# DAMAGE TO SHELLED CORN DURING TRANSPORT IN DRAG CONVEYORS

by

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# INTRODUCTION

One of the primary properties of shelled corn that is desirable in the grain trade is a low percentage of stress-cracked, broken and damaged kernels. Unfortunately, the handling of the grain through the marketing channels causes an increase in the percentage of damaged grain. The mechanical damage that grain incurs during handling can be likened to a milling process, in the sense that the same type of destructive forces are acting upon the kernels of grain. Repeated handling of grain can often result in damage excessive enough to lower its grade and thereby reduce its market value. If the mechanical damage of grain does not immediately affect the market grade it may still increase the deterioration rate during storage.

Grain can decrease in quality during storage without ever being moved. Two of the principle sources of deterioration of grain in storage are fungi and insects. Broken corn and foreign material provide a favorable enviroment for both mold growth and insect infestation. The problem is further compounded by the fact that broken corn and fine material also impede good air flow within the grain mass.

Past studies have made us aware of how factors such as velocity, impact surface, moisture content, and grain history affect the extent of grain damage. There have also been studies concerning the amount of damage caused by some commercial grain handling equipment and methods. It was the purpose of this study to continue to investigate grain damage that results from commercial methods. We intended to study the effects of drag conveyors on corn kernel damage.

# OBJECTIVES

The overall objective of this research was to evaluate the cause and extent of corn kernel damage resulting from drag conveyors. The specific objectives of this investigation were:

1. To study the effects of grain conveying rates on corn kernel damage and conveyor power requirements.

2. To study effects of different conveyor cross-sections on corn kernel damage and conveyor power requirements.

3. To study effects of conveyor length on corn kernel damage.

# LITERATURE REVIEW

## Harvesting Damage

The first mechanical damage to grain occurs during threshing when stress-cracks and breakage develop. The optimum moisture content for shelled corn for limiting this type of damage is about 22 percent with increased damage ocurring above or below this moisture content. Hall and Johnson (1970) found that cylinder speed and cylinder concave clearance of the combine were factors in influencing the damage percentage of shelled corn. Byg and Hall (1968) stated that the higher the speed of the combine cylinder, the greater the damage to the corn kernels. This can be expected due to the energy transfer from the cylinder to the kernels in excess of that needed for shelling. Mahmoud and Buchele (1975) also determined that the longer the corn kernels stayed in the shelling crescent the more damage suffered. They attributed this damage to the repetitive impacts from the rasp bars of the cylinder. Their tests also indicated that the corn sustained higher levels of damage with increase in cylinder speed.

## Drying Damage

After leaving the field most shelled corn is mechanically dried. Drying air temperatures may have an effect on grain quality. High kernel temperatures may result in stress cracks which could lead to actual breakage of the kernel. Stress-cracked corn is more susceptible to breakage during subsequent handling and tends to result in troublesome fine dust during handling. Unheated air can be used for bin drying with the only bad effect being the possibility of grain deterioration that may occur because of the slow drying time or not attaining a low enough moisture level (Christensen, 1974).

Storage Damage

The extent of grain damage in any lot of grain has a significant effect on the ability to properly store that grain. Chung and Converse (1970) stated that grain containing a high percentage of physically damaged kernels may be expected to harbor greater numbers of mold spores, insect eggs, and bacteria; and are much more likely to heat in storage than are sound grains of the same moisture content. Brooker, et al. (1974) stated that spoilage and respiration during storage account for an average of 4.5 percent cereal grain loss with an additional 1 to 3 percent loss possible by insect damage. Christensen (1974) indicated that insects can render more grain than they eat unfit for human consumption because infestation contaminates the product with insect fragments and excreta.

The problem of storing damaged grain can be further aggravated by spoutlines that can occur in piles of grain. Christensen (1974) stated that fines accumulate at a pile's peak and remain there while whole grain kernels flow away. The resulting vertical core of high dockage grain may have fines in excess of 30 percent. This is, in effect, a solid mass that all but stops air circulation while preventing the escape of any heat caused by mold and insect activity.

