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The properties of pellets from mixing bamboo and rice straw

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ABSTRACT

Rice straw pellets are the main type of biomass solid fuel and have great potential as a bioenergy resource of the future in China. But it also showed important problems because of its high content of ashes and its low gross calorific value, reducing the possibility to be used in domestic heating. It was certified that mixing different types of biomass materials was helpful to improve the properties of pellets. To improve properties of rice straw pellets and investigate the effect of mixing bamboo and rice straw on the pellet properties, some properties of pellets, manufactured using different mixing ratio of bamboo and rice straw particles, were determined in this research. It can be concluded from this research that physical properties of all pellets meet the requirements of *Pellet Fuels Institute Standard Specification for Residential/Commercial Densified* except for bulk density of pellets, manufactured using mixing ratio ($\leq$3:2) of bamboo and rice straw. The inorganic ash and gross calorific value of rice straw pellets cannot meet the requirement of *Pellet Fuels Institute Standard Specification for Residential/Commercial Densified (8.0%)* and the minimum requirement for making commercial pellets of *DIN 51731 (>17,500 J/g)*. Both properties are improved through mixing bamboo particles and rice straw particles. It is significant that inorganic ash content and gross calorific value of pellets, manufactured using mixing ratio ($\geq$3:2) of bamboo and rice straw, were lower than 8.0% and higher than 17,500 J/g, respectively. This also shows that mixing different biomass materials is an effective way to optimize properties of biomass solid fuel. All pellets after improvement are proposed as biomass solid fuel and have the potential to be developed as commercial pellets on an industrial scale in China.

1. Introduction

Currently, there is tremendous interest in using biomass solid fuel such as pellets or briquettes, substituting for fossil fuels in China. It is well known that biomass is very difficult to handle, transport, store, and utilize in its original form because of its high moisture content, irregular shape or size and low bulk density [1]. Densification increases the bulk density of biomass from an initial bulk density and products have a uniform shape or size. Fasina reported a four-fold reduction of storage space due to the pelletization of peanut hulls [2]. Transport efficiency and storage space also depend on the bulk density of pellets. Recently, the market requirement for pellets or briquettes, used to home heating or combined heat and power, is quickly increasing.

Agricultural and forest residues represent a major fuel source for potential bioenergy projects in many developing countries [3]. Some information on agricultural residue pellet is also available now, for example corn stover [4], spring-harvested reed canary-grass [5], switchgrass [6], cotton stalk [7], peanut hulls [8]. Sudhagar et al. determined mechanical properties of wheat straw, barley straw, corn stover, and switchgrass at different compressive forces, particle sizes, and moisture contents. Corn stover produced the highest pellet density at low pressure during compression. Barley straw had the highest asymptotic modulus among all biomasses [9]. Nilsson et al. analyzed the costs and energy requirements for pellet production from agricultural raw materials, such as salix, reed canary-grass, hemp, straw, screenings, rape-seed meal, rape cake, and distiller's waste [10]. China has abundant agricultural residue resources, producing more than 630 million tons of agricultural residues, and amounting to about 20% of total energy consumption in rural areas [11]. Rice is the primary food for more than 40% of the Chinese population. At present, most of these residues are burnt in situ after harvest. The field burning of rice straw in wide areas not only results in serious environmental issues, but also wastes precious resources. Faced with this situation and the increasingly large market demand for biomass solid fuel, there has recently been a revival of interest in using rice straw to produce biomass pellets.

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Bamboo is another type of biomass material that is widely cultivated in the west and south of China. Currently, the bamboo resource is very abundant and has great potential as a bioenergy resource in the future. In preliminary work, the properties of bamboo and rice straw pellets were evaluated and compared. All physical properties of both pellets meet the requirements of *Pellet Fuels Institute Standard Specification for Residential/Commercial Densified* and the rice straw pellets have better physical properties compared with bamboo pellets. The information is also very important that the inorganic ash and gross calorific value of rice straw pellets could not meet the requirement of *Pellet Fuels Institute Standard Specification for Residential/Commercial Densified* and the minimum requirement for making commercial pellets of *DIN 51731 (>17,500 J/g)* [12], respectively. Mixing different types of biomass materials to improve the properties of pellets or briquettes has been certified in several studies. Winowiski found that adding 15–60% of wheat to the turkey breeder ration that had an initial pellet durability of 32% increased the pellet durability to 45–74% [13]. The durability of rice straw cubes increased from an initial durability of 30–80% through blending 15–20% of beet pulp or ground barley [14]. This study was therefore carried out to determine properties of pellets, manufactured using bamboo and rice straw particles with different mixture ratios (by weight of 5:0, 1:4, 2:3, 3:2, 4:1 and 0:5). The objective of this research is to investigate the effect of mixing bamboo and rice straw on the pellet properties. On the other hand, the results from this research are very helpful to select process parameters to produce pellets or briquettes from bamboo and rice straw, and provide guidelines for further research.

