The Study of Banana Leaf Fiber Based Biomass Pellets Fuel

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Abstract: The use of agricultural and forestry waste to produce energy-efficient biomass energy is one of the most energy-saving methods. Through the resource study and regional economic analyses, sawdust, hay and banana leaf fiber were selected as raw materials to study the main influencing factors of the palletization due to the substantial amount. Under the optimum condition: sawdust/hay ratio of 1.49:1, fiber/particle ratio of 1:20 and the fiber length of 2.05cm, the crushing resistance increased by 12.12% and the calorific value of the mixed fuel is 17014kJ/kg. The results show that adding banana leaf fiber to hay and sawdust can greatly improve the forming rate of biomass fuel, the heat value and ash content of biomass meet the national standard. There are a large number of agricultural and forestry waste can be well utilized.

1. Introduction
Biomass energy is the only renewable carbon source with carbon neutralization characteristics. The use of agricultural and forestry waste to produce energy-efficient biomass energy is one of the most energy-saving means. According to the related researches, the annual output of biomass pellets fuel abroad was more than 4.2 million tons [1] in recent years, of which the American region accounts for about 1.1 million tons [1] and the European region represents for about 3 million tons [1]. In the early 1980s, China began to attach importance to the utilization and development of biomass pellets fuel equipment. At first, the emphasis was placed on the screw extrusion molding machine. Due to a series of shortcomings such as large power consumption, short service life, the application of biomass pellets was limited. [2]-[4] With the technology improvement, at end of 2007, Chinese output of biomass pellets were about 20 tons [1] a year. But the problem of biomass pellets such as poor forming effect and bad economic application performance still unsolved. What’s more, China has a land area and a large amount of biomass waste. There are a large number of agricultural and forestry waste not well utilized. For example, the annual output of bananas in the world is about 70 million to 80 million tons [5], of which 5 million to 6 million tons [5] are from China, and the by-products of banana phloem, banana leaves and banana pseudostems, which are almost equivalent amount to banana fruits, have not been exploited and utilized. They are often discarded as garbage. In the prophase treatment, incorporating the fibers can make the biomass particle structure more stable. In this study, banana leaf fibers were used as raw materials and added to sawdust and hay mixed particles to pressed as biomass pellets fuel, influence factors were determined by RSM [6], the crushing resistance was used as detector. With the addition of biomass fibers, the performance of pellets were improved and this technology could enhance the transport and utilize efficiency for other biomass resources, which might provide convenience for the transportation and popularization of biomass pellets fuel in the future. At the same time, the use of banana leaves has been developed, the effective utilization of resources would be realized.
2. Materials and methods

2.1. Materials
Sawdust: from a lumber mill in Xiamen. Hay: from the lawn in Xiamen. Banana leaves: from a banana plantation.

2.2. Experimental design
In this experiment, banana leaf fibers were separated and collected to mixed with sawdust and hay in various ratio. The winding effect of fiber could make a stable "solid bridge" between sawdust and hay and improve the stability of the compressed biomass materials. The main factors affecting biomass internal briquetting were investigated, such as moisture content, fiber length, fiber to particle ratio and particle size.[7] The compressive resistance of biomass mixture fuel was determined by controlling variables strictly. The optimizations of processing were ascertained by using the RSM [6], and the test was carried out to assure the best forming effect. The combustion performance of the mixed biomass pellets fuel was determined by the calorific value and ash amount. The experiments were three repetitions.

2.3. Performance test
2.3.1. Determination of smash-resistance. Based on GB/t 21923-2008 general principles for solid biomass fuel inspection, the crushing degree of the molding compound was calculated after six free falls at a height of 1.5m.
2.3.2. Determination of caorific value. The verification experiment was conducted according to the industrial analysis method of biomass pellets fuel (GB/t1.1-2009).
2.3.3. Determination of ash content. Based on the analysis method of solid biomass fuel industry (GB/t1.1-2009), the ash content of banana leaf fiber blend biomass particles under the best conditions were determined.

3. Results and discussion

3.1. Experimental data analysis
Based on our previous research, the best molding effect can be seen from the addition of banana leaf fibers with different grain sizes of sawdust and hay(>0.45mm,0.45-0.2mm,0.2-0.125mm,<0.125mm), so the particle sizes of 0.45-0.2mm are adopted as experimental materials.
According to the analysis by response surface method, three factors that have the greatest influence on the pelletization and molding process of biomass materials were selected: (A) the ratio of sawdust to hay particles, (B) the length of fibers, (C) the ratio of fibers to particles. The three-factor three-level response surface experiment design was adopted and carried out by design-expert.v8.0.6. The results show in table 1.
The F value of the model is 4.05 and the P value is 0.0394, and the model is significant. The fitted value is greater than 0.05, which is not significant, indicating that the equation is well fitted and can be used for test data analysis. Among the three factors in the design, the ratio of sawdust to hay particles (F=11.18) had the greatest effect on the pelletization and molding of biomass. The other influencing factors are the ratio of fiber to particle and the length of fiber in order of significance. The three selected factors also intersect with each other, with the most significant cross effect between the ratio of sawdust to hay particles and the fiber length (F=1.36). The interaction of other factors is not obvious. The data shows that the accuracy and precision of the model are high, and the actual value has a good correlation with the predicted value. Therefore, the model can be used to predict and analyze the conditions of the optimization experiment during the pelletization and molding of biomass materials.

