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Effect of Coffee Grounds on Physical and Heating Value Properties of Sugarcane Bagasse Pellets

K. Rattawan, W. Intagun, W. Kanoksilapatham

Abstract**—**Objective of this research is to study effect of coffee grounds on physical and heating value properties of sugarcane bagasse pellets. The coffee grounds were tested as an additive for pelletizing process of bagasse pellets. Pelletizing was performed using a Flat–die pellet mill machine. Moisture content of raw materials was controlled at 10-13%. Die temperature range during the process was 75-80 °C. Physical characteristics (bulk density and durability) of the bagasse pellet and pellets with 1-5% coffee ground were determined following the standard assigned by the Pellet Fuel Institute (PFI). The results revealed increasing values of 648±3.4, 659 ± 3.1, 679 ± 3.3 and 685 ± 3.1 kg/m^3 (for pellet bulk density); and 98.7 ± 0.11, 99.2 ± 0.26, 99.3 ± 0.19 and 99.4 ± 0.07% (for pellet durability), respectively. In addition, the heating values of the coffee ground supplemented pellets (15.9 ± 1.16, 17.0 ± 1.23 and 18.8 ± 1.34 MJ/kg) were improved comparing to the non-supplemented control (14.9 ± 1.14 MJ/kg), respectively. The results indicated that both the bulk density and durability values of the bagasse pellets were increased with the increasing proportion of the coffee ground additive.

Keywords**—**Bagasse, coffee grounds, pelletizing, heating value, sugar cane bagasse.

I. Introduction

BIOMASS pellets are cylindrical shape with a diameter of approximately 6-8 mm, and are 5-40 mm in length. The biomass pellets are symmetrical forms and high density which they are also convenient to store, transport and convert to energy. Therefore, biomass pellets are an interesting option to increase the value of agricultural residues and to use biomass efficiently. In addition, the biomass pellets can be replaced the fossil fuels for industrial heat generation. It can also reduce energy costs in the production process [1]-[5]. In present, the world's market demands for biomass pellets have increased during recent years. The global marketing of pelletized biomass fuels has set the standard for commercial trading. The prices of biomass pellet fuels are set according to their qualities: bulk density, diameter, durability, moisture content, chloride content, and heating value. The heating value or releasable energy storage is one of the most important criteria affecting the commercial value of the biomass pellets [2], [4], [6].

Biomass pellet is one of renewable energy. Biomass pellet fuels can be made from agricultural residues (such as rice husk, straw, bagasse, corncob, palm leaf, and rhizome, etc.), wood chips from furniture factories and forest residues. The producing process of pellet consists of drying and milling, pelletizing, cooling, sieving, and packaging/storing [7]-[10]. Sugarcane is one of the major economic crops of Thailand. In 2015, Thailand exported about 8 million tons of sugar, an increase of 9% from 2014 [11]-[12]. As a result, large amount of bagasse was remained as waste material, which can be used as renewable fuel for heat generation. Most of the biomass raw materials for fuel generally have asymmetrical forms, which results in low combustion efficiency. Thus, it should be transformed into the most effective form that is in the form of biomass pellets. In addition, increasing the heating value of the biomass pellets by adding some natural additives is an interesting method to improve quality of the biomass pellets.

The previous researches were conducted with aiming to improve the physical characteristics and heating values of several kinds of biomass pellets. These parameters are, for example, effects of constituents, particle sizes, moisture content, steam conditioning/preheating of feed, densification equipment variables, addition of additives and mixers [2], [4]-[8], [13]-[15]. Most additives can be classified into two types: natural and synthetic [16]-[20]. Criteria for selection of an additive include cost and environmental friendliness.

The objectives of this research are to investigate the effect of coffee ground additive (1, 3 and 5%) on physical characteristics and heating values of sugarcane bagasse pellets. The results from this research can help developing feasible solutions to improve the pellet fuel quality in the future.

II. Materials & Methods

A. Raw Materials

Sugarcane bagasse was used as raw materials for pellets productions. The bagasse was a by-product of the sugar industry from Ban Pong Sugar Co., Ltd. (Ratchaburi Province, Thailand). The coffee grounds (pure *Arabica*), a by-product of roasted coffee, were obtained from local coffee shops in Chiang Mai province. Moisture content of raw materials was determined following the procedure described in ASTM Standard D 4442-07. The average moisture contents of bagasse before and after drying were 35- 45% and 10%-13% wt/wt, respectively. The initial moisture content of coffee grounds was determined less than 10% wt/wt. The images of the bagasse and coffee grounds are shown in Figs. 1 (a) and (b). Both raw materials were received in September 2016.

