and acid-proof cements and tiles; brake linings, clutch facings; manufacture of laminating resins and baking enamels; excellent lubricant in magneto armatures in airplanes and termite proofing of timbers.

Philippine Center for Postharvest Development and Mechanization (PHilMech) has developed and introduced extraction of CNSL to several cashew processors to...
maximize the benefits of cashew nuts. On the other hand, to eradicate the waste that will be tossed back to the environment, the residue generated from the CNSL extraction process should also be converted into usable product. Converting the de-oiled cashew nut shell into briquettes will address the problem of waste disposal. The study was conducted to develop an environment-friendly fuel briquette sufficient to resist impact during handling and transport and produce the required heat for domestic cooking and also for industrial application.

2. Materials and Methods

2.1 Collection of experimental samples

The cashew nut shell samples were collected from Cashew Nut Processing Center located at Alion Kapit-Bisig Association, Sunrise Village, Alion, Mariveles, Bataan. Afterwards, CNSL of the spent shell was extracted using the Agricultural Mechanization Development Program (AMDP) designed extractor for coconut oil.

2.2 Preparation of samples

Three types of spent shells were used in the experiments: 1) de-oiled, de-oiled and treated with hexane, and carbonized de-oiled cashew nut shell. The de-oiled samples were sundried for 3 to 5 days to achieve the desired moisture content (MC) of 13 % (w.b). While the hexane treated de-oiled samples were submerged to hexane for 24 h to remove the remaining CNSL from the de-oiled samples. The samples were removed from the container and sundried for 3 to 5 days to achieve the MC of 13 %. On the other hand, carbonized de-oiled samples were sun dried for 3 days prior to carbonization process. A drum-type carbonizer was used to perform the carbonization of de-oiled cashew nut shell. The initial and final weight of the experimental samples were recorded.

2.3 Determination of chemical properties of de-oiled cashew nut shell based fuel briquettes

Representative samples of 100 g from de-oiled, de-oiled and treated with hexane, and carbonized de-oiled cashew nut shells were collected for proximate chemical analysis. The proximate chemical analysis was undertaken at Forest Products Research and Development Institute-Department of Science and Technology following the ASTM D-3172 standard procedure.

2.4 Optimization in the production of de-oiled spent cashew shell fuel briquettes

The de-oiled, de-oiled and treated with hexane, and carbonized de-oiled cashew nut samples were hammer milled to reduce their particle size to less than 2 mm using commercially available hammer mill. The time duration in operating the hammer mill and the weight of the samples were recorded.

2.5 Briquetting

A kilogram of hammer milled samples were weighed using digital weighing scale. The samples were mixed with binder using a fabricated mechanical mixer to ensure the homogenous mixing. Preliminary trial was conducted using a lower and higher amount of starch but the briquettes produced were weak, and the briquetting operation was erratic. Based from these preliminary results, the following percentage concentrations of binding agent were considered in each of the briquetting machines (piston-type: 0%, 5% and 10%, screw-type: 0%, 2% and 4%).

The production of briquettes was conducted using piston-type and screw-type briquetting machines. For the piston-type, the biomass was punched into a die by a reciprocating ram with a very high pressure thereby compressing the mass to obtain a compacted product. For the screw-type, grooved barrels low-shear and high compression was used to enhance the mixing process. The rotating screw takes the material from the feed port, through the barrel, and compacted against a tapered die. The densified material was forced into intimate and substantially sliding contact with the barrel walls. Then it was forced through the extrusion die, where the briquette with shape was formed. Before reaching the compression zone the biomass gets partially compressed. The briquettes that continuously come out from the barrel were cut to a desired length using a slicer fixed at the end of the barrel. The screw-type briquetting machine is more appropriate in producing low-viscosity materials which prevents from clogging. A 100 g mixture was loaded on each of the molder of the piston-type briquetting machine while an estimated of 50 mm in length was cut in the screw-type briquetting machine. The number of briquettes produced, time of loading, briquetting and unloading were recorded.

2.6 Drying of de-oiled spent cashew shell fuel briquettes

The de-oiled cashew nut shell based fuel briquettes were sundried to obtain a moisture content of 7±1 %. The final weight and moisture content of the briquettes after sun drying was measured and recorded.
2.7 Determination of physical and mechanical properties of briquettes

The physical and mechanical properties such as briquette density, shatter resistance and compression strength of the fuel briquettes were evaluated and analyzed.

2.7.1 Briquette density

The density of the produced fuel briquettes was determined after sun drying by measuring the volume and weight of five samples. The weighing of samples was performed using an analytical balance (OHAUS) while the dimensions were measured using a Vernier caliper. The density was determined by calculating the ratio of mass and volume of the fuel briquettes.

