Loose-Filled and Tapped Densities of Chopped Switchgrass, Corn Stover and Wheat Straw

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Paper No. 084085

Abstract

Bulk density is one of the important engineering property of biomass having significant impact on the supply logistics and processing in ethanol production facilities using lignocellulosic materials. Most of the comminuted biomass are fluffy and results in significant increase in bulk density by tapping. Switchgrass, wheat straw and corn stover were chopped in a knife mill at different operating conditions including four different screens having 50.0, 25.0, 18.75, 12.5 mm diameter. Loose-filled bulk densities were found to be 67.5 ± 18.4 kg/m^3 for switchgrass, 36.1 ± 8.6 kg/m^3 for wheat straw, and 52.1± 10.8 kg/m^3 for corn stover. Tapped bulk densities were found to be 81.8 ± 26.2 kg/m^3 for switchgrass, 42.8 ± 11.7 kg/m^3 for wheat straw, and 58.9 ± 13.4 kg/m^3 for corn stover. The maximum volume reduction ratio observed for switch grass, wheat straw and corn stover was 0.159, 0.165, and 0.154 respectively for finely chopped samples and 0.107, 0.117, and 0.098 respectively for coarsely chopped samples. By tapping, the infinite compressibility achieved was highest for chopped switchgrass followed by chopped wheat straw and corn stover indicated by the 'a' values in the sone's model. However the ease of compaction was least for chopped wheat straw followed by chopped switchgrass and corn stover. This indicated that the chopped wheat straw particle compacts very rapidly by tapping compared to chopped switchgrass and corn stover. Hausner ratio, a measure of internal friction, determined after 50 taps was in the range of 1.114 to 1.321 for chopped switchgrass, 1.105 to 1.309 for chopped wheat straw and 1.060 to 1.239 for chopped corn stover.

Introduction

- Bulk density is an important engineering property having significant impact on handling storage and transportation issues.
- Bulk density of chopped biomass is very low (<300 kg/m^3).
- Bulk density depends on material composition, particle size and distribution, particle shape, orientation of particles, specific density, moisture content and applied axial pressure.
- Bulk density increases due to vibration and tapping during handling and transportation.
- Bulk density increases due to normal load during storage.
- Hence the compaction behavior of chopped biomass is very important.

Objectives

- To study the effect of particle size on bulk density of chopped biomass
- To evaluate the compaction behavior of chopped biomass subjected to tapping

Methods and Materials

Raw material: Switchgrass, wheat straw, and corn stover chopped in a knife mill

Particle size : method no. ASAE S 424.1 (ASAE, 2004)

Loose filled bulk density

Weight of chopped biomass in a cylindrical container having 149 mm diameter and 143 mm height

$$Loose\ \ filled\ \ bulk\ \ density = \frac{Weight\ \ of\ \ the\ biomass}{Volume\ \ of\ \ the\ biomass}$$

Tapped bulk density

Cylinder with biomass was tapped on a wooden platform for 50 times

$$Tapped\ \ bulk\ \ density = \frac{Weight\ \ of\ \ the\ biomass}{Cylinder\ \ volume\ - settled\ \ volume\ \ reduction}$$

$$Hausner\ \ ratio = \frac{Tapped\ \ bulk\ \ density\ \ (\rho_L)}{Loose\ \ filled\ \ bulk\ \ density\ \ (\rho_T)}$$

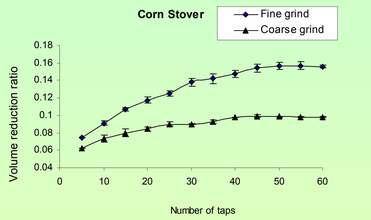
Compaction behavior

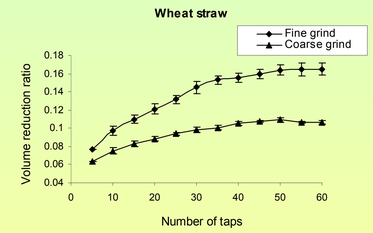
- Volume reduction was measured for every 5 taps.
- 2 Particle size each in switchgrass, wheat straw and corn stover

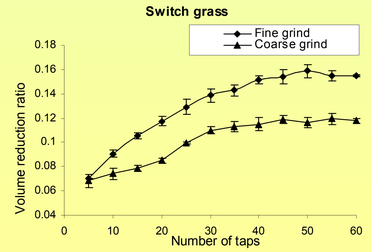
$$\gamma_n = \frac{(V_0 - V_n)}{V_0} = \frac{abn}{1 + bn}$$

