Final Report to the Minnesota Pork Board

I. Project Title: Influence of Storage Bin Design and Feed Characteristics on Flowability of Pig Diets[1]

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II. Abstract:

Two experiments were conducted to evaluate the effects of feed bin design and the use of passive agitators on flowability of feed containing 40% dried distillers grains with solubles. In Experiment 1, six bins representing 3 different styles and manufacturers (2 per design) were used. The three bin styles were: 1. galvanized steel, seamless bin with a 60 degree round discharge cone (Steel 60; Dealers Livestock, Glenwood, MN); 2. galvanized, corrugated steel bin with a 67 degree round discharge cone (Steel 67; PigTek, Milford, IN); and 3. white, poly bin with a 60 degree round discharge cone (Poly 60; Prairie Pride, Winnipeg, MB). About 6,000 lbs of a commercial finishing diet containing 40% DDGS (particle size of feed ranged from 860 to 1,015 microns) were delivered to each bin. Laboratory measures of feed flowability (Carr Indices) indicated that the feed used in these experiments would create flowability problems under commercial conditions. On days 3, 7 and 21 after feed delivery, the rate of feed flow from each bin was assessed by measuring the time required for all feed to flow from the open slide at the bottom of the cone. Feed flowed from the Poly 60 bin (1,624 lb/min) at a faster rate ($P < 0.05$) than the Steel 60 bin (1,329 lb/min) with the Steel 67 bin intermediate (1,462 lb/min). In

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Experiment 2, the same bins were used except that a passive feed flow agitator (Sure Flo Agitator, Farmer Boy Ag Supply, Myerstown, PA) was installed in one bin of each design. Feed flow was evaluated on days 2, 3, 6, 7, 20, and 21 after feed delivery. Feed flow from the Poly 60 bins (1,986 lb/min) was greater ($P < 0.05$) than flow from the Steel 60 (1,822 lb/min) or the Steel 67 (1,860 lb/min) bins. Presence of the passive agitator significantly increased feed flow in the Poly 60 bins ($P < 0.05$; 2,139 vs. 1,833 lb/min) but had no significant effect in the Steel 60 or Steel 67 bins. Results of these experiments indicate that feed bin design can influence flowability of feed containing high concentrations of DDGS. Of the bins tested, the Poly 60 bin produced the highest flow rate of feed once feed flow was established. Passive agitators installed in feed bins appear to aid feed flow in some but not all bins. The combination of a passive agitator in the Poly 60 bin produced the fastest feed flow.

III. Introduction:

Poor flowability of feed in commercial pork production systems is a continual, nagging problem for most producers. Poor flowability causes reduced rate of feed delivery to feeders or bridging of feed in the storage bin which prevents feed from reaching pigs. The bridging of feed in storage bins requires some intervention, usually pounding or beating on the bin by the barn workers to re-establish feed flow. This can lead to significant damage to bins and cause water leaks leading to feed spoilage. In addition, the workers need to leave the barn to correct the feed flow problems which likely breaches the farm's biosecurity standards because the workers probably will not shower or change clothes and footwear to re-enter the pig space. So, poor feed flowability is a common problem, that can reduce pig performance, compromises pig welfare, causes damage to bins leading to feed spoilage, may weaken biosecurity standards, and is a frustration to animal caretakers.

Flow of a bulk material is defined as "the relative movement of a bulk of particles among neighboring particles or along the container wall surface" and many factors affect flowability of a bulk material (Peleg, 1977). Some important characteristics of feed that influence flowability include: diet composition, particle size and shape, moisture level, ambient temperature and humidity, pressure leading to compaction, and addition of anti-caking agents (Ganesan et al., 2005). While there is a long list of factors that influence flowability of feed, practically speaking, few of these can be controlled or will be manipulated in commercial pork production systems. Dried distillers grains with solubles (DDGS) is notorious for its poor flowability under certain circumstances commonly experienced in commercial pork production. Anecdotal reports from the field are consistent that inclusion of high levels of DDGS (30 - 40%) in swine diets significantly reduces flowability of feed. However, the current high corn price drives pork producers to include high levels of DDGS in diets to reduce cost of feed and overall pig production costs. In this instance, economic considerations override concerns for reduced flowability of feed. Use of anti-caking agents could provide a simple solution to poor flowability but previous research with DDGS suggests common anti-caking agents are ineffective (Ganesan et al., 2008; Johnston et al., 2009).