Mechanical Handling Damage

According to Bilanski (1966), the history of the grain kernel will affect its damage resistance. The stage of maturity at which the grain was threshed, the storage conditions, and handling methods in general are factors which will influence its strength, to an undeterminable amount. A basic understanding of the type and magnitude of force and energy that damage grain would aid in designing grain-handling equipment so as to minimuze grain damage.

Bilanski found that the size, moisture content, and postion of the kernel all affected its damage resistance. Corn and soybeans required a greater amount of work to cause damage than wheat, barley, and oats. More work was required to damage grains at high moisture contents than those at a lower moisture content. The force required to damage high moisture content grain may be less since the grains are more plastic at higher moisture levels.

Fiscus, et al. (1969) conducted experiments to investigate the extent and causes of physical damage that grain incurs from the handling equipment used in marketing channels. They measured grain breakage against grain types (yellow corn, yellow soybeans, hard red spring wheat, and hard red winter wheat), handling equipment and procedures (drop tests, grain thrower, and bucket elevator), moisture content, and grain temperature. The results were: (a) corn incurred more breakage than soybeans, and soybeans more breakage than wheat, (b) dropping grain from heights of greater than 40 feet caused more breakage than any other handling method tested, (c) impact of grain on concrete caused more breakage than grain on grain, (d) the grain stream from an 8 inch orifice incurred more breakage than the grain stream from a 12-inch diameter orifice, and (e) breakage was greater at low grain moisture and temperature.

Chung, et al. (1973) conducted an investigation of mechanical damage to corn during pneumatic conveying. Damage was measured against corn kernel size and shape, corn moisture content, the air velocity of the pneumatic conveying system, and the distance the corn was conveyed. Results revealed that a high conveying velocity caused the greatest amount of corn damage with the damage more pronounced in corn at 12 percent moisture content. The effect of corn kernel size and shape were found to be minimal. The amount of damage to corn was generally high for the first 200 feet, but decreased rapidly as the conveying distance increased.

Corn kernel damage resulting from high velocity impact was studied by Keller, et al. (1972). Some of the conclusions offered by the investigation were: (a) kernel velocity, moisture content, impact surface, angle of impact, and size and shape of the corn kernels all significantly influence impact damage, (b) damage with an impact surface of urethane is one-fifth that of steel and one-sixth that of concrete, (c) reducing the impact angle from 90 degrees to 45 degrees reduces the mean total damage by 25 percent, and (d) most broken corn kernels split longitudinally.

Sands and Hall (1971) conducted tests to determine how much damage was done to shelled corn by a screw conveyor at different screw speeds, flow rates, and inclinations. They found that as the screw speed increased the level of damage to dry shelled corn increased, but was only significant when the conveyor was operated at one-fourth capacity. The screw conveyor caused only a small amount of damage when operated at full capacity, but the level of damage was seen to greatly increase when the conveyor was kept at one-fourth capacity. Inclination of the screw conveyor had little effect on the amount of damage done to shelled corn. The tests also revealed that if the corn was dried at a high temperature, the level of damage increased. It was also reported that the screw conveyor caused more damage to shelled corn at 13 percent moisture than at 22 percent moisture.

Studies by Hall (1974) found the importance of keeping screw conveyors and bucket elevators as full as possible and operating at normal speeds. Tests were conducted with a 4-inch screw conveyor; a 6-inch screw conveyor; a 6-inch U-trough conveyor; a 6-inch perforated tube screw conveyor; and a vertical bucket elevator. Results from the tests for the screw conveyors tests were in agreement with Sands and Hall (1971). Hall concluded that if screw conveyors are operated at less than full capacity, the corn can be bounced around within the conveyor and can strike metal surfaces; at full capacity, the corn cushions itself. At high speeds and at less than full capacity, a considerable amount of high velocity contact can take place between the corn and the metal surfaces of the conveyor. The perforated tube conveyor showed more damage with higher moisture corn because the surface of the corn was soft and more susceptible to damage by the perforations. The bucket elevator tests showed very little difference in fines produced between front and back loading, but more fines were generated when the unit operated at one-fourth capacity. This was attributed to the fact that the buckets were striking the grain four times as often in the bottom of the elevator in order to move the same amount of grain.

