Vol. 2 No. 1 page 74-79
DOI: 10.14456/randk.2016.10

RESEARCH & KNOWLEDGE

Research Article

The effect of particle size on the bulk density and durability of pellets: bagasse and eucalyptus bark

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(Received 19 November 2015; accepted 25 December 2015)

Abstract - This research aimed to study the effect of particle size on the bulk density and durability of biomass pellets. In this study, the biomass pellets were made from the distinctive raw materials of bagasse and eucalyptus bark. The particle sizes of the samples were 2 mm, 5 mm and 9 mm. This study applied the pelletization method in the experiment and used the Pellet Fuel Institute (PFI) Standard to verify the pellet durability and the pellet bulk density. The results show that the increase of particle sizes from 2 mm to 9 mm decreased the pellet bulk density of bagasse and eucalyptus bark by 2.92% and 4.94%, respectively. In addition, it was also found that the increase in particle size from 2 mm to 9 mm decreased the pellet durability of bagasse and eucalyptus bark by 0.88% and 1.33%, respectively. When the pellet bulk density and pellet durability of bagasse and eucalyptus bark were compared, it demonstrated that the pellet bulk density of the eucalyptus bark was higher than that of the pellet bulk density of bagasse. With regards to this study, it concludes that the decrease in the values in both the pellet bulk density and the pellet durability depended on the increase in the particle size. Therefore, the optimum particle size to produce pellets from bagasse and eucalyptus bark in this research was 2 mm.

Keywords: Particle size, pellet bulk density, pellet durability, bagasse, eucalyptus bark

1. Introduction

Thailand is confronted with an unbalance in energy consumption as more energy is consumed than produced. This unbalance of energy consumption greatly increases the imported energy in every year, which results in a high energy cost. Thus, it is necessary to find other energy sources as alternative sources. Thailand has been well known as an agricultural country with plenty of biomass production. Currently the price of biomass from agriculture residue in Thailand is still low. The government has promoted the use of indigenous products as energy sources and renewable energy. Regarding the energy situation, it reduces the financial burden of the government on imported oil (Prasertsan and Sajjakulnukit, 2006). Biomass is an important source of renewable energy, it is the second major energy source in the country, especially for households and small industries in rural areas. Biomass is produced from agricultural residues and waste products such as rice husk, straw, bagasse, corncob, palm leaf and bark (Papong *et al*., 2004; Ministry of Energy Thailand, 2011). Bagasse and eucalyptus bark are two significant waste products from industry that can be used to produce renewable fuels. Bagasse is a fibrous material with high moisture content from the remains of sugarcane after it was crushed to extract juice. It has been used as fuel and in the manufacture of pulp and building materials (Department of Alternative Energy Development and Efficiency, 2012). Bagasse produces the lowest amount of ash, it has a lower phosphorus content than most other types of biomass, which is advantageous as phosphorous has been reported to be problematic (Erlich *et al*., 2005; Kruczwk, 2008). Additionally, eucalyptus bark is a waste product from the paper industry, which has a high lignin content and pelletizes well with a high calorific value. Raw materials for fuel generally are the waste products that have asymmetrical forms and they are burnt to create the energy. However, the cost of transportation and storage of these raw materials are significantly high due to their asymmetrical shapes, which need more carrying space. This shape of the raw material, additionally, has a high moisture content and low bulk density. One of the solutions to reduce the transportation and storage cost is to compact the biomass materials in a densification, which is called a pellet. A pellet is a cylindrical organic fuel made by the compression of biomass. This pellet can be defined as a densified material that is obtained by pressing the material

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through the holes of a die. Biomass pellets can be used to replace oil fuel and natural gas because they are renewable and do not pollute the environment (Marcia *et al*., 2012; Guimarães *et al*., 2009; Kaliyan and Morey, 2010; Karkania *et al*., 2012). Pellets have proper qualifications with low moisture content and high bulk density, this has benefits for safe storage and proficient transportation (Kaliyan and Morey, 2010; Karkania *et al*, 2012; Mani *et al*., 2006; Garcia-Maraver *et al*., 2015). Both waste products can be suitably used as the raw material for pellet making, the waste products produce a pure pellet with high calorific value. Pellets have a variety of physical properties including size, bulk density and durability. These parameters have been investigated by several researchers, especially the effect of pellet qualities, such as particle size, moisture content, preheating of feed and additive (Karkania *et al*, 2012; Mani *et al*., 2006; Garcia-Maraver *et al*., 2015; Warajanont and Soponpongpiat, 2013; Kaliyan and Morey, 2005; Kaliyan and Morey, 2009; Kaliyan and Morey, 2010; Peng *et al*., 2012).

