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Densification characteristics of corn cobs

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ABSTRACT

Corn cobs are potential feedstocks for producing heat, power, fuels, and chemicals. Densification of corn cobs into briquettes/pellets would improve their bulk handling, transportation, and storage properties. In this study, densification characteristics of corn cobs were studied using a uniaxial piston-cylinder densification apparatus. With a maximum compression pressure of 150 MPa, effects of particle size (0.85 and 2.81 mm), moisture content (10 and 20% w.b.), and preheating temperature (25 and 85 °C) on the density and durability of the corn cob briquettes (with diameter of about 19.0 mm) were studied. It was found that the durability (measured using ASABE tumbling can method) of corn cob briquettes made at 25 °C was 0%. At both particle sizes, preheating of corn cob grinds with about 10% (w.b.) moisture content to 85 °C produced briquettes with a unit density of >1100 kg m^{-3} and durability of about 90%.

1. Introduction

Corn cobs are one of the potential agricultural biomass feedstocks for renewable energy industries in the U.S. to abate the current energy and the greenhouse gas problems [1]. Corn cobs can be used for producing heat, power, gas/liquid fuels, and a wide variety of chemical products such as furfural, xylitol and activated carbon [1–8]. Crofcheck and Montross [9] found a greater yield of glucose (i.e., ethanol) from corn cobs than other corn residues such as stalks or leaves plus husks.

Cobs represent about 8 to 9% of the aboveground dry matter (grain plus residues) at grain physiological maturity [10,11]. The yield of corn cobs may range from 1.42 to 1.53 dry t/ha [12]. Currently, after combining the grain, corn residues are collected as baled corn stover, which includes cobs, husks, leaves and stalks [13]. About 15 to 20% (d. b.) of aboveground corn residues (non-grain) is corn cobs [11,13,14]. Corn cob moisture content may range from 20 to 55% (w.b.) depending on the grain moisture content at the time of harvest [3,15]. With the existing corn stover collection process, most of the corn cobs are left on the field. Modifications to the existing corn combining method have been suggested to collect corn cobs in a single-pass when the grain is being combined [1,12,16]. In the U.S. Mid-West, corn cobs are collected during a limited harvest time, October–November. Therefore, there is a need to store corn cobs for year-around supply to large corn cob processing plants. Large volumes of corn cobs can be stored as piles outdoors or indoors [17,18].

The higher heating value (HHV) of corn cobs ranges from 18.3 to 18.8 MJ/kg of dry matter [3,19]. Ebeling and Jenkins [19] reported that the proximate analysis of corn cobs resulted in 80.10% volatiles, 1.36% ash, and 18.54% fixed carbon on a dry mass basis. They also reported that the ultimate analysis of corn cobs resulted in 46.58% carbon, 5.87% hydrogen, 45.46% oxygen, 0.47% nitrogen, 0.01% sulfur, 0.21% chlorine, and 1.40% ash on a dry mass basis [19]. Thus, corn cobs are suitable for heating applications especially due to their low ash contents (<2% d.b.) compared to other agricultural residues [2,3,19].

The need for densification of corn cobs into briquettes/pellets could be justified based on the end use. Corn cobs are a part of the corn stover. Corn stover includes a mixture of individual pieces of cobs, husks, stalks and leaves having different shapes and sizes. Baling of corn stover can gather these individual pieces into a large cylindrical compact with density of up to 150 kg m^{-3} (9 lb ft^{-3}) [20]. Chopping or grinding of corn stover could result in a relatively uniform product; however, chopping/grinding may not increase the bulk density significantly higher than the baled density. For example, fine grinding of corn stover using a hammer mill to a particle size of 0.34 mm resulted in a bulk density of 161 kg m^{-3} (10 lb ft^{-3}) [21]. On the other hand, corn cobs exist as individual pieces with similar shapes and sizes. The bulk density of whole corn cobs would range from 160 to 210 kg m^{-3} (10 to 13 lb ft^{-3}), which is higher than the density of corn stover bales (i.e., 150 kg m^{-3}) [17,20]. Either in baled form or chopped/ground form, corn stover may be difficult to handle, transport, store and use, whereas the whole corn cobs could be handled, transported, stored and used relatively easily compared to the baled or chopped/ground corn stover. It appears that briquetting/pelleting of corn stover or corn cobs can produce uniform products with bulk density of 500–600 kg m^{-3} (31-38 lb ft^{-3}) [21]. Therefore,

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changing the physical form of corn stover into briquettes/pellets is essential to improve its transportation, handling, storage, and use. But, corn cobs can be used without briquetting/pelleting for majority of applications such as industrial scale heating. For applications requiring high quality feedstock such as home heating, corn cobs may need to be pelleted. Furthermore, although corn cobs are almost cylindrical in shape, a mixture of whole and broken pieces of cobs may result due to breakage of cobs during combining. Therefore, corn cobs may lack free-flowing properties. We propose that densification of corn cobs into briquettes/pellets would result in consistent, high density products with uniform shapes and sizes, which can be efficiently handled, transported, stored, and used.

A literature review by Kaliyan and Morey [22] found that biomass feedstock variables such as particle size, moisture content and steam conditioning/preheating temperature affected the density and durability of densified products such as pellets and briquettes. They concluded that particle sizes of geometric mean diameters of 0.5 to 1.0 mm, moisture contents of 8 to 20% wet basis, and preheating temperatures of 65 to 100 °C produced high quality (i.e., high density and durability) densified products for a variety of biomass feedstocks such as corn stover, alfalfa, wheat straw, sawdust and animal feed materials.