The economic realities of modern pork production systems dictate that producers use finely ground diets containing high levels of bioenergy by-products (DDGS and similar corn co-products) that will continue to exhibit poor flowability. Given this reality, it appears that the industry should abandon attempts to alter the feed for improved flowability in favor of focusing on the feed handling equipment to improve feed flowability. There are potentially many design characteristics of feed storage bins such as slope and shape of the discharge cone, material used to construct the bin, presence of mechanical aids and others that influence flowability of feed.

However, there is little diversity among designs and features of storage bins currently being marketed. Historically, pork producers have spent little time and effort in selecting feed storage bins. The primary questions asked by producers are: "How much feed will the bin hold?" and "What does the bin cost?" Seldom do producers consider the flow characteristics of the bin. If feed flowability problems are to be corrected, it seems some attention to bin design as it relates to feed flowability under the economic realities of modern feed formulation and manufacturing practices is warranted.

IV. Objectives:

1. To determine the effects of design of selected commercially-available feed storage bins on flowability of feed formulated to current industry standards.
2. To determine if a passive bin agitator will influence feed flow from commercially-available feed storage bins.
3. To determine characteristics of feed and the environmental conditions of storage that are predictive of feed flowability.

V. Procedures:

Two experiments were conducted to satisfy Project Objectives 1 and 2, respectively. Objective 3 was addressed in both experiments. In each experiment, two lots (17 tons each) of a typical commercial swine finisher diet were purchased from a commercial feed mill. The diet was based on corn and soybean meal and contained 40% DDGS. Final target particle size was 600 microns. Diet formulation and processing characteristics were designed to mimic poor flowability from commercial feed storage bins. Commercial diets were delivered to the West Central Research and Outreach Center Feed Flowability research site. The research site consisted of 6 feed storage bins arranged in a single row on a concrete pad oriented in a north-south direction. There were 6 total bins representing 3 different styles and manufacturers (2 bins per style). The three bin styles were: 1. galvanized steel, seamless bin with a 60 degree round discharge cone (Steel 60; Dealers Livestock, Glenwood, MN); 2. galvanized, corrugated steel bin with a 67 degree round discharge cone (Steel 67; PigTek, Milford, IN); and 3. white, poly bin with a 60 degree round discharge cone (Poly 60; Prairie Pride, Winnipeg, MB). All bins were models currently available to commercial pork producers (Figure 1). All bins were equipped with a standard boot to allow transition to the unload auger. The opening of the boot with discharge slide fully opened measured 6 x 9.5 inches. Bins were not equipped with unload augers so that feed flow from the bin was not dictated by the speed and capacity of the auger. Instead, feed flow was measured by opening the boot slide completely and allowing feed to flow into a tractor-powered grain auger with sufficient capacity to prevent feed buildup at the bin outlet. Bin styles were selected to represent different slopes to the sides of the discharge cone or different materials on the inner wall of the bin. These different styles allowed evaluation of feed flow from bins currently being used on or available to commercial farms. Steel 67 and Poly 60 bins had a capacity of at least 6,000 pounds but Steel 60 bins had a capacity of 5,000 pounds. Bins with larger capacity (15 to 20 ton) would have been more indicative of real-world conditions, but logistical challenges of handling such a large tonnage of feed (90 tons at once), and desire for exacting uniformity of feed across the 6 bins forced us to use smaller capacity bins. We assume that the relative differences in feed flowability among the smaller capacity bins will be directly transferrable to large capacity bins.

