# Moderate Die-Pressure Banana-Peel Briquettes


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## ABSTRACT

Based on the banana productivity and the residue-to-product-ratio, the estimated quantity of banana peel generated in Thailand was calculated. It was found that seven provinces were accounted for the computed value more than 12.5 kton/year. The effect of moderate die pressure and binder ratio less than 30% on banana peel briquettes was investigated. It was found that the density of the briquettes was strongly influenced by the briquetting pressure and the binder ratio. Moreover, a relationship between the density of briquettes, briquetting pressure and binder ratio over the studied range was developed and validated. The burning profile of the banana peel was also studied by using thermogravimetric method. It was found that the rapid mass loss section and the slow mass loss section were separated at the temperature of about 673 K. In addition, ultimate analysis and the heating value examination of banana peel were also conducted. Approximately, the material is comprised of 41.47% carbon, 5.68% hydrogen and 0.37% nitrogen respectively. The heating value of the banana peel was found to be 18.89 MJ/kg.



**Keywords:** *Briquette, Briquetting, Banana peel, Banana waste, Biofuel.*


## 1. INTRODUCTION

It is widely accepted that the looming fossil-fuel depletion is one of the most crucial issues for many countries. The resulting ever increasing price of such fuels in the world market seems to adversely affect economies worldwide. The use of fossil fuels is also partially responsible for global warming due to the green house effect of emissions, such as carbon dioxide. Therefore, reducing the fuel consumption together with increasing the use of alternative renewable energy sources seems to be a promising solution to these problems since the renewable energy is generally clean, safe and environmentally friendly. Out of renewable energy sources, biomass is expected to play a major role in the foreseeable future, particularly for developing countries whose economies are largely based on agricultural. It has a potential to substantially reduce carbon dioxide emissions since nearly zero net gain $CO_2$ can be achieved when sustainable production and utilization are implemented [1-2]. Generally, biomass may be divided into three main categories viz. biomass plantation, forest residue and agricultural residue. Out of these categories of biomass, agricultural residue accounts for the largest amount available worldwide. It is considered as a cheap, indigenous and abundant energy source, particularly for these countries.

Some agricultural wastes such as woodchips can be directly utilized as fuels. Nevertheless, the majority of them are bulky, uneven, fluffy and dusty. They also have low energy density and high moisture content as compared to fossil type fuels. These characteristics make this kind of waste difficult to handle, store, transport and utilize. One of the promising solutions to these problems is the briquetting technology. The technology may be defined as a densification process for improving the handling characteristics of raw material and enhancing the volumetric calorific value of the biomass. Considerable amount of research on briquetting technology has been conducted. Examples of biomass studied are wheat straw [3-4], hazelnut shell [5], grass [6-7], cotton [8-9], olive refuse [10] as well as rice straw and husk [11].

In this study, the effect of moderate die pressure and binder ratio on the density of banana peel briquettes was investigated. Furthermore, compressive strength tests were also conducted. Constituents of the banana peel were also studied by using ultimate analyses technique. By using regression method, a relationship between briquette density, applied pressure and binder ratio was also purposed. Finally, thermogravimetric investigation was also carried out in order to understand the mass loss rate of the banana peel as it is being heated at a uniform rate.

## 2. BANANA PEEL IN THAILAND

Thailand, located in the middle part of Southeast Asia, has an area of over 51 million ha. Approximately one-third of the land has been devoted to plantation. One of the most important products of Thailand is banana. It is widely grown in this country, particularly in the northern region. This fruit is an important food crop cultivated for household consumption and market supply. The majority of bananas grown for commercial purposes are Pisang awak or “Kluay Namwa”, which is considered as an AAB (triploid) type. The production of this type of fruit does not pose any severe environmental risk. Therefore, the possibility of cultivating bananas in a sustainable way can be achieved.

Generally, for sun dried banana industries in Thailand, bananas are harvested as a bunch. Then, they are delivered to a central point for inspection, cutting, curing, peeling, drying and/or other food processing prior to the packing processes at local small-factories or at village centres. After the peeling process, the banana peels are generally either uneconomically utilized or left to be disposed as they are. In Thailand, the annual production of Pisang awak (or Kluay Namwa) banana has increased dramatically from about 1 million ton in 1995 to approximately 1.6 million ton in 2001 [12]. As a result of this, a large amount of the solid waste from the banana is generated every year. The calculated amount of banana peel available in Thailand from banana product and residue-to-product-ratio [13] is shown in Fig. 1.