The objective of this study was to investigate the effect of the particle size of bagasse and eucalyptus bark on pellet bulk density and durability. This paper, moreover, provides an optimum particle size for producing bagasse and eucalyptus bark pellets in pellet mills, the result can be further used to improve the development of the bulk density and durability.

2. Materials and method

2.1 Raw material

In this study, the raw biomass materials were the waste products from industry, which were bagasse and eucalyptus bark. The bagasse is a by-product of the sugar industry after extracting the juice, the bagasse was used as the raw material in this study. The bagasse was collected from Ban Pong Sugar Factory in Ratchaburi, Thailand. The bagasse had an initial moisture content of about 35%-45%. Raw materials of eucalyptus bark were by-products of SCG Paper Industry Co., Ltd., Ban Pong, Ratchaburi, Thailand. The initial moisture content of the eucalyptus bark was 13%-15%. Both raw materials were received in March 2014. Different particle sizes were selected for the study due to the particle size of the biomass strongly influencing its pellets quality. The raw materials of waste products from industry were bagasse and eucalyptus bark, as shown in Figure 1 (a) and 1(b).

(a) Sugarcane bagasse

(b) Eucalyptus bark

Figure 1. Raw material of waste products from industry.

2.2 Pallet fuel production

The production process of the bagasse and eucalyptus bark pellets is shown in Figure 2. First step, the raw material is prepared from sugarcane and paper industry. The raw materials have water removed to control its moisture at 10-15 % by mass (dry basis) for this study; this process was called dehumidifying. The next step was to reduce the size of the raw materials by using a screen size hammer mill machine. After being milled, the particle sizes of the raw materials had three different values: 2 mm, 5 mm and 9 mm. The following step was to form the milled biomass with a pelletization machine, this is called pelletization and shown in Figure 3. Both raw materials required compressing by a flat-die pellet mill machine (KL200B Model, China). The die temperature in this process was between 70^{o}C - 80^{o}C. Subsequently, the raw materials, which had a high temperature and softness, required a cooling process to reduce the temperatures of the pelletized fuel from 80^{o}C to 25^{o}C. This step was significant for the qualification of the pellet fuel: it can get a hard texture that is required for transportation after cooling by air. The average diameter of the pellets was 6.5 ± 0.1 mm. The final step was qualification testing in which the pellet fuel samples were brought to a specification testing corresponding to a Pellet Fuel Institute (PFI) Standard Specification to verify the durability of the pellet, the bulk density and the pellet fine content.

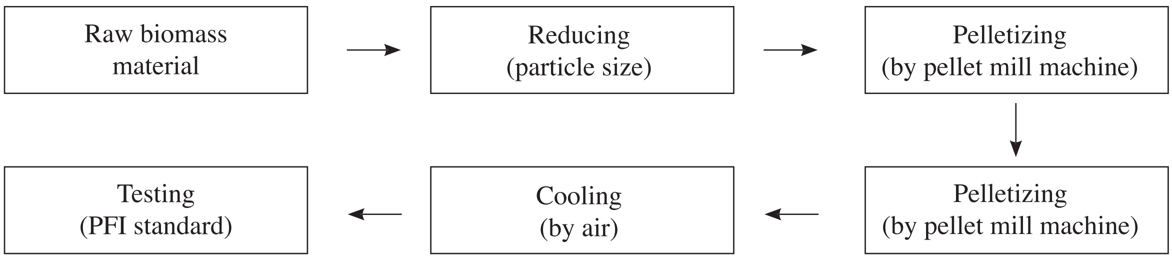

Figure 2. Production process of sugarcane bagasse and eucalyptus bark pellets.

Figure 3. Flat–die pellet mill machine.

Figure 4. Testing machine for bulk density.

