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Effects of raw material particle size on the briquetting process of rice straw

Yu Wang, Kai Wu*, Yu Sun

School of Mechanical Engineering, Nanjing University of Science and Technology, No. 200 Xiaolingwei Street, Nanjing 210094, China

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ABSTRACT

Biomass feedstocks need to be milled or chopped into particles before briquetting, and the particle size has great effects on the energy consumption and product quality. In this study, the effects of the particle size on the rice straw briquetting process were investigated. The raw materials were milled or chopped into four different sized test materials. Experiments were carried out with an electronic universal testing machine and a self-designed single pellet unit on the basis of a simplex-centroid design. Several parameters, including briquetting time, energy consumption, maximum extrusion force, product compressive strength, and product density, were tested and recorded. The experimental data were processed by the methods of regression analysis and variance analysis. Finally, effects of raw material particle size on the briquetting process, energy consumption, maximum extrusion force, product compressive strength, and product density were obtained. Results showed that, compared with simple sized materials, mixed materials achieved lower energy consumption, higher product compressive strength, and higher product density.

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1. Introduction

The current energy crisis and greenhouse gas effects have forced humans to seek renewable resources to replace traditional fossil fuels. Biomass is an indispensable renewable resource [1]. Biomass feedstocks can be used to make energy products such as methane, diesel, ethanol, and biomass densification briquetting fuels (BDBFs). BDBFs are the most direct and simple way to utilize energy from bioresources because they only need mechanical extrusion rather than complex thermo-chemical or bio-chemical treatments [2].

Biomass feedstocks can be divided into two types: forest wastes and agricultural wastes [3]. Generally, forest wastes perform better than agricultural wastes. However, due to population growth, the surging demand for food will make agricultural wastes an important source of bioenergy [4]. Rice is a globally important food crop, and the efficient utilization of the rice straw will contribute to the development of the biomass industry. Problems associated with the briquetting process of agricultural wastes include high energy consumption, serious wear, low product quality, and high risk of slagging [5,6]. Research is underway to solve these problems.

The mechanical modeling of the briquetting process is the basis of this research, but because the process is very complex and affected by various factors, few achievements have occurred. Holm et al. [7,8] derived the mathematical model of forming pressure. Xia et al. [9] built theoretic models of productivity and torque for a straw ring-die briquetting process. These models provided a basis for future research.

Previous studies have focused on adding new technology or materials to solve the problems. Torrefaction is a potential pretreatment that improves the grindability of woody biomass [10,11]. With the proper temperature, time, and atmosphere, products of torrefied biomass have higher energy density [12] and better hydrophobicity [13]. Including the proper additives can also reduce energy consumption and improve product quality. These additives are fossil fuels [14], biomass materials [15], and sugars [16]. The briquetting process can be improved by including vibration [17,18]. Although these methods reduce energy consumption and improve product quality, the additional steps could make the briquetting process more complicated and costly.

* Corresponding author.
E-mail address: 491334922@qq.com (K. Wu).

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The fundamental way to solve biomass briquetting problems is to identify the factors affecting the process and to determine how the process is affected. Husain et al. [19] investigated the briquetting process of palm fiber and established the relationship between product density and the briquetting pressure. Mani et al. [20] studied the effects of pressure, moisture content, and particle size of the raw material on the density of the pellets produced from wheat straw, barley straw, corn stover, and switchgrass. Results showed that corn stover produced the highest pellet density with a particle size of 3.2 mm and 2% moisture content. Bergström et al. [21] analyzed the effect of the particle size of Scots pine sawdust on the briquetting process, but claimed that the results are not applicable to other types of biomass materials. Kaliyan and Morey [22] obtained the optimum moisture content and temperature for the briquetting process of corn cobs. Hu et al. [23] built a regression model for the specific energy consumption of the rice straw briquetting process on the basis of orthogonal experiments. These studies investigated the factors affecting the briquetting process of different types of biomass materials, but the effects of raw material particle size on the briquetting process of rice straw have yet to be determined.

Biomass raw materials need to be broken into small particles before briquetting. Smaller particle sizes require greater energy consumption during the breaking process. The particle size affects the briquetting process, and mixing different sized materials may improve the briquetting process. Therefore, it is important to study the effects of the raw material particle size on the biomass briquetting process.

In this paper, the effect of raw material particle size on the briquetting process of rice straw was investigated. To evaluate the briquetting process, several parameters were tested including briquetting time, energy consumption, maximum extrusion force, product compressive strength, and product density. The rice straw was milled or chopped into four different sized test materials and mixed together at certain proportions, based on a simplex-centroid experimental design. The mixed materials were compressed by a universal testing machine and a self-designed single pellet unit. The final section of this paper discusses the effects of particle size based on regression analysis and variance analysis of the experimental data.

2. Experimental

2.1. Materials

Rice straw was collected in Jiangyan City, China, in the summer of 2014. It was stored in sealed bags after it was naturally air dried for 24 h. The dried rice straw was milled or chopped into four different sizes (Fig. 1). The milled materials were produced by a small crusher. The average particle size of the milled materials was determined by sieving, and turned out to be 1.8 mm. But sieving didn't work well with large chopped materials because of the stick like shape of each particles. Therefore, the three different sized chopped materials (5 mm, 10 mm, and 15 mm) were manually created, so as to make sure the accuracy of the particle size (±1 mm). Using a moisture meter and an electronic scale, water was added to each test material until the moisture content was 15% ± 1%. Materials were sealed in black bags for 24 h before use.

2.2. Devives

The single pellet unit is widely used in related researches [8,17–20,22–24]. The testing device used in this study included a universal testing machine (HRJ Company Jinan, China) and a self-designed single pellet unit (Fig. 2). The maximum load was 100 kN, and the pressing speed was between 0.01 mm/min and 1000 mm/min. The heating device heated the mold quickly to temperatures between 1 °C and 250 °C. During the test, materials were placed in the heated mold and compressed by the pressing shaft at a certain speed until the maximum compression force was reached. The force was held for 30–120 s before the biomass was extruded from the mold. Forces on the biomass during the process were recorded.

2.3. Methods

Tests were carried out based on the simplex-centroid design [25], and the test scheme is shown in Table 1. There were three duplications in each test, and the average results of each three duplications were taken as the final results. The test material name X_1 indicates milled materials; X_2, X_3, and X_4 indicate chopped materials of 5 mm, 10 mm, and 15 mm, respectively. The four test materials were mixed at a certain proportion based on the test scheme and compressed by the test device under the parameters shown in Table 2. Briquetting force, extrusion force, and the product weight, size, and compressive strength were tested and recorded. Several parameters, including briquetting time, energy consumption, maximum extrusion force, product compressive strength, and product density, were recorded.

Fig. 1. Samples of test materials.

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