## Evaluating Grain Damage

Corn kernel damage is often classified as internal or external. Moreira, et al. (1981) stated that internal cracks are important when dealing with the damage of grains because they are the initiation of damage. An internal crack can propagate to an external crack and eventually result in breakage.

Keller (1970) outlined the various methods of evaluating grain damage. The methods discussed for either external damage tests and internal damage tests are:

A. Evaluation of External Damage
   Mechanical particle sizing
   Visual inspection
   Optical scanners

B. Evaluation of Internal Damage

Fatty acid test

Standard germination test

Staining reactions

Candling device

Radiographical examination

## Power Consumption of Drag Conveyors

Literature concerning the power requirements of drag conveyors is sparse. The American Feed Manufacturers Association (Pfost, 1970 and 1976) provides methods for determining the power requirements for U-trough conveyors but the two editions provide different equations with no explanation given for the change in the later edition. The American Society of Agricultural Engineers (1983) do not have standards concerning the design of drag conveyors. The standards for screw conveyors only concern flighting design considerations and not required power.

McFate and George (1969) determined the power-capacity relationships of eight inch screw conveyors when handling shelled corn. They found trends in reduced capacity and increased horsepower with increased moisture content of the corn. Increasing angles of elevation decreased throughput and the required horsepower to convey a specific quantity at a specific speed also increased with increased angles of elevation.

# MATERIALS AND METHODS

## Corn

Two types of corn were used for this investigation. Natural air dried shelled corn harvested in 1981 (known history) with a moisture content ranging from a minimum of 12.40 percent to a maximum of 13.35 percent was used along with artificially dried shelled corn harvested in 1981 (CCC), or prior, with a moisture content ranging from a minimum of 12.75 percent to a maximum of 13.65 percent. The corn was cleaned with screening sieves in a grain cleaner to remove all broken corn and foreign material prior to testing.

## Conveying System

Two different drag conveyors (flat and U-trough) were employed during the course of this investigation. Both conveyors were assembled according to their respective manufacturer's instructions and both were set at a six degree angle with the inlet on the low end. Figure 1 is a schematic diagram of the complete test system.

The flat bottom conveyor tested was a Schlagel Powerflow Conveyor, Model 810. This conveyor was 20.32cm (8.0in) wide on the inside with plastic flights 3.81cm (1.5in) tall arranged in a staggered fashion. The chain velocity was 30.78m (101ft) per minute, which allowed a maximum capacity of 70.23m$^3$ (2000bu) per hour. The chain/flight configuration and the tail section of the conveyor can be seen in Figures 2 and 3, respectively.

The other conveyor was a U-trough configuration produced by The Essmueller Company. The inside width was 22.86cm (9in) with plastic flights 7.62cm (3in) tall at the center and spaced 53.34cm (21in) apart. The chain velocity was 52.73m (173ft) per minute which allowed a maximum capacity of 70.23m$^3$ (2000bu) per hour. Figure 4 shows the chain/flight configuration with the tail section seen in Figure 5. An overall view of the conveyor, as situated during the investigation, is seen in Figure 6.

The flow rate of corn into the conveyors was controlled with the use of a round orifice located in a vertical spout located approximately 2.75m (9ft) above the inlet of the conveyors. Chang, et al. (1983) stated that flow rates of corn for a given size orifice may vary due to difference in kernel size and geometry. The variability was thought to be acceptable during preliminary break-in tests of the system.

## Sampling System

Samples were taken at three different points in the system. The first sample was taken from a point approximately 1.50m (5ft) above the inlet, the second at a point approximately 61cm (2ft) below the outlet, and the third was taken after the corn had been discharged from the elevator leg and before it re-entered the holding bin.