## 3. EXPERIMENTATION

Pisang Awak or Kluay Namwa banana peel was used as raw material in this study. The material was gathered from a local banana factory in Northern Thailand during summer of 2006. Only banana peel was utilized in this study so the material used was homogenous. The ultimate analysis of the banana peel on dry basis was also carried out in accordance with ASTM D5373-02 [14] and ASTM D5291-02 [15]. An elemental analyzer was used for this purpose. In addition, the higher heating value of the banana peel was also investigated according to ASTM E711-87 method [16]. The calorimeter used was Parr isoperibol bomb calorimeter with an accuracy of 0.0001°C.

In the study, the material was air dried and then cut into small pieces. After that, the sample was sieved in order to remove particles larger than 3 mm before use. The sieve used was U.S. no. 7 with an accuracy of ± 0.025 mm. Molasses was utilized as the binder in this study. The binder ratio was varied from 10% to 30% by weight. A digital balance, with an accuracy of ±0.001 g, was used for this purpose. After that, by utilizing a mixer, the blending process of the mixture was carried out until it reached the required condition for making moulds. For each sample, 100 g of the mixture was briquetted at ambient temperature in a calibrated laboratory-scale hydraulic press. Pressure of the hydraulic machine used in the study was controlled by a pressure switch. The accuracy of the pressure switch was 1% with a maximum pressure of 34 MPa. A hardened steel cylindrical mould with an inner diameter of 38 mm and a height of 250 mm was used as a die to produce briquettes. After feeding the mixture into the die, pressure was applied until it reached the desired value with a dwell time of 10 s. Three ultimate pressures viz. 5, 7 and 9 MPa were applied to the samples. In this study, five briquettes were prepared for each set of the experimental conditions.

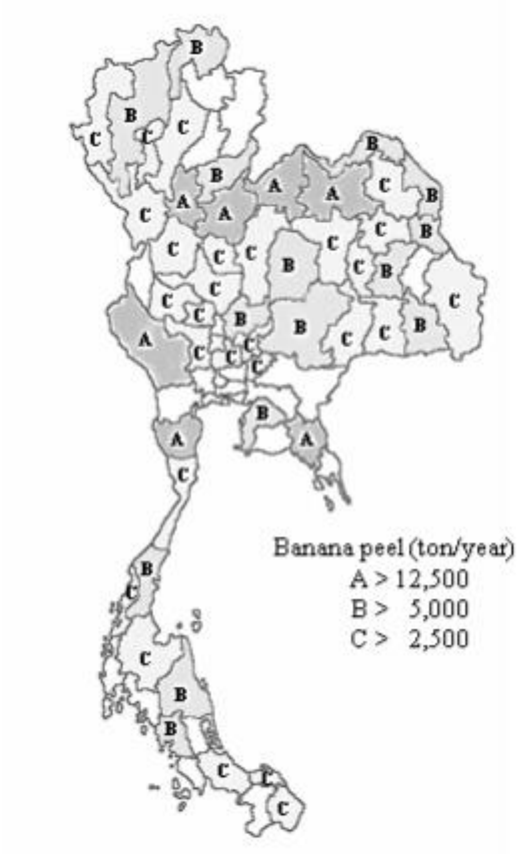


Fig. 1 Estimated quantity of banana peel generated in Thailand.

Some methods and standard tests were applied to determine the durability and physical characteristics of briquettes. According to ASAE Standard S269.4, the method was adopted for determining moisture contents of the briquettes [17]. Then, the compressive strengths of the briquettes were also investigated [18]. In this study, it was conducted by using an Instron table model 1150 universal testing machine. The capacity of the machine was up to 50 kN with an accuracy of 0.5% of applied force. The flat surfaces of the samples were placed between two horizontal plates of the machine. After applying an increased load until the samples failed, the strength values were calculated from the loads at the fracture point and cross-sectional areas of the briquettes. The relaxed density of all samples was also investigated. The measurement was conducted at 7day after removal from the die. It was examined according to the ASAE S269.4.

Furthermore, according to ASTM E1131-03 [19], thermogravimetric test of the banana peel was carried out using a thermal gravity analyzer, Perkin Elmer. The temperature range of the TGA was from room temperature to 1173 K with an accuracy of ±2 K. In addition, the accuracy of the balance of TGA was 0.1%. The temperature studied was increased from room temperature to 1123 K with a heating rate of 20 K/min.

## 4. RESULTS AND DISCUSSION

### Banana peel properties and heating profile

According to the test, it was found that the moisture content of the samples was about 15%. Also, the ultimate analyses results show that the banana peel is comprised of 41.47% carbon, 5.68% hydrogen and 0.37% nitrogen. Finally, it was also found that the higher heating value of banana peel on dry basis is 18.89 MJ/kg, which is rather higher compared to the values of several kinds of biomass material such as palm fibre, palm shell [5] and hazelnut shell [18].

