The Production and Properties of Fuel Briquettes from Animal and Agricultural Bio-Waste to Renewable Energy Source in Rural Community

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Abstract

Biomass energy is a basic energy requirement of rural communities in developing countries. Thailand is an agricultural country that has huge agricultural waste. Bio-waste is of interest, as animal waste (cow dung) and plant waste (rice straw and corncob) are easily found in many areas of Thailand. This research aimed to study the production and properties of bio-waste converted to fuel briquettes as an energy source for cooking fuel. The production results tested the suitable ratio of binders for fuel briquettes with the ratio between starch and water at 4:6 percent by weight. The ratio 2:1:7 cow dung:residue (rice straw, corn cob, rice straw+corn cob):binder with percent by weight was suitable for fuel briquettes which had good shape, smooth surface, strong shape and continuously flowed while extruding them from the fuel briquette machine. The property of fuel briquettes regarding the compressive strength was highest at 1.02±0.12 MPa of cow dung:corncob:binder. The heating value of cow dung:corncob+rice straw:binder was highest at 14.18 MJ/kg. The percentage ash content of cow dung:corncob+rice straw:binder was lowest at 12.95%, and the bulk density of cow dung:corncob+rice straw:binder was highest at 898.24 kg/m^3. As a result, these fuel briquettes from bio-waste could be used as an alternative energy source for developing countries. There is potential for it to be a renewable energy source in many parts of Thailand.

Keywords:

Fuel Briquettes, Agricultural Bio-Waste, Rural Communities

1. Introduction

Biomass energy provides basic energy for space heating, power generation, and cooking and heating of rural and urban household's particularly in developing countries [1]. Agricultural waste covers a wide range of different species with a large variation in composition and fuel characteristics. However, the percentage composition of combustible elements in the agricultural waste, whether in loose form or briquette form, is very low compared to fossil fuels [2]. Thailand is one of the important agricultural countries where more than half of the population practices agriculture. Bio-waste refers to organic substances in parts of a plant and animal waste, e.g., rice straw, corncob, baggage, palm fiber and fruit bunches, animal dung, etc. Bio-waste can be converted into fuel for cooking and for other thermal processes [3]. In rural communities, the burning of agricultural waste in loose form results in loss of fuel and widespread air pollution, which has become a problem. However, briquettes of agricultural waste could solve this problem. Agricultural waste briquettes have the following advantages over loose waste: increased calorific value per unit volume, the fuel is easy to transport and store, and it is uniform in size and quality [4]. The increasing fossil fuel price affects people in rural communities who have low-income rates per household. Bio-waste sources are an important energy source, and they make up the biggest share of the renewable energy consumption structure in Thailand. For example, 70% of rural people depend on bio-waste to fuel their daily cooking demands [5].

This study showed how bio-waste products made from local material blends of rice straw, corn cob and cow dung could be utilized as fuel briquettes in rural communities in Thailand. The main topic of fuel briquettes studied were the addition of binder, material ratios, drying or dehumidification and physical properties, e.g., compressive strength, heating value, ash content, moisture content, bulk density, fuel consumption and specific fuel consumption, as shown in Fig.1.

