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Improved bulk density of bamboo pellets as biomass for energy production

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ABSTRACT

To the best of our knowledge, there is the lack of sufficient information concerning bamboo pellets. In the preliminary research, bamboo pellets showed a low bulk density which could not meet requirement of Pellet Fuels Institute Standard Specification for Residential/Commercial Densified (*PFI*). To improve its bulk density, pellets were manufactured using mixtures of bamboo and pine particles and the properties were investigated. It was found that adding pine particles to bamboo particles was an effective way to improve bulk density of bamboo pellets. When adding 40% pine particles to bamboo particles, bulk density of pellets increased from 0.54 g/cm^3 to 0.60 g/cm^3, meeting grade requirement of *PFI* utility. Furthermore, length, diameter and inorganic ash of pellets were also improved. Fine contents of pellets decreased from premium grade to utility grade according to *PFI* standard. Net calorific value also slightly decreased but it could meet the requirement of *DIN 51731* (>17,500 J/g). The effect of this interaction on bulk density, inorganic ash, Net calorific value, combustion rate and heat release rate were significant. The results from this research will be very helpful to develop bamboo pellets and provide guidelines for further research.

1. Introduction

Biomass is widely recognized as a renewable and sustainable energy source around the world. Biomass particles can be compacted to cylindrical pellets, the main type of solid fuels [1]. Some advantages of biomass pellets include the higher bulk and energy density, the better flow and storage property and the lower material wastage [2]. Recently, biomass pellets are well suitable for home heating in China. Wood resources or wood wastes are considered as the most dominant raw materials for biomass pellets except for agricultural residues. Agricultural and forestry residues represented the major fuel sources for potential bio-energy projects in many developing countries [3]. Magelli et al. investigated the fuel consumptions and emissions of wood pellets in British Columbia [4]. Rhen et al. analyzed the effect of the compositions in woods pellets on combustion characteristics. It was found that bark pellets had up to a 50% longer char combustion time than stem pellets [5]. Ohman et al. analyzed slagging tendencies of wood pellets during combustion in residential pellet burners [6]. Li et al. investigated pelletization of torrefied sawdust from a fluidized bed reactor to quantify the energy consumption and pellet properties. They found that torrefied sawdust had a higher energy consumption at the same compression temperature, compared to untreated sawdust [7]. Lam et al. investigated energy input and quality of pellets made from steam-exploded Douglas Fir. It was found that the steam-treated wood required more energy to compact into pellets and had a higher breaking strength than untreated wood [8].

The market demands for biomass pellets have largely increased during recent years. Market demands of biomass pellets are about fifty million ton in China now. One of the greatest barriers is deficient in biomass resources. Bamboo is a main type of biomass materials and has been widely cultivated in China. The total areas of bamboo have been more than five million hectares and that of moso bamboo *(Phyllostachys heterocycla)* have been more than three million hectares [9]. They have great potentials as bio-energy resources of the future due to fast growth. To the best of our knowledge, there is the lack of sufficient information concerning bamboo pellets. Liu et al. analyzed the moisture of bamboo for pellets [10] and investigated the effect of carbonization temperature and residue time on properties of bamboo pellets [11]. In the preliminary research, bamboo pellets were also successfully

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manufactured using the pellet mill. A low bulk density of bamboo pellets was observed, which could not meet requirement of *PFI* standard.

It is well known that mixing different types of biomass materials is an effective way to improve the properties of pellets. To improve the bulk density of bamboo pellets, pine particles, a main type of wood wastes in China, were added to bamboo particles with different mass ratios in the manufacturing process of bamboo pellets. Pellet properties were determined based on *PFI* standard. The objective of this research is to investigate the effect of mixing bamboo and pine particles on pellet properties. Furthermore, the results from this research will also be very helpful to select an effective way to improve properties of bamboo pellets and provide guidelines for further research.

2. Materials and methods

2.1. Materials

Moso bamboo (4 years old) was taken from a bamboo plantation located in Louisiana, US. Its initial moisture content was about 6.1%. Bamboo materials were cut off to sample size with 40 mm (longitudinal) by 3–8 mm (radial) by 20–30 mm (tangential). Pine particles were directly taken from the USDA Forest Service Forest Products Laboratory (FPL), came from American Wood Fibers of Schofield, WI. Its initial moisture content was about 5.1%.