Figure 1. Commercial feed bins used for study at West Central Research and Outreach Center, Morris, MN

Experiment 1 - This experiment was designed to evaluate flowability of feed from the bin styles previously described. During summer, 17 tons of feed were delivered to the research site and divided evenly among the 6 feed bins. The feed was allowed to sit, undisturbed in the bin for 3 days. On the third day, a grain auger was placed under the bin and the cone was opened to allow feed to flow freely (Figure 2). Time was recorded from the moment the cone was opened until all feed flowed out of the bin. Discharged feed was augered into a bulk feed wagon such that feed flow was not limited by the auger (Figure 3). The previously-tared feed wagon and tractor were weighed on a truck scale to determine the quantity of feed that flowed out of the bin. Feed flow was calculated as the weight of feed delivered per minute. If bridging occurred, a rubber mallet was used to pound on the bin cone to initiate feed flow. The number of taps required to establish feed flow was recorded. In addition, a subjective flowability score (1 = free flowing, 10 = completely bridged) was assigned to the feed flow as described by Johnston et al.

(2009). Once the bin was emptied, the feed was augered back into the bin and this procedure was repeated 7 and 21 days after initial delivery. After the 21-day test, feed was removed from all bins and sold to a local pork producer. The procedures described above were repeated with a second lot of feed (17 tons) in the fall when ambient temperatures were expected to be cooler and humidity was lower.

Figure 2. Auger placement for feed flow evaluation

Figure 3. Feed wagon used to weigh feed for flow evaluations

On the day of feed delivery, a representative sample of the feed was collected, sealed in a plastic bag, and frozen for subsequent laboratory analysis. Laboratory analyses included: particle size, bulk density, moisture content, and proximate analysis (crude protein, crude fat, ash, crude fiber, Nitrogen free extract). In addition, each sample was subjected to a suite of bench-top tests to estimate flowability of the feed samples. These tests included the following Carr Indices: angle of repose, loose bulk density, packed bulk density, compressibility, and Hausner ratio. These Carr Indices were targeted for study based on prior work by Bhadra et al (2009) and Ganesan et al. (2007), which identified these parameters as key flowability indicators.

Feed samples collected on days 3, 7, and 21 were used to determine moisture content of feed and the poured and drained angles of repose were determined using a modified Hele-Shaw cell as described by Johnston et al. (2009). Daily high and low temperature and humidity in the headspace of each bin and outside the bins was recorded by a datalogger (Hobo Pro Series Model H08-032-08 or Hobo Pro V II).

The primary response criterion was amount of feed delivered from each bin per unit time. These data were analyzed statistically using the Mixed procedure of SAS (SAS version 9.3, Cary, NC) with repeated measures in time. The statistical model included the fixed effects of bin type (Steel 60, Poly 60, Steel 67), day after feed delivery and their interaction. Trial (summer or fall) was included as a random effect. Previous research reported from our lab indicated that flowability of feed is reduced substantially once moisture content exceeds 10% (Johnston et al., 2009). So, moisture content of feed measured on the day of feed flow determinations was used as a covariate in all statistical analyses.

Experiment 2 - This experiment was designed to evaluate the utility of a passive feed agitator to improve flowability of feed from the storage bins described in Experiment 1.

Procedures and data collected for this experiment were identical to Experiment 1 with two notable exceptions. First, one randomly selected bin of each type was equipped with a passive feed flow agitator (Sure Flo Agitator, Farmer Boy Ag Supply, Myerstown, PA). This agitator resembles a traffic cone that mounts inside the bin cone just above the outlet of the cone (Figure 4). These agitators have the advantage of low cost but their effectiveness in improving flowability of feed has not been evaluated objectively. Secondly, because effects of bin type and agitator would be confounded in this experiment, we conducted the feed flow evaluations on days 2, 3, 6, 7, 20, and 21. This approach provided replication in time for each bin-agitator combination.

Figure 4. Passive feed flow agitator used in Experiment 2.

Statistical analysis of data was similar to that described for experiment 1 using the Mixed Procedure of SAS. The statistical model included fixed effects of bin design, agitator, day after feed delivery, and all two- and three-way interactions. Moisture content of feed on the day of feed flow evaluations was used as a covariate in all analyses. Trial was included in the statistical model as a random effect.