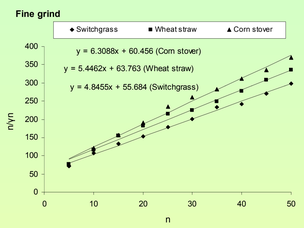
$$\frac{n}{\gamma_n} = \frac{1}{ab} + \frac{n}{a}$$

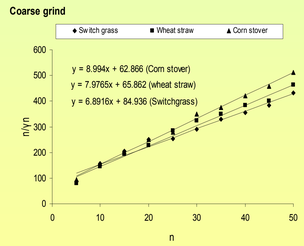
Results and discussion

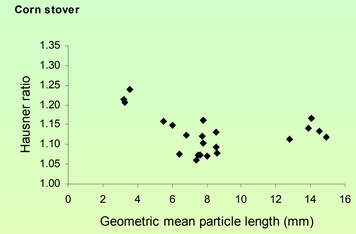


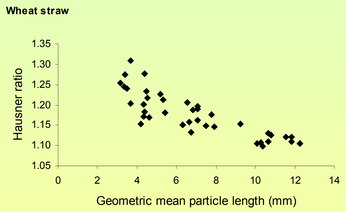


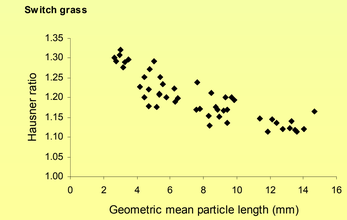












Chopped corn stover

Treatment No.	X_{gm} (mm)	S_{gm} (mm)	Loose filled bulk density (Kg/m^3)	Tapped bulk density (Kg/m^3)	Hausner ratio
1	3.22	2.42	65.16^{bc}	79.12^{bc}	1.214
2	3.26	2.37	66.56^{b}	80.24^{b}	1.205
3	3.56	2.27	69.05^{a}	85.55^{a}	1.239
4	5.49	2.50	62.18^{d}	72.06^{fg}	1.159
5	6.40	2.49	54.83^{ij}	62.91^{lm}	1.147
6	6.42	2.59	56.22^{hi}	60.43^{no}	1.075
7	6.85	2.50	50.10^{lm}	56.30^{qr}	1.124
8	7.40	2.46	51.35^{kl}	54.41^{rs}	1.060
9	7.52	2.31	59.07^{e-g}	63.33^{lm}	1.072
10	7.65	2.31	54.38^{ij}	58.34^{o-q}	1.073
11	7.73	2.22	50.80^{kl}	56.90^{pq}	1.120
12	7.80	2.33	40.95^{no}	45.13^{u}	1.102
13	7.80	2.27	53.79^{ij}	62.49^{mn}	1.162
14	8.02	2.10	65.88^{b}	70.59^{gh}	1.071
15	8.55	2.20	61.89^{d}	67.61^{ij}	1.092
16	8.56	2.41	50.60^{k-m}	57.17^{pq}	1.165
17	8.62	2.39	48.21^{m}	51.98^{s}	1.078
18	12.79	2.09	34.44^{qr}	38.35^{w}	1.114
19	13.86	2.27	39.16^{op}	44.66^{u}	11.14
20	14.03	2.28	42.39^{n}	49.45^{t}	1.167
21	14.48	2.18	36.78^{pq}	41.73^{v}	1.135
22	14.89	2.22	33.23^{r}	37.17^{w}	1.119

$TBD_{CS} = 86.364 - 3.27 * X_{gm}$ R²=0.74

$BD_{CS} = 74.305 - 2.643 * X_{gm}$ R²=0.74

Chopped wheat straw

Treatment No.	X_{gm} (mm)	S_{gm} (mm)	Loose filled bulk density (Kg/m^3)	Tapped bulk density (Kg/m^3)	Hausner ratio
1	3.17	2.06	52.21^{a}	65.49^{a}	1.254
2	3.35	2.12	50.46^{b}	62.75^{b}	1.244
3	3.50	2.08	48.12^{c}	59.70^{d}	1.241
4	3.67	2.18	50.79^{ab}	60.09^{bcd}	1.203
5	4.21	2.15	43.91^{e}	50.67^{efg}	1.154
6	4.33	2.16	41.30^{gf}	48.35^{h}	1.171
7	4.37	2.13	38.55^{h}	49.22^{gh}	1.277
8	4.40	2.09	42.33^{f}	50.04^{fgh}	1.182
9	4.52	2.11	40.77^{g}	49.63^{fgh}	1.217
10	4.61	2.19	44.41^{e}	51.89^{e}	1.168
11	5.33	2.23	37.23^{ih}	45.17^{ij}	1.212
12	5.42	2.27	32.96^{lm}	38.95^{o}	1.182
13	6.53	2.29	34.95^{kl}	41.56^{lm}	1.206
14	6.67	2.44	34.28^{kl}	39.67^{no}	1.157
15	6.86	2.40	35.50^{ijk}	42.18^{klm}	1.188
16	7.06	2.15	38.49^{h}	44.74^{ij}	1.162
17	7.09	2.37	38.21^{h}	45.44^{i}	1.189
18	7.48	2.49	33.97^{klm}	39.05^{o}	1.149
19	7.91	2.39	37.41^{hi}	42.88^{kl}	1.146
20	9.25	2.70	31.05^{h}	35.81^{p}	1.153
21	10.25	2.63	25.11^{p}	27.78^{r}	1.106
22	10.39	2.38	24.57^{p}	26.96^{rs}	1.097
23	10.68	2.48	24.33^{p}	27.49^{r}	1.130
24	10.78	2.72	27.59^{o}	31.05^{q}	1.126
25	11.57	2.42	22.31^{q}	25.01^{r}	1.121
26	11.82	2.55	24.23^{p}	26.90^{rs}	1.110

