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Quality optimization in briquettes made from rice milling by-products

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ABSTRACT

In order to produce briquettes that meet the needs of consumers, different combinations of raw materials and methods were used to produce rice-husk briquettes using a locally fabricated multi-piston press. Particle size, husk–bran ratio, drying method, and water temperature for briquetting were the main influencers of the hardness of rice-husk briquettes at constant pressure. The briquetting process increased the density of rice husk from 120 to 600 kg/m^3. The average time for making nine briquettes (loading, compressing, ejection, and transfer to drying tray) was 3.6 min (150 briquettes/h) using the locally fabricated piston press. Briquettes produced using fine particles (<0.3 mm), hot (97 °C) water, husk–bran ratios of 0:1, 1:2, 1:1, 1:0, 2:1, and dried in the sun for 21 days had mean hardness values of 132, 89, 76, 62, and 31 N. Four types of fuel briquettes were produced: husk–bran–palm press fiber (HBF), husk–bran–palm press sludge (HBS), husk–bran only (HBO), and husk–biochar–clay (HBC). The four types of briquettes recorded shorter start-up time (<5 min) than charcoal (10 min). The average flame temperatures of HBF, HBS, and HBO during the first 20 min were higher (898 °C) than the average temperature of charcoal (546 °C). The characteristics of HBF and HBO briquettes provide the best option for consumers, especially those in the rice parboiling industry, as these briquettes recorded the following values for hardness (170 and 101 N, respectively), start-up time (2 and 3 min), burning rate (126 and 145 g/min), specific fuel consumption (121 and 136 g/l), and flame temperature (684 °C and 728 °C). It was concluded that briquettes could be produced from rice-milling by-products with acceptable quality using this affordable technology.

Introduction

Rice (*Oryza* spp.) is an important source of calories in sub-Saharan Africa (SSA) and production is likely to increase to satisfy the ever-increasing demand. In 2014, SSA produced about 22.1 million tonnes (Mt) of paddy, equivalent to 4.6% of the world's production (IRRI, 2015). On average, paddy consists of 72% rice, 5%–8% bran, and 20%–22% husk (Prasad et al., 2001). Thus, the milling of 22.1 Mt of paddy will generate about 4.8 Mt of husk. Since the 2007–2008 food crisis, African governments and their development partners have established programs for increasing rice production with an expected increase in rice milling by-products.

The generation of revenue from rice-milling by-products is very low in SSA. Although rice bran is highly nutritive (Saunders and Betschart, 1979; Amissah et al., 2003), this by-product is mainly used in SSA only as an ingredient in the production of livestock feed. However, when bran is mixed with husk, as is the case when rice is milled in Engelberg type mills, the use of this product as a livestock feed is not desirable due to the high amount of silica in husk (So et al., 2008). Studies have demonstrated the potential of using rice bran in the production of useful chemicals (Li et al., 2012), oil (Rohman, 2014), biodiesel (Saravanan et al, 2007; Lin et al., 2009; Gunawan et al., 2011), soluble fiber (Wan et al., 2012), phenolic compounds (Pourali et al., 2010), activated carbon (Suzuki et al., 2007), and beverages (Faccin et al., 2009). Unlike bran, the majority of rice husk produced in SSA is disposed of by burning in open fields or abandoned behind rice milling facilities. This pollutes the air and land, and generates greenhouse gases such as methane (CH_4), nitrous oxide (N_2O), and unburnt carbon (Lim et al., 2012a; Mai Thao et al., 2011). Very few of the technologies that add value to rice husk have been tested in SSA. These include the use of rice husk as biofuel for the generation of heat and electricity (Sookkumnerd et al., 2005; Goyal et al., 2008; Lim et al., 2012a), biosorption of heavy metals from

Abbreviations: ASTM, American Society for Testing and Materials; GLM, generalized linear model; HBC, husk–biochar–clay; HBF, husk–bran–palm press fiber; HBO, husk–bran only; HBS, husk–bran–palm press sludge; HHV, higher heating value; RHA, rice-husk ash; WBT, Water Boiling Test.

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single and mixed metal solutions (Krishnani et al., 2008; El-Shafey, 2010), vermicomposting for the production of organic fertilizer (Lim et al., 2012b), as animal feed after physical, chemical, or biological treatment (Vadiveloo et al., 2009), and as a support for solid-state fermentation (Kapilan and Arasaratnam, 2011). Rice husk ash (RHA), a product of rice-husk combustion, is useful as a material for building and construction (Khan et al., 2012; Yuzer et al., 2013), glass ceramic tiles and whiteware (Prasad et al., 2001; Andreola et al., 2013), reinforcement of aluminum alloy (Saravanan and Senthil Kumar, 2013), production of silica powder, activated carbon, and carbon–silica composite (Kumagai and Sasaki, 2009; An et al., 2011).

Fuelwood and farm residues are the most common cooking fuels in SSA, representing 74% and 12%, respectively, of the total fuel used. Firewood collection places a substantial time and labor burden on families, particularly women, and can place additional pressure on local forest resources, particularly in places where wood is scarce (Adkins et al., 2012). In communities where fuelwood is scarce, the use of rice husks to generate heat for households and the local artisanal food-processing industry will be a suitable alternative. In addition, the use of rice husk may serve as a first step toward valorizing the huge quantities of this rice-milling by-product.

