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Original Article

Size Reduction Characteristics of Yellow Poplar in a Laboratory Knife Mill[1]

Hyoung-Woo Lee[2,†]

ABSTRACT

Size reduction is one of the major pre-processing operations in using biomass as a source of energy or raw materials for forest products industry. The grinding characteristics of dried yellow poplar wood chips were investigated using laboratory knife mill with three different screen aperture diameters to provide the basic information for the optimizing of size reduction processes in biomass industry. Average specific energy consumptions were 0.157, 0.137, and 0.093 Wh/g for the screen aperture diameters of 5.0, 7.5, and 9.0 mm, respectively. According to the results of size distribution analysis of ground particles, the sizes of the most of ground particles were much smaller than the aperture diameters of the screens installed on knife mill used in this study.

Keywords : size reduction, biomass, knife mill, specific energy consumption for milling, particle size distribution, *Liriodendron tulipifera* L.

1. INTRODUCTION

Size reduction is one of the major pre-processing operations in using biomass as a source of energy or raw materials for forest products industry. The design and choice of the grinders for the size reduction is important for reducing the energy input in preparing biomass or raw materials (Naimi *et al*., 2006). For instance, the size, shape, and uniformity of raw material are important quality characteristics for the manufacturing of biomass pellets. Size reduction of biomass is also necessary in biofuel industry such as bio-ethanol because large-size biomass cannot be converted to biofuels efficiently (Zhang, 2014). Proper ground size of corn stover for acid hydrolysis in making ethanol was found to be 20 mesh and about 6 mm for gasification (Womac *et al*., 2007).

Comprehensive knowledge for particle size reduction of biomass is lacking in scientific literature. The lack of studies about the effects of aperture diameter of grinder screens on energy consumption in size reduction and particle

1 Date Received November 19, 2015, Date Accepted December 28, 2015
2 College of Agriculture and Life Science, Chonnam National University, Gwangju 61186, Republic of Korea
† Corresponding author: Hyoung-Woo Lee (e-mail: dryingeng@daum.net)

size distribution makes it difficult to decide which screen aperture diameter should be selected in order to minimize the energy consumption in size reduction and maximize the productivity in manufacturing biomass fuels or wood products.

This work was carried out to investigate the grinding characteristics of dried yellow poplar wood chips to provide the basic information for the optimizing of size reduction processes in biomass industry.

2. MATERIALS and METHODS

2.1. Material preparation

Yellow poplar (*Liriodendron tulipifera* L.) wood chips were provided by Korea Forestry Research Institute (KFRI). Average moisture content of yellow poplar wood chips were measured as 8% (wet based) by oven-drying method. The wood chips that could not pass the sieve with aperture size of 31.5 mm were rejected to simulate the industrial process.

2.2. Analysis of energy consumption

A laboratory scale knife mill (Model No. LKM2015, Drying Engineering, Inc., Korea) was used for size-reduction of wood chip. It was equipped with a three-phase 3.75 kW electric motor. The rotation speed of the motor was 1720 rpm.

Fig. 1 shows experimental setup for knife milling of wood chips. Four knives (107 mm long and 30 mm wide) were mounted on the rotor inside the milling chamber. Two cutting bars were mounted on the inside wall of the milling chamber. Wood chips were cut into particles between the knives and the cutting bars. The gap between the knives and the cutting bars was set at 3 mm. Screen with three aperture sizes (9, 7.5, and 5 mm, respectively) were used in this study (Fig. 2). During knife milling, wood particles that are smaller than the screen aperture diameter will pass through the screen. But those larger than the screen aperture diameter will be recirculated and milled further.

Energy consumption is the electricity consumed by the electric motor of the knife mill. Lee *et al*. (2005) studied on the power consumption in peripheral milling of twelve Korean domestic wood species by measuring the electricity consumed by the planer. Electric current to the motor was measured using a AC current clamp (Model No. OM-PLCV, Omega Engineering, Inc,, USA). Current data were collected using software through data logger (Model No. OM-PL, Omega Engineering, Inc., USA). The sampling rate was set at one reading per second. Data acquisition began before the wood chip sample was loaded into the knife mill chamber to identify the current data during the idling period with no load in the knife mill chamber. In this study the currents during the idling period ranged 5.1 ~ 5.3 A. The current increased immediately after the sample loading and decreased to the current during the idling period after all the particles were discharged from the knife mill chamber. Therefore, it was

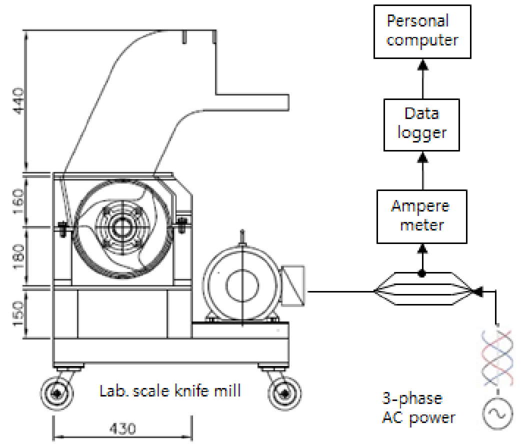

Fig. 1. Experimental setup for knife milling of wood chips.

possible to identify the current data only for the particle loading period. Weights of sample per one charge were 100, 150, and 200 g/charge, respectively for each screen aperture diameter.