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(a) Sugarcane bagasse (b) Coffee ground

Fig. 1 Raw material and additive

B. Production Process

In order to study the effect of coffee ground residue on physical characteristics and heating values of sugarcane bagasse pellets, bagasse was mixed with coffee grounds to obtain 0, 1, 3 and 5% wt/wt, respectively.

Biomass pellet production process includes drying, grinding, pelletizing and cooling. Moisture contents of the raw materials were controlled. After the drying process, the bagasse was grinded to small particles size of 5 mm using a hammer mill screen size machine. In the pelletizing, biomass pellets were produced using a flat-die pellet mill machine (KL200B Model, China), as shown in Fig. 2. The die temperature range during the process was 75-80 ^{o}C. The pellets were pressed through the flat die by pan grinder roller. The pellets were placed in the room temperature for 24 hours before they were subjected to pellet fuel qualification testing. The average diameter of the pellets obtained was 6.0 ± 0.1 mm.

Fig. 2 Flat–die pellet mill machine

C. Pellet Physical Properties

Bulk densities of the pellet products were determined according to method described in the ASTM E-873-82 [21]. Pellet bulk density was calculated using:

$$\rho_{bulk} = \frac{W_b}{V_b} \quad (1)$$

where ρ_{bulk} = Pellets bulk density (kg/m^3); W_b = The total weight of the pellets (kg).

Durability was determined using tumbling method following the standard method of the PFI Standard Specification. Briefly, 500 g of pellet samples was filled into a standard chamber (125×300 ×300 mm). The chamber was rotated at 500 rpm for 10 minutes. This step was repeated five times. Then the samples were sieved to remove fine particles. The durability of pellets was calculated using:

$$PDI = \frac{(WPW)}{IW} \times 100 \quad (2)$$

where PDI = Pellet durability index (%); WPW = The weight of pellets after tumbling (kg); IW = weight of pellets before tumbling (kg).

D. Heating Value

The heating value (calorific value) of a combustible material is defined as the quantity of heat liberated by the complete burning of a unit mass under oxygen gas in a constant volume process. The heating value of pellet samples was determined using a bomb calorimeter according to ASTM Standard D 5865. Bomb calorimeter consists of cylinder stainless steel vessel. The lid contains two stainless steel electrodes and an oxygen inlet valve. The copper calorimeter is provided with electrically operated stirrer. The calorimeter in turn is surrounded by an air-jacket and then water jacket to prevent heat losses due to radiation. The burning of the samples and the liberated heat cause the temperature to rise which was converted to the energy equivalent of the calorimeter. The heat of combustion of samples is defined as the number of heat units liberated by unit mass of a sample when burned with oxygen in an enclosure of constant volume. The bomb calorimeter is shown in Fig 3.

Fig. 3 Bomb calorimeter

III. Results and Discussion

A. Effect of Additive on Physical Characteristics

Fig. 4 shows effect of additive on the physical appearance of the pellet products. The texture of bagasse pellets without additive (CG0%) was rather rough, compared to those with coffee grounds. It can be seen that texture of the product with coffee grounds (CG1%, CG3% and CG5%) was improved: smooth and shiny. No substantial different was detectable among the coffee grounds supplementing pellets.

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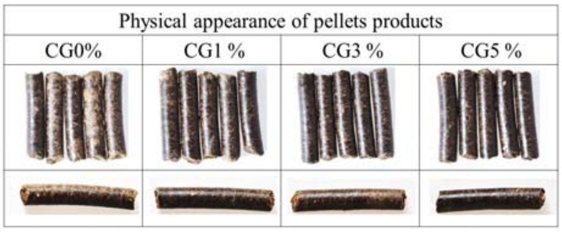

Fig. 4 Physical appearance of pellet products

The pellets' bulk densities are shown in Fig. 5. The results revealed that bulk density of control (CG0%), bagasse with 1% (CG1%), bagasse with 3% (CG3%), bagasse with 5% (CG5%) coffee grounds were 648 ± 3.4, 659 ± 3.1, 679 ± 3.3 and 685 ± 3.1 kg/m^3, respectively. The bulk densities of all samples are in acceptable range of the PFI standard (609-737 kg/m^3). From this, results revealed that the highest bulk density values were belonging to the pellet with 5% coffee ground. It was observed that the increasing percentages of coffee grounds caused increasing the bulk densities of the pellets. However, the results from statistical analysis revealed that the effect of additive at 3% and 5% by weight is insignificant ($T = 2.295$, $DF = 3$, $p = 0.105$). The similar result has also been studied by other researches that lignin and protein content in coffee grounds might be plasticized under heating during the pelletizing process, which might act as a binder between bagasse particles and consequently resulting in a higher pellets bulk density [5], [7], [15]-[16], [20].

