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Effect of compressive load and particle size on compression characteristics of selected varieties of wheat straw grinds

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In this study, the effect of compressive load and particle size on compression characteristics of four varieties (Strongfield, Blackbird, DT773 and DT818) of wheat straw grown at two different fields was investigated. Particle size, bulk and particle densities of all wheat straw samples were determined after grinding. Ground wheat straw samples were densified in a cylindrical die at 90 °C using an Instron testing machine. The wheat straw samples with 9% moisture content were compressed at five levels of compressive pressures (31.6, 63.2, 94.7, 126.4 and 138.9 MPa) and two levels of particle sizes (1.6 and 3.2 mm). Dimensions and mass of all compressed samples were measured to calculate the pellet density. The specific energy required to compress and eject the pellets was calculated from force-displacement data. Applied compressive force and particle size significantly affected the pellet density of wheat straw samples. The pellet density was in the range of 699–1064 kg m^{-3} increasing with pressure and particle size. The total specific energy required for compression and ejection of pellets varied from 4.35 to 33.64 MJ t^{-1} that increased with compressive load and particle size. Higher compressive forces and particle size increased the durability of pellets to more than 95%. Blackbird variety was the most compressible of the four varieties of wheat straw.

1. Introduction

Biomass such as agricultural residues are one of the most important sources of fixed carbon that have been considered as renewable energy sources by both developed and developing countries in recent years [1]. Greenhouse gas reduction, energy security, and use of renewable sources have encouraged nations to explore alternative sources of energy such as agricultural residue. Cereal straw is the largest biomass feedstock in the world among the agricultural residues [2]. While these residues are by-product of cereal production, they can be considered as an abundant, inexpensive and readily available source of renewable lignocellulosic biomass [3].

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Cereal straw could be utilized as feedstock for production of fuel pellets or briquettes, ethanol and gaseous fuels.

Because of irregular shape and size and low bulk density, it is very difficult to handle, transport, store, and utilize the cereal straw in its original form [4]. Densification of biomass into durable pellets is an effective solution to these problems and it can reduce material waste. Densification of biomass is an efficient method for a number of reasons such as improvement of handling and storage characteristics, lowering transportation costs, enhancing volumetric calorific value, improvement of control over the combustion process, increasing the uniformity of physical properties for making uniform, clean and stable pellets for production of environment-friendly fuel [4,5]. Biomass can be compressed and stabilized to 7–10 times densities of the standard bales by the application of pressures between 400 and 800 MPa during the densification process [6]. The bulk density of loose and standard baled straw is approximately 40 and 100 kg^{-3}, respectively and can be increased to 600–1200 kg m^{-3} using densification process [7].

The quality of final pellets can be improved by optimization of the physical and chemical characteristics of raw materials as well as the densification process variables (pressure and temperature). Therefore, it is very important to know the mechanical and compaction characteristics of different biomass to optimize the densification process. It is also important to understand the compaction mechanisms of different biomass in order to design energy-efficient compaction process and equipment and to quantify the effects of various process variables on pellet density and pellet durability.

Previously, some studies have been conducted on the compaction and mechanical properties of different biomass including wheat straw [8], ground steam exploded of wheat straw [9,10] and microwave-chemical pretreated wheat straw [11], but nothing has been reported regarding the effect of compression parameters on densification characteristics of different varieties of wheat straw. Since the response of selected varieties of wheat straw to compression is unknown and has not been investigated yet, the objective of this study was to determine the effect of compressive load and particle size of biomass grind on density, durability and specific energy required for making the pellets from selected varieties of wheat straw.

2. Material and methods

2.1. Biomass samples

In this study, four different cultivars of wheat straw (Strongfield, Blackbird, DT773 and DT818) grown at two different locations (Field X2 and Field 17) were acquired in December 2009 from the Semiarid Prairie Agricultural Research Centre (SPARC), Agriculture and Agri-Food Canada, Swift Current, Saskatchewan, Canada. Wheat straw samples were collected shortly after the grain reached harvest maturity in both fields and transferred in plastic bags to University of Saskatchewan for compression experiments. Strongfield is the current mainstream durum variety which covers most of the acreage in Western Canada and it is strong straw wheat. DT773 is taller than Strongfield with strong straw. It has a different ancestry to Strongfield. Blackbird is a different subspecies of durum wheat. In some classifications, it is considered a different species i.e. *Triticum carthlicum*. Traditional durums such as Strongfield are *Triticum turgidum*. Blackbird is weak strawed. DT818 is an advanced durum line that has not yet qualified as a registered variety. It has Strongfield in its pedigree. Field X2 and Field 17 refers to two locations that the four cultivars were grown in the same year. Field X2 is located in Swift Current SK, latitude: 50° 16′ North, longitude: 107° 44′ West, elevation: 825 m with Orthic Brown Chernozemic Swinton loam and Field 17 is located in Swift Current SK, latitude 50° 18′ North, longitude 107° 45′ West, elevation: 730 m with Rego Brown Chernozemic alluvial clay loam. The initial moisture content of the straw samples ranged from 4.77 to 5.55% (w.b.) measured according to ASABE Standard S358.2 [12] in three replicates.

2.2. Sample preparation

After chopping the wheat straw samples manually, they were ground using a hammer mill (Glen Mills Inc., Clifton, NJ) powered by a 1.5 kW electric motor with two different screen opening sizes of 3.2 and 1.6 mm. Then the samples were wetted by spraying water to adjust the moisture content to 9% (w.b.) and stored in a sealed bag at 4 °C for a minimum of 72 h.

2.3. Particle size analysis

The geometric mean diameter of ground wheat straw samples was determined following ASABE Standard S319 [13]. A 100 g sample was placed on a stack of sieves arranged from the largest to the smallest opening. The sieve numbers were 14, 20, 40, 60, 80 and 100 (sieve opening sizes: 1.410, 0.840, 0.425, 0.250, 0.177 and 0.150 mm, respectively). The Ro-Tap sieve shaker (W. S. Tyler Inc., Mentor, OH) was used to shake and separate the ground material for 10 min, where afterwards, the mass retained on each sieve was weighed. The geometric mean diameter (d_{gw}) of the samples and geometric standard deviation of particle diameter (S_{gw}) were calculated according to aforementioned standard in three replicates for each wheat straw samples.

2.4. Bulk and particle density analysis

The bulk density of ground wheat straw samples was calculated from the mass and volume of a standard cylindrical steel container (SWA951, Superior Scale Co. Ltd., Winnipeg, MB) with 0.5 L volume that was filled with the samples after passing through a funnel. Since the sample was fluffy and did not flow down readily through the funnel, a thin steel rod was used to clear the blockage in the funnel. After filling the cup, excess biomass materials were removed and the mass of sample was determined [8–11].

A gas multi-pycnometer (QuantaChrome, Boynton Beach, FL) was used to determine the particle density of ground straw samples by calculating the displaced volume of nitrogen gas by a known mass of material. Five replicates were performed for both bulk and particle density measurements.