2.3 Pellet fuel qualification testing

This study employed the PFI Standard Specification to verify the pellet durability and the pellet bulk density. The testing procedure for measuring the pellet bulk density and the pellet durability is explained in the following. The pellet bulk density could be determined by filling biomass pellet fuel samples into a standard box of size 305 mm x 305 mm x 305 mm (length×width×height) according to ASTM E-873-82 (ASTM Standards, 2006). The testing machine is shown in Figure 4. The biomass pellet fuel samples were released from a height of 610 mm into a shaking box and released at a 150 mm height for five times to ensure that the box was full of the biomass pellet fuel sample. Finally, the box was weighted and the value of the pellet bulk density was calculated. The pellet bulk density was calculated by using the following formula:

$$\rho_{bulk} = \frac{W_b}{V_b} \tag{1}$$

where ρ_{bulk} is the pellet bulk density, W_b is the total weight of the pellets, and V_b is the volume of the measuring standard box.

In addition, the effectiveness of the inter-particle bonds created during the densification process was measured in terms of durability. This test can help to control the pellet quality to feed the manufacturing industry, for which the pellet fuel must have a high durability. The durability of the pellet fuels was determined by a tumbling method according to EN 15210-1. This test simulates the mechanical handling of biomass pellet fuel samples, and it is used to predict the possibility of fines being produced due to mechanical handling. The test equipment for the tumbling method is shown in Figure 5. The pellet fuel without any fine particles of 500 g is filled into the chamber and exposed to 500 rotations in a time interval of 10 minutes. After tumbling, the sample is removed and sieved, and the percentage of the whole pellets was calculated using the following formula:

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

where PDI is the Pellet Durability Index, WPW is the weight of the pellets after tumbling, and IW is the weight of the pellets before tumbling.

The fines produced, or pellet fines content (%*Fines*), was determined from the mass loss of the pellet fuel sample. The initial mass was recorded. The pellet fuel sample was shaken on a 1/8 screen mesh 10 times by side to side shaking. This testing was recorded in terms of the percentage of fine in the tested pellet fuel sample. The percentage of fine (%*Fines*) was calculated using the following formula:

$$\%Fines = \frac{\lfloor (W_p + W_f) \rfloor - W_p)}{W_i} \times 100 \qquad (3)$$

where $\%Fines$ is the fines produce or pellet fines content, W_p is the weight of the base pan, W_f is the weight of the fines and W_i is the initial sample weight.

Figure 5. Durability testing machine.

3. Result and discussion

3.1 Effect of particle size on bulk density of pellet fuel

The pellets of bagasse and eucalyptus bark were in a cylindrical form that had an average diameter of 6.5±0.1 mm. The pellet bulk density of the pellet fuel sample was measured using the standard box according to ASTM E-873. Figure 6 shows the result of the pellet bulk density values of bagasse and eucalyptus bark in particle sizes for the raw material of 2 mm, 5 mm and 9 mm. The pellet bulk density values of bagasse pellets in the sizes of 2 mm, 5 mm and 9 mm were 635.56±1.28 kg/m^3, 632.78±1.17 kg/m^3 and 616.97±2.15 kg/m^3, respectively. The pellet bulk density values of the eucalyptus bark pellets were 743.73±4.39 kg/m^3, 720.82±4.23 kg/m^3 and 706.93±5.12 kg/m^3, respectively. Comparing the pellet bulk densities of the two materials in this experiment, the eucalyptus bark had a higher density than the bagasse due to the pellets generating more voids between the particles. However, it should be noted that the pellet bulk densities of bagasse and eucalyptus bark were similar; the increasing particle size of the raw materials caused the decrease in the pellet bulk density. This happened because the particle contact area of the two materials generated a strong bond. Moreover, the contacted area of a large particle was less than the contacted area of a small particle. This result is similar to previous studies in which scholars made use of a screen size for pine sawdust pellets (Kaliyan and Morey, 2009; Peng *et al*., 2012). Therefore, the decrease in the pellet bulk density with increase in the particle size of the raw bagasse and eucalyptus bark could be seen from this experimental result so that the increase in the particle size from 2 mm to 9 mm caused a decrease in the pellet bulk density of 2.92% in bagasse and of 4.94% in eucalyptus bark.

