An Experimental Research of Biomass Crushing System

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Abstract. Biomass crushing is precondition for utilization and transformation of biomass energy. Compressive strength of biomass raw materials is generally small with long fiber, and multiple crushing methods like shocking, shearing and grinding should be used to realize high-efficiency crushing. Based on this, this paper researched and developed a set of biomass fine crushing system, and conducted an optimized study of main parameters influencing crushing process—revolving speed, between blade and cutter head and material moisture content. Results indicated that this set of crushing system could complete fine crushing of biomass, particle size of crushed products was controlled below 250µm, crushing energy consumption was between 70—120kwh/t, both of which were mainly decided by material moisture content and operating parameters of crusher. Revolving speed of crusher was elevated, proportion of particles (d<106µm) with fine particle size in crushed products increased, and unit energy consumption of crushing increased; narrowing space between blade and cutter head could improve crushing effect of biomass, but unit energy consumption increased; the higher the moisture content was, the less the content of fine particles in crushed products would be, and the greater unit energy consumption would be. By comprehensive comparison, the optimal operating conditions for crushing were: revolving speed was 3600r/min, space between impulse blade and cutter head was 8mm, moisture content was 10.6%, energy consumption was 98kwh/t, product particle size distribution was: those with particle size below 106µm occupied 71.5% and those between 106µm—250µm occupied 28.5%.

1. Introduction
With increasing exhaustion of fossil energy and gradual appearance of its environmental impact, biomass energy has drawn extensive global concern by virtue of its renewability and cleanness. At present, utilization methods of biomass energy include: biomass transformation method, mechanical extraction method and thermochemical transformation method, whereby thermochemical transformation method is applied the most extensively. According to chemical reaction kinetics and thermal transmission theory, crush preprocessing of biomass can improve its thermal transformation efficiency. On the one hand, reducing biomass particle size can increase specific surface area of particles, be good for heat transfer and mass transfer of chemical reaction process, reduce standing time of materials in reactor, increase processing ability of reactor, reduce temperature gradient inside particles and improve the yield. On the other hand, biomass energy density is low and range of heat value change is large, crush preprocessing can make biomass feeding even, fluctuation of heat value of stokehold feeding small, bio oil yield and components maintain stable, and then improve heat treatment efficiency of biomass and pollution control efficiency[1].

Biomass not only includes cotton stalk and branch which present brittleness with high lignin content and big relative hardness but also include straw and corn stalk with high cellulose and
hemicelluloses contents with strong toughness, so it’s suitable to adopt multiple methods like shocking, shearing and grinding to crush biomass[2]. Existing material crushing equipments are mostly designed for materials like industrial minerals with strong brittleness and big compressive strength such as jaw crusher, impact crusher and roll crusher, etc. Crushing force used by this kind of crushing system is not applicable to biomass crushing. Although there are some small crushers for fodder and traditional Chinese machine, such as ordinary hammer-shape crusher, water drop-like crusher, vertical spindle type crusher, etc., crushing energy consumption is high and particle size of crushed products is big, so it’s not applicable to mass crushing[3].

This paper introduced a set of biomass fine crusher, investigated main factors influencing crushing performance by taking particle size of crushed products and crushing energy consumption as indexes, and the purpose of this paper was to optimize technological parameters and provide basic theory and data for follow-up industrialized application of this crushing system.

2. Overview of Crushing System

The experimental system mainly consisted of coarse crusher, fine crusher, particle collection device (cyclone dust collector and bag-type dust collector) and draught fan, etc., in the whole operating process, after materials were added coarse feeding entrance, and they were initially crushed in coarse crusher. Under the effect of draught fan, particles with small particle size \( (d<5 \text{ mm}) \) were carried into fine crusher to conduct secondary crushing, particles with small particle size \( (d<250\mu\text{m}) \) after shocking, grinding and shearing would be drawn from exit at upper end of crushing chamber into cyclone dust collector, and those with large diameter would stay in the crusher to be crushed again. The whole process proceeded under negative pressure. Crushing system is as shown in Figure 1.

![Biomass Crushing System](image)

**Figure 1.** Biomass Crushing System

1. Coarse crusher  2. Fine crusher  3. Cyclone dust collector  4. Bag-type dust collector

Coarse crusher mainly consisted of hopper, feeding inlet, crushing chamber and discharge port. Crushing chamber was circular structure. Principal axis was fixed at two sides of crushing chamber with bearings, and electromotor drive axis through belt. Blades in crusher were uniformly distributed on axis, which ensured dynamic balance and static balance of axis and made materials uniformly distribute in crushing chamber. Some biomasses with high content of biomasses like straw and cotton stalk had hard texture, making impact load subjected by blade have certain influence on pin and axis of blade, so blades in this crusher was not designed as fixed type, and a loose welding form existed between blade and lockpin[4]. Materials in crushing chamber went shearing and grinding under high speed, collided, stroke and rubbed...
among blades, and then materials mutually collided and rubbed, then materials were gradually crushed into small particles and short cellosilk\[5\]. Coarse crusher structure is as shown in Figure 2.