2. Materials and methods

2.1. Materials

Moso bamboo and rice straw were used in this study. Moso bamboo aging with 4 years was taken from a bamboo plantation located in Louisiana, US. The initial moisture content of the bamboo was about 6.13% and the density was about 0.65 g/cm^3. Bamboo materials were cut off to sample size 40 mm (longitudinal) by 3–8 mm (radial) by 20–30 mm (tangential). Rice straw was obtained from California, US. It was approximately 1 m tall at harvest and cut above the water line leaving the lower third as stubble in the field. This rice was also harvested with a conventional straw walker combine rather than a rotary, which optimizes straw quality by retaining much longer sections of stalks for bailing. The initial moisture content of the straw was about 8.1%.

The bamboo and rice straw were broken down into particles using a wood particle mill at the USDA Forest Service Forest Products Laboratory. The bamboo and rice straw particles (particle size of less than 2.0 mm) were uniformly mixed with different weight ratio (5:0, 1:4, 2:3, 3:2, 4:1 and 0:5). About 10 g mixtures in each weight ratio were randomly weighed using a precision digital balance (0.0001 Resolution). They were dried at temperature 105 °C until their mass stabilized and then the final weight was recorded. Moisture content of mixture was determined through mass change of samples. Then 5 kg of mixtures in each weight ratio were conditioned by adding predetermined amounts of distilled water to the samples [15] and then placed into a conditioning room with temperature 27 °C, humidity 65% for 48 h to enable uniform moisture distribution. The final moisture contents of mixtures were 16.03%, 15.97%, 15.56%, 15.73%, 15.81% and 15.86%, respectively.

2.2. Pellet formation

The pellets were manufactured using laboratory pellet mill (L-175), made by the Amandus Kahl Co. of Hamburg, Germany. The pellet mill parameters were set to a rotary speed of 235 rpm, press channel of 20.0 mm and pellet diameter of 6.0 mm. Mixture particles were continuously fed into the pellet mill and formed into pellets. The pellets were collected and kept in the laboratory more than a week, and then their properties were tested.

2.3. Property test

Some properties of pellets were selected and determined based on *Pellet Fuels Institute Standard Specification for Residential/Commercial Densified*.

2.3.1. Pellet dimensions

The pellets were cylindrical in the shape. In order to determine dimensions and unit mass, ten pellets were randomly selected in each experiment. The length (L) and diameter (D) of each pellet were measured using a digital vernier caliper. The mass of each pellet (m) was also weighed using a precision digital balance.

2.3.2. Unit density

Unit density (ρ_u) of each pellet was determined by weighing the individual pellet and calculating its volume based on its length and diameter as per the following equations.

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

$$\rho_u = m_u/V_u \tag{2}$$

where, V_u 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_u is the density of individual pellet (g/cm^3), and m_u is the mass of individual pellet (g).

2.3.3. Bulk density

Bulk density (ρ_b) was calculated as the ratio of the material mass to the container volume. The pellets were leveled to the top surface of the container and were weighed using a digital balance. The container volume was calculated by measuring its length and diameter.

$$\rho_b = m_b/V_b \tag{3}$$

where, ρ_b is the bulk density (g/cm^3), V_b is the volume of container (cm^3), and m_b is the total mass of pellets (g).

2.3.4. Pellet fines content

Pellet fines content (P_f) was determined using a 3.17 mm (1/8 in) wire screen sieve according to *Pellet Fuels Institute Standard Specification for Residential/Commercial Densified*. A sampling of pellets were randomly selected and divided into ten groups. The initial mass of each group sample was weighed using a precision digital balance. The groups were placed on the wire screen sieve and tilted from side to side ten times. The final mass was then weighed and recorded. The pellet fines content was calculated using the following equation:

$$P_f = \left(m_i - m_f\right)\Big/m_i \times 100\% \tag{4}$$

where, P_f is fine of samples (%), m_i is initial mass of samples (g), and m_f is final mass of samples (g).