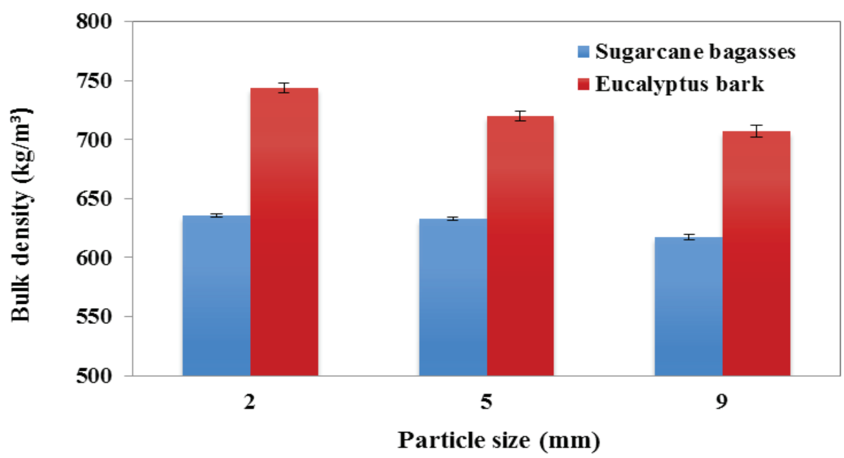

Figure 6. Effect of particle size on bulk density of bagasse and eucalyptus bark pellets.

3.2 Effect of particle size on durability of pellet fuel

The particle size effect on the durability of pellet fuel in this study was made from different particle sizes of bagasse and eucalyptus bark. Figure 7 shows the results of the pellet durability values for bagasse with particle sizes of 2 mm, 5 mm and 9 mm, which were 96.04±0.25 %, 95.26±0.08 % and 95.19±0.21%, respectively. The pellet durability values of eucalyptus bark were 97.31±0.19 %, 96.75±0.20 % and 96.01±0.19 %, respectively. Comparing the pellet durability of the eucalyptus bark and bagasse, it was found that the pellet durability of the eucalyptus bark was higher than the bagasse. In addition, it demonstrated that the increase in the particle sizes of the bagasse and eucalyptus from 2 mm to 9 mm caused a decrease in their pellet durability to 0.88 % and 1.33%, respectively. Due to the inter-particle bonds that occurred during the pelletization process a solid bridge between the particles was created, the bonds of the smaller particle size were higher than for the large particle size. During the pelletization process, the solid bridges in the biomass can be formed between particles due to the hardening of the binders and solidification of melted components. Moreover, the large particle size causes cracks and fractures in the pellets (Kaliyan and Morey, 2010; Peng *et al*., 2012). The same tendency was found regarding the particle size of corn stover pellets (Kaliyan and Morey, 2005). Thus, it can be concluded that the particle size affected the pellet durability of bagasse and eucalyptus bark pellets; the pellet durability depended on the increase in the particle size.

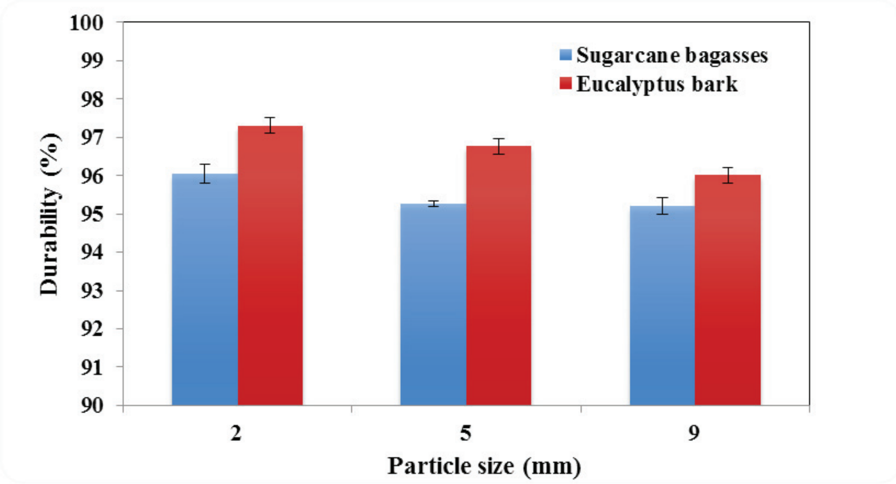

Figure 7. Effect of particle size on durability of bagasse and eucalyptus bark pellets.