![Figure 2. Coarse crusher](image)

1. Material  2. Feeding Inlet  3. Impulse Blade  4. Fixed Blade  5. Outer Cylinder  6. Discharge Port

Fine crusher consists of feeding pipe, crushing chamber, discharging pipe and actuating unit, and there are totally 12 groups of blades in crushing chamber. When operating, as materials entering fine crushing system have passed initial crushing of previous coarse crusher, average particle size is less than 5mm, so materials in fine crusher uses high-speed revolution of motor to realize grinding between blades and blinding between materials so as to reach finer particle size\[6\]. Fine crusher structure is as shown in Figure 3 and operating parameters of crushing devices are as shown in Table 1.

![Figure 3. Fine crusher](image)

1. Feeding Inlet  2. Blade  3. Fixed Blade  4. Outer Cylinder  5. Discharging Port

Particle collector consists of cyclone dust collector and bag-type dust collector. Draught fan is placed between cyclone dust collector and bag-type dust collector to make inside cyclone dust collector be under negative pressure status and lead flow direction of materials. After deceleration
through cyclone dust collector, materials fall in receiving hopper, and a small quantity of quite fine particles, after air draft through draught fan, reach receiving cloth bag to be collected from the upper end of hopper.

Table 1. Operating Parameters of Crushing Devices

| Crushing Device  | Size (mm) | Motor Power (KW) | Motor Speed (r/min) | Rated Current (A) | Transmission Ratio |
|------------------|-----------|------------------|---------------------|------------------|-------------------|
| Fine Crusher     | 1000×600  | 15               | 2960                | 15.4             | 1:1               |
| Coarse Crusher   | 500×800   | 15               | 2890                | 28.9             | 1:1.5             |

3. Experimental Research of Biomass Crushing

3.1. Experimental Method
This experiment mainly discusses about the influences of revolving speed of fine crusher, space between blades and raw material moisture content on particle size distribution and crushing energy consumption of crushed products, and experimental conditions are as shown in Table 2.

Table 2. Experimental Conditions

| No. | Revolving speed (r/min) | Spacing (mm) | Moisture Content (%) |
|-----|-------------------------|--------------|---------------------|
| 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                |

3.2. Analysis and Testing Method
Particle size distribution of crushed products and crushing unit energy consumption are main standards of measuring crushing performance. Particle size distribution is screened by vibrating screen. Calculation method of crushing unit energy consumption is as following:

Wattmeter is used to conduct online measurement of motor power when crusher is operating, consumed total power (power of coarse crusher, power of fine crusher and power of draught fan) is recorded as $P_N$, crushing time is recorded as $t_E$, and mass of crushed biomass products is recorded as $M$. Then unit energy consumption $E_N$ of biomass crushing is calculated through equation (1) [7]:

$$E_N = \frac{P_N t_E}{m_M}$$  \hspace{1cm} (1)

3.3. Experimental Results and Discussion

3.3.1. The Influence of Revolving Speed on Crushing Performance.
Figure 4 and Figure 5 are respectively particle size distribution and unit energy consumption of crushed biomass products at different revolving speeds. Revolving speed of crusher is implemented through changing motor frequency.
As revolving speed of crusher increases, content of particles with fine particle size in products presents increasing tendency. When revolving speed increases from 3000 r/min to 4200 r/min, proportion occupied by particles with particle size being within 106-150 μm is the largest, particle size distribution presents normal distribution. This is because crushing methods are various of biomass in fine crusher, crushing of biomass in crushing chamber is mainly implemented through impact effect of impulse blade under high-speed revolution, meshing effect of impulse blade and sieve mesh on cutterhead, grinding effect generated by small space between impulse blade and cutterhead and mutual collision between particles of high concentration [8]. The higher the revolving speed is, the greater impact effect generated by impulse blade will be, meshing force between impulse blade and fixed blade will be enhanced, collision probability between particles of high concentration increases, crushing effect will be better, and the greater the proportion of particles with fine particle size in crushed products will be.

Variation tendency of unit energy consumption with revolving speed of crusher is as shown in Figure 5. It can be seen from Figure 5 that when revolving speed increases from 3000 r/min to 4200 r/min, unit energy consumption is gradually on progressive increases. This is because: when crushing is being operated, energy reaching as high as 20% is used to overcome friction energy consumption brought by high revolving speed of crusher rotor and energy consumption brought by idling of impulse blade. Large space between crushed materials and material feeding discontinuity make impulse blade be under idling status in some operating period in the crushing process, and the higher the revolving speed of rotor is, the greater the energy consumed by idling of blade will be, energy loss caused by friction will abruptly increase, which result in increasing unit energy consumption.
consumption of crushed products [9].

Hence, optimal revolving speed should be selected in crushing process, which can not only meet quality requirement of crushed products but also reduce crushing energy consumption. The optimal revolving speed in this experiment is 3600r/min.

3.3.2. The Influence of Space between Blade and Cutterhead of Crusher on Crushing Performance.

Figure 6 and Figure 7 are respectively variation tendencies of particle size distribution of crushed products and crushing unit energy consumption with space between blades when revolving speed of crusher is 4200rpm/min. Different spaces between blades are implemented by adding washer between blades.