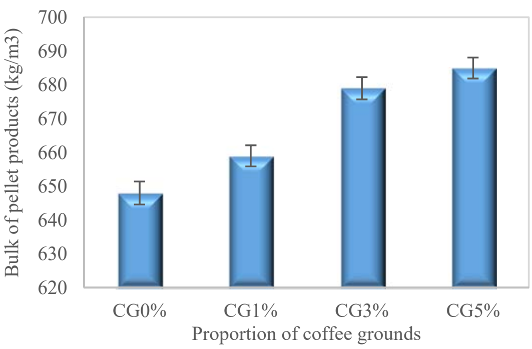

Fig. 5 Effect of proportion of coffee grounds on bulk density of pellets products

In this research, the durability of the pellets with different additive ratio of coffee grounds is shown in Fig. 6. The pellet durabilities of the CG0%, CG1%, CG3%, and CG5% were 98.7 ± 0.11, 99.2 ± 0.26, 99.3 ± 0.19 and 99.4 ± 0.07%, respectively. All durability values are in acceptable range according to the PFI standard value for durability (≥ 95 %). Statistical analysis showed that addition of additive (1-5%) affects the pellets durability ($F_{3,8} = 8.455$, $p < 0.05$). In addition, it is demonstrated that pellet product of CG5% revealed the highest value. However, no significant difference ($F_{2,6} = 0.719$, $p = 0.525$) was tested. Similar explanation to this observation is likely resulting from lignin and protein in coffee grounds [5], [7], [15]-[16], [20]. These results are consistent with the previous work on effects of kraft lignin additives (%4) on a wood fuel pellet quality [16].

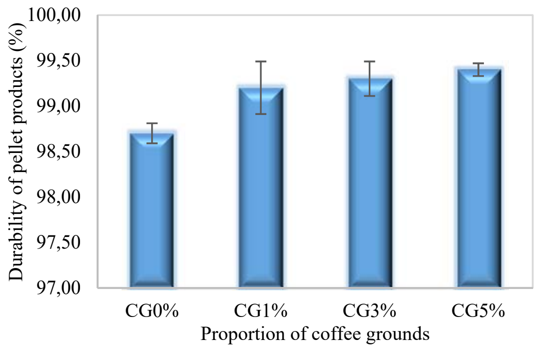

Fig. 6 Effect of proportion of coffee grounds on durability of pellets products

B. Effect of Additive on Heating Values

The heating values of bagasse pellets from both non-additive and additives are depicted in Fig. 7. The heating value of the bagasse without additive (CG0%) was 14.9 ± 1.14 MJ/kg, and with 1%, 3% and 5% of coffee ground (CG1%, CG3%, and CG5%) were 15.9 ± 1.16, 17.0 ± 1.23 and 18.8 ± 1.34 MJ/kg, respectively. In this study, heating value of coffee ground was revealed (23.36 MJ/kg) higher than the value bagasse pellet (CG0%) mentioned above. The result implies that the increase in heating values of bagasse pellets might result from storage energy of coffee grounds. These results correspond to the previous work observed on coffee meal on wood pellets from Larch and Tulip tree [15].

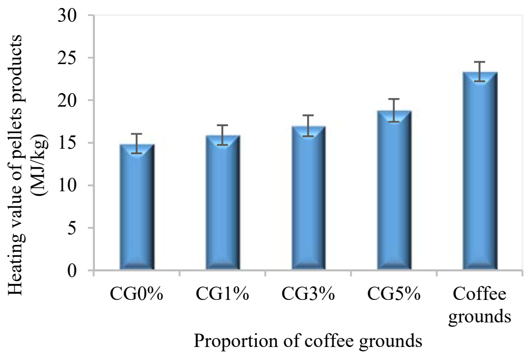

Fig. 7 Effect of proportion of coffee grounds on heating value of pellets products

IV. Conclusions

Concentrations of 1% to 5 % of coffee grounds were added to the bagasse pellets. The results obtained that the addition of coffee grounds affected the physical characteristics and heating values of bagasse pellets. The coffee grounds as additive improved texture of the pellets product. The texture of bagasse pellets with coffee grounds was smooth and shiny than homogeneous pellets. Moreover, the increasing proportion of coffee grounds increased the bulk density and durability of the pellets. Additionally, the heating value of bagasse pellet with coffee grounds showed higher values than the bagasse pellets without additive, indicating that the additive can help increasing quality of pellets.

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