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INTERACTION OF PARTICLE SIZE, MOISTURE CONTENT AND COMPRESSION PRESSURE ON THE BULK DENSITY OF WOOD CHIP AND STRAW

Mozammel H, Shahab S, Tony B, Sudhagar M*, Ladan J, Lim J

Department of Chemical & Biological Engineering, University of British Columbia, 2360 East Mall, Vancouver BC V6T 1Z3

M Afzal

Forest Engineering Program, University of New Brunswick, Fredericton, NB E3B 6C2

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Abstract

Biomass material is highly heterogeneous in origin and form. Handling and storage of biomass materials are major hindrance of producing bio-based energy due to their high moisture content, low bulk densities and low heating values. In order to use biomass energy competitively with other fuels and to get the maximum possible energy output at a low cost, main target should be to carry the greatest possible amount of biomass material per load within legal restrictions. This study investigated the effect of particle size, vibration, moisture content and compression pressure on the bulk density of straws and wood chips. The bulk densities of small and large size wood chip varied from 180-314 and 158 to 308 kg/m^3 respectively in the moisture content range of 10.7 to 55.71% (wet basis). The bulk density of straw varied from 24 to 54 kg/m^3 depending on the particle size at 8.45% moisture content. Tapping increased about 20% of bulk density for wood chip and 32 to 43% for straw depending on the particle size. Compaction increased the bulk density of straw from 24 to 260 kg/m^3 after applying pressure of 630 kPa. The bulk density of straw must be enhanced to meet the transportation criteria. **Keywords**: bulk density, straw, wood chips, compaction.

INTRODUCTION

Biomass is a substantial renewable resource that can be used as fuel for producing electric power and other energy products. Huge amount of biomass waste is generated from forestry, wood processing industry, agriculture, and municipalities. It includes wood residues, crop residues, tree trimmings, wastepaper, yard waste, etc. In its natural form, most biomass is difficult to utilize as a fuel because it is bulky, wet, and dispersed (Balatinecz 1983). Disadvantages of biomass as an energy source include inefficient transportation and large volumes required for storage. Solving these problems is where biomass densification gains extreme importance. Biomass densification is defined as compression or compaction of biomass to remove inter- and intra-particle voids.

Biomass production, optimization of the transport system, as well as harvesting, is crucial for its economic success. The product form to transport, the mode of transport and interaction between the transport system and operations are also important. In particular, optimizing transport of energy crop or residues generally requires carrying the greatest possible amount of material per load within legal restrictions. Many factors influence which form is best to use in transporting biomass material. Trailer-size limits vary from country to country, but assuming a 12.2 by 2.6 by 2.7 m trailer with a maximum allowable payload of 24.5 tonnes, the material being hauled would need a green bulk density of about 286 kg/m^3 to make maximum legal gross vehicle weight and transport function most efficiently (Timothy 1995).

Biomass densification is of the utmost importance for economical shipping and handling in the biomass industry. Trucks and other biomass hauling equipment are rarely able to maximize their hauled loads due to the bulkiness of handling biomass (Timothy 2003). The objectives of this study were i) to define a relationship among bulk density, particle size, moisture content and applied pressure for wood chips and barley straw, ii) to observe similarities or differences in the values for the constants in the defined relation due to differences in moisture, particle size or type of biomass.

EXPERIMENTAL STUDIES

Sample and its Preparation

Wood Chips Wood chips were collected from the Pulp and Paper Research Institute of Canada (Paprican), 3800 Wesbrook Mall, Vancouver BC V6S 2L9 situated at the southern corner UBC campus. The chips were from Pine (*Pinus Contorta var. Latifolia*) sapwood, mature. Paprican stores the chips in a 10 kg polyvinyl bag and keeps in -10ºC. The wood chips were sorted out into two groups. The chip length ranges from 10-25mm was defined in this study as small size and length above 25 mm as large size. The most chips of small size fall in the length range of 16-22 mm. The maximum length of large size chips were 57 mm, mostly in the range of 30-36 mm. The widths of both types of chips varied between 20-25 mm and a thickness of 2.5 to 3.5 mm. The moisture content of wood chips as received was 55.71% on wet basis. For measurement of bulk densities at lower moisture content, wood chips were put on the floor in thin layer form for a couple of hours at room temperature. As for example moisture content reduced from 55.17 to 10.7% after keeping it on floor throughout the whole night (about 12 hours)