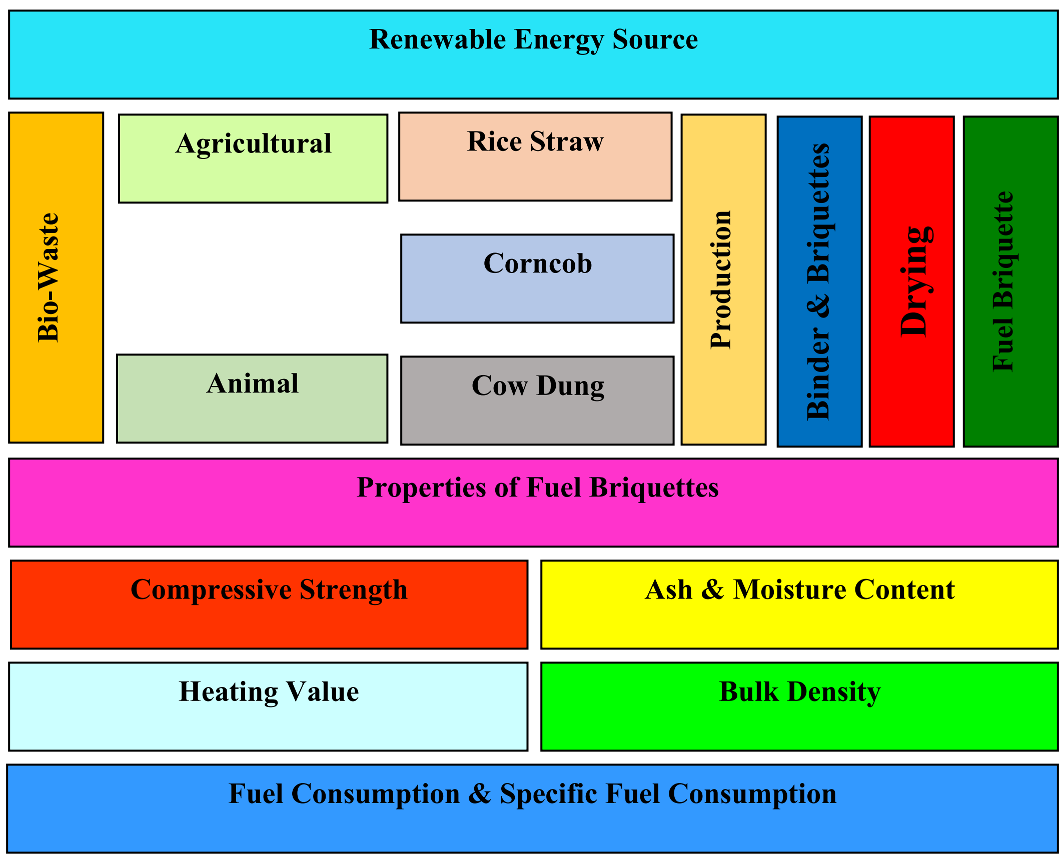

Fig. 1 An experimental framework for fuel briquette.

2. Materials and Methods

2.1 Materials, Equipment Preparation and Methods

The experimental process is presented in Fig. 2. The raw material consisted of cow dung, rice straw, corncob, and rice straw + corncob, which were dried for at least 5 days in open sunshine until the moisture content was less than 8 percentage of wet basis (%w.b.) [6]. It was then crushed into small particles sizes about 1 mm or less, with a sieve shaker and Tyler's sieves of various diameters or particle sizes. Suitable raw material combinations were made for the briquette process. Then, this was used as input for the briquette machine to produce a briquette sample. The briquette machine compressed the mixed material with a rotary screw at 10 hp and 3-phase motor power that rotated the screw at a speed of about 140 rpm. The extruded fuel briquette had a hollow cylinder shape with outer and inner diameters within 40 and 15 mm, respectively, and the length could be controlled as required for the fuel briquette. The binder was prepared by adding cassava starch mixed with water at ten different weight ratios (Starch:Water) 9:1, 8:2, 7:3, 6:4, 5:5, 4:6, 3:7, 2:8, and 1:9. The ratio of materials for the fuel briquettes were composed of three main materials mixing by weigh (Cow Dung:Biomass Residue:Binder) 8:1:1, 7:2:1, 7:1:2, 6:3:1, 6:2:2, 6:1:3, 5:4:1, 5:3:2, 5:2:3, 5:1:4, 4:5:1, 4:4:2, 4:3:3, 4:2:4, 4:1:5, 3:6:1, 3:5:2, 3:4:3, 3:3:4, 3:2:5, 3:1:6, 2:7:1, 2:6:2, 2:5:3, 2:4:4, 2:3:5, 2:2:6, 2:1:7, 1:8:1, 1:7:2, 1:6:3, 1:5:4, 1:4:5, 1:3:6, 1:2:7, 1:1:8. The next step in the fuel briquette drying process was decreased by open sun drying until the moisture content was below 8 percentage of wet basis (%w.b.). The solar intensity was measured using a pyranometer (Kipp & Zonen model CM 11, accuracy ±0.5%) and temperatures measured by Type K thermocouples (±2%). The voltage signals of the pyranometer and thermocouple were recorded every 10 minutes with a multi-channel data logger (Yogogawa model HR 1300).