2.3.5. Pellet durability

Pellet durability (P_d) was determined by mass loss of samples. Some pellets were randomly selected and weighed using a precision digital balance. The initial mass was recorded. They were then put into a vibrating sieve with screen size 3.17 mm (1/8 in). After 10 min, they were weighed again and the final mass was recorded. Pellet durability was calculated using the following equation:

$$P_d = 100 - \left(m_i - m_f\right) \Big/ m_i \times 100\% \tag{5}$$

where, P_d is pellet durability (%), m_i is initial mass of samples (g), and m_f is final mass of samples (g).

2.3.6. Inorganic ash

Inorganic ash (I_a) of pellets was determined based on inorganic material content expressed as a percent. The temperature for creating ash was from *SN EN 14775:2010-04* (Solid biofuels – Determination of ash content).

1. Five empty crucibles were ignited in an XD-1200N muffle furnace (made by Aremco Products, Inc.) at 550 °C for 2 h, cooled in a desiccator, and weighed using a precision digital balance.
2. About 2 g pellets were placed in each crucible and weighed together, prior to being placed in a drying oven at 105 °C. After 2 h, they were removed and cooled to room temperature in a desiccator prior to being weighed.
3. The crucibles were returned to the drying oven at 105 °C for 2 h, then cooled and weighed. When weight variance of the crucible was less than 0.2%, the final weight was recorded.
4. The crucibles were again placed in the muffle furnace at 550 °C and ignited until all carbon was eliminated.
5. The crucibles were removed from the muffle furnace and cooled in the desiccator prior to being weighed for the final time using a precision digital balance.
6. Inorganic ash content was calculated based on the following equation.

$$I_a = (W_1/W_2) \times 100\% \tag{6}$$

where, I_a is inorganic ash content (%), W_1 is weight of inorganic ash (g), and W_2 is weight of oven-dry bamboo pellets (g).

2.3.7. Gross calorific value

The gross calorific value (G_c) is the amount of energy per unit mass released upon complete combustion. The gross calorific value of bamboo pellets was tested using the PARR 1266 Bomb Calorimeter. Before testing gross calorific value of bamboo pellets, the calorimeter was calibrated with tablets of benzoic acid whose calorific value was 26,465 J/g. In this test, about 1 g pellets were introduced into the bomb, which was charged slowly with pure oxygen (>99.95 vol.%, quality 3.5) to a pressure of 3.0 ± 0.2 MPa without displacing the original air. No aid to combustion was used and five samples were tested.

3. Results and discussion

3.1. Pellet dimension

Fig. 1 illustrated pellet dimension and the data presented were the mean of measurements made on fifteen pellets. The mean length and diameter of bamboo pellets slightly ranged. The geometric dimensions of pellets, both diameter and length, are important factors with respect to combustion. Experience shows that thinner pellets allowed a more uniform combustion rate than thicker ones, especially in small furnaces. The length of the pellets affected the fuel feeding properties. The shorter the pellets, the easier the continuous flow could be arranged [16]. The diameter change of pellets could be due to water migrating from pellets and disrupting formed bonds in the pelletization process [15].

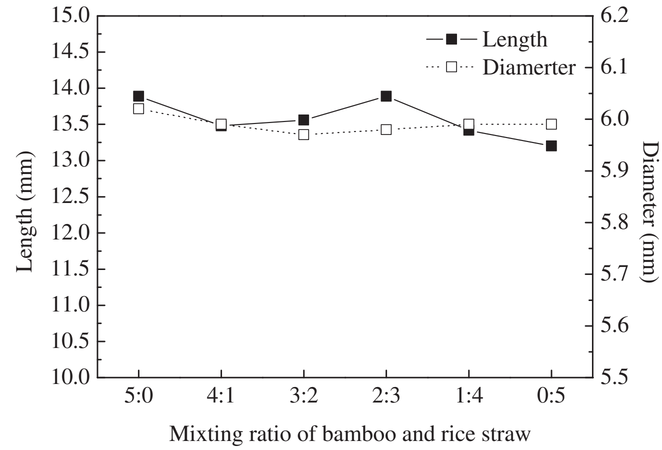

Fig. 1. The length and diameter of pellets.