Bamboo and pine materials were milled into particles using a wood particle mill at FPL, respectively. Bamboo and pine particles (particle size of less than 2.0 mm) were uniformly mixed with different mass ratios (100% bamboo/0% pine, 80% bamboo/20% pine, 60% bamboo/40% pine, 40% bamboo/60% pine, 20% bamboo/80% pine and 0% bamboo/100% pine). About ten g mixtures in each mass ratio were randomly weighed using a precision digital balance (0.0001 Resolution). They were dried at temperature 105 °C until the mass stabilized and then the final mass was recorded. Moisture content of mixtures was calculated according to mass loss of samples. Then five kg of mixtures in each mass ratio were conditioned by adding predetermined amounts of distilled water to the samples [12]. They were transferred to separate Ziploc bags and sealed tightly. Finally, they were placed into a conditioning room with temperature 27 °C, humidity 65% for 48 h to enable moisture uniform distribution. The final moisture content of mixtures in each mass ratio were 15.97%, 15.86%, 15.96%, 15.83%, 15.91% and 15.75%, respectively.

2.2. Pellet formation

Biomass pellets were manufactured using laboratory pellet mill (L-175), made by the Amandus Kahl Co. of Hamburg, Germany. Pellet mill parameters were set to a rotary speed of 235 rpm and pellet diameter of 6.0 mm. Particles mixtures were continuously fed into the pellet mill and compacted into pellets. The temperature of pellets was about 70 °C after exiting die due to particle friction. Pellets were kept in the laboratory more than a week with temperature 27 °C, humidity 50% to stabilize their properties.

2.3. Property test

Pellet properties were determined according to *PFI* standard.

2.3.1. Pellet dimensions

Pellets are cylindrical in shape. In order to determine dimensions and unit mass, fifteen pellets were randomly selected in each mass ratio. Length (L) and diameter (D) of each pellet were measured using a digital vernier caliper (0.01 Resolution). Mass of each pellet (m) was also weighed using a precision digital balance (0.0001 Resolution).

2.3.2. Particle density

Particle density (ρ_p) of pellet was calculated according to the following equations.

$$V_p = \pi \Big/ 4D^2L \tag{1}$$

$$\rho_p = m_p / V_p \tag{2}$$

where, V_p is the volume of individual pellet (cm^3), D is the diameter of individual pellet (mm), L is the length of individual pellet (mm), ρ_p is the density of individual pellet (g/cm^3), and m_p is the mass of individual pellet (g).

2.3.3. Bulk density

Bulk density (ρ_b) was determined in accordance with *ASTM 873* standard (Test Method for Bulk Density of Densified particulate Biomass Fuels).

2.3.4. Fine contents

Fine contents (P_f) were determined in accordance with *PFI* standard.

2.3.5. Inorganic ash

Inorganic ash (I_a) of pellets was determined in accordance with *D 1102-84* Standard (Test Method for Ash in Wood).

2.3.6. Net calorific value

Net calorific value (N_c) of pellets was determined in accordance with *ASTM E 711* Standard (Test Method for gross calorific Value of Refuse-Derived fuel by the Bomb Calorimeter).

2.3.7. Combustion rate and heat release rate

Combustion time was recorded according to the *PARR 1266 Bomb Calorimeter* during determining net calorific value. Based on the mass of the pellets and combustion time, the combustion rate (C_r) was calculated by using following equation.

$$C_r = m/t \tag{3}$$

where, Cr is the average combustion rate, (g/s); m is the mass of pellets, (g); t is combustion time, (s).

By knowing the net calorific value and combustion rate, heat release rate (Hr) could be calculated by using the following equation.

$$H_r = N_c \times C_r \tag{4}$$

where, H_r is the heat release rate, (J/s); N_c is the net calorific value, (J/g); and Cr was the average combustion rate, (g/s).

2.3.8. Proximate and ultimate analysis

Volatile matters were determined in according with GB/T 212-2008. C, H and N were determined in according with GB/T 476-2008. S was determined in according with GB/T 217-2007. Heave metals (Na, Mg, Al, Si, K, Ca, Ti, Fe, Zn) were determined according to standard analysis methods using inductively couple plasma mass spectrometry (ICP-MS).

2.3.9. Synergistic analysis

To investigate whether synergistic interactions occurred between bamboo particles and pine particles during pelleting, the