# Enhancement of Physical Properties and Energy Costs in Bagasse Pellets using Agro-waste Additive

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***Abstract –*** *This study investigates the improvement of physical characteristics and energy costs in bagasse pellets using agro-waste additives. The additives were coffee grounds (CG) and corn cobs (CC), with varying proportions. The bagasse pellets were evaluated according to the standards set by the Pellet Fuels Institute. The results demonstrate that increasing the additive content significantly improved both bulk density and durability. The study revealed that the addition of coffee grounds and corn cobs at 5% improved the physical properties compared to no additives (0%). The bulk density values increased by 5.06% for coffee grounds and 3.13% for corn cobs. Furthermore, the durability values increased by 0.76% for coffee grounds and 0.37% for corn cobs. However, coffee ground additives enhance the quality of pellet fuel more effectively than corn cob additives. Due to the fine and uniform particles of coffee grounds, this results in reduced void spaces between the particles. Additionally, the coffee grounds act as a natural binder during the densification process, which enhances the durability of the pellets. It was shown that the energy costs associated with the production process of bagasse pellets using additives decreased. The reductions were 8.32% for coffee grounds and 7.55% for corn cobs. Thus, the agro-waste additives were coffee grounds and corn cobs, which improve the physical properties of the pellet. Additionally, the additives lower energy costs and enhance the performance of bagasse-based biomass pellets, providing an energy solution for a sustainable energy future.*

***Keywords*** – Bulk density, coffee grounds, corn cob, energy costs, natural additives.

## 1. INTRODUCTION

The demand for alternative energy is rising due to the depletion of fuel reserves. Additionally, the use of fossil fuels contributes to global warming and the greenhouse effect. There is a need for alternative energy sources to replace fossil fuels. Biomass is the organic material that can be converted into energy. Its advantages include a suitable heat value for producing heat or electricity [1]-[4]. As such, biomass energy has garnered ongoing interest and research as a viable alternative energy source to fossil fuels, as well as an environmentally friendly option. Thailand is one of the countries with significant biomass potential. Every year, it generates waste materials from the agricultural sector, including bagasse, cassava roots, rice husks, palm kernel shells, cassava pulp, corn cobs, and rice straws, along with wood chips. This also includes waste from industrial plants that process agricultural products and waste generated by communities [5]-[7]. The material that remains after juice extraction is called bagasse. This fibrous substance is a type of lignocellulosic biomass and consists of the leftover parts of sugarcane, which often contain high moisture levels. Bagasse is an important by-product of the sugarcane industry and can be utilized to produce renewable fuels. Using biomass to produce heat directly has limitations, including asymmetrical shape, storage space, and high transportation costs. Thus, biomass conversion technology is crucial for improving the quality of biomass fuels [8]-[11]. Currently, the pelletization is a focus because it offers several advantages, including uniform shape, lower moisture content, higher density, durability, reduced transportation costs, and lower storage costs [11]-[14]. The purpose of adding additives during the pellet fuel production process is to modify the physical and chemical properties of biomass for optimal combustion. Additionally, certain additives can help reduce the rate of slagging formation that occurs during biomass combustion. Additives are a substance added to biomass to improve its properties and performance, which can be categorized into two distinct types: natural additives and synthetic additives. Natural additives tend to have lower material costs and are more environmentally friendly compared to synthetic options. However, it is essential to determine the appropriate quantity to be added, which typically falls within a range of approximately 15%, depending on the type of additive used. Corn cobs and coffee grounds are effective biomass sources that can serve as natural additives to enhance the physical properties and chemical composition of biomass fuels. Additionally, these natural additives are suitable for use as sustainable fuels and environmentally friendly alternatives [15]-[18]. Corn cobs are the hard cores left over after the corn kernels have been harvested as agro-waste additives. The chemical composition of corn cobs includes cellulose, hemicellulose, and lignin. Additionally, corn cobs have the potential to be used as biomass fuel for

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heating production. Coffee grounds are a byproduct of coffee production and have potential as a renewable fuel source [18]-[21]. This research aims to investigate the use of coffee grounds and corn cobs as additives to improve the physical properties of bagasse pellets and reduce energy production costs. Various proportions of each additive will be tested. The bulk density and durability will be analyzed following the PFI Standard.

## 2. RESEARCH METHODOLOGY

### *2.1 Raw Materials and Production Processes*

In this research, the raw material was bagasse. The additives considered in this study were coffee grounds and corncob, both of which are agro-waste. After the drying process, the bagasse achieves a moisture content between 14%. The moisture content of the coffee grounds and corncob was below 10%. After the drying process, the materials were ground to a particle size of 5 mm. The reduction of particle size biomass is called the grinding process. The study investigated the effects of these additives at three different ratios: 1%, 3%, and 5%. The pelletizing process was conducted using a flat-die pellet mill, maintaining a die temperature of 70°C. Following the pelletizing process, the samples were subjected to cooling at room temperature, specifically 25°C.

