

Physicomechanical Properties of Rice Husk Pellets for Domestic Combustion in Myanmar

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Abstract: Myanmar produces 26.21 million tons of rice annually that results in 5.24 million tons of remaining rice husk of which only around 30% is used for electricity and heat production in the country. Myanmar needs more energy consumption to develop the agricultural economy and biomass energy in the future of the country. The proximate and ultimate analysis of rice husk and produced rice husk pellets were determined as well as analyzing the physicochemical and mechanical properties. The rice husk pellets without doing size reduction were manufactured in a ring die pellet mill. Loose and pellet-formed rice husk were compared based on the ISO 17225-6 standard for the characterization of herbaceous biomass. Pelletizing increased the bulk density of rice husk by a factor of 4.5. The net calorific value of Myanmar rice husk pellets was 3.67 kW·h/kg with a moisture content of 7.48% and the large amount of ash forming constituents. The result showed that the diameter, length, and durability of the produced pellets complied with ISO 17225-6 standard. However, the net calorific value and bulk density could only be partially fulfilled according to the ISO standard depending on the process parameters.

Keywords: Rice husk, pellets, bulk density, calorific value, durability.

1. Introduction

The 2015 and 2016 Myanmar Statistical Yearbooks reported an annual paddy rice production of 26.21 million tons, which resulted in 5.24 million tons of rice husk from 17.82 million sown acres [1, 2]. Of those 5.24 million tons, 30% of this rice husk is used in rice husk gasifier and boiler-based system to produce electricity and heat. Given its low bulk density of about 85-110 kg/m³ [3], the remaining 70% of the rice husk poses large challenges for disposal in the rice milling. The total amounts of biomass consumption in the rural area of Myanmar, conducted by fire-stove accounts for 8.85 tons per household per annum. The use of rice husk pellets instead of wood fuels plays an important role in cooking and cottage industries in both urban and rural area [4].

Lignocellulosic biomasses, such as herbaceous

crops, agricultural, and forest residues are the most promising renewable sources for the efficient and clean supply of heat, power, and fuel [5]. In the recent year, these types of biomass feedstock were used to produce pellets for combustion. Sewage sludge-containing proteins and carbohydrates were used as a natural binder to improve the strength of fiber grid in the pellets [6]. Of the many types of pellet mills, flat die pellet mills are widely used employed for small-to-medium scale and up to large scale pellet production and round/ring die pellets mills for medium-to-large scale pellet production [7]. Biomass pelletization has provoked significant interest in Myanmar in recent years as a technique for utilizing residues as an energy source. Several parameters affect the produced quality of pelletized biomass: feedstock variables (feedstock type, moisture content, particle size, shape, and distribution); feedstock composition (cellulose, hemicellulose, lignin, protein, fat, and wax); process variables (die diameter,

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length-to-diameter ratio, die speed, die temperature, pressure, feed rate, binder usage, and pre-heating) to fulfill and achieve customers' requirements for pellet quality and emissions generated by combustion [6, 8]. Density, abrasion, and durability should be measured as the quality parameters for biomass pellets after production within one week to one month to determine their dimensional stability [9].

The aim of this work is to investigate the physicomechanical properties of Myanmar rice husk pellets. This includes compliance with the ISO 17225-6 standard for herbaceous biomass.

2. Raw Material

Rice husk before entering the pellet mill and rice husk pellets on a vibrating screen with a round-hole sieve (3.18 mm) were collected for further analysis. Myanmar Biomass Power Co., Ltd supplied these solid biofuels from a biomass power plant located in the country's Bago Division administrative region, which produces the third largest amount of paddy in Myanmar.

3. Rice Husk Pelletization

The pelletizing process was carried out by a pelletizer with a perforated ultra-wear stainless steel round/ring die using three rollers (Yulong 6th generation XGJ 850, 220 kW) and a capacity of (2.5-3.5 ton/h). Rice husk was used as delivered without prior drying and moisture content on wet basis of $10.44\% \pm 0.0115\%$. Because the press diameter-to-die channel length ratio depends on the raw material, a compression ratio of 1:5.5 was used for the rice husk. The rollers compressed and forced the rice husk under high pressure through the die holes. Each hole acts as an individual mold with a fixed diameter of 8 mm and a length of 85 mm. The fractional force between the rice husk and die holes increases and leads to elevated temperature. The pellet temperature after discharge was about 93 \pm 2 °C. The pellets showed a soft appearance at elevated temperatures due to lignin



Fig. 1 Photos of (a) rice husk, and (b) rice husk pellets manufactured.

present in the rice husk, which acts as a binder. The pellets extruded through the die holes were cooled and dried to be solid and strengthened prior to being sieved with a vibrating round-hole screen. The obtained clean and dust-free pellets were packaged in bags for further analysis. Fig. 1 shows the rice husk as a raw material obtained from the rice mills (a) and as manufactured pellets (b).

