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Research Article

Influence of the Feed Moisture, Rotor Speed, and Blades Gap on the Performances of a Biomass Pulverization Technology

Siyi Luo,[1] Yangmin Zhou,[1] Chuijie Yi,[1] Yin Luo,[2] and Jie Fu[3]

[1] *School of Environmental and Municipal Engineering, Qingdao Technological University, Qingdao 266033, China*
[2] *State Key Laboratory of Pharmaceutical Biotechnology, School of Life Sciences, Nanjing University, Nanjing 210093, China*
[3] *Environmental Engineering Program, Department of Civil Engineering, Auburn University, Auburn, AL 36849, USA*

Correspondence should be addressed to Siyi Luo; 156176878@qq.com and Jie Fu; jzf0017@auburn.edu

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Recently, a novel biomass pulverization technology was proposed by our group. In this paper, further detailed studies of this technology were carried out. The effects of feed moisture and crusher operational parameters (rotor speed and blades gap) on product particle size distribution and energy consumption were investigated. The results showed that higher rotor speed and smaller blades gap could improve the hit probability between blades and materials and enhance the impacting and grinding effects to generate finer products, however, resulting in the increase of energy consumption. Under dry conditions finer particles were much more easily achieved, and there was a tendency for the specific energy to increase with increasing feed moisture. Therefore, it is necessary for the raw biomass material to be dried before pulverization.

1. Introduction

Concerns about the depletion of fossil fuel reserves and the pollution caused by continuously increasing energy demands have made biomass an attractive alternative energy source [1]. However, the disadvantages of raw materials (i.e., variability of quality and calorific value, difficulty in controlling the rate of burning and in mechanizing continuous feeding) limit the industrial application of biomass [2, 3]. Several disadvantages may be attributed to the adverse effect of heterogeneity, which could be eliminated by pulverization pretreatment [4].

Several types of size reduction units are in common use for the pulverization of biomass, such as cutter mill [5], vibration mill [6], and refiner. Cutter mill relies on shear force; vibration mill bases on impact and shear stress; refiner works through grinding force. The above pulverization technologies can crush biomass into micron dimension products; however, the energy consumption of these processes was very high [6]. At present, research activities mainly focus on the development of novel biomass pulverization technology with higher efficiency and lower energy consumption.

In our previous work [7], a novel biomass pulverization technology was developed, which can break wood chip (22 mm) into wood powder (150 μm) with lower energy consumption (80 kWht^{-1}). The novel crushing system was mainly composed of primary crusher, advanced crusher, cyclone dust extractor, bag filter for collection of products, fan, and so forth (shown in Figure 1).

The production procedure was as follows [7]. The raw biomass materials were firstly crushed in the primary crusher, where particles with particle size less than 5 mm were generated, and then they were automatically pushed into the advanced crusher by the driving force from the fan. After further pulverization in the advanced crusher, the fine particles with particle size below 250 μm were driven into cyclone dust extractor and bag filter in sequence by the driving force from the fan, while the coarser particles stayed in the crusher for further fragmentation.

It is very important for maximizing energy utilization to optimize the operation conditions of the crushing system. Because the crushing forces in the crusher are shearing force, impacting force, and grinding force, blades gap and rotor

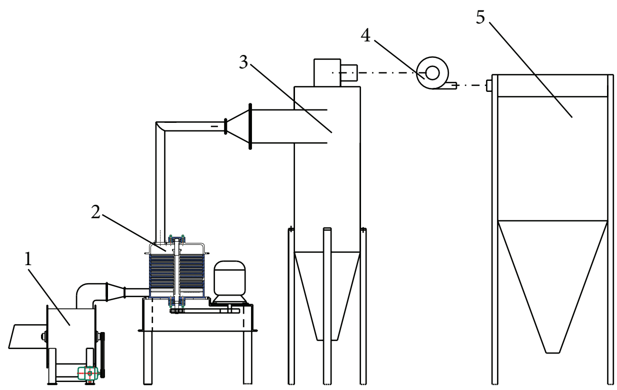

Figure 1: The schematic of the biomass crushing system: 1: primary crusher, 2: advanced crusher, 3: cyclone dust extractor, 4: fan, and 5: bags filter.

speed are key influencing factors for energy efficiency and product quality [8]. In addition, the effect of raw material characteristics should also be taken into account. Feed moisture, a widely concerned parameter when referring to parameters optimization, showed a significant effect on the behavior of crusher in our previous study [9]. Some researches indicate that at high moisture content, the materials tend to absorb the impact energy of the crusher and deform rather than break. High feed moisture also has adverse effect on products quality.