Fig. 2 The production of fuel briquettes.

2.2 Physical Properties

2.2.1 Compressive Strength Testing

The compressive strength in the cleft of the fuel briquettes was tested following with ASTM D 2166-85 [4,7,11] by using the Universal Test Machine (Lloyd Instruments Ltd, LR50K) with a load cell capacity of 50 KN at room temperature. The cross-head speed was 0.305 mm/min. Three samples of fuel briquettes for testing were horizontally placed in the compression test base, and a load was applied at a constant rate until the fuel briquette cracked. Then, compressive strength was computed as follows:

$$Compressive\ Strength\ in\ cleft = 3x\frac{[The\ load\ at\ break\ point\ (N)]}{[l_1(mm)+l_2(mm)+l_3(mm)]} \quad (1)$$

Where, $l_1(mm), l_2(mm), l_3(mm)$ were the length of the fuel briquette at points one, two and three, respectively.

2.2.2 The Heating Value

The heating value of the fuel briquette samples was investigated by using an adiabatic bomb calorimeter following ASTM D 5865 [4,7,11]. The briquette fuel samples were ground powder and compressed pellets. The pellets were weighed and placed in a crucible chamber. Then, the heater coil was arranged with a U shape and touched only the sample. After that, samples were placed in a bomb and compressed with oxygen gas at 30 atmospheric pressure. And then, the sample component was placed in a bomb calorimeter chamber and added 2 litres of distilled water in a tank. In the next step, the bomb calorimeter was ignited and recorded the results. About 0.4 g of each sample was completely burnt in the bomb calorimeter. The different temperature between the maximum and minimum was used to compute the heating values of the fuel briquettes as follows:

$$Q = \frac{[(C_{water}+C_{cal})(T_2-T_1)]}{W_f} \quad (2)$$

Where, Q = Calorific value of the fuel briquette (kJ/kg)
W_f = Weight of the fuel briquette sample (kg)
C_{cal} = Heat capacity of the bomb calorimeter (kJ/˚C)
T_2-T_1 = The difference temperature (˚C)
C_{water} = Heat capacity of water (kJ/˚C)

2.2.3 The Moisture Content

The moisture content of the briquette samples was measured following ASTM D 3173 [4,7,11] using the oven drying method. The weight of each sample (3 g) was prepared with weight balance (Mettler, Type PJ3000), and was then placed in an oven at 105 ºC for one hour. The dry sample was weighed again. The moisture content of the sample was calculated as follows:

$$Moisture\ Content(\%w.b.) = \frac{(W_2-W_3)}{(W_2-W_1)}x100 \quad (3)$$

Where, W_1 = weight of crucible (g),
W_2 = weight of crucible+sample (g),
W_3 = weight of crucible+sample, after drying (g)