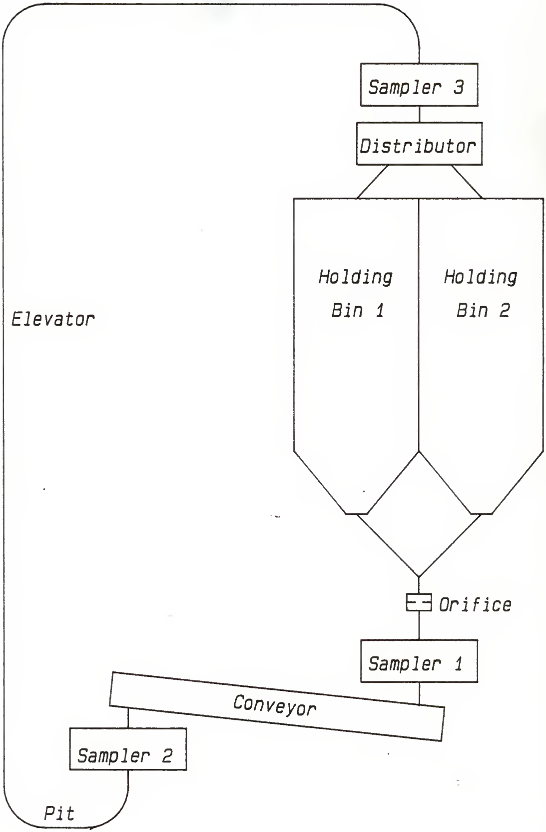


Figure 1. Schematic diagram of the testing system.

Figure 2. Chain/flight configuration of the flat bottom conveyor.

Figure 3. Tail section of the flat bottom conveyor.

The first sample was taken by a Gamet Automatic Sampler. The sampler was set to operate on 20 second intervals. Figure 7 shows the sampler in its position at the inlet of the conveyor. The corn sample was then split twice by a Boerner sample divider to obtain both working and reference samples.

Sample number two was taken with a pelican. The pelican was swung across the flow of grain at the conveyor outlet at approximate 20 second intervals. This sample was then split three times with a Boerner divider to obtain working and reference samples. The same person operated the pelican throughout the tests to control sample variability.

The third sample was obtained with a Carter-Day Mechanical Sampler, Style No. 132. This sampler was also set to operate at 20 second intervals with the samples being split twice to obtain working and reference samples.

All samples were double bagged and analyzed within a 72 hour period of the tests to avoid variations in moisture content.

Moisture Measurement

The only concern for moisture content of the corn during this investigation was that it remain within a range of one percent. A Dickey-John GAC II, Grain Analysis Computer, was used to measure moisture content. This machine provided fast operation and a printed copy of the data for each sample.

Figure 4. Chain/flight configuration of the U-trough conveyor.

Figure 5. Tail section of the U-trough conveyor.

Figure 6. U-trough conveyor in position for testing.

Figure 7. Gamet Automatic Sampler situated at the inlet of the conveyor.

Damage Measurement

Due to the large number of samples taken a Carter Dockage Tester, Style No. XT2, was used to determine the amount of broken corn and foreign material.

Power Consumption Measurement

Equipment limitations prohibited recording the power consumption as accurately as originally desired. The power readings were taken directly from a General Electric three-phase power meter. The time for the disk to make one complete revolution was recorded and the power was calculated from the equation:

$$L = \frac{Kh \;\; * \; Rev \;\; * \; 3600}{t}$$

where L = load in Watts.

Kh = power meter factor.

Rev = number of revolutions of disk.

t = total time in seconds.

Experimental Design

In conducting the investigation of damage to corn due to conveying by a drag conveyor, four variables were studied: conveying distance, conveying rate, type of corn, and type of conveyor. Levels of each experimental variable are summarized in Table 1. The experiment design was a factorial design with three independent variables and 12 repeated measures - the twelve repeated measures are the three samples of the system taken four times during the process of completing one test for the purpose of simulating conveying distance. Including all different levels of each independent variable, there were (3x2x2) 12 treatment combinations and two replications at each treatment combination for a total of 24 tests.

Table 1. Levels of Experimental Variables.

| Experimental Variables | Levels 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| Conveying distance | 7.32m (24ft) | 14.64m (48ft) | 21.96m (72ft) | 29.28m (96ft) |
| Conveying rate | $17.56m^3$/hr (500bu/hr) | $35.12m^3$/hr (1000bu/hr) | $70.23m^3$/hr (2000bu/hr) | ---- |
| Type of corn | Known History | CCC | ---- | ---- |
| Type of conveyor | Flat Bottom | U-trough | ---- | ---- |

It was decided that repeated runs through the conveyor would satisfactorily simulate longer conveying distances. This would be similar to the methods used by Sands and Hall (1971) and Hall (1974) for tests involving screw conveyors. As with these tests, it was recognized that this would not be exactly equivalent to handling grain with a single conveyor of a given length. Not having the ability to choose conveying distance randomly prevented it from being considered as an independent variable.