2.7.2 Shatter resistance

The shatter resistance of the fuel briquettes was measured to determine its durability during handling and transport. The shatter resistance test may simulate the forces encountered during emptying of densified products from trucks into ground, or from chutes into bins. The shatter resistance of briquettes was determined as follows. Representative briquettes from each formulation were selected for drop test. The briquette with known weight and dimensions was dropped on the concrete floor from the height of 1 m. The weight of disintegrated briquettes and its size were recorded. The performance of the briquettes was expressed as the resistance to produce fine particles; which means, good performance would be indicated by greater mass fraction of 6.35 mm particles remaining after the drop tests. The shatter resistance of the briquettes was calculated using the Eqs. (1) and (2).

\[
WL = \frac{W_1 - W_2}{W_1} \times 100 \quad (1)
\]
\[
SR = 100 - WL \quad (2)
\]

where,

\(WL\) = Weight loss, %

\(W_1\) = weight of briquette before shattering, g

\(W_2\) = weight of briquette after shattering, g

\(SR\) = Shatter Resistance, %

2.7.3 Compressive strength

Compressive resistance test simulates the compressive stress due to weight of the top briquettes on the lower briquettes during storage in containers. The hardness of the produced briquettes was determined using a universal testing machine (Instron). The compressive resistance of the fuel briquettes was determined by diametrical compression test. The flat surface of the briquette sample was placed on the horizontal metal plate of the machine. A 5 kN load was applied at a cross head speed of 10 mm/min until the briquette failed by means of cracking or breaking.

2.8 Determination of thermal properties of briquettes

The thermal properties of de-oiled spent cashew shell based briquettes were evaluated in terms of heating value, water boiling test and thermal efficiency.

2.8.1 Heating value

The heating value is an indication of the energy the material possesses as potential fuel. The heating value of the produced briquettes was determined using LECO AC-350 bomb calorimeter. The test was done at the Forest Products Research and Development Institute (FPRDI) of the Department of Science and Technology.

2.8.2 Water boiling test

The water boiling test as described by Rathore was adopted in this study. The volume of the kettle was measured and filled by 2/3 of water. The kettle with cover was placed on top of the charcoal stove. A thermometer was fixed in central part of kettle. A 500 g of briquettes were measured for testing. The ambient temperature and initial temperature of water in the kettle were measured. Final temperature of water after boiling was observed.

The water was heated until the briquettes were used up, then the kettle cover was removed, and evaporation was continued for 20 min. Afterwards, the kettle was separated from the stove; the temperature of the kettle was lowered for 2 h and the volume of water was measured.

2.9 Statistical analysis

The data gathered were analyzed using 3 x 3 factorials in completely randomized design (CRD) both for piston-type and screw-type briquetting machines. ANOVA table was utilized to determine the level of significance among treatments. The difference among means was analyzed using Duncan’s Multiple Range Test (DMRT).

3. Results and Discussion

3.1 Description of fuel briquettes

The de-oiled cashew nut shell based fuel is cylindrical in shape with hole in the center to promote efficient combustion of briquettes. The briquette has an approximate length of 50 mm with an outside and inside diameter of 50 mm and 16 mm, respectively. The briquettes were sundried from an initial moisture content of 43-51% (wet basis) down to 6-8% (wet basis). It is not advisable to dry the briquette below 6% because of possible moisture intake and expansion of the material and becoming fragile.

3.2 Proximate analysis of fuel briquettes

The raw de-oiled sample obtained the highest volatile combustible matter while carbonized de-oiled samples obtained the highest fixed carbon and ash content as shown...
in Table 1. The fixed carbon acts as generator burning while volatile matter indicated easy ignition of fuel. Moreover, ash content has a negative effect on the heating value.

3.3 Physical properties of briquettes

3.3.1 Briquettes sensity

Table 2 shows that the average briquettes density of de-oiled spent cashew shell produced in piston type was lower than screw-type. This could be due to the amount of pressure applied. By the application of high pressure, particles are brought close together, causing inter-particle attraction forces which make solid bridges between the particles. Solano et al. reported that a screw type briquetting machine achieved higher density by 200 kg/m³ than piston type.

On the other hand, the briquettes density using screw-type briquetting machine increases with binder concentration which is in agreement with the study of cacao pod husk briquettes of Tuates et al. Likewise, carbonized de-oiled spent cashew shell briquettes required more binder to improve its briquettes density because it cannot withstand and easily broken during the experiment.

Adding more binder leads to increased briquette density as observed using screw type briquetting machine.

The analysis of variance revealed no significant differences on the kind of material and the amount of binding agent applied using piston type. Likewise, there were significant differences on the kind of material and the amount of binding agent applied using screw-type briquetting machine.

3.3.2 Shatter resistance

Table 3 shows that the carbonized de-oiled cashew nut shell briquettes using piston-type and screw-type briquetting machine are weak due to burnt remaining CNSL contained in the shell. Also, this can be associated to the low amount of starch used in the formulation of briquettes. Bisana and Laxamana reported that carbonized materials require more binder in the production of fuel briquettes.