2.2.4 The Percentage of Ash Content

The percentage of ash content was determined with ASTM D 3174 [4,7,11] by heating 2 g of the fuel briquette samples in the furnace at a temperature of 550°C for 10 minutes. The weights of the dried sample (A), and the weight of the ash after 4 hours cooling down in desiccators (C) were obtained. The percentage of ash content was determined as follows:

$$\text{Percent of Ash Content} = \frac{C}{A} x100 \qquad (4)$$

2.2.5 The Fuel Consumption and Specific Fuel Consumption

The fuel consumption and specific fuel consumption [11-12] were measured by the fuel use, total time, volume and the temperature of the boiling water. This was carried out to compare the potential of the fuel briquettes. The time taken for each sample of fuel briquettes to boil an equal volume of water was measured as well as the same different temperatures to heat up under similar conditions. A 0.5 kg sample of fuel briquettes was used to boil 1,000 cm^3 (1 litre) of water using the same container, environment and stove. The fuel properties of the fuel consumption and specific fuel consumption were also determined as follows:

$$\text{Fuel Consumption, (FC)} = \frac{[\text{Mass of Fuel Consumed,(kg)}]}{[\text{Total time taken,(hr)}]} \qquad (5)$$

The specific fuel consumption indicates the ratio of the mass of fuel consumed (kg) to the quantity of boiling water (litre).

$$\text{The Specific Fuel Consumption, (SFC)} = \frac{[\text{Mass of Fuel Consumed,(kg)}]}{[\text{Total mass of boiling water,(litres)}]} \qquad (6)$$

2.2.6 The Bulk Density

The bulk density of fuel briquettes was assessed as a simple process [4,7]. First, a cylindrical shape of fuel briquettes was placed in a fixed volume container for determination. Next, the empty container was weighed to determine the bulk density and then the container was filled with fuel briquettes and weighed again. Finally, the bulk density was tested by the mass of fuel briquettes and the volume of a container and was then calculated by using the formula:

$$\text{Bulk Density} = \frac{[\text{Mass of Briquettes,(kg)}]}{[\text{Volume of Container,}(m^3)]} \qquad (7)$$

3. Results and Discussion

3.1 The Suitable Binder and Fuel Briquettes Ratio

The experimental ratio of a binder for fuel briquettes was tested and the ratio between starch and water percent by weight is shown in Table 1. The ratios 9:1 and 8:2 were very dry like powder, hard viscosity and the ratios 7:3 and 6:4 were sticky, with high viscosity. The ratios 5:5, 4:6, and 3:7 were homogenous which the ratio 4:6 was suitable as a binder. It was a good stick and well adhesion. The ratios 2:8 and 1:9 were not sticky like liquid and did not stick together between starch and water (not homogeneous). The experimental ratio of fuel briquette was tested with the ratio of cow dung:residue:binder percent by weight shown in Table 2. The ratio 2:4:4 and more cow dung:residue:binder was not extruded as a briquette rod and was very dry. The ratio 2:3:5 was not a briquette rod too, and the ratio 2:2:6 lost its shape and was not strong. The ratio 2:1:7 was suitable for fuel briquettes rod, as they had a good shape, smooth surface, strong shape and continuously flowed while extruded from the fuel briquettes machine. The ratios 1:8:1, 1:7:2, 1:6:3, 1:5:4 and 1:4:5 were not a briquette rod and very dry like powder. The ratios 1:3:6, 1:2:7 lost their shape and were not strong, and 1:1:8 was not a briquette rod and did not set its shape as a liquid.

Table 1 The suitable ratios of binders.

Starch: Water (% by weight)	Characteristics
9 : 1	Powder, Hard viscosity, Not homogeneous
8 : 2	Powder, Hard viscosity, Not homogeneous
7 : 3	Solid, High viscosity, Not homogeneous
6 : 4	High viscosity, Over stick
5 : 5	Homogeneous, stick
4 : 6	Homogeneous, Good stick, Good adhesion
3 : 7	Homogeneous, Less stick
2 : 8	Liquid, Not homogeneous, Poor stick
1 : 9	Liquid, Not homogeneous, Not stick