Thermochemical conversion of rice husk to produce heat energy can be achieved via direct combustion, gasification, and pyrolysis (Lim et al., 2012a). High-tech systems exist for each of these processes, but their adoption and sustainability among smallholder processors in SSA remain to be seen. Small-scale rice-husk gasifier stoves—especially affordable ones that burn efficiently with a continuous fuel recharging system—appear to be promising in SSA. Rice-husk gasifier stoves will be more useful for households in the vicinity of rice milling facilities (Parmigiani et al., 2014), since the high volatility and low density of rice husk (120 kg/m^3) can cause challenges in handling and transportation. For households that are not within the vicinity of rice milling facilities or factories that may require husk or husk–bran mixtures as raw materials, these challenges can be overcome by densification (briquetting or pelleting) at husk production sites. In addition, it may be useful to convert the char produced from the gasification process into briquettes for use as clean fuel.

Briquetting technologies, such as the heated die screw press briquetting (Toan et al., 2000; Ahiduzzaman and Islam, 2013) and single piston and die press (Chin and Siddiqui, 2000; Bhattacharya et al., 2002), and the subsequent use of briquettes as fuel is common in China, India, Taiwan, Thailand, and Vietnam. Although massive investments have been made in briquetting in SSA, very few commercial success stories have been documented (Mwampamba et al., 2013). The quality, availability, convenience, and price of briquettes appear to be major factors hindering widespread adoption of briquetting technologies in the region. In addition, dependency on importation of equipment, spare parts, and after-sales service limits the scale at which briquetting production can occur and, to a large extent, explains why there are few briquetting factories in the region (Grover et al., 1994; Mwampamba et al., 2013).

Although the potential to use briquettes as fuel in SSA is high, the low price of fuelwood, punitive legal and fiscal requirements for briquette producers, and supply-driven approaches to industry development have limited the growth of fuel briquettes in the region (Mwampamba et al., 2013). Consumers prefer briquettes that are sufficiently hard with good burning characteristics (low moisture content, easy to light, high burning rate, low specific fuel consumption, low ash content, high flame temperature, and long burning time). Briquettes currently sold in SSA are hard to light, slow to burn, crumble easily when put out, and require additional ventilation of the stoves (Mwampamba et al., 2013). The production of briquettes of acceptable quality from rice-milling by-products at rice milling sites using affordable technologies is crucial to adding value to rice husk or husk–bran mixtures in SSA. Production of briquettes from rice husk or husk–bran mixtures with sufficient hardness and acceptable burning properties is a big problem, especially when using low-cost equipment. This paper presents the production and analysis of briquettes using different combinations of materials, methods, and low-cost equipment with the hope of getting briquettes with optimum performance (hardness and burning characteristics).

Material and methods

Construction of the briquetting machine

A multi-piston briquetting hydraulic press with nine cylinders was constructed at the Africa Rice Center (AfricaRice), Cotonou, Benin. All materials used for construction were acquired from local vendors.

The total pressure (P) and pressure exerted on each briquette (Pc) were derived from Eq. (1) which was subsequently used to develop Eqs. (2) and (3).

$$P = \frac{F}{S} \tag{1}$$

$$P - \frac{4F}{\pi\left(D^2 - d^2\right)} \tag{2}$$

$$Pc = \frac{P}{9} \tag{3}$$

where F is force in newtons, S is total surface area in square meters, D is the diameter of the cylinder in millimeters, d is the diameter of the central rod in the cylinder in millimeters, and 9 is the number of cylinder and piston systems per machine.

Biomass

Two types of rice residues produced in SSA were used in this study: pure husk from rubber-roll type mills and husk–bran mixtures from Engelberg type mills (Ndindeng et al., 2014). The bulk density of husk was 120 kg/m^3, and its moisture content was 12.6%.

Sample preparation

Separate rice husk and bran from rubber-roll type mills were collected from the AfricaRice Grain Quality and Postharvest Unit. The husk and bran were ground separately using a commercial hammer mill (Songhai Center, Porto Novo, Benin) to reduce the size of the particles. Each sample was separated into three particle sizes (large = particle sizes ≥ 1 mm; medium = 0.301–0.99 mm; fine ≤ 0.300 mm) using mesh 18 and mesh 50. The samples were first sieved with mesh 18 and then with mesh 50. Particles remaining in sieve mesh 18 were large, while those that remained in sieve mesh 50 were of medium size, and those that passed through sieve mesh 50 were the fine particles. Husk–bran mixtures were also ground and sieved with sieve mesh 18 to get a mixture of fine and medium-sized particles.

Production of briquettes

Description of the briquetting machine

The main components of the rice-husk briquetter (Fig. 1) are a frame assembly that holds together a hydraulic jack, plates, and a system of cylinders and pistons. The force generated by the jack drives the pistons sitting on the vertical mobile plate through the cylinders and compresses the biomass in the cylinders against the horizontal mobile plate. When the material to be briquetted is put in the cylinders, the upward-moving piston compresses the material against the horizontal mobile plate. When the material is fully compressed, the pressure on the horizontal mobile plate is eased by slightly releasing the force applied by the jack using the force-easing key. This action allows the