Straw The straw sample was collected from Richmond Country Farms, 12900 Stevenston HWY, Richmond, BC. The bales were of rectangular shape with a moisture content of 8.45% (wb) as received. The straw samples were ground by a Yardworks shredder (Electric garden shredder, model 60-3802-0) and the fines were separated through sieving. Ground straws were re-feeding into the shredder several times and an average particle size of 50, 25, 13, and 6 mm were sorted out by sieving with different mesh size. A portion of the chop at 8.45% (wb) moisture content was set aside for bulk density measurement and compression test. Another portion of the chop was further conditioned by spraying a predetermined amount of distilled water over the samples, thoroughly mixed and kept for 48 h at 5ºC to obtain chops with different moisture contents (wb). Equation (1) was used for the amount of moisture to be added to get desired moisture content of samples. The equation was based on mass balance of moisture content for 1 kg of samples.

$$MC_s + X = (1 + X) * MC_d \quad (1)$$

Where MC_c = Moisture content of the sample, MC_d = Desired moisture content, and X = the water to be added in 1 kg of the samples.

Measurement of bulk density

The bulk density of wood chips and straw samples were measured following the standard method of the American Society of Agricultural Engineers (ASAE 2001). The bucket used for measuring bulk density had a diameter of 24.8 cm and height of 25.3 cm. The procedures for measurement were as follows.

1. Obtained a weight of the clean, dry empty bucket and record the weight.
2. Filled it with water. Knowing the density of water at corresponding temperature, found the volume of the bucket.
3. Gathered a sample of the material to be analyzed.
4. Filled the bucket by pouring the material from a height of 610 mm to overflowing, and the excess material was removed by dragging a straight edge across the top. Material was scraped off until the straight edge could be slid along the top of the bucket in two directions without removing any more material.
5. Recorded the weight of the bucket with the material. Subtracted the weight of the empty bucket to obtain the weight of sample. The sample weight divided by the bucket volume gave the loose bulk density of the material.
6. Picked-up the pail and drop the bucket containing the sample onto a firm flat surface from a height of 150 mm 5 times.
7. Then added additional feedstock and fill to the two-thirds full level.
8. Repeated the procedure (#4) a second time, dropping the pail 5 times from 150 mm.
9. Added material to the pail to fill it to the top, and repeated the dropping procedure (#4) a third time. After the third time, filled the bucket to the rim without repeating the dropping procedure (#4).
10. Weighed the pail and its contents on as accurate a scale as was available and recorded it.
11. Repeated the procedure (#5) to get the tapped bulk density of the sample.

Compaction

This experiment consisted of compacting wood chips and straw samples using an Instron Model 1011 testing machine (Instron Corp., Canton, MA). The load and stroke data output from the

Instron machine was converted to bulk density and applied pressure. The maximum load that can be applied by the load cell was 22250 N (5000 lb). But for the safety of the machine, limit of maximum load was set at 13350 N (3000 lb).

Test Apparatus A tube and plunger apparatus was constructed for use with the Instron Model 1011 testing machine to study the compression behaviour of straw samples. The tube was a section of steel pipe, arbitrarily chosen with a 16.2 cm inside diameter and 16.2 cm height. A circular piece of steel plate was welded to the bottom of the tube to form the base. The plunger was steel rod of diameter 1.97 cm, attached with another circular plate of diameter slightly less than 16.2 cm so that it can go through the steel tube. Both the tube wall and circular plate thickness were 0.5 cm. The plunger through the circular plate compresses the samples from the top of the steel pipe. The upper part of the plunger had a 2 cm threaded rod connecting it to the load cell of the Instron machine. The threaded portion had a major diameter of 0.9 cm.