Table 2 The suitable ratio for fuel briquettes

Binder Ratio Starch:Water (% by weight)	Fuel Briquettes Ratio (% by weight)	Fuel briquettes Cow dung:Residue:Binder		
		Rice Straw	Corncob	Rice Straw+Corncob
4 : 6	5:1:4, 5:2:3, 5:3:2, 5:4:1, 4:1:5, 4:2:4, 4:3:3, 4:4:2, 4:5:1, 3:1:6, 3:2:5, 3:3:4, 3:4:3, 3:5:2, 3:6:1	Not briquette rod	Not briquette rod	Not briquette rod
	2:4:4	Not briquette rod, very dry	Not briquette rod, very dry	Not briquette rod, very dry
	2:3:5	Not briquette rod, Powder	Not shape, mold sticking	Not briquette rod, Powder
	2:2:6	Loses its shape, not strong	Loses its shape, not strong	Loses its shape, not strong
	2:1:7	Good shaped, strong	Good shaped, strong	Good shaped, strong
	1:8:1 1:7:2 1:6:3 1:5:4	Not briquette rod, very dry	Not briquette rod, very dry	Not briquette rod, very dry
	1:4:5	Not sticking, not briquette rod, powder	Not shaped, mold sticking	Not sticking, not briquette rod, powder
	1:3:6 1:2:7	Loses its shape, not strong	Loses its shape, not strong	Loses its shape, not strong
	1:1:8	Not briquette rod, Liquid	Not briquette rod, Liquid	Not briquette rod, Liquid

3.2 The Fuel Briquette Drying

The moisture content of fuel briquettes decreased with open sun drying after 7 days below 8 (%w.b.). The solar intensity, wind velocity and temperature were monitored from 07.00 - 17.00. The solar intensity was around 100 – 1,100 w/m^2 as shown in Fig. 4. The same trend of maximum solar intensity and temperature appeared during 12.00 – 14.00 pm and accumulated high heat each day. The average ambient temperature and the average surface temperature, as shown in Fig. 5, were proximately tested at 31°C and 38°C, respectively. The wind velocity was recorded around 1-2 m/s. The moisture content of the fuel briquette sharply decreased after 3 days and then slowly decreased until it was less than 8 %w.b., as shown in Fig. 3.

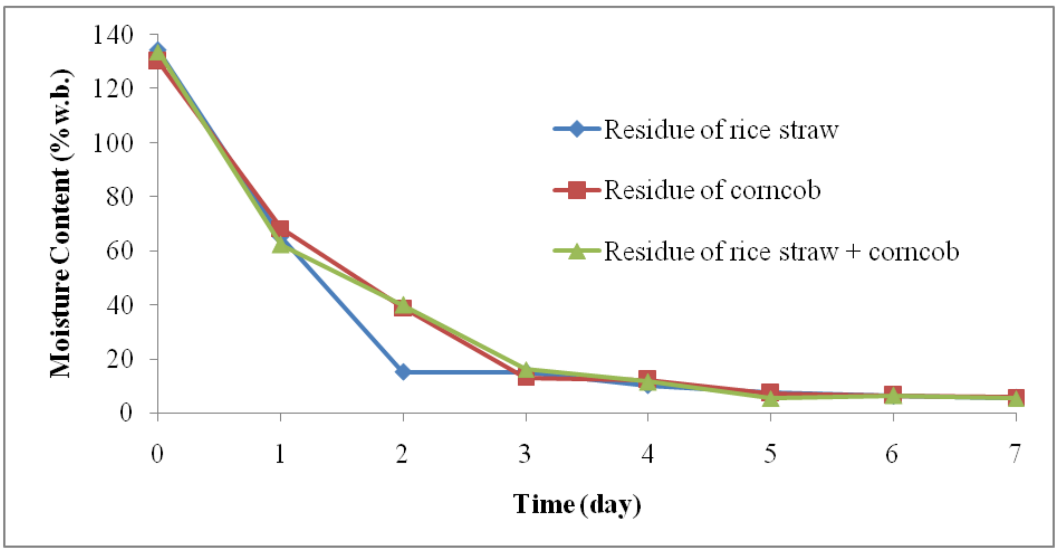

Fig. 3 The moisture content of fuel briquettes drying.