Characteristics of feed (e.g. particle size, bulk density, moisture content, water activity, nutrient content, angle of repose, Hausner ratio, and compressibility) were used to predict flowability from the bin using classification and regression tree (CART) analysis as described by Johnston et al. (2009). The objective of this analysis was to identify traits of the feed used in both experiments that were predictive of feed flowability.

VI. Results and Discussion:

Each experiment was conducted in two separate trials, one during summer conditions and one during cooler temperatures of fall. Beginning and ending dates for each trial and environmental conditions during each trial are presented in Table 1. Daily high and low temperatures and humidity readings represent the average of the highest and lowest reading for each day of the trial. Temperature and humidity recorders were placed on the underside of the feed boots of two bins. Summer trials were conducted during hotter weather than the fall trials as expected. We expected the summer trials to also have higher humidity readings than the fall trials. This expectation held true for Experiment 1 but not for Experiment 2.

Table 1. Outdoor temperature (°F) and relative humidity (%) conditions for each trial

Season	Start date	End date	Daily High Temperature	Daily Low Temperature	Daily High Humidity	Daily Low Humidity
			Experiment 1			
Summer	6/12/12	7/3/12	85.6	61.9	94.3	39.4
Fall	9/10/12	10/1/12	74.6	45.2	74.7	23.3
			Experiment 2			
Summer	7/17/12	8/7/12	87.6	66.0	100.0	50.0
Fall	10/9/12	10/30/12	53.4	37.2	92.7	57.7

The feed used in this trial was manufactured by a commercial mill located within 5 miles of the research site. Feed was formulated for finishing pigs according to a local feed company's specifications. The only restriction imposed on the formulation was that the feed must contain

40% DDGS. Four different lots of feed (one per trial) were used in this study. Characteristics of the feed for each trial are displayed in Table 2. These characteristics were evaluated on feed samples collected the day feed was delivered to the research site. The DDGS used in the feed was sourced from two different local ethanol plants. But, it was not possible to accurately identify the specific DDGS source for each lot of feed. In general, particle size of the diet seemed to be greater than our targeted particle size of 600 microns. In part, the mean particle size of the feed was increased due to the presence of syrup balls contributed by DDGS.

Table 2. Characteristics of feed used in each trial

Season	Moisture, %	Crude protein, %	Crude fat, %	Crude fiber, %	Bulk Density, lb/ft^3	Particle size, microns
			Experiment 1			
Summer	12.83	15.19	5.79	3.23	40.5	1015
Fall	11.77	17.02	5.34	3.44	41.7	736
			Experiment 2			
Summer	12.00	17.70	4.58	3.51	43.0	860
Fall	14.38	16.54	4.76	3.26	43.6	863

Angle of Repose (degrees) - Angle of Repose is defined as the angle which forms between a horizontal plane and the slope of a pile (at rest) which has been formed by flow of the bulk material from some elevation. In general, Angle of Repose is related to many of the flow properties of the material, and is thus an indirect indication of general flowability behavior. Angle of Repose is a function of physical properties of the particles, such as size, shape, and porosity. It is also affected by feed production practices, such as milling, mixing, drying, and cooling. Bulk solids with an Angle of Repose between approximately 25^o and 35^o are generally considered free flowing. Higher values indicate poor flowability. In this study, Angle of Repose values ranged from 49 to 70 degrees (Table 3), which indicated that all feed mixtures would potentially have poor flowability behavior.

Loose Bulk Density (BD_L, kg/m^3) - Although not an actual indicator of flowability, per se, Bulk Density is used to determine effective capacities for storage bins and containers. This parameter is defined as the mass of a granular material that will occupy a specific volume. Bulk density includes not only particle mass, but also the air entrained in the void spaces between the particles. Bulk Density of the feeds ranged from 516 to 550 kg/m^3 (32.1 – 35.5 lb/ft^3). Anecdotally, a Bulk Density of approximately 30 lb/ft^3 is common for DDGS. The higher bulk density observed in these feed samples was due to the other feed constituents in the mixture. Bulk density is a function of particle size and shape, the mass of each individual particle, and how the particles are placed into the storage vessel.