The present work is mainly concerned with detailed studies of the effects of feed moisture and crusher operational parameters (rotor speed and blades gap) on product size distribution and energy consumption. The results would be helpful in the design of high-efficiency crushing system and the selection of technical parameters for minimal energy consumption under pulverization.

2. Experimental

2.1. Material. Approximately 100 kg of raw material for pulverization tests was cotton stalk, obtained from Qingdao City, China. In order to eliminate the adverse effects of material properties on experimental repeatability, the cotton stalk was artificially broken into about 500 mm in length. Then the crushed cotton stalk was solar dried for 2–7 days. According to the difference in drying time, the raw material was separated into four groups, with the moisture levels being 10.6%, 16.1%, 18.8%, and 24.2%, respectively.

2.2. Equipment. The lab-scale crushing system was mainly composed of primary crusher, advanced crusher, cyclone dust extractor, bag filter for collection of products, fan, and so forth. The structures of primary and advanced crushers were specifically described in the previous paper [7]. The technical parameters of the crushing system are shown in Table 1.

2.3. Procedure. During pulverization tests, all operating parameters were recorded, including rotor speed, blades gap, energy consumption of power equipment (like primary crusher, advanced crusher, fan, etc.), and output rate. As the effects of primary crusher on specific energy and product size distribution are less pronounced, this paper mainly focused on the discussion of operating parameters of advanced crusher. The rotor speed and blades gap of primary crusher were kept constant at 2000 rpm/min and 50 mm, respectively. The experimental conditions were summarized in Table 2.

Table 1: Technical parameters of the lab-scale crushing system.

Parameter	Primary crusher	Advance crusher
Drive power/KW	10	15
Rotation speed/rpm/min	2000	3000
Number of rotating blades	8	12
Length of rotating blade/mm	400	450
Working load/kg/h	50	50
Blades gap/mm	50	20

Table 2: Operation conditions of advanced crusher.

Run number	Rotor speed/r/min	Blades gap/mm	Feed moisture/%
1	3000	20	10.6
2	3600	20	10.6
3	4200	20	10.6
4	4200	10	10.6
5	4200	8	10.6
6	4200	5	10.6
7	4200	10	16.1
8	4200	10	18.8
9	4200	10	24.2

2.4. Analysis. To assess the performance of the crushing system, the following variables are defined and determined.

2.4.1. Specific Energy. The driving motors of primary crusher and advanced crusher were coupled to commercial wattmeter to measure the consumed power online, P_P and P_A, respectively. Based on the power plots shown on the wattmeter screen, the net exposure time, t_E, could be estimated. The total power (P_N) was estimated as follows:

$$P_N = P_P + P_A + P_F, \quad (1)$$

where P_F was the power of the driving motor of fan. The specific energy E_N was given by

$$E_N = \frac{P_N t_E}{m_M}, \quad (2)$$

where m_M represented the product mass.

2.4.2. Particle Size Distribution. The collected products were sieved in a commercial mechanical sieve shaker. The duration of sieving was 10 min for each sample, which was previously determined through trials to be optimal. After sieving, the mass retained on each sieve was weighed.

Table 3: Effect on rotor speed of advanced crusher on specific energy consumption.

Rotor speed/r/min	Specific energy/kWht^{-1}
3000	72.0
3600	83.4
4200	88.1

3. Results and Discussion

3.1. Effects of Rotor Speed. Drobny et al. [10] indicated that with hammer mill higher rotor speed generated finer particles with higher energy consumption. The same results were achieved by Fitzgerald and Themelis [8] on size reduction of municipal solid waste (MSW), which showed that the specific energy could be optimized by lowering rotor speed.

The particle size distribution and specific energy consumption obtained with different rotor speeds are shown in Figure 2 and Table 3, respectively. Different rotate speeds were achieved by changing the belt pulley diameter ratio of rotor to motor.