### *2.2 Physical Properties Testing*

The bulk density and durability were evaluated using the PFI Standard. The bulk density test was conducted according to ASTM E-873-08. Bulk density was calculated using Equation 1.

$$\rho_{bulk} = \frac{W}{V} \tag{1}$$

where $\rho_{bulk}$ is bulk density (kg/m$^3$), $W$ is the total weight of the samples (kg), and $V$ is the volume of the standard box (m$^3$)

Durability is the ability of a material to remain intact under various handling conditions. The EN 15210-1 standard for the tumbling method was utilized to assess durability. The durability can be calculated using Equation 2.

$$\text{PDI}= \frac{WPW}{IW} \times 100 \tag{2}$$

where $PDI$ is pellets durability index (%), WPW is the weight of the samples after tumbling (g), and IW is the weight of the samples before tumbling (g).

Additionally, the mass yield of biomass pellets can also be calculated using Equation 3.

$$Y_m = \frac{M_T}{M_O} \times 100 \tag{3}$$

where $Y_m$ is mass yield (%), $M_T$ is the mass before pelletizing (g), and $M_O$ is the mass after pelletizing process (g).

### *2.3 Energy Cost Analysis*

In this study, the analysis of energy costs can be divided into two processes: the grinding process and the pelletizing process. The grinding machine is illustrated in Figures 1. A flat-die pellet mill machine for the pelletizing process is illustrated in Figures 2.

**Fig. 1. The grinding machine**.

**Fig. 2. The pellet mill machine**.

Both machines used in pellet production require electricity, which significantly contributes to the energy costs of pellet production. Equation 4 calculates the energy consumption involved in the pelletizing process.

$$E_p = \frac{E_{use}}{W_f} \tag{4}$$

where $E_p$is energy consumption (kWh/kg), $E_{use}$ is total energy (kWh), and $W_f$ is final weight of samples (kg).

Moreover, the total energy consumption was also calculated using Equation 5.

$$E_{total} = E_G + E_P \tag{5}$$

when $E_{total}$ is the total energy consumption of pellet production (kWh/ton), $E_P$is the energy consumption for pelletizing (kWh/ton), $E_G$ is the energy consumption for grinding (kWh/ton).

## 3. RESULTS AND DISCUSSION

### *3.1 Physical Characteristics of Pellets*

The physical characteristics of pellets of bagasse samples with additives is illustrated in Figures 3. The additives used are coffee grounds, referred to as "CG," and corn cob, referred to as "CC". The properties of the pellets were examined at additive ratios of 1%, 3%, and 5%. In addition, the bagasse pellets with coffee grounds at these ratios are referred to as "CG1%," "CG3% ", and "CG5%," while those with corn cob are referred to "CC1%," "CC3%," and "CC5%." The results indicate that the bagasse pellet without any additives (0%) exhibits cracks on its external surface. The results indicate that the bagasse pellet without any additives (0%) has cracks on its external surface. On the other hand, the pellet samples that included additives displayed similar physical characteristics. As the proportion of additives increased, the cracks on the external surface were reduced, and the texture appeared shinier. Additionally, it was found that the addition of coffee grounds resulted in a shinier texture compared to the corn cob pellets. Furthermore, the colour of the pellets containing coffee grounds was darker than that of those made with corn cobs.

0% CG1% CG3% CG5% CC1% CC3% CC5%

**Fig. 3. The physical appearance of bagasse pellets with coffee grounds and corn cobs at 1%, 3%, and 5%.**

### *3.2 Bulk Density of Pellets*

Figure 4 illustrates the relationship between additive addition and bulk density values. The average bulk density of bagasse pellets without additives (0%) is 684.34 ± 5.76 kg/m³. When bagasse pellets are added with coffee grounds at 1%, 3%, and 5% by weight, the average density values are 692.79 ± 8.93 kg/m³, 701.51 ± 4.76 kg/m³, and 718.96 ± 5.45 kg/m³. Furthermore, the bulk density of pellets with corn cob are 692.99 ± 6.47 kg/m³, 700.34 ± 1.33 kg/m³, and 705.76 ± 1.73 kg/m³. The experimental results indicated that adding coffee grounds and corn cob significantly increased the bulk density compared to samples made without additives (0%). Additionally, the bulk density of pellets with 5% coffee grounds increased by 5.06%, while the increase for corn cobs was 3.13%, compared to pellets without additives. The uniform and fine particle size of coffee grounds enhances efficient packing during the compression process, which reduces void spaces and increases structural cohesion, leading to denser and more mechanically stable pellets [12],[23]-[24]. Thus, increasing the quantity of additives demonstrates a positive effect on the bulk density pellets across all examined cases.