Packed Bulk Density (BD_P, kg/m^3) - Actually, there are two unique types of bulk density that are important: Loose Bulk Density (BD_L) and Packed Bulk Density (BD_P). Loose Bulk Density is the most commonly measured density, because it is the easiest to measure, and is determined by pouring a quantity of granular material into a container of known volume. This trait is representative of a bulk solid which has not been subjected to compression or packing. Packed Bulk Density is the bulk density of the material after it has been compressed and thus some of the entrained air has been removed. This is representative of the material's actual bulk density during storage and transport, and is a more realistic quantity to use in terms of quantifying flowability. Packed Bulk Densities ranged from 678 to 707 kg/m^3 (42.2 to 44.0 lb/ft^3), which was considerably higher than the Loose Bulk Densities of the feeds and suggests poor flowability.

Compressibility (C, %) - Some granular materials have a propensity to become tightly packed; others do not. After determining Loose and Packed Bulk Densities, the Compressibility of a material can be calculated as:

$$C = \left(\frac{BD_P - BD_L}{BD_P} \right) x100$$

where C is Compressibility (%), BD_P is the Packed Bulk Density, and BD_L is the Loose Bulk Density. This parameter provides an indication of particle size, shape, uniformity, and cohesion, and thus the overall flowability of the material. Bulk solids with a Compressibility value less than about 18% are considered free flowing; but those higher than 18% are considered problematic. Compressibility values ranged from 20.9 to 24.4%, which indicates that these feeds would probably have flow problems from real bins.

Hausner Ratio (HR, -) - Hausner Ratio is related to Compressibility, and is defined as:

$$\mathrm{HR} = \frac{\mathrm{BD_P}}{\mathrm{BD_L}}$$

Non-compressible materials have an HR defined as 1.0. The greater the HR for a feed sample, the worse the flowability. In this study, HR ranged from 1.27 to 1.32, which essentially predicts 27 to 32% worse flowability than ideal granular material which is free-flowing.

Overall, the laboratory-scale flowability assessments indicated that all feed samples would exhibit poor flowability from real bins. So, the feeds used were expected to create flowability challenges so that feed bin design could be properly evaluated.

Table 3. Flowability characteristics of feed used in each trial (parentheses indicate standard deviation)

Season	Angle of Repose (deg)	Loose Bulk Density (kg/m^3)	Packed Bulk Density (kg/m^3)	Compressibility (%)	Hausner Ratio (-)
			Experiment 1		
Summer	49.33	539.1	686.8	21.50	1.27
	(3.03)	(3.10)	(0.92)	(0.01)	(0.01)
Fall	63.00	516.53	678.13	23.82	1.31
	(5.74)	(2.27)	(3.92)	(0.63)	(0.01)
			Experiment 2		
Summer	70.47	535.09	707.35	24.35	1.32
	(4.88)	(1.30)	(3.13)	(0.21)	(0.01)
Fall	63.17	550.21	696.03	20.94	1.27
	(5.23)	(2.60)	(8.38)	(0.84)	(0.01)

Experiment 1 – This experiment was designed to evaluate the effects of bin design on flowability of feed after 3, 7 or 21 days of storage. There were no significant interactions between bin design and day of storage for any trait measured in this experiment. So, only main effects will be discussed. Bin design did not affect the average temperature or relative humidity in the headspace of the bin (Table 4). Temperatures and humidity readings presented are averaged over both trials from readings recorded every 30 minutes throughout the experiment. Relative humidity was consistent from day 3 (56.2%) to day 7 (55.6%) but significantly declined ($P < 0.05$) by day 21 (52.2%).

We used a modified Hele-Shaw cell to measure both drained and poured angles of repose (Figure 5; McGlinchey, 2005). Flowability of feed is inversely related to both drained and poured angles of repose. A larger angle measured indicates reduced flowability. Neither drained nor poured angles of repose were influenced by feed bin design. This observation is not surprising since the angle of repose is a property of the feed and influenced by the size and shape of feed particles, and the interaction among feed particles. It seems unlikely that the bin design would influence these properties of the feed so consequently, angle of repose measurements were not affected by bin design.

