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TECHNICAL NOTE:

PACKING FACTORS OF FEED PRODUCTS IN STORAGE STRUCTURES

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ABSTRACT. *Experiments were conducted to measure the changes in bulk density of cracked corn, corn meal, soybean meal, cotton seed meal, and distillers dried grain (without solubles) when subjected to simulated overburden pressures. All materials were tested at two moisture content levels (approximately 8% and 12% w.b.) and seven pressures between 0 and 69 kPa (0 and 10 psi). A mathematical model was fitted to the data to predict the bulk density of each feed ingredient as a function of pressure and moisture content. These relationships were inserted into a previously developed computer model to predict ingredient packing within conventional storage structures based on Janssen's equation as a function of feed product type, moisture content of the material, friction characteristics of the bin wall material, material height, and bin diameter. Cracked corn experienced the smallest amount of packing (approximately 4.3% in a bin with a diameter of 1.8 m and a height of 1.8 m), while distillers dried grain (without solubles) had approximately 8.1% packing in the same sized bin. With a bin diameter of 5.5 m and a height of 5.5 m, distillers dried grain (without solubles) and cracked corn had a packing factor of 13.3% and 6.8%, respectively. As moisture content increased the amount of packing increased for all materials. The data presented can be used for inventory control and management.*

Keywords. *Bulk density, Coefficient of friction, Silo, Bin, Packing, Compressibility, Feed, Storage.*

Feed mill operators and processors are frequently required to determine the inventory of many different feed products held in storage structures. This task is complicated by the fact that all granular materials compress (pack) a finite amount when pressure is applied to them. The material at the bottom of a storage bin will be compressed by the weight of the material stacked above it. The packing effect ultimately increases the capacity of a storage bin. Initial bulk density and moisture content have been shown to affect the packing of wheat, shelled corn, and other grain products (Thompson et al., 1987) and are believed to affect the packing of granular feed ingredients. Information on the influence of moisture content and bulk density are required to predict the packing of feed ingredients under loads exerted in storage structures to accurately determine product inventory.

Thompson et al. (1987) developed a computer model to predict the packing of whole grains in storage structures. The program requires information on the packing behavior of the material being stored, coefficient of friction of the material against the bin wall, geometry of the storage bin and the initial physical characteristics of the stored material. The program uses functional relationships that were determined experimentally to predict the variations in bulk density of different meals as a function of the overburden pressure and moisture content of the material. This information was employed in the differential form of Janssen's equation (1895) to predict the pressures that exist in a storage bin of any given diameter and height. Capacities of hopper bottomed bins or flat-bottomed storage structures may be evaluated with the program. Specifically, the program predicts the total mass in a given structure, the packing factor of the material, and confidence limits of the estimated capacity.

Previous work has dealt with the theory of particle packing (Smalley, 1971). This research considered the packing of regular uniform shapes and has provided important insights for understanding packing theory. It does not relate well to the situations encountered in packing of granular materials such as whole grains and ground feed products because the particles in these materials are of random size and shape and are compressible. Therefore, most work that relates directly to the packing of granular materials has been empirical in nature rather than theoretical.

An early publication by Bates (1925) describes a method for estimating the quantity of material in storage bins and the packing of granular materials. Since the standard unit of measurement is bushels, a volume measurement, the number of standard, uncompacted bushels in a bin is greater than the volumetric capacity due to packing. Bates suggested that the

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number of standard bushels 770 kg/m^3 (60 lb/bu or 48.2 lb/ft^3) of wheat in a bin is dependent on the dimension and shape of a bin, the depth of material, and the test weight of the material in the bin. From experimentation the average packing for wheat was found to be 4.85% of the initial, uncompacted test weight per bushel. While Bates proposed that the packing of a granular material was a function of the depth of material in a bin, the 4.85% packing factor was used to predict the packing for all depths of grain due to limited data. Only the packing factor for wheat was reported, but reference was made to the fact that different packing factors would exist for other agricultural materials.