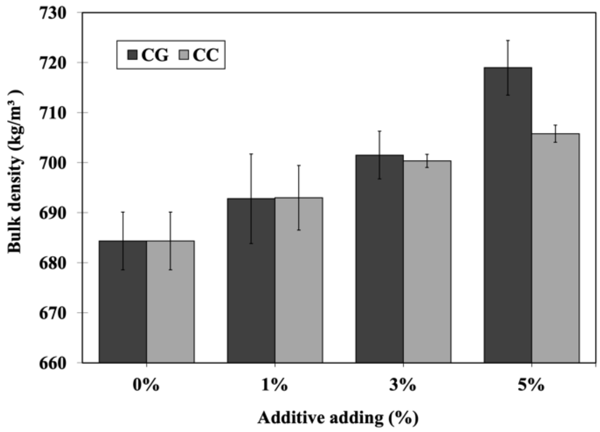


**Fig. 4. The bulk density of pellets with the additive of coffee grounds and corn cobs.**

### *3.3 Durability of Pellets*

The impact of adding coffee grounds and corn cob on the pellet durability is illustrated in Figure 5. The results indicate that the durability without additives is 98.45 ± 0.01%. When coffee grounds are added at 1%, 3%, and 5%, the durability values are 98.82 ± 0.07%, 99.01 ± 0.01%, and 99.20 ± 0.01%, respectively. Similarly, the durability of bagasse pellets with corn cob added at 1%, 3%, and 5% is measured at 98.54 ± 0.20%, 98.76 ± 0.01%, and 98.81 ± 0.07%, respectively. These experimental results demonstrate that the durability of bagasse pellets with both additives at 1%, 3%, and 5% by weight shows significant improvements compared to bagasse pellets without any additives (0%). The addition of coffee grounds at a 5% concentration showed the highest durability values. Furthermore, the durability values increased by 0.76% for coffee grounds and 0.37% for corn cobs. However, coffee ground additives enhance the quality of pellet fuel more effectively than corn cob additives. The result of this research has shown that pellets made from coffee grounds are more durable than those made from corn cobs. This increased durability is attributed to the fat and oil content in coffee grounds, which acts as a natural binder during the densification process. The heat and pressure conditions of pelletization cause the components of the biomass to partially melt, helping to fuse adjacent particles. Furthermore, the lipids and polysaccharides in coffee grounds can create thermoplastic conditions when compressed, which enhances interfacial adhesion and improves durability.

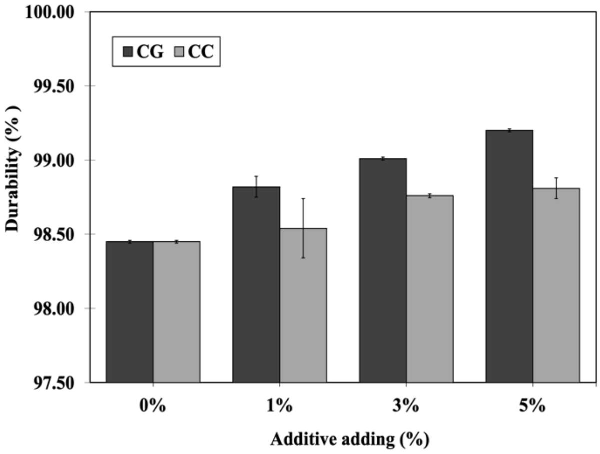


**Fig. 5. The durability of pellets with coffee grounds and corn cobs at 1%, 3%, and 5%.**

### *3.4 Yield of Pellets*

The impact of adding an additive on the mass yield of bagasse pellets was demonstrated in Figure 6. The mass yield of pellets without additives (0%) was at 97.33±0.28 %. The results indicated that the mass yield of pellets with coffee grounds at 1%, 3%, and 5% by weight were 97.56±0.31 %, 97.75±0.34 %, and 99.43±0.25 %, respectively. Furthermore, the results demonstrated that the mass yield of bagasse pellets with corn cob added at 1%, 3%, and 5% were 97.75± 0.25%, 98.32 ± 0.21%, and 98.58 ± 0.11%, respectively. The experimental results indicated that both types of additives enhanced the mass yield. Adding 5% coffee grounds resulted in the highest mass yield, a 10% increase compared to the pellet without additives.

