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Physical and frictional properties of non-treated and steam exploded barley, canola, oat and wheat straw grinds

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ABSTRACT

During storage and handling, accurate knowledge of the physical and frictional behaviors of biomass grinds is essential for the efficient design of equipment. Therefore, experiments were performed on non-treated and steam exploded barley, canola, oat and wheat straw grinds to determine their coefficient of internal friction and cohesion at three hammer mill screen sizes of 6.4, 3.2 and 1.6 mm, three normal stress values of 9.8, 19.6 and 39.2 kPa at 10% moisture content (wb). At any specific hammer mill screen size, the geometric mean particle size and bulk density of non-treated straw was significantly larger than steam exploded straw. The bulk density of ground straw significantly increased with a decrease in hammer mill screen sizes. The steam exploded straw grinds resulted in higher coefficient of internal friction compared to non-treated straw grinds primarily because of lower bulk densities. The coefficient of friction for non-treated barley, canola, oat and wheat straw were in the range of 0.505 to 0.584, 0.661 to 0.665, 0.498 to 0.590, and 0.532 to 0.591, respectively. Similarly, the coefficient of friction for steam exploded barley, canola, oat and wheat straw were in the range of 0.562 to 0.738, 0.708 to 0.841, 0.660 to 0.860, and 0.616 to 1.036, respectively, which were higher than non-treated straw of the kind. Power, logarithmic or exponential equations were developed to predict the coefficient of internal friction and cohesion with respect to average geometric mean particle sizes for non-treated and steam explode barley, canola, oat and wheat straw grinds.

1. Introduction

Efficient and economic production and processing of agricultural biomass residue as feedstock are critical for the viability of a biofuel industry [1,2]. Due to their heterogeneous nature, agricultural biomass materials possess inherently low bulk densities, and often require densification to improve their handling characteristics and logistics of transportation and storage [3,4]. The bulk density of loose and standard baled straw is approximately 40 kg/m^3 and 100 kg/m^3, respectively, compared with the bulk density of unprocessed wood residue, which is approximately 250 kg/m^3 [5,6]. Fuels with high bulk density are advantageous because they represent a high energy-for-volume value. Consequently, these fuels need less storage space for a given refueling time. Inadequate bulk densities can be improved by either briquetting or pelleting of the biomass [7,8]. A bulk density of 650 kg/m^3 is stated as design value for wood pellet producers [9].

Prior to densification, biomass grinds need to be efficiently stored, handled and transported. Physical and frictional properties of biomass have a significant effect on the design of new and modification of existing bins, hoppers and feeders [10]. The frictional behavior of biomass grinds in all engineering applications is described by two independent parameters: the coefficient of internal friction, and the coefficient of wall friction. The former determines the stress distribution within particles undergoing strain, and the latter describes the magnitude of the stresses between the particle and the walls of its container [11]. The classic law of friction states that frictional force is directly proportional to the total force that acts normal to the shear surfaces [12]. Frictional force depends on the nature of the materials in contact but is independent of the area of contact or sliding velocity [13]. Material properties such as moisture content and particle size affect the frictional properties and densification performance of an individual feedstock [4,12]. In addition, the determination of the coefficient of friction is essential for the design of production and handling equipment and in storage structures [14].

Mani et al. [3] studied the coefficient of wall friction properties of corn stover at two grind sizes of 6.35 and 3.18 mm, and three moisture contents of 7, 11 and 15% (wb) on a galvanized steel surface. It was observed that the adhesion coefficient did not exhibit dependence on moisture content. The coefficient of wall friction of corn stover grind increased from 0.18 to 0.26 with an increase in moisture content from 7% to 15%. No clear trend was observed for the adhesion coefficient.

Shaw and Tabil [4] performed studies to determine the mechanical properties of peat moss, wheat straw, oat hulls and flax shives at 9–

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10% moisture content (wb) having geometric mean particle sizes of 0.74, 0.65, 0.47 and 0.64 mm, respectively, on a mild steel surface. It was found that peat moss and oat hulls had the highest (0.68) and lowest (0.39) wall coefficients of friction, respectively. While, the adhesion coefficient values ranged from 0.2635 kPa for peat moss, to 16.203 kPa for flax shives.

Afzalinia and Roberge [15] studied the static friction coefficient of alfalfa, barley straw, wheat straw and green barley on a polished steel surface at high pressure levels closer to baling or densification pressures, which were in the range of 200 to 735 kPa. The data revealed that the coefficient of friction of alfalfa and barley straw increased from 0.15 to 0.26 and 0.14 to 0.27 with an increase in material moisture content from 12.0 to 45.7% (wb), respectively. In addition, coefficients of friction for wheat straw at 10% moisture content and whole green barley at 51% moisture content were 0.13 and 0.21, respectively.