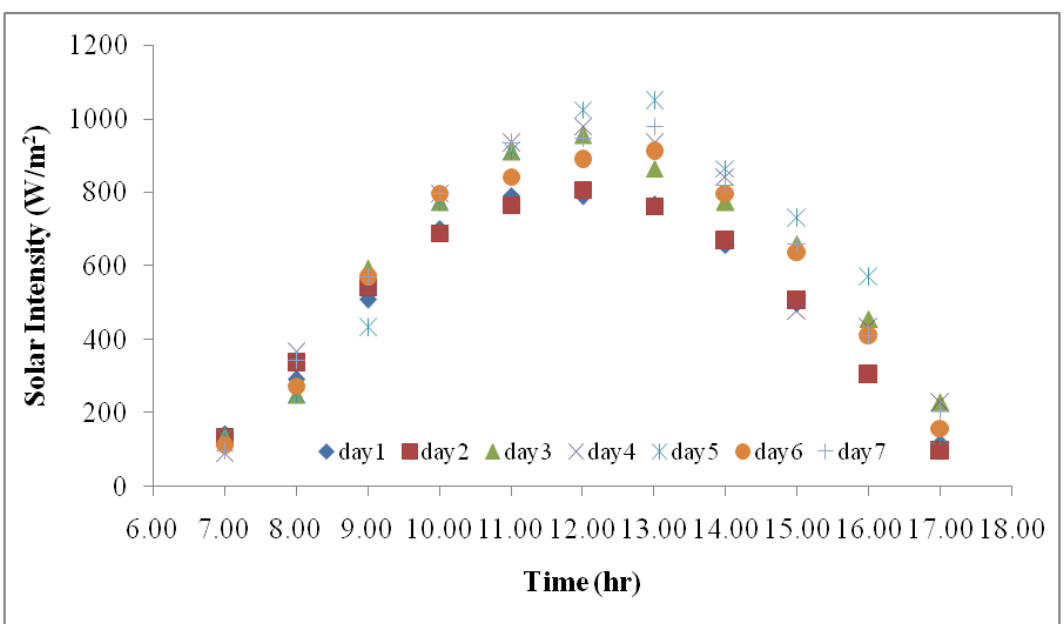

Fig. 4 The solar intensity of fuel briquettes drying.