The processing time was identified and the average current during this processing time was calculated in each test. The input voltage was three-phase 380 V. The energy consumed during each test that lasted for t seconds was calculated using the following equation (Zhang *et al.*, 2012):

$$E_t = \frac{\sqrt{3} \cdot I_{avg} \cdot V \cdot t}{3600} \quad [1]$$

E_t : energy consumption (Wh)
I_{avg} : average current (A)
V : input voltage (V)
t : processing time (s)

Dividing E_t by the weight (w) of the wood particles loaded into the knife mill chamber

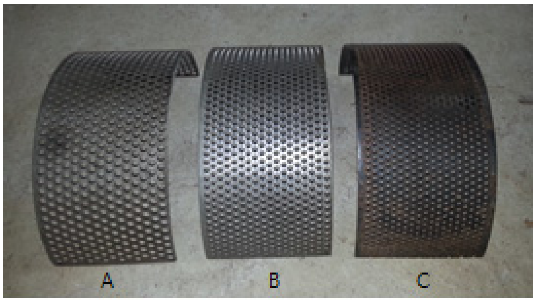

Fig. 2. Screens used in knife milling (A: aperture size 9.0 mm, B: aperture size 7.5 mm, C: aperture size 5.0 mm).

gives the specific energy consumption (energy consumption per unit weight of sample loaded), as expressed in Equation [2]:

$$E = \frac{E_t}{w} \quad [2]$$

E : specific energy consumption (Wh/g)
w : weight of sample loaded (g)

2.3. Size distribution and moisture contents of particles

Wood particles produced by knife milling were not uniform in their sizes. Particle size distributions were determined using a sieve shaker. A stack of four sieves were arranged from the largest to the smallest in aperture size. The aperture sizes used were 4, 2, 1, and 0.5 mm. A pan with no opening was put at the bottom of these sieves. 100 g of wood particles were loaded onto the top sieve. The sieve shaker was on for 5 minutes. Afterwards, wood particles retained on each sieves were collected and weighed. The percentage of the wood

Table 1. Energy consumptions in knife milling of yellow poplar wood chips with three different screen aperture diameters and at three different sample input rates

Screen aperture diameter	9.0 mm			7.5 mm			5.0 mm		
w (g)	100	150	200	100	150	200	100	150	200
I_{avg} (A)	5.9	6.1	7.0	6.5	7	7.6	6.1	6.5	7.3
t (sec.)	9	13	18	14	20	24	16	22	30
E_t (Wh)	9.32	13.55	19.12	14.37	21.15	25.71	16.18	22.76	31.78
E (Wh/g)	0.09	0.09	0.10	0.14	0.14	0.13	0.16	0.15	0.16

(w(g) : weight of sample loaded per charge, I_{avg}(A) : average current per charge, t(sec.) : processing tiem per charge, E_t(Wh) : total energy consumption per charge, E(Wh/g) : specific energy consumption)

particles in each of the five particle size ranges (> 4.0 mm, 4.0 ~ 2.0 mm, 2.0 ~ 1.0 mm, 1.0 ~0.5 mm, and < 0.5 mm) was translated to particle size distribution.

The moisture contents of particles were determined by oven-drying method for each screen aperture size.

3. RESULTS and DISCUSSION

3.1. Energy consumption in knife milling

Fig. 3 shows the ampere curves at the sample input rate of 200 g/charge with three screen aperture diameters of 9.0, 7.5, and 5.0 mm. As expected, amperes increased instantly after wood chip samples were put into the knife mill. Then amperes went down gradually as the milled wood chips were discharged.

As shown in Table 1, energy consumption in knife milling of wood chips increased dramatically with decrease of screen aperture diameter. For instance, energy consumption was as high as 0.15 ~ 0.16 (average 0.157) Wh/g for 5.0 mm screen and only 0.9 ~ 0.10 (average 0.093) Wh/g for 9.0 mm screen. That for 7.0 mm screen was 0.13 ~ 0.14 (average 0.137) Wh/g. Energy consumption increased by about 69% as the screen aperture diameter decreased from 9.0 mm to 5.0 mm.