Procedure The steel tube was filled with wood chips or straw from a bucket of material scooped from a bin containing a large supply. It was filled to overflowing, and the excess material was removed by dragging a straight edge across the top. Material was scraped off until the straight edge could be slid along the top of the tube in two directions without removing any more material. The tube was then weighed, and placed on the platform of Instron machine. The plunger was screwed up with the load cell. After filling, the tube was loaded using a plunger-plate assembly. The maximum allowable pressure would be about 1080 kPa considering the maximum load cell force of 22250 N. Once this pressure was achieved, the compression was stopped and the load was released.

RESULTS AND DISCUSSIONS

A number of experiments were carried out to study the effect of moisture content, particle size, vibration and compaction pressure on bulk density. The results of bulk density for wood chips have been shown in Fig. 1. Loose bulk density of pine wood chips varied from 180 to 214 kg/m^3 in the moisture content range of 10.7-55.71% for small size. The tapped bulk density varied from 209-387 kg/m^3 in the same moisture content range. The average bulk density of the wood chips on dry matter basis is 146 kg/m^3 which are comparable to Hasan (1976) and Haygreen (1981). They found bulk density of green pine and hardwood as 140 and 192 kg/m^3 on dry basis respectively. The bulk density of wood chips increased an average amount of 20% due to tapping. Timothy et al. (1994) also found 20% increase of bulk densities with the chipped material from pine, mixed hardwood and sycamore by the application of vibration.

As depicted in Fig.1, the bulk density of large size wood chips decreased in comparison with the small size. It varied from 158 to 308 kg/m^3 in the moisture content range between 10.7 to 55.71%. An average of 7.44 and 8.2% decrease were observed due to the change in particle size for loose and tapped bulk density respectively. This is quite logical as the particle size becomes larger, the gap between the particles increased keeping more unoccupied space. This results lower mass of the particle in the same container i.e. lower bulk density. The changes of bulk densities of wood chips with respect to moisture content are best described as linear with R^2 value from 0.93-0.95. The equations stating the relationship between bulk density and moisture content for different cases are shown in Fig.1.

Similar types of results were found for straw. The bulk densities of straw at different particle size are shown in Fig. 2. It is seen that an average of 38% increase of bulk density occurred due to tapping of different size. The increase of bulk density increased with the increase of particle size as lower size particle comparatively closely packed while pouring from into the bulk density container. Increase of bulk density due to particle size from 6 to 13, 25 and 50 mm were 13.3, 40 and 54.9%. This can be explained in the way that 6 mm particles are close to 12 mm size particles. The unoccupied space due to this size difference is also narrow in comparison with the particles of 25 or 50 mm sizes. The changes of bulk and tapped bulk density with respect to particle size can be described as 2nd order polynomial with a R^2 value of 0.99.

During compaction, components of biomass are brought closer to each other. Then, air voids are reduced and stems are flattened. The biomass experiences the greatest amount of deformation in the early stages of compression. However, the load is smallest at the beginning and keeps increasing to the end of compression. Therefore, an inverse relationship exists between the deformation of the plant material and the magnitude of the load.

Compaction of wood chip is not necessary as the bulk density of wood chip already meet the legal restriction for transportation. In addition, wood chips are not easily compressible. Compaction of straw is a must for transportation as it has very low density. Compaction played a significant role to increase the bulk density of straw as depicted in Fig. 3 for different particle sizes. The maximum compaction pressure used for these experiments was about 630 kPa considering the safety of the machine. The effect of compaction pressure on bulk density for larger particles was more in comparison with smaller particles, because smaller particles are closed packed leaving less space among particles. As for example bulk density of 6 mm size straw increased from 54.4 to 206 kg/m^3 while for 50 mm size it increased from 23 to 260 kg/m^3. The variations of bulk density with compaction pressure is best described as power curve with R^2=0.98-99. The equations for different particle sizes are mentioned in Fig. 3.

CONCLUSION

Densification is essential for efficient and cost effective transportation of biomass residues. Smaller size wood chip easily meet the criteria for transportation. Low bulk density biomass residues like straw needs compaction to increase density to the required level. Tapping might increase density a little bit but that is not adequate for transportation.