A more detailed method was used for estimating the packing factors of granular materials in a storage bin in a publication by the Illinois Agricultural Auditing Association (1980). In this publication, packing factors were provided for seven different types of grain based on the initial test weight of the material and the quantity (bushels) stored per foot of depth in the structure. A technique was also provided for measuring the irregular surface depth from the top of the bin so that the average depth of grain could be estimated. For wheat with a test weight of 770 kg/m^3 (48.2 lb/ft^3), a packing factor of 2% was predicted by this method for rectangular bins with a cross sectional area of 3.5 m^2 (38 ft^2), which is an average increase of 15.4 kg/m^3 (0.96 lb/ft^3). In contrast, wheat stored in a circular bin with a diameter of 10.5 m (86.6 m^2) [34.5 ft (935 ft^2)] or greater would have a packing factor of 10%, an average increase in bulk density of 77.0 kg/m^3 (4.82 lb/ft^3).

Attempts have been made to determine the packing factors of granular materials on-site. In a study performed by Malm and Backer (1985), packing factors were estimated by measuring the top surface settlement of the stored material in a bin at 7 to 14 days after filling and then again at 23 to 40 days after filling. The maximum settlement that occurred was determined to be 2.5%. However, difficulties were encountered in accurately measuring the amount of settlement of the grain mass because the surface was disturbed when the cooperators took grain samples. Nevertheless, a set of packing factors for six different crops was proposed from this study.

Other studies have been conducted to determine the effects of grain spreaders on the in-bin bulk density of wheat. Chang et al. (1981, 1983) determined that when a spreader was used, the in-bin bulk density of wheat was approximately 5% to 9% higher than when no spreader was used. Stephens and Foster (1976) found similar results and determined that grain spouted into a bin increased the average bulk density of the sample's test weight by an average of 3.7%. For bins filled with a spreader, it was determined that the in-bin bulk density increased from 12% to 19% depending on the type of spreader used. Chang et al. (1983) also determined relative pack factors for different filling methods. These were presented in equation form and used to describe airflow resistance in bins.

Thompson et al. (1987) conducted packing tests for whole grains using two varieties each of six different grains. Changes in bulk density at different pressures [between 0 and 172 kPa (0 to 25 psi)] were determined at two moisture content levels [nominally 10% and 16% wet basis (w.b.), all moisture contents are presented in percent wet basis]. Mathematical expressions were developed to represent compression curves and were incorporated into a computer program that utilized the differential form of Janssen's equation to predict the packing of grains in bins of a given diameter and height. For a moderate sized grain bin with a diameter of 11.9 m and an eave height of 11.9 m (39 × 39 ft), the pack factors were computed to be 3.8% for corn, 4.0% for sorghum, 4.1% for soybeans, 4.6% for hard red winter wheat, 6.1% for soft red winter wheat, and 7.2% for rough rice.

The packing of corn meal, soybean meal, citrus pulp, and wheat at pressures between 0 and 27.5 kPa (0 and 4 psi) was measured by Clower et al. (1973). The ratio of lateral to vertical pressures was also determined for each material. Mathematical relationships were developed from the data to relate vertical pressure to bulk density. However, the effect of moisture content was not investigated in these experiments.

The objective of this study was to determine the change in bulk density (packing) as a function of pressure of corn meal, cotton seed meal, cracked corn, distillers dried grain (without solubles), and soybean meal at two moisture content levels and to modify the model of Thompson et al. (1987) to predict the packing of feed ingredients in storage structures.

MATERIALS AND METHODS

Feed materials were procured from a local vendor, sampled for moisture content using the oven method (*ASABE Standards*, 2007), sealed in plastic bags, and placed in refrigerated storage. Received materials were sufficiently and uniformly dry to perform the low moisture tests. Distilled water was added by spraying a prescribed amount of fine mist to each material to increase the moisture content to the desired level (from ~8% to 12%). High moisture materials were placed in refrigerated storage to allow moisture to equilibrate within each sample while the low moisture materials were tested (10 to 14 days) and checked daily to determine that no free moisture had transferred to the interior surface of the bag. All samples were allowed to warm to room temperature prior to testing. The moisture content of the samples for the material with a nominal moisture content of 8% was 8.5%, 7.6%, 8.9%, 8.1%, and 7.7% for corn meal, cotton seed meal, cracked corn, distillers dried grain (without solubles), and soybean meal, respectively. For the nominal moisture content of 12%, the actual moisture content was 12.6%, 11.8%, 12.0%, 12.1%, and 11.7% for corn meal, cotton seed meal, cracked corn, distillers dried grain (without solubles), and soybean meal, respectively. The samples were thoroughly mixed during moisture equilibration and before testing. No effort was made to determine the particle size distribution of these materials, although this data should be included in future work.

