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Effects of operating variables on durability of fuel briquettes from rice husks and corn cobs

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ABSTRACT

Biomass densification processes increase fuel energy density for more efficient transport. This study presents new data to show that blending different types of biomass improves the properties of densified biomass briquettes. The specific objectives were to investigate the effects of sample batch (biomass source), material ratio (rice husks to corn cobs), addition of binder (starch and water mixture) and compaction pressure, on briquette properties, using a factorial experiment.

Briquettes had a unit density of up to 1.9 times the loose biomass bulk density, and were stronger than briquettes from the individual materials. Considering average values from two biomass sources, an unconfined compressive strength of 176 kPa was achieved at a compaction pressure of 31 MPa for a 3:7 blend of rice husks to corn cobs with 10% binder. These briquettes were durable, with only 4% mass loss during abrasion and 10% mass loss during shattering tests. They absorbed 36% less water than loose corn cobs. Statistical analysis of the results showed that starch and water addition was required for adequate briquette strength, but significantly reduced green and relaxed densities. The source of the biomass had a significant effect on densification, which emphasises the need to understand factors underlying biomass variability.

1. Introduction

1.1. Energy from agricultural biomass

Biomass has received tremendous attention both in developed and developing countries as a renewable energy source [e.g., 1,2]. A major drawback of biomass energy is the competition between energy and food crops for cultivable land [3,4]. This issue is resolved by the use of agricultural residues, which would otherwise be wasted, for energy generation. However, although agricultural residues form one of the biggest potential sources of biomass energy in most developing countries, their efficient exploitation for energy is presently uncommon [1, 5]. At present, agricultural residues are combusted directly without optimisation of energy efficiency or control of air emissions, or they are left on farm land/processing sites to decay, potentially releasing greenhouse gases and/or polluting surface waters.

1.2. Biomass densification

Since direct use of unprocessed biomass feedstock can lead to problems during storage, transportation, handling and processing [6], numerous strategies have been developed to convert various types of biomass into secondary fuels that have better characteristics compared to the parent material(s). These strategies include biomass densification.

Biomass densification involves its compaction into a pellet or briquette of up to ten times higher density than the parent material(s) [7,8]. Such processing increases biomass bulk and energy density per unit volume, leading to lower storage requirements, more efficient transportation, reduced particulate emissions per unit volume of material transported or combusted, and uniform feeding into industrial equipment such as boilers, gasifiers and domestic stoves for rural applications [1,9,10].

Research by other workers has demonstrated that agricultural residues such as rice husks, corn cobs, and olive husks can be densified into briquettes [e.g., 1,10,11]. Due to variations in properties of different biomass materials, some feedstocks are more easily densified than others. Biomass materials with a higher lignin, starch or protein content exhibit better compaction than those with higher cellulosic content [8]. This has prompted addition of biomass containing higher amounts of these components to other biomass. For example, blending sawdust from Scots pine with wheat straw resulted in more durable pellets

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compared to wheat straw alone [12], rice bran was used as a binder in briquetting rice straw [13] and olive refuse blended with fibrous paper mill waste [54], for reportedly improved briquette durability.

1.3. Rice husks and corn cobs

Rice and corn are examples of major crops that result in generation of huge amounts of waste from their cultivation and processing, including rice husks and corn cobs. Around 134 Mt of rice husks were produced globally from 671 Mt of rice production in the year 2008 [14]; in the same year, approximately 135 Mt of corn cobs were produced from 797 Mt of corn production [15].

Table 1 compares energy, ash, moisture contents, bulk density and porosity of rice husks and corn cobs, as gathered from sources in the literature [1,14,16–29]. It can be estimated that the total annual generation of rice husks and corn cobs has an energy content of 4 EJ, which represents about 1% of the world total primary energy consumption [30].

Problems have been encountered with the use of briquettes produced from these individual materials. Briquettes produced from rice husks have been reported to cause clogging of industrial boilers and domestic stoves due to their high ash content [31], which is also abrasive and wears equipment quickly due to the high silica content of the rice husk ash [14]. Briquettes produced from corn cobs have a tendency for water absorption due to the high porosity of corn cob particles. High moisture contents are undesirable in thermochemical processes such as pyrolysis and gasification due to the energy requirement for drying of biomass and the reduced heating value of the product gas [32,33].