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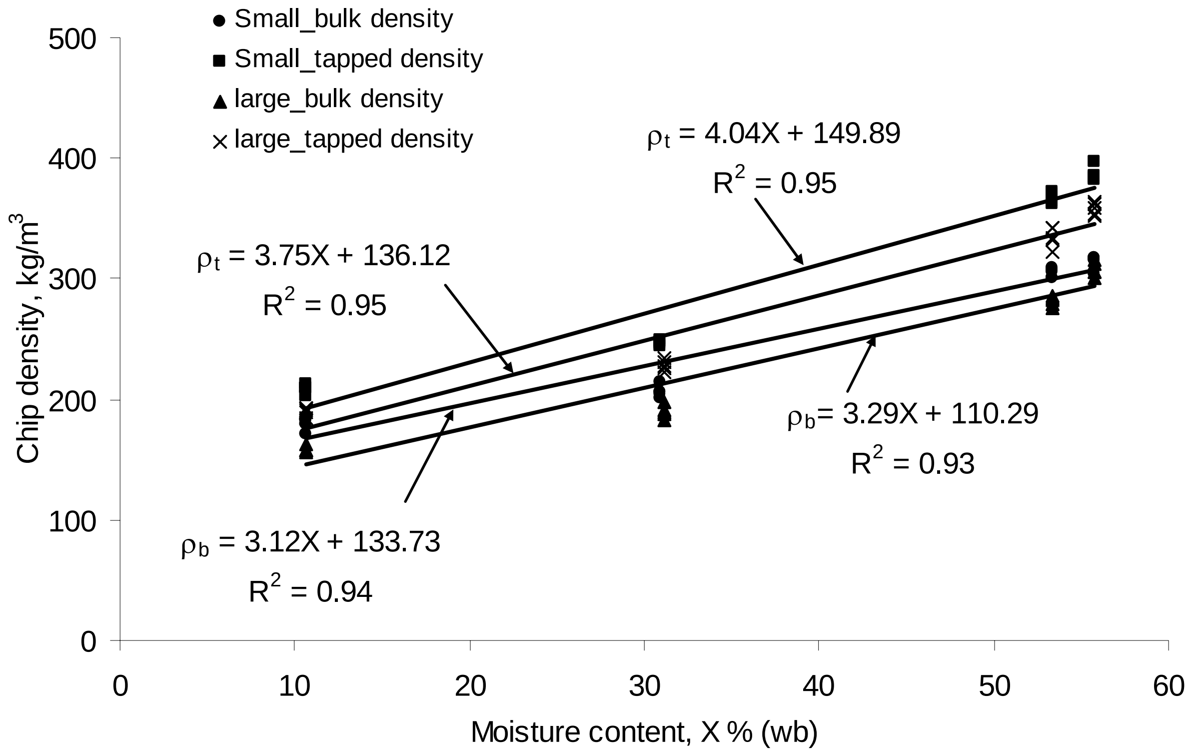