The trend shown in Figure 2 was similar with the results reported in the previous studies. The products size distribution became much finer with increasing rotor speed, which can be explained as follows: higher rotor speed improved the hit probability between the blades and materials, enhancing the impacting and grinding effects. The variation of specific energy with rotor speed showed an increasing trend (Table 3). The specific energy consumption changed from 72.0 kWht^{-1} at 3000 rpm/min to 88.1 kWht^{-1} at 4200 rpm/min and increased by 22.4%. It can be explained as follows: up to 20% of high speed crusher power was wasted on bearing friction and windage of the rotor; meanwhile many interspaces between raw materials and discontinued feeding lead to the blades idling, increasing energy consumption consequently. And the trend became much more pronounced at higher rotor speed. In general, it is necessary to choose a proper rotor speed based on reasonable energy costs and the desired products size distribution in industrial production.

3.2. Effects of Blades Gap. The particle diameter distribution and specific energy were plotted against the blades gap in Figures 3 and 4, respectively.

As shown in Figure 3, the smaller the blades gap, the finer the products size distribution was. As the blades gap was 20 mm, 42.8% of biomass powders were below 106 μm in size, and for the blades gap of 8 mm the value was 71.5%. In the unconfined crushing system the energy transfer is a hit-or-miss proposition [11]; the narrow spaces between blades increase the density of particles in crushing chamber and intercollision proposition, as well as enhancing meshing and grinding effects between blades and particles. Alternatively the increase of blades gap makes the material easy to rotate under fragmentation due to increased torque, causing the decline of products quality.

As torque was kept constant, the decrease of blades gap can result in the increase of shear stress. This was illustrated in

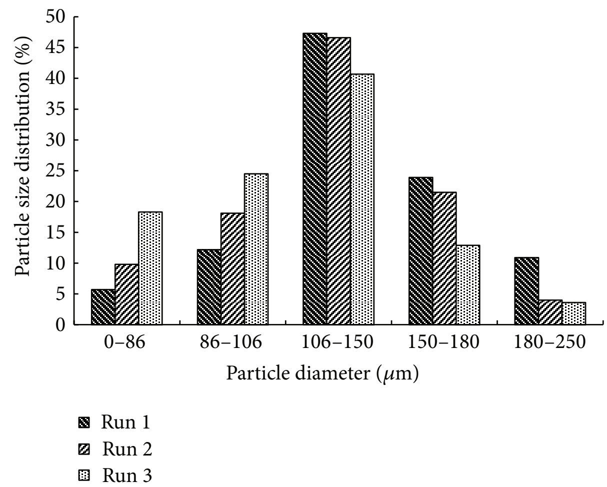

Figure 2: Product size distribution of pulverized biomass as a function of rotor speed of advanced crusher.

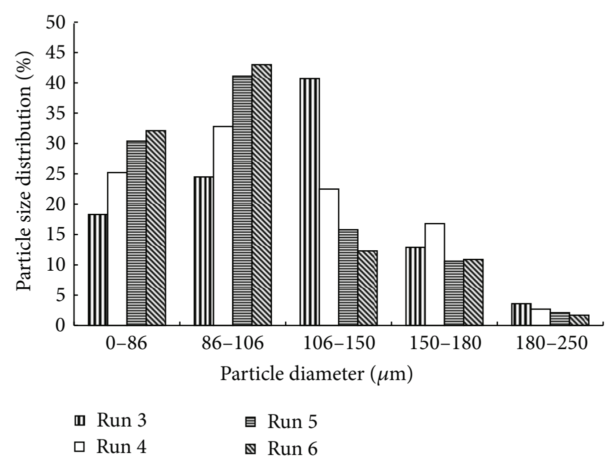

Figure 3: Product size distribution of pulverized biomass as a function of blades gap of advanced crusher.

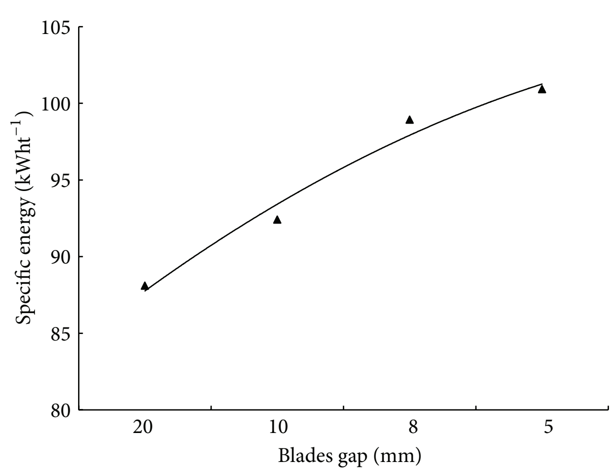

Figure 4: Effect on blades gap of advanced crusher on specific energy consumption.