Feed flow rate out of the bins was influenced ($P < 0.05$) by design of the bin and day of storage. Feed flowed significantly faster from the Poly 60 bin compared with the Steel 60 bin with feed flow from the Steel 67 being intermediate. Since the size of the opening in the boot was the same for all bins and the slope of bin cones were the same for Poly 60 and Steel 60, one might surmise that the polyethylene material used to manufacture the Poly 60 bins contributed to the improved feed flow from Poly 60 compared with Steel 60 bins. Materials used in the Steel 67 bin were very similar to those used in the Steel 60 bin so the improved feed flow from the Steel 67 bin may be attributable to the steeper slope of the sides of the cone on this bin. Interestingly, the bin with the slowest flow rate (Steel 60) required the fewest ($P < 0.05$) number of taps to establish the feed flow. Feed flow was greater ($P < 0.05$) on day 3 (1,680 lb/min) compared with days 7 (1,399 lb/min) and 21 (1,337 lb/min). An explanation for this difference is not readily apparent.

Table 4. Effect of bin design on headspace conditions in bins and flowability of feed (Exp. 1)

Trait	Steel 60	Poly 60	Steel 67	SE	Sign. Effects P <
Avg. temperature, °F	74.4	73.2	72.7	5.27	NS
Avg. relative humidity, %	55.3	54.7	53.9	5.30	Day 0.01
Drained angle of repose, °	54.2	53.8	53.3	2.31	NS
Poured angle of repose, °	28.3	28.9	30.0	0.58	NS
Feed flow, lb/min[1]	1329.3[a]	1624.7[b]	1462.6[ab]	311.1	Bin 0.05 Day 0.05
Taps required[2]	3.8[a]	7.5[b]	6.0[b]	2.23	Bin 0.01
Flowability score[3]	3.7[a]	4.9[b]	4.2[ab]	1.32	Bin 0.01

[1]Means with different superscripts differ ($P < 0.05$).
[2]Number of taps on bin required to establish feed flow.
[3]Subjective score assigned to flowability (1 = free flowing; 10 = completely bridged).

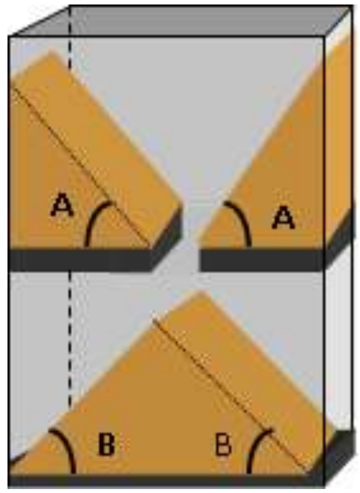

Figure 5. Modified Hele-Shaw cell used to measure drained angle of repose (indicated by angle labeled "A") and poured angle of repose (indicated by angle labeled "B"; Johnston et al., 2009).

Experiment 2 – Unlike Experiment 1, average temperature in the bin headspace tended to be higher ($P < 0.06$) for Steel 60 compared with Steel 67 bins (Table 5). This may be due to the relative location of these bins. The Steel 60 bins were located randomly on the south end of the research site while the Steel 67 bins were located on the north end of the research site. All the bins were arranged in a row that was oriented in a north-south direction. The second trial of this experiment was conducted during the coolest period of the study. It is possible that the Steel 60 bins received greater sunshine and were warmer because of their location compared with the Steel 67 bins. Similar to Experiment 1, drained and poured angles of repose were not affected by bin design or the presence of agitators in the bins. This result was expected.

We observed an interactive effect ($P < 0.01$) of bin design and presence of agitators on flow rate of feed out of the bins. Presence of an agitator significantly increased feed flow in the Poly 60 bin compared to the Poly 60 bin without an agitator. In the other steel bins, presence of the agitator did not have an effect on feed flow. The presence of an agitator improved ($P < 0.01$)

feed flow (1,967 vs. 1,812 lb/min); but the effect was not observed equally across all bin designs as evidenced by the significant interaction discussed previously. Poly 60 bins supported greater ($P < 0.01$) feed flow (1,986 vs 1,822 or 1,860 lb/min) than Steel 60 or Steel 67 bins, respectively. Unlike Experiment 1, there was no difference in the number of taps required to establish feed flow across the 6 bin-agitator combinations.