The bench top compression apparatus described by Thompson and Ross (1983) was used to simulate the overburden pressure expected in typical storage structures. A 0.3-m square steel box was filled to a depth of 0.1 m with the feed ingredient and a simulated overburden pressure was applied using compressed air through a flexible diaphragm on the bottom. As the material was packed due to the air pressure, a dial gauge was used to measure the displacement and the change in bulk density was calculated. Pressure and change in density data were used to develop functional mathematical relationships that were inserted into the computer model (Thompson et al., 1987) that predicts the internal pressure at various depths and ultimately the packing of each material in a given storage bin.

Each material was subjected to vertical pressures of 0, 3.4, 6.9, 10.3, 13.8, 20.7, 34.5, and 68.9 kPa (0, 0.5, 1, 1.5, 2, 3, 5, and 10 psi). These pressures simulate the stress conditions created by various depths of overbearing feed material and were selected because they represent the range of conditions which are thought to exist in most commercial and farm bins (Thompson et al., 1987). Tests were conducted at nominal moisture content levels of 8% and 12% w.b., which represent typical values for storing feed products. Three replications were performed at each level of pressure and moisture content for each material.

A mathematical expression was developed using a statistical model (SAS Institute, Cary, N.C.) to predict the variation in bulk density as a function of internal pressure and moisture content for each feed product. These expressions were based on the combined data from each material tested. For each product the final expression was of the form:

$$D_p - D_o = a * P + b * P^{0.5} + c(P * MC) \tag{1}$$

where

D_p = predicted packed bulk density kg/m^3 (lb/ft^3) at a given pressure
D_o = test weight or uncompacted bulk density kg/m^3 (lb/ft^3)
a,b,c = coefficients determined from the SAS program
P = applied pressure simulating overbearing feed kPa (psi)
MC = moisture content of the material (percent w.b.)

A function of this form was adopted because it produced a zero intercept regardless of the moisture content of the granular material. The regression coefficients (a, b, and c) were determined using SAS based on the measured moisture content of the material (table 1).

Description of the Model to Predict Packing

The computer model from Thompson et al. (1987) was modified using the parameters fit to equation 1to predict the packing of feed materials in storage bins. The computer program utilizes the differential form of Janssen's equation to predict the variation in material properties (change in bulk density, coefficient of friction, and lateral to vertical pressure ratio) and pressures within a storage bin. A detailed explanation of this equation is given by Ross et al. (1979). The differential form varies from the classical Janssen equation by including the effects of variable material properties. The differential form of Janssen's equation which is used in the solution is:

$$\frac{\partial P}{\partial Y} = D(P) - \left(\frac{kP\mu}{R} \right) \tag{2}$$

where

D(P) = bulk density as a function of pressure for the granular material, kg/m^3 (lb/ft^3)
k = lateral to vertical pressure ratio (dimensionless)
μ = coefficient of friction of the material on the bin wall (dimensionless)
R = hydraulic radius of the storage structure, m (ft)
P = vertical pressure, kPa (psi)
Y = depth of material in the bin, m (ft)

Numerous assumptions and inputs to the model are required to predict the amount of packing. The moisture content of the material effects the packing of the feed material. The packing of the feed ingredients was tested at a moisture content of approximately 8% and 12%. However, it is believed that the packing data could be extrapolated and used over a moisture content range from 6% to 14%. This is based on the results of Thompson and Ross (1983) who found an 8% change in packing at a pressure of 7 kPa when the moisture content of wheat was increased from 12% to 16%. Therefore, it is believed that the packing data for feed ingredients could be extrapolated within the moisture content range of 6% to 14% with acceptable accuracy.

Three different types of wall surfaces can be used in the model: corrugated steel, concrete, or smooth steel. These wall surfaces are used to estimate the default values for the coefficient of friction of the material on the bin wall surface, μ, which is an input value to the differential form of Janssen's equation. Default values for the coefficient of friction based on the wall material can be used or a value from the user can be inputted in the range of 0.19 and 0.61. The default values of μ are based on the values suggested by the European Standard Design Loads in Buildings (DIN, 1987). Recommended values for the coefficient of friction for corrugated steel, concrete, and smooth steel are 0.6, 0.4, and 0.25, respectively. The standard recommends these values for the coefficient of friction used when experimental results are not available for a specific granular material (either whole or ground grain).

The value of k is an input value to the differential form of Janssen's (Ross et al., 1979) equation and is the ratio of the lateral to vertical pressures in the stored material. A default value of 0.5 is suggested, however, the program will allow the use of k values ranging from 0.2 to 1.1. The DIN standard recommends a default value of 0.5 for granular materials when the parameter is not known.