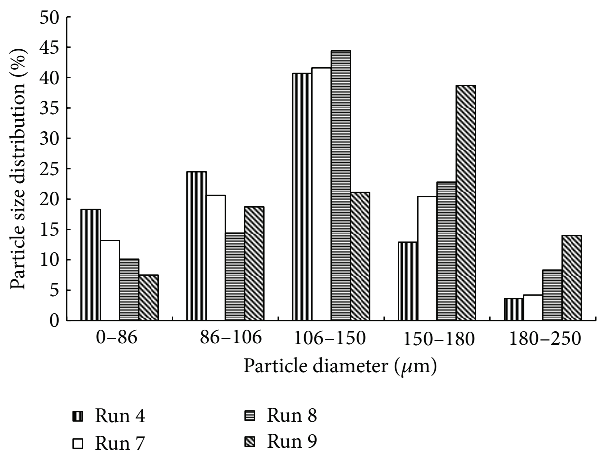

Figure 5: Effect of feed moisture on particle size distribution of pulverized biomass.

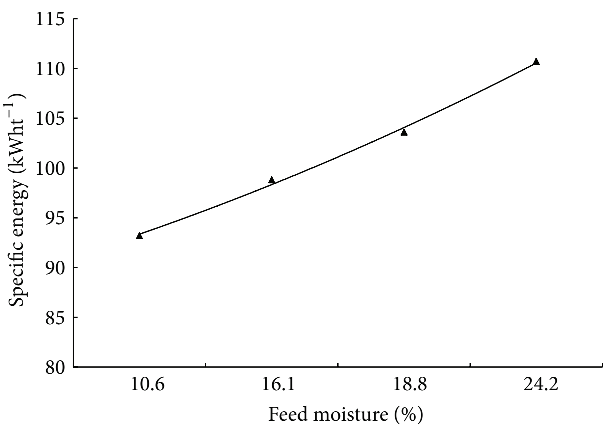

Figure 6: Effect of feed moisture on specific energy.

Figure 4, which showed that with the decrease of blades gap, the energy consumption appears to be an increasing trend.

It can also be seen in Figure 3 that the effect of blades gap on particles size became less significant when the blades gaps was below 8 mm. The finer products (particle size below 106 μm) percentages were 71.5% and 75.3%, respectively, as blades gap were 8 mm and 5 mm, while the specific energy went on increasing. Consequently, there existed an optimum value of blades gap for the pulverization of cotton stalk in the crusher, and 8 mm was an optimal value for blades gap in this test.

3.3. Effects of Feed Moisture. The particle size distribution and specific energy, as a function of feed moisture were shown in Figures 5 and 6, respectively.

The results presented in Figure 5 indicated that there was a pronounced effect of feed moisture on product size distribution. As can be observed, a coarser product size distribution can be achieved at higher moisture contents. An explanation may be that volume and surface fragmentation occurs by impact and grind method, and the addition of water in material lowers the strength of crushing forces due to lubrication.

With respect to specific energy, the value steadily increased with the increase of feed moisture, which can be seen in Figure 6. As shown in (1), residence time (net explore time t_E) is a key factor influencing specific energy. The residence time of particles in crushing chamber is decided by the flow rate of the fan and coarser particles content. Higher feed moisture causes the products to contain large amounts of coarser particles, resulting in the increases of residence time and energy consumption.

In summary, the drying process is necessary for the pulverization of biomass and the drying conditions (like temperature and time, etc.) are decided based on comprehensive consideration of energy costs and product size requirements. For the pulverization of cotton stalk in the crushing system, the feed moisture should be below 16%. Factually, in other pulverization processes, such as preshredding of MSW [12], a predrying process is usually needed prior to pulverization operation.

4. Conclusions

In the paper, a novel biomass pulverization technology was introduced, and the effects of feed moisture and crusher operation parameters (rotor speed and blades gap) on product size distribution and energy consumption were discussed.