CART analysis – The CART procedure considers all characteristics of the feed simultaneously and selects the one characteristic that has the most influence on feed flow rate. Feed flow rate was most influenced by bulk density of the feed in this study. When bulk density of the diet was greater than 43 lb/ft^3, flow rate was 2,180 lbs/min but flow rate dropped to 1,529 lbs/min when bulk density was less than 43 lb/ft^3. Bulk density of the feed accounted for about 63 percent of the variation in flow rate observed in this experiment. This result should be viewed with caution since in total over both experiments, there were only four lots of feed used with six observations of flow rate for each lot of feed. The main objective of these studies was to study the effects of bin design on flow rate so it was important that feed be as uniform as possible from one trial to the next. Uniformity of feed from one trial to the next was important to minimize the effects of feed characteristics on flow rate so that effects of bin design could be detected. This uniformity in feed characteristics reduced utility of the CART analysis which is most robust when there are a large number of samples spanning a wide range of characteristics. In previous CART analysis of feed ingredient flow (Johnston et al., 2009), moisture content of feed surfaced as the most useful characteristic to predict feed flow when moisture content ranged from 7.6 to 12.2%. In that study, feed flow increased significantly when moisture content was less than 10%. In the current study, moisture content of feed ranged from 11.8 to 14.4%. This range was much narrower and overall moisture was generally higher than our previous study. No samples were 10% or less in moisture content. Consequently, moisture content of feed in the current study may have been too high to reasonably affect feed flow rate.

General discussion – In both experiments, feed flow from the Poly 60 bins was significantly greater than from the steel bins. Our results seem to indicate an advantage in flowability of feed containing a high concentration of DDGS for the bins constructed of Polyethylene material. It would appear that material used for bin construction has a larger effect on feed flowability than does slope of the bin's discharge cone since there was no advantage for the 67 degree slope over the 60 degree slope in galvanized steel bins. Presence of a passive agitator in the bin cone was most beneficial in the polyethylene bin compared with bins constructed of steel. However, there was weak evidence that the agitator provided some benefit in the steel bin with a steeper slope to the discharge cone.

VII. Conclusions:

Results of these experiments indicate that feed bin design can influence flowability of feed containing high concentrations of DDGS. Of the bins tested, the Poly 60 bin produced the highest flow rate of feed once feed flow was established. Passive agitators installed in feed bins appear to aid feed flow in some but not all bins. The combination of a passive agitator in the Poly 60 bin produced the fastest feed flow.

Acknowledgements:

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Table 5. Effect of bin design and flow assist agitators on headspace conditions in bins and flowability of feed (Exp. 2)

Trait	Steel 60 No agitator	Steel 60 Agitator	Poly 60 No agitator	Poly 60 Agitator	Steel 67 No agitator	Steel 67 Agitator	SE	Sign. Effects P <
Avg. temperature, °F	68.1	68.7	67.3	67.1	66.2	65.8	19.5	Bin 0.10 Day 0.05
Avg. relative humidity, %	58.3	65.0	65.0	61.3	61.1	63.8	1.62	Day 0.01 Bin x Agit. 0.10
Drained angle of repose, °	54.0	54.1	54.4	54.4	54.2	54.1	1.38	NS
Poured angle of repose, °	26.7	26.2	27.4	26.5	27.3	27.6	1.83	Day 0.05
Feed flow, lb/min[1]	1822.8[b]	1823.1[b]	1833.2[b]	2138.8[a]	1780.3[b]	1940.7[b]	405.8	Bin 0.01 Agit. 0.01 Bin x Agit. 0.01
Taps required[2]	2.1	2.0	5.2	2.5	3.2	2.0	3.1	NS
Flowability score[3]	2.3	2.6	4.2	2.9	3.7	2.3	3.0	NS

[1]Means with different superscripts differ ($P < 0.05$)
[2]Number of taps on bin required to establish feed flow.
[3]Subjective score assigned to flowability (1 = free flowing; 10 = completely bridged).