3.2. Pellet density

Pellet density is very important in evaluating product properties. Several national standards describe particle density of pellets and briquettes as a quality indicator of densified fuels [17]. The maximum throughput for a large-scale biomass bulk terminal is set at 40 tons per annum, both solid and liquid biomass, which implies that substantial storage facilities, spaces and handing systems are required [18]. Transport, handling efficiency and storage space requirements depend on the bulk density of pellets. Adequate storage spaces are necessary in order to safely keep a large supply of feedstock on hand. Higher bulk density leads to greater transport efficiency and lower storage space requirements. Fig. 2 showed bulk density and unit density of pellets. The data presented were the mean of measurements made on fifteen pellets. It was found that the bulk density of pellets increased with increase in rice straw content of mixture. The values were 0.54 g/cm^3, 0.56 g/cm^3, 0.57 g/cm^3, 0.60 g/cm^3, 0.62 g/cm^3 and 0.64 g/cm^3 for different pellets, manufactured using mixing ratios of bamboo and rice straw, respectively. For unit density, however, the pellets from mixture were lower than that from bamboo (1.25 g/cm^3) and rice straw (1.35 g/cm^3).

3.3. Pellet strength

The strength of pellets is also an important factor connected with handling and transportation. In this research, the strength of pellets included two parameters, durability and fine content

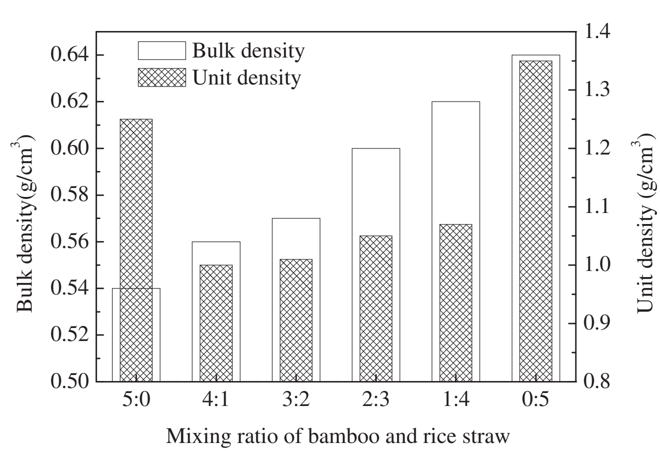

Fig. 2. Bulk density and unit density of pellets.

showed in Fig. 3. Pellet durability increased with increases in rice straw content of mixture and the maximum (99.03%) was observed in mixing ratio (2:3) of bamboo and rice straw. Then pellet durability decreased with increased in rice straw content of mixture. The information was very important that the durability of pellets from mixture and rice straw was higher than that of bamboo pellets. It was also confirmed that durability of bamboo pellets was improved through mixing bamboo and rice straw. For fine content, the minimum (0.26%) was also found to mixing ratio (2:3) of bamboo and rice straw. Bhattacharya et al. found that compressive strength of briquettes increased through mixing of 25, 50, 75, and 100% (by weight) of rice husk with water hyacinth [19]. Chen et al. found that pellet durability increased as the percentage of bark in furnish increased from 33.3 to 50% [20].

In summary, some physical properties of pellets, including length, diameter, unit density, bulk density, durability and fine content, were determined in this research. Some physical properties of bamboo pellets were improved through mixing bamboo particles and rice straw particles, especially bulk density, durability and fine content. Compression formation of different materials utilizing natural binder or binding type of particles included attractive forces between solid particles, interfacial forces, capillary pressure, adhesive and cohesive forces, mechanical interlocking behavior and formation of solid bridges [21]. It was found in preliminary work that the bonding between particles was created mainly through solid bridges for bamboo pellets. This bonding for corn stover and switchgrass pellets has also been confirmed. The solid bridges between particles were made by natural binders in the biomass expressed during the densification process [22]. Bamboo and rice straw are mainly composed of hemicelluloses, cellulose and lignin, even though the contents of these compositions are different. Their cellulose, hemicelluloses and lignin contents were showed in Table 1. It is well known that hemicelluloses, lignin and protein are essentially amorphous polymers in the biomass components. Activating (softening) the natural binders using moisture and temperature in the range of glass-transition is important to make durable particle–particle bonding. Lignin has a glass-transition in the temperature range of 60 °C–200 °C, depending upon the moisture content and measuring technology [23]. Olsson and Salmen showed that the α_1 transition of moist wood usually occurs between 60 °C and 95 °C, due to the glass–rubber transition of lignin [24]. Hemicelluloses had a glass-transition of between −23 °C and 200 °C, depending upon the moisture content [25]. In the pelletization process, the difference in particle bonding and physical properties of bamboo pellets probably

Table 1
Chemical composition of bamboo and rice straw.