4. Analytical Methods

The cellulose, hemicellulose, lignin, crude protein, crude fiber, and crude fat contents were characterized according to the Verband Deutscher Landwirtschaftlicher Untersuchungs- und Forschungsanstalten (VDLUFA) [10]. Acid detergent fiber (ADF), neutral detergent fiber (NDF) and acid detergent lignin (ADL) were employed to determine cellulose, hemicellulose, and lignin contents in the rice husk. Cellulose (ADF-ADL) and hemicellulose (NDF-ADF) were subsequently calculated using these values [11].

4.1 Proximate Analysis

The proximate analysis of rice husk and rice husk pellets (solid biomass fuels) was determined by the following standards developed by the American Society for Testing and Materials (ASTM): E871 for moisture content; E872/E897 for volatile matter; E830/D1102 for ash (ASH) and by difference of fixed carbon within the biomass solid fuels [12-14].

4.2 Ultimate Analysis

The major solid biofuel constituents such as carbon (C), hydrogen (H), nitrogen (N), and sulfur (S) were determined using a Flash Smart CHNS analyzer (Thermo Fisher Scientific, USA). Oxygen was assumed to represent 100% of the difference. The data obtained from ultimate analysis were used to calculate the gross calorific value (higher heating value), defined as the amount of heat released by the unit mass or volume of fuel. Eqs. (1) and (2) developed by Channiwala and Parikh [15, 16] were applied to calculate the higher heating value (HHV):

$$HHV = 349.1 C + 1178.3 H + 100.5 S - 103.4 O - 15.1 N - 21.1 ASH kJ/kg$$
(1)

The relationship between HHV and lower heating value, LHV, is given by:

LHV = HHV -
$$h_g \left(\frac{9 H}{100} + \frac{M}{100}\right)$$
 (2)

where, H is the hydrogen percentage and M is moisture percentage. The latent heat of steam h_g is 2260 kJ/kg.

4.3 Bulk Density

The bulk densities were determined in a 5 L standard container with an inner diameter of 167 mm and inner height of 228 mm, according to the ISO

17828 (EN15103) [17, 18]. In brief, solid biofuels were slowly poured into the container from a 25 cm height above the container opening to form a maximum height cone. The container containing solid fuels was compacted by being dropped from a height of 15 cm to fill the empty space. Filling and compacting were repeated three times until the container overflowed. Next, a strike-off stick (15×50 mm) was used to remove excess solid biofuels by sliding it across the top of the container. The final weight of the solid biomass fuels was recorded. This procedure was performed five times with 5 L each of rice husk and rice husk pellets based on their wet bases. The bulk density of solid biomass fuels was calculated using the following Eq. (3):

$$D_{\rm ad}({\rm at}M_{\rm ad}), {\rm g/}{cm^3} = \frac{(M_2 - M_1)}{V}$$
 (3)

where, D_{ad} is the bulk wet basis density, M_{ad} is wet basis moisture content, M_1 is mass of the empty container, M_2 is mass of the container fully loaded with pellets, V is volume of the container.

4.4 Particle Density

Pellet particle density, including pore volume, was measured using the buoyancy method [19]. The wetting agent (polyethylene glycol) with a 1.5 g/L concentration was used to reduce the surface tension. The effect of the temperature on the liquid density was neglected due to laboratory conditions. The pellet particle density (ρ_u) [20, 21] was calculated according to Eq. (4):

$$\rho_u = \frac{m_u}{m_u - m_s} \rho_w \tag{4}$$

where, ρ_w is the density of the liquid at a given temperature, m_u is the weight of the test sample in air, and m_s is the weight of the sample in liquid.

4.5 Energy Density

Pellet energy density was estimated as a product of the bulk wet basis density (kg/m^3) and net calorific value with moisture content (MJ/kg) of the fuels [22].