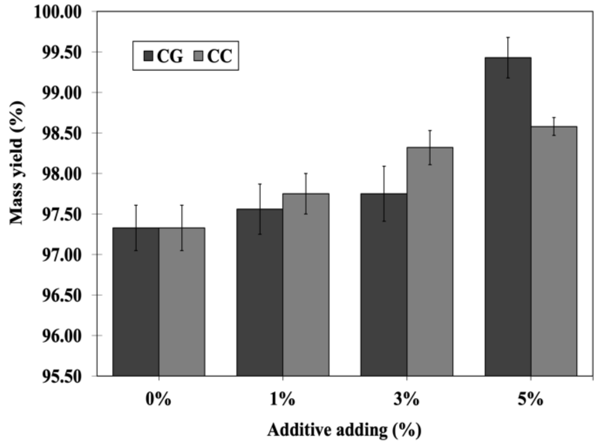


Fig. 6. **The mass yield of pellets using coffee grounds and corn cobs at 1%, 3%, and 5%.**

### *3.5 Energy Analysis of the Production Process*

The impact of adding an additive on energy consumption during production is illustrated in Figure 7. The energy consumption to produce pellets without additives is noted to be 128 kWh per ton. A comprehensive evaluation was conducted to assess the energy consumption of bagasse pellets when combined with coffee grounds at varying percentages of 1%, 3%, and 5%. The measured energy consumption values were 119.67 kWh/ton, 119.34 kWh/ton, and 117.35 kWh/ton. Additionally, the energy consumption of bagasse pellets mixed with corn cob was 119.35 kWh/ton, 118.95 kWh/ton, and 118.34 kWh/ton. Both additives were found to influence energy consumption of pellets production process. As the amount of additive increased, the energy consumption value tended to decrease. In addition, the addition of 5% coffee grounds resulted in an 8.32% reduction in energy consumption, while the incorporation of corn cobs led to a 7.55% decrease when compared to fuel without additives. The impact of the addition on energy costs was illustrated in Figures 8. The energy cost of producing bagasse pellets without an additive was 770 baht per ton. Moreover, the energy costs associated with pellets blended with coffee grounds at concentrations of 1%, 3%, and 5% were recorded at 737 baht/ton, 736 baht/ton, and 728baht/ton, respectively.

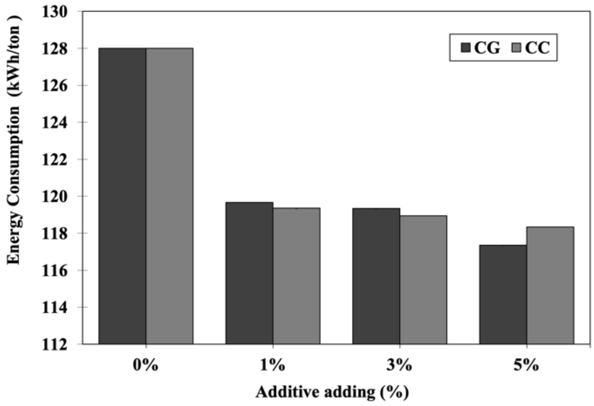


**Fig. 7. The energy consumption of pellets production process with coffee grounds and corn cobs at 1%, 3%, and 5%.**

Additionally, the energy costs with corn cob were 736 bath/ton, 735 bath/ton, and 732 bath/ton, respectively. Both additives significantly impacted energy consumption. As the amount of each additive increased, energy costs generally decreased. Furthermore, the addition of 5% coffee grounds led to a substantial reduction in energy costs.

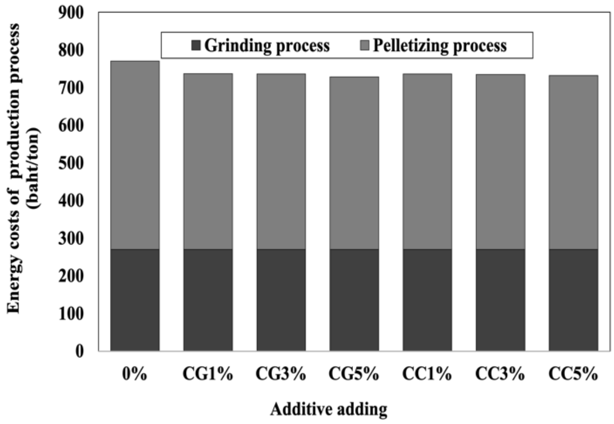


**Fig. 8. Energy cost of production process for bagasse pellets with additives**

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## 4. CONCLUSIONS

The study revealed that the addition of coffee grounds and corn cobs at 5% improved the physical properties compared to no additives (0%). The bulk density values increased by 5.06% for coffee grounds and 3.13% for corn cobs. Furthermore, the durability values increased by 0.76% for coffee grounds and 0.37% for corn cobs. %. Furthermore, the durability values increased by 0.76% for coffee grounds and 0.37% for corn cobs. However, coffee ground additives enhance the quality of pellet fuel more effectively than corn cob additives. Moreover, the addition of 5% coffee grounds resulted in an 8.32% reduction in energy consumption, while the incorporation of corn cobs led to a 7.55% decrease when compared to fuel without additives. From this research, the coffee grounds and corn cob can improve pellet quality. Furthermore, it can lower energy costs in the production process. Therefore, these promising additives enhance both the performance and economic feasibility of bagasse pellets.

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