The analysis of variance revealed significant differences on the kind of material and the amount of binding agent applied using piston type and screw-type briquetting machines.
3.3.3 Compressive strength

The compressive test was a criterion of briquette durability. The highest compressive strength of 106.39 kPa was obtained in briquettes with highest proportion of binding agent (4%) using screw-type briquetting machine (Table 4). The analysis of variance revealed significant differences on the kind of material and the amount of binding agent applied using piston type. Likewise, there were significant differences on the kind of material and the amount of binding agent applied using screw-type briquetting machine. Several researchers reported that it was difficult to obtain repeatability of the results from the compressive resistance test for the same quality of pellets/briquettes.\textsuperscript{12, 7, 13, 14} However, increase in compressive strength of briquettes with high percent of binding agent was observed. This can be associated to the high amount of binding agent’s viscosity. According to Kaliyan \textit{et al.},\textsuperscript{5} highly viscous binders such as starch adhere to the surfaces of solid particles to generate strong bonds that are very similar to those of solid bridges. Many viscous binders harden after cooling and form solid bridges.

3.4 Thermal properties of briquettes

3.4.1 Heating value

Table 5 shows the gross heating value of de-oiled cashew nut shell based fuel briquettes. These gross heating values are comparable with the study of Sengar \textit{et al.}\textsuperscript{15}.

3.4.2 Water boiling test

The water boiling test of de-oiled cashew nut shell based fuel briquettes was undertaken to determine its suitability as fuel for cooking as well as for industrial applications. It took 4.7 to 7.3 min to fire the briquettes and the time to boil the 1.4 L of water using 500 g of briquettes ranged from 12.7 to 29.9 min (Table 6). On the other hand, the average burning time from ignition of the briquettes to ash ranged from 73.0 to 118.9 min.

3.4.3 Energy consumption

Table 7 shows the amount of energy and LPG needed to produce a ton of raw de-oiled cashew nut shell briquettes with 5% binding agent using a piston type briquetting machine. The machines utilized electricity and LPG for most of the cashew briquetting operations. The total electricity consumption is 150.91 kWh/t while LPG consumption is 1.32 kg equivalent to 66.20 MJ/t. Electricity is consumed in hammer mill, mechanical mixer and briquetting machine. Briquetting machine registered...
Table 7 Energy consumption of de-oiled spent cashew shell briquettes

| Operations                | Energy Consumption |
|---------------------------|--------------------|
|                           | Machine, kWh LPG, MJ |
| Drying                   | 0.00 0.00          |
| Hammer milling            | 6.67 0.00          |
| Binder preparation        | 0.00 66.20         |
| Mixing                    | 22.99 0.00         |
| Briquetting               | 121.24 0.00        |
| Drying                   | 0.00 0.00          |
| Total                     | 150.91 66.20       |

the highest electricity consumption of around 80.53% of the total electricity consumed. LPG is used only in cooking of the binder. Sun drying method was used to dry de-oiled cashew nut shell and briquettes. The energy consumed in the production of a ton of briquettes is only 3.36% of the energy contained in a ton of de-oiled cashew nut shell briquettes with a value of 609 MJ. The result is nearly comparable to the wood sawdust-based (4.37%) and cacao pod husk briquettes (5.25%)\cite{10,16}.

4. Conclusions

The hexane treated de-oiled cashew nut shell using both piston-type and screw type briquetting machines with 10 % and 4 % binding agent obtained highest briquette density and shatter resistance of 0.87 ± 0.03 g/cm³ & 0.83 ± 0.04 g/cm³, 99.54 ± 0.08 % & 99.89 ± 0.07 %, respectively. While the highest compressive strength of 102.91 ± 0.00 kPa & 106.36 ± 0.00 kPa were obtained in 5% binding agent using piston-type and 4% binding agent using screw-type, respectively. The total electricity consumption is 150.91 kWh while LPG consumption is 1.32 kg in the production of a ton of briquettes which is equivalent to 3.36% energy demand. The carbonized de-oiled cashew nut shell briquettes did not produce smoke during water boiling test but required more binder to improve its briquette density.

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Table 6 Water boiling test of de-oiled cashew nut shell briquettes

| Fuel Briquettes                      | Ignition time (min) | Water boiling test (min) | Burning time (min) |
|--------------------------------------|---------------------|--------------------------|--------------------|
| De-oiled cashew nut shell             | 4.7 ± 0.06         | 23.9 ± 4.02              | 73.0 ± 13.87       |
| Hexane treated de-oiled cashew nut shell | 4.9 ± 0.12     | 127 ± 6.36               | 98.2 ± 24.15       |
| Carbonized de-oiled cashew nut shell | 7.3 ± 0.15         | 299 ± 4.54               | 118.9 ± 14.10      |

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