4.6 Durability

The mechanical durability of the rice husk pellets was measured according to ISO 17831-1 (ASAE S269.4 standard) [23, 24]. In brief, pellets were pre-sieved with around-hole sieve (3.65 mm) to remove any fine materials. And 500 g of initial test pellets were fed in a rectangular stainless steel container with an inner dimension of 300 mm \times 300 $mm \times 125 mm$. A baffle with a dimension of 230 mm \times 50 mm was mounted diagonally on the container's 300 mm \times 300 mm inner side. The filled container was tumbled at 50 rpm for 10 min. The tumbled pellets were sieved again with a 3.65 mm sieve. The mass of pellets retained on the sieve was recorded and this procedure was performed five times. The pellet durability according to it wet basis was calculated using the following Eq. (5):

Durability (%) =
$$\frac{m_f}{m_i} \times 100$$
 (5)

where, m_i is the initial mass of pre-sieved pellets before the tumbling process (g) and m_f is the remaining pellets' mass after the tumbling process (g) and sieving.

4.7 Energy Dispersive X-Ray Fluorescence (EDXRF) Analysis

Rice husk ash composition analysis (expressed as the equivalent oxides for each element) was measured using an EDX-7000, Energy Dispersive X-ray fluorescence spectrometer (Shimadzu, Japan) at 50 kV and 13 μ A. Samples were scanned from 0-40 keV for 60 s at ambient atmosphere.

4.8 Statistical Analysis

Design-Expert software, version 11 (DX11) was used to analyze the results obtained from experiments that were run at least three times using the methods described above. The weight percent from the experimental data in this study were expressed as the mean \pm SD (standard deviation). The level of significance, 0.05, corresponds to a 95% confidence interval.

5. Results and Discussion

Rice husk's organic composition is mainly comprised of cellulose, hemicellulose, lignin, and silica, as well as small quantities of metal oxides. Table 1 shows rice husk ash composition, which most likely consists of fat, crude protein, and fiber. The rice husk cellulose content was $41.70\% \pm 0.3606\%$. Cellulose content has not been a suitable adhesive for biomass pelletizing. However, the lignin content, which acted as an adhesive to the cellulose fiber within the rice husk, was $13.70\% \pm 0.1900\%$. This subsequently contributed to the formation of pellets without binders. The silicon dioxide (SiO₂) content observed in the rice husk ash was $96.06\% \pm 0.6463\%$. Despite silica being most prevalent, the rice husk ash also contained a small amount of oxides, with potassium oxide having the highest concentration of the elemental oxides. Alkali metal oxide as potassium oxide can react with silica to form silicates, which may lead to sintering within the reactor. Calcium oxide (CaO) can also react with sulfur to produce sulfate; however, the rice husk sulfur content was low $(0.05\% \pm 0.0058\%).$

Table 2 shows the proximate analysis, ultimate analysis, and higher heating value (HHV), which are the most important data for characterizing lignocellulosic biomass. The moisture content in the rice husk decreased from $10.44\% \pm 0.0115\%$ to 7.48% \pm 0.1514% after pelletizing due to fraction-generated heat that occurred during the process. In addition, some surface moisture from the pellets was removed while the pellets were carried on the conveyor before packaging. Solid biofuel ash content was $16.14\% \pm$ 0.2297% in mass given its constituents like silicon, potassium, calcium and a trace amount of inorganic constituent oxide in the rice husk, as exhibited in Table 1. Increasing the biomass ash content lowers the heating value risk of fouling and slagging inside the reactor as well as dust emission. The main chemical elements, carbon (C), hydrogen (H), and oxygen (O) could determine the calorific value of a fuel. The

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Rice husk chemical composition	wt % on wet-basis Mean ± SD	Rice husk ash constituents	wt % on dried-basis Mean ± SD
Cellulose	41.70 ± 0.3606	Silicon dioxide	96.06 ± 0.6463
Hemicellulose	22.10 ± 0.3000	Potassium oxide	2.51 ± 0.3345
Lignin	13.70 ± 0.1900	Calcium oxide	0.55 ± 0.1110
Fat	0.05 ± 0.0900	Sulfur trioxide	0.41 ± 0.0686
Crude protein	0.25 ± 0.0252	Iron oxide	0.20 ± 0.1131
Crude fibre	4.29 ± 0.0252	Manganese (II) oxide	0.21 ± 0.0007

 Table 1
 Chemical composition of rice husk and inorganic constituents of rice husk ash.