Fig. 1 Variation of bulk density with moisture contents for wood chips

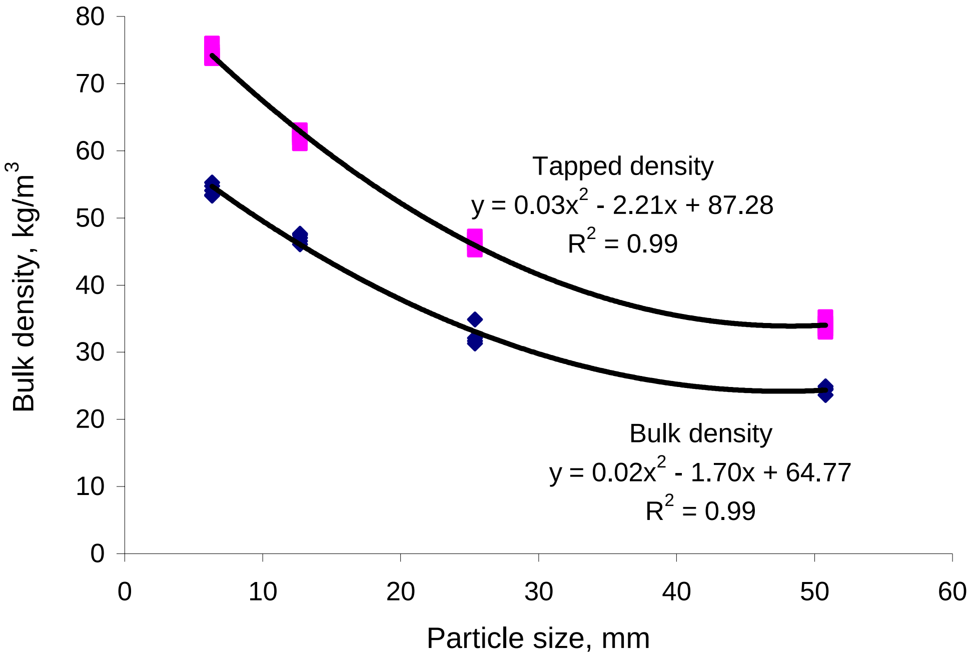

Fig. 2 Variation of bulk density of straw with particle size and tapping

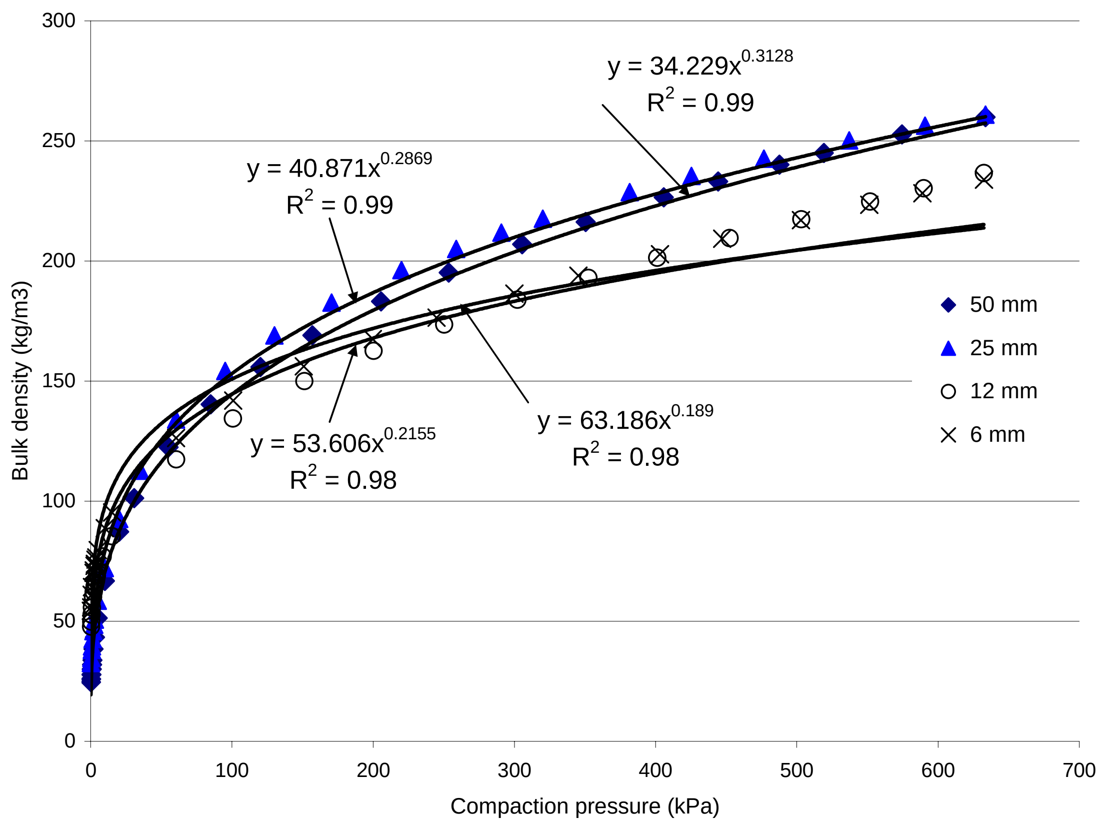

Fig. 3 Bulk density of straw at different compaction pressure