1.3.1. Material ratio

Blending of rice husks and corn cobs will result in fuel briquettes with a lower ash content compared to briquettes produced from rice husks alone. On the other hand, briquettes containing rice husks are expected to absorb less water than briquettes from corn cobs alone, due to the lower water absorbency of the thick outer walls of rice husks [20]. Material ratio is the proportion of individual rice husks or corn cob residue in the blend of both residues.

1.3.2. Sample batch

The variability of biomass materials have resulted in inconsistency in the characteristics of fuel briquettes produced from different types of residues [8,56], this may even apply to the same type of residues grown at different season or different locations. It becomes necessary to understand the influence of the variability on biomass densification and fuel briquette's quality.

1.3.3. Binder

Despite the additional cost, additional binders are often added in the densification of biomass residues, as they may not naturally contain adequate proportions of binders.

Starch has been used as a binder in some densification processes, such as in compaction of sorghum residue, and corn cobs individually [34,35], and has been reported to improve briquette characteristics. Starch is a polysaccharide, which is widely available. It has a high energy content and is a good binding agent due to its chemical and structural properties [36]. Addition of water and heat to starch granules causes swelling, which results in the formation of intermolecular hydrogen bonds between the amylose and amylopectin components of starch, followed by loss of the individual crystalline structure of the two components [37]. This leads to formation of a viscous solution that undergoes retrogradation, i.e., gelling, during cooling or storage. The viscosity of hydrated starch increases its shear and tensile strengths. The fluidity and viscoelasticity of the produced solution [37] give it the ability to occupy the void spaces present within and between biomass particles, forming solid bridges that become stronger upon air-drying.

Table 1
Comparison of basic properties of rice husks and corn cobs.

Properties	Rice husks	Corn cobs	Reference
Calorific value (kJ/kg dry mass)	16,000	18,000	[14,16,18,19]
Ash content (% dry mass)	20	<2	[1,14,18,21,22]
Moisture content (% undried mass)	8–12	20–55	[14,17,19,21,22]
Bulk density (unprocessed) (kg/m^3 dry mass)	100–150	160–210	[14,17,21–23]
Bulk density (ground to <0.85 mm) (kg/m^3 dry mass)	331–380	282	[21,22]
Porosity (% dry volume)	63–73[a]	68	[21,22]
Water absorption (% dried mass)	105	327[b]	[20,23]
Lignin (% dry mass)	19.2	15.3	[25,29]
Protein (% dry mass)	1.8	2.7	[24,26,27]
Starch (% wt dry mass)	<1	1.61	[24,28]

[a] Range of 4 different types including long and short grain rice.
[b] Average water absorption on whole small cobs.

1.3.4. Pressure

During the densification process, an increase in pressure results in plastic and elastic deformations, molecule diffusion and closing up of void spaces between particles to form a compacted solid. Briquettes manufactured at lower pressures of 30 to 60 MPa crumble easily, while those produced at higher pressures of 150 to 250 MPa remain compacted and durable [56], for example, increasing the compaction pressure from 1 to 10 MPa increased the shear strength of briquettes from 2.8×10^{-2} kPa to 9.6×10^{-2} kPa [43]. Currently, efforts are directed towards improving the quality of fuel briquettes produced at lower pressures.

1.3.5. Objectives

This study investigated the effects of sample batch (biomass source), material ratio, addition of binder, and compaction pressure, on properties related to the durability of fuel briquettes made from blends of rice husks and corn cobs, including their strength, resistance to impact and abrasion, and water absorption.

2. Materials and methods

2.1. Sourcing, preparation and characterisation of raw materials

Two bulk samples of air dried rice husks, and corn cobs, as well as a sample of starch were sourced and collected from local farms and milling sites in Niger State, Nigeria. Rice husks were used as received from the milling site, since they have a particle size of <2 mm, which can readily undergo densification. The mass median diameter ("D50") of the rice husks was 0.7 mm. Corn cobs were used with a particle size of <1.6 mm, based on preliminary experiments which found that larger particles (2–10 mm) were less easily compacted. Corn cob particles obtained using a hammer mill fitted with 1 mm screen were blended with larger particles (1–1.6 mm) that had been manually crushed. The mass median diameter of the resulting blend was 0.8 mm. Characterisation of rice husks and corn cobs included determination of bulk density by BS EN 15103 [38], moisture content by BS EN 14774-2 [39], particle size by sieve analysis according to DD CENT/TS 15149-2 [40], water absorption by adaptation of BS EN 772-21 [41] and specific gravity using a Micromeritics helium pycnometer (ACCU Pyc 1330). The porosity of materials was determined using Eq. (1).