Table 2	Proximate, ultimate an	alysis, and HHV	of rice husk and	produced rice husk	pellets.
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Fuel properties	Rice husk Mean ± SD	Produced rice husk pellets Mean ± SD		
Proximate analysis (wt %)				
Moisture	10.44 ± 0.0115	7.48 ± 0.1514		
Ash	16.14 ± 0.2297	16.07 ± 0.0923		
Volatile matter	62.95 ± 0.3904	62.53 ± 0.0135		
Fixed carbon	10.47 ± 0.4509	13.92 ± 0.1204		
Ultimate analysis (wt %)				
Carbon, C	40.30 ± 0.0640	40.95 ± 0.0370		
Hydrogen, H	5.26 ± 0.0619	5.10 ± 0.0370		
Nitrogen, N	0.36 ± 0.0330	0.30 ± 0.0129		
Sulfur, S	0.05 ± 0.0058	0.05 ± 0.0037		
Oxygen, O	54.03 ± 0.0374	53.60 ± 0.0673		
Elemental mole ratio				
H/C	1.56 ± 0.0206	1.48 ± 0.0098		
O/C	1.01 ± 0.0013	0.98 ± 0.0021		
Calorific value (MJ/kg)				
Calculated higher heating value (HHV)	14.34 ± 0.0573	14.42 ± 0.0607		

Table 3 Physical, mechanical properties of rice husk and produced rice husk pellets, and ISO 17225-6 specifications forpellet produced on an herbaceous biomass wet basis.

Fuel properties	Rice husk Mean ± SD	Produced rice husk pellets Mean ± SD	ISO 17225-6			
Physical property						
Width or diameter (mm)	(0.62-2.48)	7.88 ± 0.0212	6-10			
Length (L) (mm)	6.93-7.53	$9.97 \pm 0.3021 \leq L \leq 75 \pm 0.5630$	$3.15 < L \le 40$			
Net calorific value (kW·h/kg)	3.62 ± 0.0451	3.67 ± 0.0534	\geq 4			
Bulk density (kg/m ³)	130.38 ± 0.0306	565.03 ± 0.1760	≥ 600			
Energy density (GJ/ m ³)	1.69 ± 0.0015	7.53 ± 0.0694	NA			
Particle density (kg/m ³)	-	1.32 ± 0.1901	NA			
Mechanical property						
Durability (%)	-	$> 99 \pm 0.0756$	≥ 97.5			

NA means "Not Announced".

calorific value of the rice husk pellets was slightly higher than that of the rice husk. This was because of a moderate decrease in the rice husk pellets' elemental mole ratios, (H/C) and (O/C), compared to the rice husk's elemental ratio. In contrast, an increase in elemental mole ratios and moisture content reduces fuel's calorific value.

Table 3 shows the physicomechanical properties of rice husk based on wet basis and manufactured rice husk pellets, and also provides a comparison of produced pellets and those produced from herbaceous biomass according to ISO 17225-6 standards [25]. Furthermore, Table 3 shows that the particle density of the rice husk pellets produced from rice husk without modifying its particle size and moisture content was 1.32 kg/m^3 . The bulk density of the rice husk pellets was 4.5 times higher than that of the rice husk, which leads to improvements in handling and transportation, while also decreasing the storage, transportation and storage footprint area. In addition, the pellet energy density also increased due to its increased bulk density and net calorific value. Missagia and Guerroero [26] reported that the net calorific value of Brazilian rice husk pellet was 3.61 kW·h/kg with a moisture content of 8.5%. The rice husk ranged from 5-6 on the Moh's scale of hardness, which involves scratching the material with apatite and feldspar metal. The physicomechanical properties of the manufactured rice husk pellets were then compared with ISO 17225-6 standards while the produced rice husk's diameter, length, and durability complied with these standards, net calorific value and pellet bulk density were influenced by moisture content, particle size, feedstock composition, and machine-specific parameters, which affected whether it met these standards.

6. Conclusions

Rice husk and rice husk pellets made in a ring die pellet machine were compared based on their physicomechanical properties and thermal stabiliy. The silicon and potassium, which acted as an ash-forming oxide in the rice husk feedstock, represented the majority of the composition with 96.06% and 2.51%, respectively. The net calorific value of Myanmar rice husk pellets was 3.67 kW·h/kg with a moisture content of 7.48% and the large amount of ash forming constituents. The pelletizing process decreased the rice husk moisture content due to the emerging fraction heat. The amount of lignin as a basic binding agent was 13.70% (wet basis). The bulk density was increased 4.5 times by pelletizing the rice husk. Increasing the bulk density in pellet promotes better handling and feeding of the biomass feedstock with less dust formation and improves transportation and storage. Next, the diameter, length, and durability of rice husk pellets manufactured met the ISO 17225-6 standard. The net calorific value and bulk density of pellets produced were moderately lower than the standard due to depending on the composition of rice husk, particle size of raw materials and depending on the holding time in press channel.

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