$BD_{WS} = 55.244 - 2.79 * X_{gm}$ R²=0.87

$TBD_{WS} = 69.100 - 3.81 * X_{gm}$ R²=0.87

Chopped switch grass

Treatment No.	X_{gm} (mm)	S_{gm} (mm)	Loose filled bulk density (Kg/m^3)	Tapped bulk density (Kg/m^3)	Hausner ratio
1	2.65	2.51	105.03^{a}	136.56^{a}	1.300
2	2.99	2.47	104.60^{a}	136.86^{a}	1.308
3	3.17	2.65	103.50^{ab}	132.07^{bc}	1.276
4	3.49	2.69	104.18^{a}	134.10^{ab}	1.296
5	4.21	2.77	82.86^{e}	101.69^{e}	1.227
6	4.45	2.50	81.26^{e-g}	101.78^{e}	1.253
7	4.70	2.54	77.38^{hi}	94.47^{g}	1.221
8	5.04	2.70	73.26^{kl}	94.59^{g}	1.291
9	5.33	2.69	70.69^{m}	85.51^{k}	1.210
10	5.41	2.66	75.49^{i-k}	94.58^{g}	1.253
11	5.77	2.65	76.41^{ij}	91.69^{g-l}	1.200
12	6.29	2.78	68.12^{n}	81.06^{l}	1.910
13	7.55	2.80	66.11^{n}	77.25^{m}	1.168
14	7.81	2.77	58.91^{pq}	69.01^{o-q}	1.171
15	8.39	2.84	50.33^{w}	56.84^{tu}	1.129
16	8.77	2.63	58.01^{p-t}	68.20^{pq}	1.176
17	8.97	2.65	59.79^{op}	68.91^{o-q}	1.153
18	9.35	2.58	59.84^{op}	71.79^{no}	1.200
19	9.43	2.64	58.10^{p-s}	67.95^{q}	1.169
20	9.83	2.78	60.04^{op}	71.72^{no}	1.195
21	11.86	2.62	54.96^{uv}	61.21^{s}	1.114
22	12.32	2.54	45.26^{yz}	51.63^{wx}	1.141
23	12.79	2.55	43.67^{za}	48.93^{x-z}	1.121
24	13.50	2.55	42.16^{zab}	47.12^{yz}	1.118
25	14.06	2.64	43.97^{za}	49.30^{xy}	1.121

$BD_{SG} = 103.37 - 4.670 * X_{gm}$ R²=0.80

$TBD_{SG} = 132.58 - 6.60 * X_{gm}$ R²=0.80

Sample	a	b
Wheat straw (fine)	0.191^{b}	0.090^{f}
Wheat straw (Coarse)	0.121^{e}	0.128^{c}
Switch grass (fine)	0.195^{a}	0.097^{e}
Switch grass (Coarse)	0.140^{d}	0.161^{b}
Corn Stover (fine)	0.186^{c}	0.100^{d}
Corn Stover (Coarse)	0.108^{f}	0.173^{a}

Conclusions

- Chopped switchgrass had highest loose filled bulk density and tapped bulk density followed by chopped corn stover and wheat straw.
- Chopped switchgrass had the maximum infinite compressibility by tapping followed by wheat straw and corn stover.
- Chopped wheat straw settled rapidly during tapping compared to chopped switchgrass and corn stover.
- Chopped corn stover had the maximum difficulty in packing, minimum infinite compressibility.

Acknowledgement

This research was supported in part by the USDA-NRCS Grant Agreement 68-3A75-4-136 and USDA-DOE Biomass Research and Development Initiative DE-PA36-04G094002