The height of material in the storage bin is limited to a maximum height of 61 m (200 ft). The material height is defined as the position where the feed surface meets the bin wall. The angle of repose is required to estimate an equivalent depth in the bin due to the surcharge cone. The angle of repose was measured using the procedure described by Mohsenin (1980). The sample was placed in a funnel and poured until the sample stopped the material flowing through

Table 1. Regression coefficients determined for equation 1 to predict changes in bulk density at a given vertical pressure and moisture content for corn meal, cotton seed meal, cracked corn, distillers dried grain (without solubles), and soybean meal.

Material	a kg/m^3 kPa (lb/ft^3 psi)	b kg/m^3 kPa$^{0.5}$ (lb/ft^3 psi$^{0.5}$)	c kg/m^3 kPa (lb/ft^3 psi)	r^2
Corn meal	-2.342 (-1.0079)	33.58 (5.5042)	0.0560 (0.0241)	0.99
Cotton seed meal	-2.108 (-0.9075)	29.14 (4.7766)	0.0047 (0.0020)	0.98
Cracked corn	-0.4663 (-0.2007)	13.02 (2.134)	0.0091 (0.0039)	0.97
Distillers dried grain (without solubles)	-5.137 (-2.2111)	23.10 (3.7868)	0.3998 (0.1721)	0.98
Soybean meal	-2.0990 (-1.2865)	21.30 (3.4912)	0.2069 (0.0890)	0.99

the funnel. The angle of repose was measured using a protractor at three points around the cone and the experiment was conducted in triplicate. An equivalent depth of material is used in the program that takes into account the surcharge cone. There is an option in the program that would allow for the height and angle of hopper bottom bins to be considered. The bin diameter is required to calculate the hydraulic radius of the storage structure, which is an input variable to the differential form of Janssen's equation.

The values of k and μ in equation 2 are assumed to be constant throughout the bin, while D, the bulk density of the stored material, is allowed to vary in a manner described by equation 1. To solve the differential equation with variable density, a fourth order Runge-Kutta solution technique was used (Kreyszig, 1972). Several different step sizes were investigated to determine the accuracy and behavior of the function while decreasing the required run time of the program. A step size of 0.3 m (1 ft) was chosen because it proved to be the largest step size possible for the given function without sacrificing any accuracy. The variation in both pressure and bulk density could be determined for any size bin by using the differential form of Janssen's equation. The program also estimates the upper and lower 95% confidence limits for these values.

The amount of particle packing of the stored material was determined by:

$$\%Packing = 100\left(\frac{D_y}{D_o} - 1\right) \tag{3}$$

where

D_y = average packed bulk density of the stored material in the bin of depth y, kg/m^3 (lb/ft^3) and

D_o = initial uncompacted bulk density of the material, kg/m^3 (lb/ft^3)

The average bulk density of the stored material was estimated by using a weighted average of the calculated bulk density for each step. Equation 3 estimates the percent packing by taking the ratio of the average bulk density of the material in the storage bin at depth y to the initial uncompacted bulk density of the material. This method accounts for the volume change resulting from packing. Upper and lower 95% confidence values are also estimated for the bin capacity based on the experimentally determined variation in bulk density and pressure using the differential form of Janssen's equation.

RESULTS AND DISCUSSION

EXPERIMENTAL RESULTS

It was determined from previous test results that the variation in bulk density was a function of the type of feed material, moisture content, and overburden pressure. A representative sample of the results observed for soybean meal is shown in figure 1. These parabolic shaped curves are similar to those determined for the other materials that were tested.

The change in bulk density was predicted at a fixed moisture content of 12% and plotted in figure 2. A curve for shelled corn is also shown for comparison purposes (Thompson et al., 1987).

The pressure-density data reveals that the feed products tested behave in a similar manner but to a different extent. When subjected to equal levels of overburden pressure, distillers dried grains (without solubles) yielded the largest amount of packing while cracked corn and cotton seed meal experienced a lower degree of packing. One possible explanation is the difference in particle size distribution of each feed material, however the particle size distribution was not determined.