3.3 Effect of particle size on pellet fines content

Figure 8 shows the particle size distribution of the pellet fines content of bagasse and eucalyptus bark. It was found that the pellet fines contents (%*Fines*) of the bagasse pellet with the particle sizes of 2 mm, 5 mm and 9 mm were 0.04±0.01 %, 0.05±0.01 % and 0.05±0.01 %, respectively. It should be noted that the different particle sizes of bagasse did not affect the pellet fines content. Furthermore, the pellet fines content values of the eucalyptus bark pellets with the particle sizes of 2 mm, 5 mm and 9 mm were 0.03±0.01 %, 0.09±0.01 % and 0.10±0.01 %, respectively. With regards to this study, the increases in the pellet fines content values depended on the increase in the particle size.

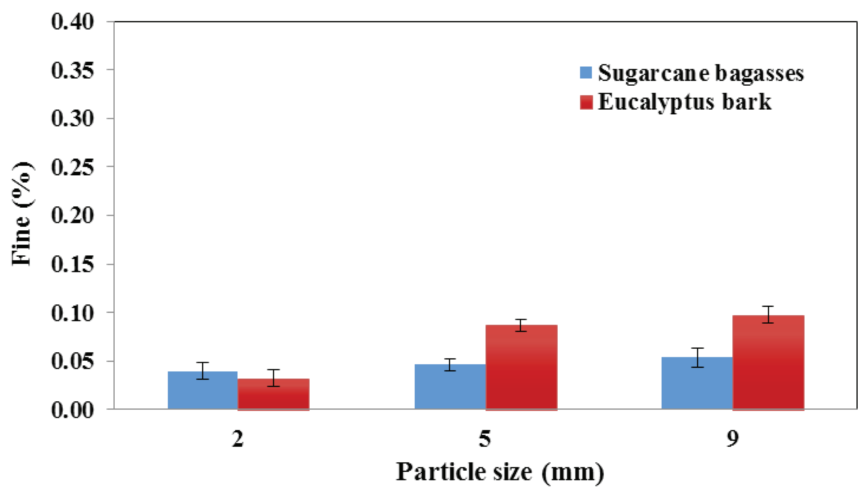

Figure 8. Effect of particle size on pellet fines content of bagasse and eucalyptus bark.

4. Conclusion

According to the experimental results, the increase in particle size of bagasse and eucalyptus bark decreased the pellet bulk density and the pellet durability. All the results for the bulk density, durability and pellet fines content were made after the qualification testing and confirmed to the requirements of the PFI Standard Specification for Residential/Commercial Densified. It could be seen that the increase in particle size from 2 mm to 9 mm caused a decrease in the pellet bulk density of bagasse by 2.92% and of eucalyptus bark by 4.94%. In addition, it also demonstrated that the increase in particle size from 2 mm to 9 mm caused decreases in the pellet durability of bagasse and eucalyptus bark of 0.88 % and 1.33 %, respectively. When comparing the pellet bulk density and the pellet durability of bagasse and eucalyptus bark, it was found that the pellet bulk density and the pellet durability of eucalyptus bark were higher than for bagasse. However, it was also shown that the pellet bulk density and pellet durability of bagasse and eucalyptus bark had similar results. With regards to this study, the decrease in the values of both the pellet bulk density and the pellet durability depended on the increase in the particle size. Moreover, the optimum particle size for producing pellets from the waste products of bagasse and eucalyptus bark in this research was two millimeters.

Acknowledgements
The authors gratefully acknowledge the Department of Mechanical Engineering, Faculty of Engineering and Industrial Technology, Silpakorn University (Sanam Chandra Palace Campus) for all support. We wish to thank Kanoknut Pratheepsakunthong, Kamonchanok Panyajirawut, Nutchanon Kominand and Amornchai Sahawongwattana for very helpful assistance.

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