Fasina et al. [10] determined the internal frictional and cohesion properties of peanut hull, switchgrass and poultry litter at hammer mill screen sizes of 0.79, 1.59 and 3.2 mm. They have determined that both peanut hull and switchgrass can be classified as cohesive materials while poultry litter can be classified as easy flowing material. In addition, the hammer mill screen size did not have any significant effect on the angle of internal friction and cohesive properties of these materials. The average angles of internal friction for peanut hull, switchgrass and poultry litter were 42.82° ± 1.34, 41.76° ± 0.92, and 41.26° ± 1.43, respectively.

Chevanan et al. (2008) determined the frictional properties of chopped switchgrass (7.81 and 13.50 mm), wheat straw (7.09 and 10.39 mm) and corn stover (7.80 and 14.89 mm) using a direct shear cell at four applied normal stresses of 1.23, 2.46, 3.67 and 4.92 kPa. The chopped biomass coefficient of internal friction was in the range of 0.765 to 1.586 for the various normal pressures [16]. The friction coefficient increased for reduced normal pressure for all three chopped biomass types, however, changing the particle size caused no statistically significant difference in the friction coefficients except at the lowest normal pressure of 1.23 kPa for chopped corn stover and chopped wheat straw.

Larsson [12] determined the influence of normal stress on the coefficient of kinematic wall friction of reed canary grass powder from a hammer mill screen size of 4.0 mm at low (0.52 to 7.52 kPa) and high (23 to 275 MPa) normal stresses. It was observed that at both low and high normal stresses, the coefficient of kinematic wall friction was negatively correlated to normal stress. However, a high friction

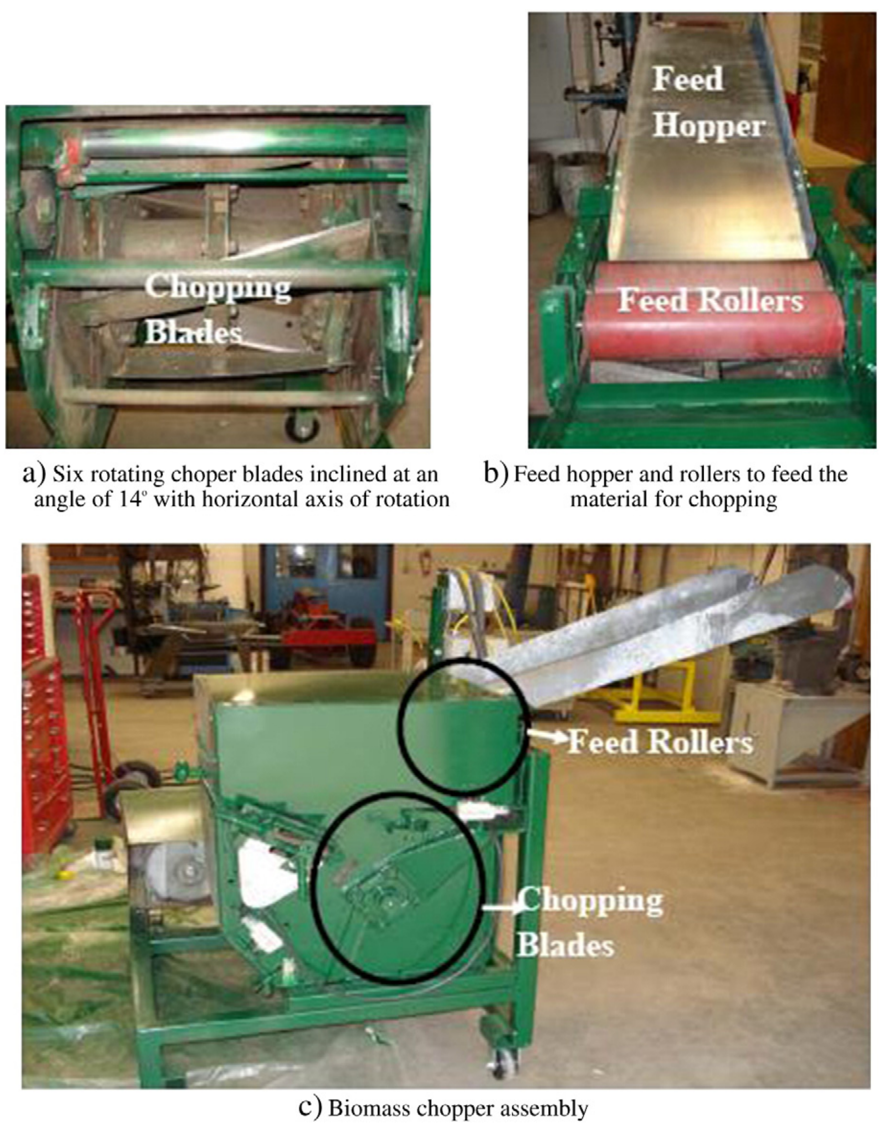

Fig. 1. Biomass chopper fabricated at the Department of Agricultural and Bioresource Engineering, University of Saskatchewan, Canada.