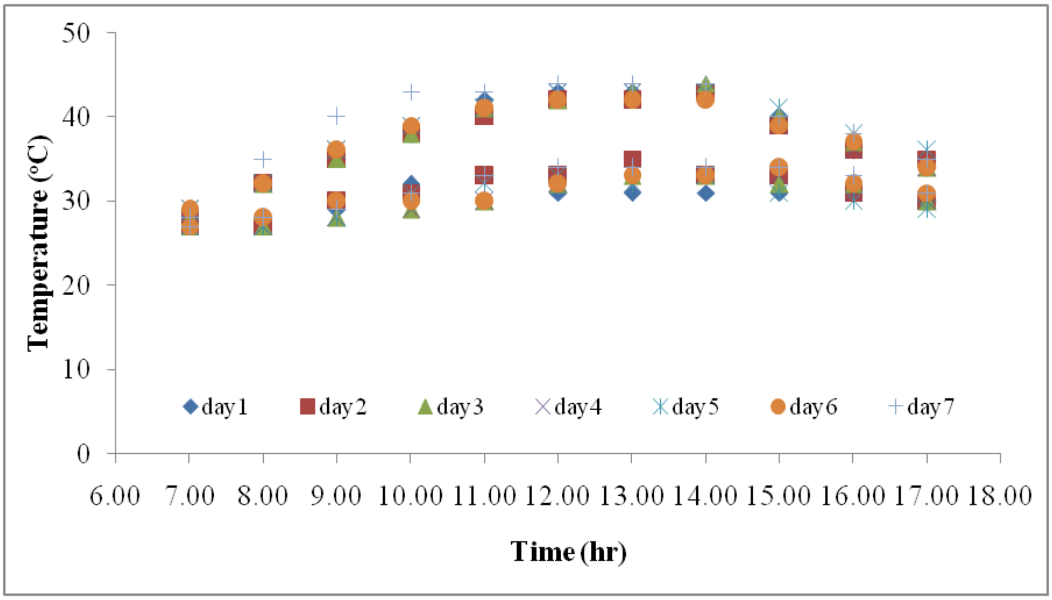

Fig. 5 The ambient and surface temperature of fuel briquettes drying.

3.3. The Physical Properties of Fuel Briquettes

3.3.1 The Compressive Strength Testing

The compressive strength testing results are shown in Table 3. There was higher compressive strength of 1.02±0.12 MPa in the fuel briquettes of cow dung:corncob:binder than in the fuel briquettes of cow dung:corncob+rice straw:binder which was tested for compressive strength of 0.93±0.11 MPa, and the fuel briquettes of cow dung:rice straw:binder displayed compressive strength of 0.84±0.11 MPa. The values of compressive strength testing were affected by cellulose of materials which the compositions of cellulose were shown 45.15% and 30.01% in a corn cob and rice straw, respectively [8]. Also, the three types of fuel briquette were higher than the compressive strength of industry standards, 0.38 Mpa [9].

Table 3 The compressive strength testing of fuel briquettes.

Binder Ratio Starch:Water (% by weight)	Fuel Briquettes Ratio (% by weight)	Compressive Strength of Fuel Briquettes (MPa) Cow dung:Residue:Binder		
		Rice Straw	Corncob	Rice Straw+Corncob
4 : 6	2:1:7	0.84±0.11	1.02±0.12	0.93±0.11

3.3.2 The Heating Value

The initial heating value of the raw material and applied fuel resources were displayed in Table 5 and had passed the process to the fuel briquettes. The heating value of the fuel briquettes was tested, and the heating value is shown in Table 4. The fuel briquettes of cow dung:corncob+rice straw:binder had a 14.18 MJ/kg heating value. The fuel briquettes of cow dung:corncob:binder and cow dung:rice straw:binder were closely valued at 13.96 and 13.93 MJ/kg heating value according to [19-21]. Also, the heating value of all fuel briquettes was mixed with cow dung as follows [10].

Table 4 The Properties of fuel briquettes

Fuel Briquettes	Heating Value, MJ/kg	Moisture Content, (%w.b.)	Ash, (%)	Fuel Consumption, (kg/hr)	Specific Fuel Consumption, (kg/litre)	Bulk Density, (kg/m³)
cow dung:rice straw:binder	13.93	7.88	17.34	5.60	0.36	814.09
cow dung:corncob:binder	13.96	7.21	21.82	4.63	0.30	679.62
cow dung:corncob+ rice straw:binder	14.18	7.94	12.95	4.95	0.32	898.24
Charcoal	28.26	3.69	3.86	2.25	0.18	994.72

Table 5 The Properties of Bio-Waste and Bio-Briquette

Fuel	Heating Value (MJ/kg)	Reference
Cow dung	18.60	[14]
Corn cob	17.73	[15]
Rice straw	15.30	[16]
Cow dung Pellet	16.34	[19]
Corn cob Briquette	16.13	[20]
Rice straw Briquette	15.60	[21]

3.3.3 The Moisture Content

The moisture content of fuel briquettes that were dried and tested is shown in Table 4. The moisture content of fuel briquettes of cow dung:rice straw:binder, cow dung:corncob:binder and cow dung:corncob+rice straw:binder were 7.88, 7.21 and 7.94 %w.b., respectively. The moisture content of fuel briquettes was the same trend as the bulk density value caused by the low density of fuel briquettes which had a lot of porosity, so it could easily force moisture from the inner to outer surfaces of the fuel briquettes.