3.2. The effect of modification conditions
As shown in figure 1a. It can be seen that the surface map exhibits a "convex" shape. After the ratio of the fixed fiber to the particle, the degree of crushing increases first and then decreases with the growth of the fiber, and reaches a maximum at a rate close to 2 (1-3 cm). The ratio of swadust to hay is similar
to the change of fiber length. The anti-fragmentation degree increases first with the increase of proportion, and then decreases slightly. The pelletization molding effect of biomass pellet fuel also changes. Because the P-value is greater than 0.05, the fiber length, there is no significant interaction between the ratio of sawdust and hay to the degree of fragmentation.

Table 1. Analysis of Variance

| Source variance                      | Square Sum | Degrees of freedom | Mean square | F value | P value | F > Fa | Significance |
|--------------------------------------|------------|--------------------|-------------|---------|---------|--------|--------------|
| Regression                           | 174.89     | 9                  | 19.43       | 4.05    | 0.0394  |        | significant  |
| A: The ratio of sawdust to hay particles | 57.03     | 1                  | 57.03       | 11.88   | 0.0107  |        | significant  |
| B: The length of fibers              | 2.38       | 1                  | 2.38        | 0.49    | 0.5045  |        |              |
| C: The ratio of fibers to particles  | 23.26      | 1                  | 23.26       | 4.84    | 0.0637  |        |              |
| AB                                   | 6.55       | 1                  | 6.55        | 1.36    | 0.2809  |        |              |
| AC                                   | 0.94       | 1                  | 0.94        | 0.2     | 0.6714  |        |              |
| BC                                   | 0.36       | 1                  | 0.36        | 0.075   | 0.7921  |        |              |
| $A^2$                                 | 22.01      | 1                  | 22.01       | 4.58    | 0.0695  |        |              |
| $B^2$                                 | 54.16      | 1                  | 54.16       | 11.28   | 0.0121  |        | significant  |
| $C^2$                                 | 1.98       | 1                  | 1.98        | 0.41    | 0.5408  |        |              |
| Stagger                              | 33.61      | 7                  | 4.8         |         |        |        |              |
| Lack of fit                          | 25.41      | 3                  | 8.47        | 4.13    | 0.1022  |        | not significant |
| Pure Error                           | 8.2        | 4                  | 2.05        |         |        |        |              |
| TotalDispersion                      | 208.5      | 16                 |             |         |         |        |              |

P < 0.05

Figure 1b presented the results of the interaction between fiber to particle ratio and the ratio of swadust to hay against fracture. When the fiber length is constant, the ratio of swadust to hay is 0 (0:1), and the ratio of fiber to particle is 1 (1:60), the degree of crush resistance is the lowest. Then, the increase of fiber strengthens the forming effect, and the crushing resistance rises remarkably, mainly because the fiber can be connected with the particles to reinforce the molding, otherwise the pellet fuel is too loose, so that the crushing resistance is not good. The P value of AC is also greater than 0.05, and there is no significant interaction effect.
The interaction between fiber-to-particle ratio and fiber length shows in figure 1c. It can be seen that the fiber to particle ratio has a greater influence on the degree of breakage than the fiber length. After fixing the ratio of swadust to hay particles, the P value of BC is greater than 0.05, and there is no significant interaction effect. Both B and C variables have a slight arc effect, but the fiber length is about the median value. When the fiber weight is on the high side, the crush resistance is the highest.

![Figure 1-a. Response surface plots for A and C.](image)

![Figure 1-b. Response surface plots for A and B](image)

![Figure 1-c. Response surface plots for B and C](image)

3.3. **Optimized study of biomass pelletization molding**

Finally, according to the Design-Expert.V8.0.6 software, the best effect conditions for pelletization of biomass mixed materials. When the ratio of swadust to hay particles is 1.49:1, the fiber length is 2.05 cm, and the fiber to particle ratio is 20:1, the compression resistance of the tablet is the best. The samples with 3 swadust and hay particles ratio of 1.49:1, fiber length of 2.05 cm and fiber to particle ratio of 1:20 were pressed to test whether it was the best condition. The results of 3 times of crushing resistance test show that the average degree of crushing resistance is 95.87%, so the results of pelletization molding of biomass materials under the condition were the best under the influence of certain error.

4. **Conclusion**

In this work, the results show that adding banana leaf fibers to hay and swadust can greatly improve the forming rate of biomass fuel and the heat value and ash content of biomass conform with the national standard. The optimum ratio is sawdust/ hay ratio of 1.49:1, fiber/particle ratio of 1:20 and the fiber length of 2.05 cm, the crushing resistance increased by 12.12% and the calorific value of the mixed fuel is 17014kJ/kg. Biomass energy is one of the key renewable energy sources in China, especially the development of biomass fuel technology. Banana leaf fiber added with fiber winding around hay and sawdust greatly improved the anti-crushing performance, which can play a role in transportation. The potential cost saving form transportation will be practiced in future work. The fiber winding mechanism and effect of different forms of fiber will be verified by experiment in future. In addition, the sulfur content and chlorine content of biomass fuel are both less than 0.07%. Therefore, the content of harmful gases in biomass granule fuel combustion is extremely low, and the emission of less harmful gases is less.

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