APPLICATION OF MODEL

Feed ingredient packing was strongly influenced by type and moisture content. Thompson et al. (1987) felt the changes in bulk density were probably caused by a rearrangement of particles in the test apparatus that corresponds to a decrease in the void space between the

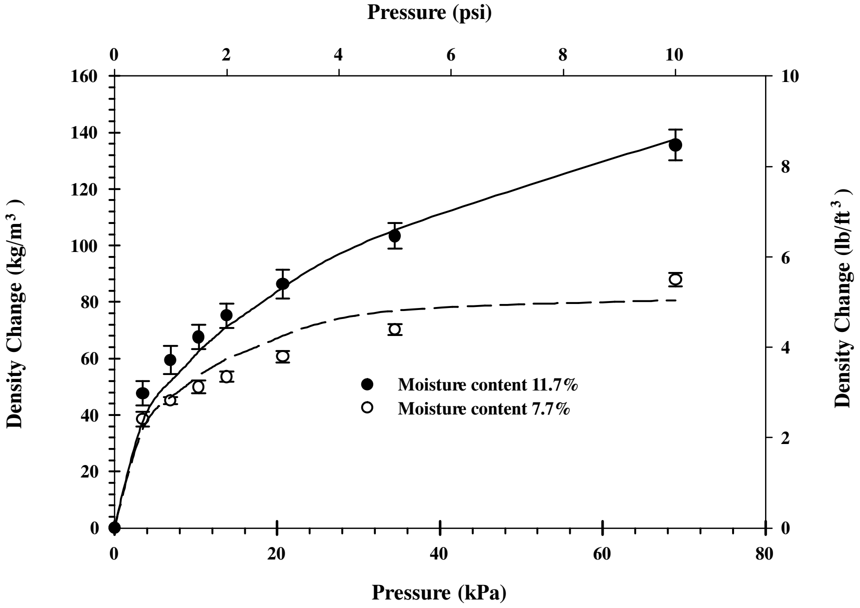

Figure 1. Observed (error bars are standard error) and predicted change in bulk density for soybean meal as a function of internal pressure and moisture content.

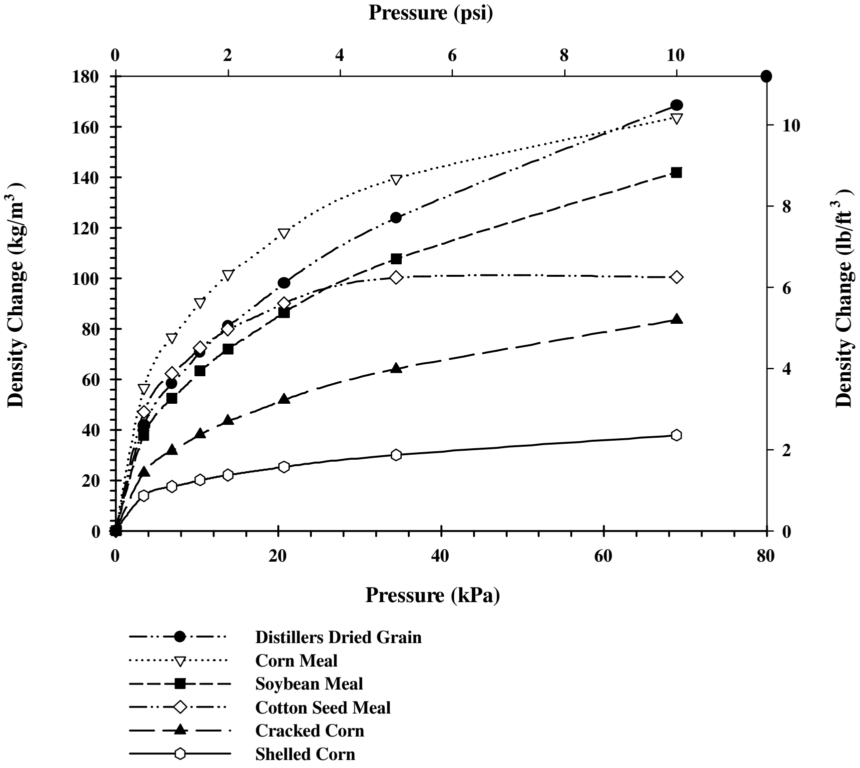

Figure 2. Predicted bulk density change of five feed ingredients and shelled corn at a moisture content of 12%.

particles. It is believed the same mechanism is responsible for changes in bulk density of feed ingredients.