3.3.4 The Percentage Ash Content

The percent of ash content of the fuel briquettes was studied and is shown in Table 4. The results of ash content contrasted the value of bulk density. The percent of ash content of the fuel briquettes made of cow dung:corncob+rice straw:binder was lowest, at 12.95%. The percent of ash content of the fuel briquettes made of cow dung:rice straw:binder and cow dung: corncob:binder were 17.34% and 21.82%, respectively.

3.3.5 The Fuel Consumption and Specific Fuel Consumption

The fuel consumption and specific fuel consumption of fuel briquettes were tested and the results are displayed in Table 4 according to the specific fuel consumption shown by Onuegbu TU et al. [12] and Rotimi Moses Davies [13]. The fuel consumption and specific fuel consumption of the fuel briquettes of cow dung: corncob:binder were lowest, at 4.63 kg/hr and 0.30 kg/litre, respectively. The fuel consumption of fuel briquettes of cow dung: corncob+rice straw:binder and cow dung:rice straw:binder were 4.95 and 5.60 kg/hr, respectively. The specific fuel consumption of fuel briquettes of cow dung: corncob+rice straw:binder and cow dung:rice straw:binder were 0.32 and 0.36 kg/litre, respectively.

3.3.6 The Bulk Density

The bulk density of the fuel briquettes was studied in Table 4. The bulk density of cow dung:corncob+rice straw:binder fuel briquettes was highest at 898.24 kg/m^3, while the briquettes made of cow dung:rice straw:binder and cow dung: corncob:binder were 814.09 and 679.62 kg/m^3, respectively. The results of bulk density related to other properties of fuel briquettes of ash content and moisture content. Also, the high bulk density affected the less ash content and reached the difficult driving force of moisture to the outer surface of fuel briquettes.

3.3.7 The Fuel Briquette Utilization in Rural Community

In rural communities, people use 16.7% firewood for cooking that could be equivalent to any energy source. Mainly firewood and charcoal were from forests which decreased by 25.6 % [17]. Biomass waste could be made into a usable fuel form by densification, which has to be interesting many developing countries worldwide, as a simple technique for energy sources [18]. It is one of the routes for each household to self-energy sources in their community. There are several types of materials in all regions of Thailand that could be used as biomass energy sources. They can be found in both plant and animal waste from agricultural processing plants and converted into fuel sources [19-21]. The production of fuel briquettes from waste material not only reduces the amount of unused waste but could be used as a good alternative source of energy for developing countries as well.

4. Conclusion

This experiment studied the ratio between starch and water, which was 4:6 percent by weight for a binder to the mixed component of bio-material and the ratio of cow dung:residue (rice straw, corn cob, rice straw + corn cob):binder fuel briquettes at 2:1:7 percent by weight was suitable for fuel briquettes forming that had a good shape, smooth surface, strong shape and continuously flowed while extruding the fuel briquette. The moisture content of fuel briquettes decreased until it was less than 8 %w.b. by open sun drying for 7 days. The physical properties of the fuel briquette were performed in many topics following these. The highest compressive strength (1.02±0.12 MPa) was found in the fuel briquettes of cow dung:corncob:binder. The fuel briquettes of cow dung:corncob+rice straw:binder had the highest heating value (14.18 MJ/kg). The percent of ash content in the fuel briquettes of cow dung:corncob+rice straw:binder was lowest, at 12.95%. The moisture content of the fuel briquettes of cow dung:corncob:binder was lowest, at 7.21 %w.b.. The bulk density of the fuel briquettes of cow dung:corncob+rice straw:binder was highest, at 898.24 kg/m^3. The fuel consumption and specific fuel consumption of the fuel briquettes of cow dung: corncob:binder were lowest, at 4.63 kg/hr and 0.30 kg/litre, respectively. Fuel briquettes from bio-waste (rice straw, corn cob and cow dung) could be a renewable energy source with high potential and efficiency for household energy use in many areas of Thailand.

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