Species	Cellulose (%)	Hemicelluloses (%)	Lignin (%)	Ash (%)
Moso bamboo	42–50	24–28	24–26	1.3–2.0
Rice straw	41–57	33	8–19	8–38

resulted from the glass-transition of natural binders. In this research, the formation temperature was more than 70 °C due to particle rubs. Liu et al. found that there was an α-transition (α_1) peaking due to the glass–rubber transition of lignin at about 65 °C (Outer of bamboo), 83 °C (Middle of bamboo), and 75 °C (Inner of bamboo), respectively [26]. Stelte et al. found that the glass-transition of softening lignin from wheat straw was about 53 °C [27]. Lignin can be classified into three major groups based on the chemical structure of their monomer units, which are softwood lignin, hardwood lignin and grass lignin [28]. The lignin of rice straw and wheat straw can be similar and the glass-transition of rice straw can occur at a lower temperature than that of bamboo. This causes a weaker mechanical strength of bamboo pellets than that of pellets from mixture and rice straw.

3.4. Combustion properties of pellets

Fig. 4 shows inorganic ash, gross calorific value of pellets. It was found that the inorganic ash content of rice straw pellets (15.94%) was obviously higher than that of bamboo pellets (1.75%). The inorganic ash of biomass pellets depended on the composition of mineral constituents in the source fuel [29]. It was confirmed that the main ash-forming elements of biomass materials included Na, Mg, Si, Al, Fe, Ca, Na, K, Zn and Ti [30]. The difference in inorganic ash content of bamboo and rice straw pellets was due to these element variations, which were showed in Table 2. It was very important that inorganic ash content of rice straw pellets could not meet the requirement of *Pellet Fuels Institute Standard Specification for Residential/Commercial Densified* (≤8.0%). It was also valuable information that inorganic ash content of pellets, manufactured using mixing ratio (≥3:2) of bamboo and rice straw, was lower than 8.0%.

The most important parameter to characterize combustibility of a substance is gross calorific value. The number of units of energy produced by the combustion of a unit mass of a fuel is termed gross calorific value. The calorific value of biomass can be expressed as follows: higher heating value at constant volume (dry basis), low heating value at constant pressure (dry basis) and low heating

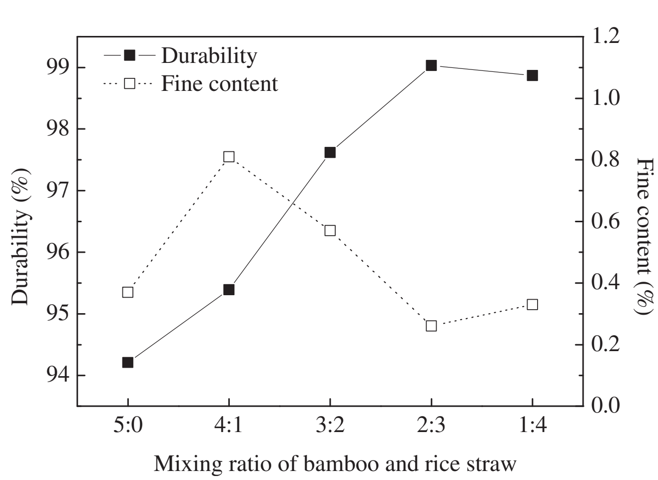

Fig. 3. Durability and fine content of pellets.

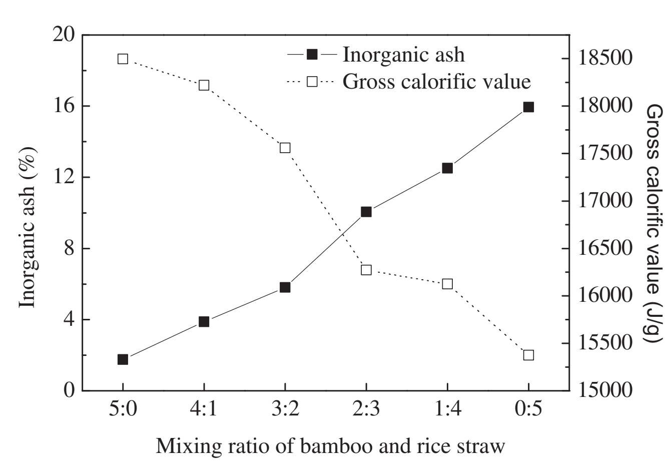

Fig. 4. The combustion properties of pellets.