The computer technique utilized in this program is based on the differential form of Janssen's equation 2 which is a function of material properties of the feed ingredients (change in bulk density, coefficient of friction, and lateral to vertical pressure ratio) and the geometry of the storage structure. Results of the compression tests were used to correlate variations in bulk density as a function of pressure and moisture content. The angle of repose measured was 44°, 44°, 37°, 37°, and 39° for corn meal, cotton seed meal, cracked corn, distillers grain (without solubles) and soybean meal, respectively, that was used to determine the equivalent depth due to the surcharge cone. The results obtained from Janssen's equation are a function of the coefficient of friction (μ) and lateral to vertical pressure coefficient (k). Previous work with whole grains indicated that μ had more effect on the packing factor than k (Thompson et al., 1987). Future work should include measurements of the coefficient of friction of the feed ingredients.

Examples of the predicted packing factors utilizing the computer program are shown in table 2 for soybean meal in a hopper bottom bin with variations in μ, bin height, bin diameter, and feed moisture content. The results shown indicate that the packing factors varied between 4.4% in a small shallow bin filled with low moisture soybean meal to 8.8% for a large deep bin filled with high moisture material. Increasing material depth increased the internal pressure in the bin, which caused an increase in packing. It was observed that a change in material depth had a larger effect on packing than does the bin diameter. These changes are amplified by increases in moisture content and decreases in the friction coefficient. Changes in packing due to variations in μ were

Table 2. Predicted packing factors (%) for soybean meal in a hopper bottom bin (hopper 60°), a k value of 0.5, and D_o = 580 kg/m^3 (37 lb/ft^3).[a]

Material Height, m (ft)	Moisture Content (wb)					
	8%			12%		
	Bin Diameter, m (ft)			Bin Diameter, m (ft)		
	1.8 (6)	3.6 (12)	5.5 (18)	1.8 (6)	3.6 (12)	5.5 (18)
	μ = 0.5					
1.8 (6)	4.4	5	5.3	4.9	5.6	6.1
3.6 (12)	5	5.7	6.1	5.7	6.7	7.2
5.5 (18)	5.3	6.2	6.6	6.1	7.3	8
	μ = 0.25					
1.8 (6)	4.8	5.2	5.5	5.5	6	6.4
3.6 (12)	5.8	6.2	6.5	6.7	7.4	7.4
5.5 (18)	6.3	6.9	7.1	7.5	8.4	8.8

[a] Contact the authors for a copy of the model to determine the packing of other products and bin configurations.

Table 3. Predicted packing factors[a] (%) for selected feed materials in round, flat bottom bins.

Bin[b] Size	Corn Meal	Cotton Seed Meal	Cracked Corn	Distillers Dried Grain (without solubles)	Soybean Meal
D_0[c]	655 (41)	590 (37)	630 (39)	610 (38)	580 (36)
D = 1.8 (6); H = 1.8 (6)	7.6	6.5	4.3	8.1	5.1
D = 3.6 (12); H = 3.6 (12)	10.0	8.4	5.7	11.0	6.9
D = 5.5 (18); H = 5.5 (18)	11.6	9.7	6.8	13.3	8.2

[a] Assumptions are a moisture content of 12% (w.b.), the interior wall surface is corrugated steel (μ = 0.5) and the lateral to vertical pressure coefficient (k) is 0.5.

[b] D refers to the diameter of the storage bin m (ft). H refers to the cylinder height of the stored material in the bin m (ft).

[c] D_o refers to the initial bulk density of the stored material kg/m^3 (lb/ft^3).

of the same magnitude as the effect of changing bin diameter or height for the conditions shown.

Increasing the moisture content of soybean meal from 8% to 12% increased the magnitude of packing (fig. 1). At an internal pressure of 55.2 kPa (8 psi) the estimated bulk density of soybean meal increased by 85 and 130 kg/m^3 (5.3 and 8.1 lb/ft^3) at a moisture content of 8% and 12%, respectively. At an internal pressure of 55.2 kPa (8 psi) the bulk density of 12% moisture distillers dried grain (without solubles), corn meal, soybean meal, cotton seed meal, and cracked corn increased by 153, 157, 130, 103, and 77 kg/m^3 (9.6, 9.8, 8.1, 6.4, and 4.8 lb/ft^3), respectively (fig. 2). However, at a moisture content of 8% and an internal pressure of 55.2 kPa (8 psi) the bulk density increased by 65, 145, 85, 102, and 75 kg/m^3 (4.0, 9.1, 5.3, 6.4, and 4.7 lb/ft^3) for distillers dried grain (without solubles), corn meal, soybean meal, cotton seed meal, and cracked corn, respectively (eq. 1). All materials, except corn meal, had a larger increase in bulk density at a moisture content of 12% relative to 8%.