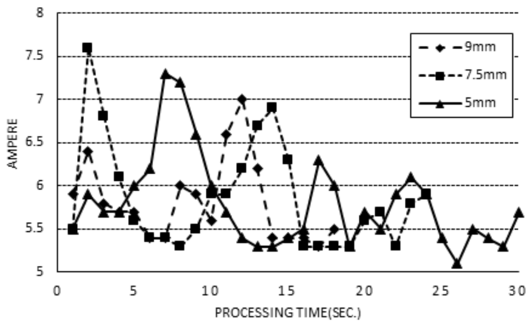

Fig. 3. Ampere curves at the sample input rate of 200 g/charge with three screen aperture diameters of 9.0, 7.5, and 5.0 mm.

Zhang *et al.* (2012) reported energy consumption 0.16 Wh/g for 4 mm screen in knife-milling of poplar wood chips with moisture content of 10%.

As sample input rate per charge (100, 150, and 200 g/charge) increased, processing time also increased. However, the effect of sample input rate on the energy consumption per unit weight could not recognized. This may be due to the knife mill capacity that is too big for the sample input rate per charge.

3.2. Particle size distribution

Fig. 4 shows the effect of the knife mill screen aperture diameter on the particle size distribution. Decreased screen aperture diameter resulted in decreased particle size, as expected. Percentages of particles in the size smaller than 2.0 mm were about 67, 43, and 27% for knife mill screen aperture diameter of 5, 7.5, and 9 mm, respectively. On the other hand, percentages of particles in the size larger than 4.0 mm were 0, 2, and about 12% for 5, 7.5, and 9 mm, respectively. It was found that the sizes of most ground particle were much smaller than the aperture diameters of the screens installed on knife mill this study.

Particle size is very important from a flow and mechanical interlocking aspect during the pelletizing process. Although fine particles produce more durable pellets, fine grinding is undesirable because of increased cost of production due to the increase of power consumption in grinding and pelletizing process. A mixture of different particle sizes would give optimum pellet quality because the mixture of particles will make inter-particle bonding with nearly no inter-particle spaces (Kaliyan and Morey, 2008). However an amount of fines (particles smaller than 0.5 mm in diameter) that is too high in the raw material has a negative impact both on friction and pellet quality. As a rule of thumb, the amount of fines should not exceed 10 to 20% unless a binding agent is added (Stelte *et al.*, 2012). In this study the amounts of fines did not exceed 4% with all the aperture diameters of screens in the knife mill.

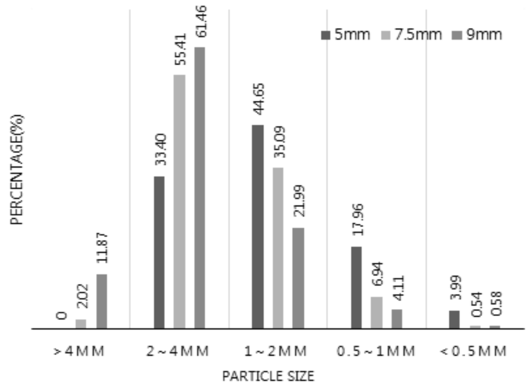

Fig. 4. Particle size distributions of yellow poplar wood chips through the knife mill with three screen different aperture diameters of 9.0, 7.5, and 5.0 mm.

Optimal particle size distribution should be determined according to the diameter of pellets to be produced and the biomass species used. Then the proper screen aperture size can be selected for size reduction process. It can be recommended that particles from the proper grinding process are separated into several particle size groups and particles from each group are mixed into the optimal particle size distribution for pellet production.

Table 2 shows the average moisture contents (wet-based) of wood chips and particles produced. Ground particles showed slightly lower moisture contents than that of wood chips. These moisture content reductions seem to be mainly due to the heat induced by the friction

Table 2. Average moisture contents (MC) of wood chips and ground particles

Item	MC (%)
Wood chips	8.00
Particles ground with screen aperture diameter of 5.0 mm	7.76
Particles ground with screen aperture diameter of 7.5 mm	7.23
Particles ground with screen aperture diameter of 9.0 mm	7.83

during grinding.

4. CONCLUSION

In this study the specific energy consumptions in size reduction process of dried yellow poplar wood chips were investigated with three different screen aperture diameters. Size distributions of ground particles were also investigated.

Average specific energy consumptions were 0.157, 0.137, and 0.093 Wh/g for the screen aperture diameters of 5.0, 7.5, and 9.0 mm, respectively. Average specific energy consumption increased by about 69% as the screen aperture diameter decreased from 9.0 to 5.0 mm.

The sizes of the most of ground particles were much smaller than the aperture diameters of the screens installed on knife mill used this study.

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