Table 2
Ash-forming elements of bamboo and rice straw pellets.

Pellet species	Na (mg/kg)	Mg (mg/kg)	Al (mg/kg)	Si (mg/kg)	K (mg/kg)	Ca (mg/kg)	Ti (mg/kg)	Fe (mg/kg)	Zn (mg/kg)
Bamboo	242.83	229.46	35.09	358.14	4032.58	965.027	18.07	111.93	20.88
Rice straw	718.27	1136.92	51.23	2321.88	11,234.3	2407.38	7.02	187.81	45.43

value at constant pressure (wet basis or as received) [31]. In this research, the low heating value was used for all pellets because it is perhaps the most practical measure of energy content. It was obvious that the gross calorific value of bamboo pellets was higher than that of rice straw pellets. The different compositions of bamboo and rice straw led to the variations of gross calorific value. It was confirmed that gross calorific value of pellets was most affected by the composition of materials [31]. Gross calorific value of rice straw pellets could not meet the minimum requirement for making commercial pellets of *DIN 51731 (>17,500 J/g)* [12]. It is significant that gross calorific value of pellets, manufactured using mixing ratio ($\geq$3:2) of bamboo and rice straw, was higher than 17,500 J/g.

In summary, combustion properties, such as inorganic ash and gross calorific value, exhibited measured differences for various pellet types. The inorganic ash and gross calorific value of rice straw pellets could not meet the requirement of *Pellet Fuels Institute Standard Specification for Residential/Commercial Densified* and the minimum requirement for making commercial pellets of *DIN 51731 (>17,500 J/g)*. But these properties were improved through mixing rice straw and bamboo particles. It was also confirmed that mixing different biomass materials was an effective way to optimize properties of biomass solid fuel.

4. Conclusions

It can be concluded from this research that physical properties of all pellets meet the requirements of *Pellet Fuels Institute Standard Specification for Residential/Commercial Densified* except for bulk density of pellets, manufactured using mixing ratio ($\leq$3:2) of bamboo and rice straw. The inorganic ash and gross calorific value of rice straw pellets cannot meet the requirement of *Pellet Fuels Institute Standard Specification for Residential/Commercial Densified (8.0%)* and the minimum requirement for making commercial pellets of *DIN 51731 (>17,500 J/g)*. Both properties are improved through mixing bamboo particles and rice straw particles. It is significant that inorganic ash content and gross calorific value of pellets, manufactured using mixing ratio ($\geq$3:2) of bamboo and rice straw, was lower than 8.0% and higher than 17,500 J/g, respectively. This also shows that mixing different biomass materials is an effective way to optimize properties of biomass solid fuel. All pellets after improvement are proposed as biomass solid fuel and have the potential to be developed as commercial pellets on an industrial scale in China.