It can be seen from Figure 6 that the smaller the space between impulse blade and cutterhead is, the greater the content of biomass particles with fine particle size in crushed products will be. When space between blades is 20mm, particle size of 42.8% biomass particles is below 106 μm, when space between impulse blade and cutterhead reduces to 8mm, content of biomass particles with particle size being 106 μm below increases to 71.5%. This is because in particle-type crushing system, transmission of crushing force is mainly implemented by direct contact between impulse blade and crushed materials, the smaller the space between impulse blade and cutterhead, the greater the concentration of crushing materials in crushing chamber will be, and the higher the collision probability between materials and blades will be [10]. Small space between blades is good for implementation of meshing force between blade and cutterhead, and in the meantime, it promotes grinding effect of blade and cutterhead on materials to a great extent and improves crushing effect of biomass particles.

Variation tendency of crushing unit energy consumption with space between blades is as shown in Figure 7. It can be seen from Figure 7 that with decreasing space between blade and cutterhead, crushing unit energy consumption presents increasing tendency. This is because space is small, then crushing space of particles consisting between blade and cutterhead is small, particle concentration is high, and resistance encountered by blades when doing crushing operation, which result in increasing crushing energy consumption[11].

It can also be seen from Figure 6 that the influence of space between blade and cutterhead on particle size distribution of crushed products changes not obviously within a small space scope, when the space reaches 8mm, content of biomass particles with particle size being below106 μm is 71.5%, when space reduced to 5mm, the content of biomass particles with particle size being below106 μm is 75.3%. However, when the space reduced from 8mm to 5mm, unit energy consumption increases from 98kwh/t to 110kwh/t.

Generally speaking, reducing the space between blade and cutterhead can elevate percentage content of particles with small particle size in crushed products, but will result in increasing energy consumption. Hence, in this experiment, the optimal space between blade and cutterhead is selected as 8mm.

![Figure 6. The Influence of Space Between Blade and Cutterhead of Fine Crusher on Particle Size Distribution of Crushed Products](image-url)
3.3.3. The Influence of Material Moisture Content on Crushing Performance. It could be seen from Figure 8 that influence of material moisture content on quality of crushed products was quite obvious, the higher moisture content was, the smaller the content of particles with small particle size in crushed products would be. This was because: increasing moisture content in materials would improve toughness of materials and reduce crushing effect to a certain degree.

The influence of material moisture content on unit energy consumption of crushing was as shown in Figure 9: it could be seen that energy consumption presented increasing tendency with material moisture content. It could be seen from calculation formula (1) of unit energy consumption of crushing that: standing time of materials in crusher was one of key factors influencing energy consumption of crusher, while standing time was decided by air speed of draught fan and content of coarse biomass particles in crushing chamber. High moisture content resulted in increasing content of particles with coarse particle size, lengthened standing time of particles in crushing chamber and increased energy consumption of crushing. In the meantime, as increasing moisture content resulted in decreasing content of dry basis substances in materials, it also resulted in increasing energy consumption of crushing to a certain degree [12]. It could be seen from above analysis that it’s necessary to do dry preprocessing of materials before biomass crushing, and drying conditions should be determined by comprehensive consideration of energy consumption of crushing and product quality. In this experiment, the optimal moisture content was 10.6%.

Figure 7. The Influence of Space between Blade and Cutterhead of Fine Crusher on Unit Energy Consumption

Figure 8. The Influence of Moisture Content on Particle Size Distribution of Crushed Products
4. Conclusion
This paper proposed a new type of crushing equipment which consisted of coarse crusher, fine crusher, particle collection device (cyclone dust collector and bag-type dust collector) and draught fan, etc., particle size of crushed biomass could reach 250µm. It made an experimental study of the influences of revolving speed, space between crusher blade and cutterhead and material moisture content on crushing performance, and then it drew the following conclusions:

(1) With increasing revolving speed of crusher, content of particles (d < 106µm) with fine particle size in products presented increasing tendency, unit energy consumption increased as revolving speed of crusher increased, so optimal revolving speed during crushing process should be selected to satisfy quality requirements for crushing products and reduce crushing energy consumption. Optimal revolving speed in this experiment was 3600r/min.

(2) The smaller the space between impulse blade and cutterhead was, the greater the content of biomass particles with fine particle size in crushed products would be. With decreasing space between blades, unit energy consumption of crushing presented increasing tendency, and the influence of space between blades in particle size distribution of crushed products changed not obviously within scope of space between blades. With overall consideration, reducing space between blades could improve percentage composition of particles with small particle size in crushed products, but would result in increasing energy consumption of crushing, hence, in the experiment, optimal space between blades was selected as 8mm.

(3) High moisture content resulted in increasing content of particles with coarse particle size in crushed products, lengthened standing time of particles in crushing chamber and increased energy consumption of crushing. In the meantime, as increasing moisture content gave rise to reducing content of dry basis substances in materials and resulted in increasing energy consumption of crushing to a certain degree. Hence, it’s necessary to do dry preprocessing before biomass crushing.

5. References
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