Fig. 2 shows the burning profile of the banana peel used in the experiments as the temperature increased. As can be seen from the figure, the burning profile can be categorised into two main sections, viz., rapid burning section and slow burning one. The rapid burning section and slow burning section of banana peel was separated at the temperature of about 673 K. The peak of the graph represents a rapid loss in mass of the material. This may be because of the release of some volatile matters including the ignition of the combustible part of the biomass. The maximum rate of mass loss was approximately 10.2 %/min at 586 K. Approximately 54% of the combustible part of the material was burnt in this section. It was followed by a considerably decrease in the rate of mass loss which represents the slow burning region. According to the experiment, it was also indicated that the rates of these small mass losses were less than 2.5 %/min. These small losses of mass continued until the temperature was increased to 1123 K. This can be categorised as the slow burning of the semi-carbonised residue.

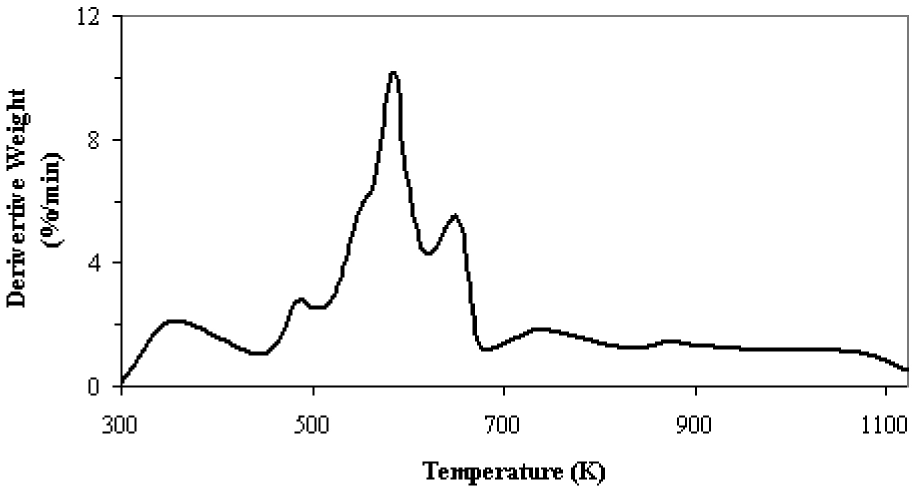


Fig. 2 Mass loss rate of the banana peel from the thermogravimetric analysis.

### Relaxed density

The relaxation of briquettes took place after removing from the die. The rate of relaxation gradually decreased until almost stable at one week. The density was found to be increased with an increase in briquetting pressure. However, the rate of increase density was found to gradually decrease as the pressure exceeds 7 MPa. In the same way, it can be seen that the density was also increased with an increase in binder ratio.

Moreover, the relationship between relaxed density, briquetting pressure as well as binder ratio over the range and condition studied was also developed by using regression technique. The proposed relationship is valid for briquetting pressure ranging from 5-9 MPa and molasses binder ratio ranging from 10-30%.

$$D = -155.21P^2B^2 + 54.22P^2B - 1.77P^2 + 2042.00PB^2 - 688.78PB + 29.71P - 6967.85B^2 + 2606.48B + 785.22$$

where D: the relaxed density ($kg/m^3$), P: briquetting pressure (MPa) and B: binder ratio (%).

The adequacy investigation of the regression was evaluated by using the coefficient of multiple determinations for prediction: $R^2_{prediction}$ [20]. It was found that the $R^2_{prediction}$ is 97%. This statistic gives the indication of the predictive capability of the regression equation. Hence, the proposed equation can be expected to explain approximately 97% of the variability in predicting new observation.

The compressive strength was calculated from the load at the fracture point and the cross-sectional area of the briquette. It was found that the average values for 5MPa, 7MPa and 9MPa briquettes were 778.23, 884.50 and 901.03 kPa, respectively. For moderate pressure range, the strength values from this study were found to be considerably higher than the values of palm-residue briquettes [18].

## 5. CONCLUSION

Banana peel, by product from banana industries, with molasses can be compacted into briquettes by moderate-pressure briquetting process. The density of the briquettes is strongly affected by the briquette pressure and the binder ratio. It was found that the rate of increase density was gradually decreased as the briquetting pressure was over 7 MPa. Also, a slowly decrease in the rate of increase density was reported for the case of briquettes with binder ratio greater than 20%.A relationship between the briquette density, briquetting pressure and binder ratio was also developed and validated. The average compressive strength of the briquettes was over 700 kPa. With regard to the raw material, banana peel, it was found that the maximum mass loss rate was at 586 K. The rapid burning section and slow burning section of banana peel was separated at the temperature of about 673 K. The heating value of the material was slightly higher than several kinds of agricultural residues.

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