Acknowledgments

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References

[1] Kaliyan N, Morey RV. Factors affecting strength and durability of densified biomass products. Biomass and Bioenergy 2009;33:337–59.
[2] Fasina OO. Physical properties of peanut hull pellets. Bioresource Technology 2008;99:1259–66.
[3] McMullen J, Fasina O, Wood W, Feng YC, Mills G. Physical characteristics of pellets from poultry litter. ASABE Paper No. 046005. St. Joseph, Michigan: American Society of Agricultural and Biological Engineers; 2004.
[4] Sudhagar M, Tabilb LG, Sokhansanj S. Specific energy requirement for compacting corn stover. Bioresource Technology 2006;97:1420–6.
[5] Paulrud S, Nilsson C. Briquetting and combustion of spring-harvested reed canary-grass: effect of fuel composition. Biomass and Bioenergy 2001;20:25–35.
[6] Colley Z, Fasina OO, Bransby D, Lee YY. Moisture effect on the physical characteristics of switchgrass pellets. Transactions of the ASABE 2006;49:1845–51.
[7] Abasaeed AE. Briquetting of carbonized cotton stalk. Energy 1992;17:877–82.
[8] Fasina OO, Sokhansanj S. Effect of moisture content on bulk handling properties of alfalfa pellets. Canadian Agricultural Engineer 1993;35:269–73.
[9] Sudhagar M, Tabilb LG, Sokhansanj S. Effects of compressive force, particle size and moisture content on mechanical properties of biomass pellets from grasses. Biomass and Bioenergy 2006;30:648–54.
[10] Nilsson D, Bernesson S, Hansson P. Pellet production from agricultural raw materials – a systems study. Biomass and Bioenergy 2011;35:679–89.
[11] Chen LJ, Li X, .Han LJ. Renewable energy from agro-residues in China: solid biofuels and biomass briquetting technology. Renewable and Sustainable Energy Reviews 2009;13:2689–95.
[12] Faizal HM, Latiff ZA, Wahid MA, Darus AN. Study on characteristics of briquettes contain different mixing ratio of EFB fiber and mesocarp fiber. International Meeting on Advances in Thermo-Fluids; 2009.
[13] Winowiski T. Wheat and pellet quality. Feed Management 1988;39:58–64.
[14] Waelti H, Dobie JB. Cubability of rice straw as affected by various binders. Transactions of the ASABE 1973;16:380–3.
[15] Mahapatra AK, Harris DL, Durham DL, Lucas S, Terrill TH, Kouakou B, et al. Effects of moisture change on the physical and thermal properties of sericea lespedeza pellets. International Agricultural Engineer Journal 2010;1:23–9.
[16] Paivi L. Quality properties of pelletised sawdust, logging residues and bark. Biomass and Bioenergy 2001;20:351–60.
[17] Filbakk T, Raida J, Juha N, Olav H. The effect if bark content on quality parameters of Scots pine (*Pinus sylvestris* L.) pellets. Biomass and Bioenergy 2011;35:3342–9.
[18] Wu MR, Schott DL, Lodewijks G. Physical properties of solid biomass. Biomass and Bioenergy 2011;35:2093–105.
[19] Bhattacharya SC, Saunier GY, Shah N, Islam N. Densification of biomass residues in Asia. In: Egneus H, Ellegard A, editors. Bioenergy 84. Biomass conversion, vol. III. London: Elsevier Applied Science Publishers; 1985. p. 559–63.
[20] Chen PYS, Haygreen JG, Graham MA. An evaluation of wood/coal pellets made in a laboratory pelletizer. Forest Products Journal 1989;39:53–8.
[21] Holt GA, Blodgett TL, Nakayama FS. Physical and combustion characteristics of pellet fuel from cotton gin by-products produced by select processing treatments. Industrial Crops Product 2006;24:204–13.
[22] Kaliyan Nalladurai, Morey R Vance. Natural binders and solid bridge type binding mechanisms in briquettes and pellets made from corn stover and switchgrass. Bioresource Technology 2010;101:1082–90.
[23] Salmen L. Thermal expansion of water saturated wood. Holzfurchung 1990;44:17–9.
[24] Olsson AM, Salmen L. The effect of lignin composition on viscoelastic properties of wood. Nordic Pulp Paper Research 1997;12:140–4.
[25] Kelley SS, Rials TG, Glasser WG. Relaxation behavior of the amorphous components of wood. Journal Material Science 1987;22:617–24.
[26] Liu ZJ, Jiang ZH, Cai ZY, Fei BH, Yu Y, Liu XE. Moisture of bamboo for pellets. BioResources 2012;7:1548–57.
[27] Stelte W, Clemons C, Holm JK, Ahrenfeldt J, Henriksen UB, Sanadi AR. Thermal transition of the amorphous polymers in wheat straw. Industrial Crops Product 2011;34:1053–6.
[28] Sun R. Cereal straw as a resource for sustainable biomaterials and biofuels: chemistry, extractives, lignin, hemicelluloses and cellulose. Elsevier; Amsterdam.
[29] Dick EP, Ryabov GA, Tugov AN, Soboleva AN. Comparing properties of coal ash and alternative-fuel ash. Thermal Engineering 2007;54:231–5.
[30] Werkelin J, Lindberg D, Bostrom D, Skrifvars BJ, Hupa M. Ash-forming elements in four Scandinavian wood species, part 3: combustion of five spruce samples. Biomass and Bioenergy 2011;35:725–33.
[31] Telmo C, Lousada J. Heating values of wood pellets from different species. Biomass and Bioenergy 2011;35:2634–9.