The main objective of this research was to study the densification characteristics of corn cobs. The specific objective was to investigate the effects of particle size, moisture content, and preheating temperature on corn cob briquette density and durability at a compression pressure of 150 MPa. The briquetting study was conducted at a compression pressure of 150 MPa because commercial roll press briquetting or pelleting machines operate at or around 150 MPa pressure [22].

2. Materials and methods

2.1. Corn cob samples

The corn cob (from an unspecified variety of field corn) samples used in this study were supplied by Agricultural Utilization Research Institute (AURI), Waseca, MN as coarsely ground cobs. The whole corn cobs were collected during the fall (October) 2007 harvest season and were stored at about 12–15% (w.b.) moisture content in cardboard containers until used for this study in May 2008. At AURI, the whole corn cobs were ground using an 18.7 kW (25.0 hp) hammer mill (Jacobson Quality Machinery, Minneapolis, MN) fitted with 6.4 mm (1/4 in) screen. The coarsely ground corn cobs had a moisture content of 7.5% (w.b.) due to the moisture loss from the corn cobs during the hammer milling process (Table 1). This coarser corn cob grind served as one of the two particle sizes tested in the study. The second particle size tested was a finer corn cob grind. To obtain the finer corn cob grind sample, the hammer milled corn cobs were further ground in a 0.25 kW (0.33 hp) Wiley mill (Thomas Scientific, Swedesboro, NJ) fitted with 2.0 mm screen.

Table 1
Properties of corn cob grinds used for the study.

Grinding machine with the screen size used for grinding[a]	Moisture content of the grind (% w.b.) ($n=3$)[b]	Particle size of the grind (mm) ($n=3$)[c]	Bulk density of the grind (kg m^{-3}) ($n=3$)[b]
Hammer mill with 6.4 mm (1/4 in) screen	7.5 ± 0.1	2.81 ± 0.31	229.0 ± 9.8
Wiley mill with 2.0 mm screen [d]	7.4 ± 0.2	0.85 ± 0.25	316.3 ± 2.1

[a] The screen size represents the diameter of the holes in the screen.
[b] Mean ± standard deviation.
[c] Geometric mean particle diameter (mm) ± geometric standard deviation.
[d] Corn cobs hammer milled using 6.4 mm screen was re-ground in Wiley mill with 2.0 mm screen.

Table 2
Compositions of corn cobs, corn stover, and switchgrass.

Component	Corn cobs used in this study (% of dry matter) ($n=1$)	Corn stover [21] (% of dry matter) ($n=1$)	Switchgrass [21] (% of dry matter) ($n=1$)
Cellulose[a]	40.0	49.4	43.8
Hemicellulose[b]	41.4	26.2	28.8
Lignin[c]	5.8	8.8	9.2
Crude protein	2.5	3.6	3.9
Starch	2.1	0.4	1.0
Crude fat	0.7	0.7	0.9
Water soluble carbohydrates	1.1	7.9	2.2
Moisture content	1.7	5.4	5.7
Ash	1.8	11.2	5.0

[a] Cellulose = acid detergent fiber – lignin.
[b] Hemicellulose = neutral detergent fiber – acid detergent fiber. The hemicellulose content is higher than cellulose content because of the approximate estimation of hemicellulose content by the difference between neutral detergent fiber and acid detergent fiber contents.
[c] Lignin values measured for the biomass materials were acid insoluble lignin contents (not total lignin contents, which would be much higher than the values reported in Table 2 [21]).

Moisture content of the corn cob grinds was determined using the procedure given in ASABE Standard S358.2 [23]. The moisture content values reported in this article are on a wet mass basis unless mentioned otherwise. To increase the moisture content of the grinds to 10% or 20% (w.b.), a predetermined amount of distilled water was added to the grinds, thoroughly mixed and stored in zip-lock plastic bags at 5 °C for 48 h for tempering. Bulk density of the corn cob grinds was calculated from the mass of grind that occupied a 250-mL glass container (Table 1). While measuring the bulk density of the grinds, the glass container with the sample was tapped gently for about 4 to 6 times on a lab-bench to remove large voids inside the sample as well as to reduce the sample filling errors. Particle size and its distribution of the corn cob grinds were determined based on ASABE Standard S319.3 [24] (Table 1). A corn cob grind sample was sent to a forage analysis laboratory (Dairy One, Ithaca, NY; www.DairyOne.com) to determine the chemical composition of corn cobs based on the analytical procedures given by AOAC International [25] (Table 2).

2.2. Briquetting procedure

Corn cob briquettes were made using a uniaxial, piston-cylinder densification apparatus in the laboratory (Fig. 1). The details of the

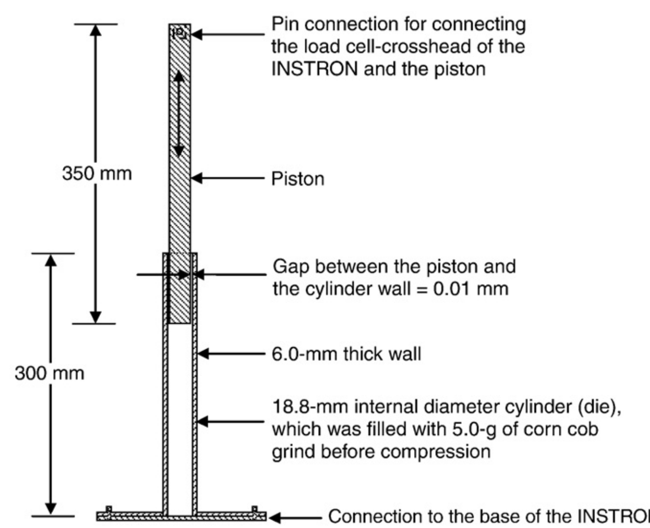

Fig. 1. Schematic of piston-cylinder compression/densification apparatus.