Higher rotor speed generated much finer particles with higher energy consumption. Decreasing blades gap can improve products quality; however, it resulted in the increase of specific energy. The effect became less significant when the blades gap was below 8 mm. Higher feed moisture resulted in the decline of products quality and the increase of energy consumption. Thus, it is necessary for the raw biomass material to be dried before pulverization.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

Acknowledgments

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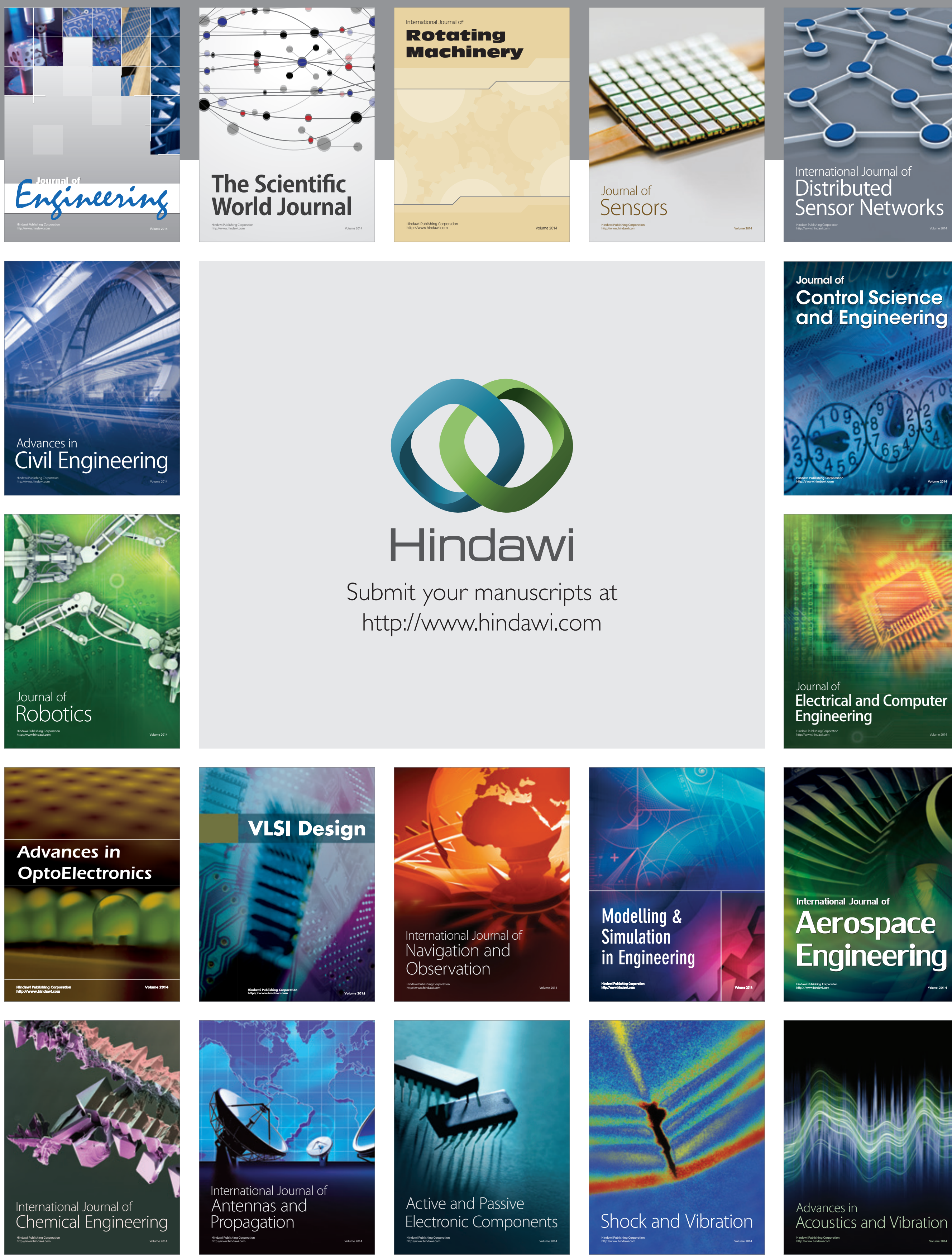
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