This new packing data was also used to predict the packing factors shown in table 3 for the five products tested in various sizes of round, flat bottom structures. These results reflect the variations observed during the compression tests and illustrate the variations that exist between different feed materials. Distiller's dried grain and corn meal yielded the largest amount of packing in all bins under the simulated conditions, while cotton seed and soybean meal yielded moderate amounts of packing relative to the other products that were tested. Cracked corn yielded the least amount of packing in all cases. Predicted packing factors ranged from 4.3% for cracked corn in the 1.8- × 1.8-m (6- × 6-ft) bin to 13.3% for distiller's dried grains in the 5.5- × 5.5-m (18- × 18-ft) bin.

SUMMARY AND CONCLUSIONS

Experiments were conducted to determine the packing of corn meal, cotton seed meal, cracked corn, distiller's dried grain, and soybean meal. Mathematical expressions were developed for each feed material to describe the changes in bulk density as a function of the overburden pressure exerted on the material and the moisture content of the product. This information was used as a database for a computer program that was designed to determine the amount of packing and the mass of material in a given size storage structure. The differential form of Janssen's equation was used to predict packing factors.

When using this program it was determined that variations existed in the predicted packing factors by the type of feed product, the moisture content of the material, friction characteristics of the bin wall material, material height, and bin diameter. Increasing moisture content resulted in much higher packing factors, with distillers dried grain (without solubles) exhibiting the highest level of packing and cracked corn having the lowest level of packing.

REFERENCES

ASABE Standards, 54th Ed. 2007. S352.2. Moisture measurement - unground grains and seeds. St. Joseph, Mich.: ASABE.

Bates, E. N. 1925. Estimating the quantity of grain in bins. United States Department of Agriculture, Miscellaneous Circular No. 41. Washington, D.C.: USDA.

Chang, C. S., L. E. Shackelford, F. S. Lai, C. R. Martin, and B. S. Miller. 1981. Bulk properties of corn as affected by multiple-point grain spreaders. *Transactions of the ASAE* 24(6): 1632-1636.

Chang, C. S., H. H. Converse, and C. R. Martin. 1983. Bulk properties of grain as affected by self-propelled type grain spreaders. *Transactions of the ASAE* 26 (5): 1543-1550.

Clower, R. E., I. J. Ross, and G. M. White. 1973. Properties of compressible granular materials as related to forces in bulk storage structures. *Transactions of the ASAE* 16(3): 478-481.

DIN, 1055. 1987. Design loads in buildings: loads in silo bins. Sheet 6. Beuth, Berlin, Germany.

Illinois Agricultural Auditing Association. 1980. Test pack factor tables. Bloomington, Ill.

Janssen, H. A. 1895. Verrsuche uber qetreidedruck in silozellen. *VDI Zeitschrift, V.* 39: 1045-1049.

Kreyszig, E. 1972. *Advanced Engineering Mathematics.* New York: John Wiley and Sons, Inc.

Malm, J. K., and L. F. Backer. 1985. Compaction factors for six crops. *Transactions of the ASAE* 28(5): 1634-1636.

Mohsenin, N. N. 1980. *Physical Properties of Plant and Animal Materials, Vol. I – Structure, Physical Characteristics, and Mechanical Properties.* New York: Gordon and Breach Science Publishers.

Ross, I. J., T. C. Bridges, O. J. Loewer, and J. N. Walker. 1979. Grain bin loads as affected by grain moisture and vertical pressure. *Transactions of the ASAE* 22(3): 592-597.

Smalley, I. J. 1971. Variations on the particle packing theme of Graton and Fraser. *Powder Technology* 4(2): 97-101.

Stephens, L. E., and G. H. Foster. 1976. Grain bulk properties as affected by mechanical grain spreader. *Transactions of the ASAE* 19(2): 354-358,363.

Thompson, S. A., and I. J. Ross. 1983. Compressibility and frictional coefficients of wheat. *Transactions of the ASAE* 26(4): 1171-1176, 1180.

Thompson, S. A., S. G. McNeill, I. J. Ross, and T. C. Bridges. 1987. Packing factors of whole grains in storage structures. *Applied Engineering in Agriculture* 3(2): 215-221.