The conveying rates chosen were 17.56$m^3$ (500bu) per hour, 35.12$m^3$ (1000bu) per hour, and the maximum conveying rate of the conveyors of 70.23$m^3$ (2000bu) per hour. Hall (1974) reported that screw conveyors and bucket elevators did the least amount of damage to grain when operated at full capacity. The conveying rates chosen will help to determine if this holds true for drag conveyors.

Natural air dried corn (known history) and artificially dried corn (CCC) were both chosen to be tested.

Both types of drag conveyors, flat bottom and U-trough, were chosen for testing. These two types of drag conveyors are both commonly used in the grain trade industry.

Experimental Procedure

Approximately 66.72$m^3$ (1900bu) of each type of shelled corn, natural air dried and artificially dried, were passed through screening sieves in a grain cleaner to remove the broken corn and foreign material that were originally contained. The corn was then placed in separate holding bins with test lots of 5.27$m^3$ (150bu) being removed as they were needed for tests.

The flat bottom conveyor was tested first with the conveying rates being chosen at random. A 5.27$m^3$ (150bu) lot of shelled corn was placed in holding bin one, as shown in the schematic diagram of Figure 1. The elevator leg and sampler three were then started, and the distributor was set for holding bin two. Sampler one was then started and the corn was released from the holding bin simultaneously. During the cycle, sample two was taken manually with a pelican and the power readings were also recorded manually when possible.

When one cycle of the system had been completed all samples were split, bagged, and identified before another cycle was started. The time required for the cycle was recorded for the purpose of calculating the actual conveying rate, and the power readings were also recorded when available.

The cycle was then repeated with the exception that the grain was coming from bin two instead of bin one. A total of four cycles were completed before discarding the lot of grain. The four cycles through the system constituted one complete test.

# RESULTS AND DISCUSSION

## Corn Kernel Damage

Corn kernel damage resulting from drag conveyors was evaluated by removing broken corn and foreign material (BCFM) from a representative sample with a Carter Dockage Tester. The results of the percentage of BCFM obtained for all tests are shown in Table 2 for the flat bottom conveyor and in Table 3 for the U-trough conveyor in Appendix I. The damage due to the drag conveyors was determined from the difference of the samples taken at locations one and two during the same cycle (Fig. 1). By subtracting the percentage BCFM found in sample one from the percentage of BCFM found in sample two we were able to determine the percentage of damage caused by the drag conveyors. Likewise, the damage resulting from the drop into the receiving pit and the handling by the bucket elevator could be determined from the difference of the samples taken at locations two and three. The damage resulting from the drop into the holding bins can be determined from the difference of the samples taken at location three and location one of the subsequent cycle.

Plotting of the data for the damage due to drag conveyors for any particular set of investigation parameters shows a scattering of points. The scattering observed is seen in Figure 8 for the tests involving the flat bottom conveyor with natural air dried corn at a conveying rate of 17.56m$^3$ (500bu) per hour and in Figure 9 for the tests involving the U-trough conveyor with natural air dried corn at a conveying rate of $17.56m^3$ (500bu) per hour.

No definite trend in the percentage of BCFM, with respect to the variables examined, was observed. Therefore, statistical analyses were performed to examine the effect of each variable on corn kernel damage.

The statistical design for the investigation was a factorial design with three factors and 12 repeated measures. An analysis of variance computer program[1] was employed to analyze the following statistical model:

$$D_{ijkn} = C_i + G_j + F_k + CG_{ij} + CF_{ik} + GF_{jk} + CGF_{ijk} + E_{ijkn}$$

where $D_{ijkn}$ = a difference in damage + the grand average of all $D_{ijkn}$.

$C_i$ = the true average effect for the i treatment of conveyor type.

$G_j$ = the true average effect for the j treatment of type of corn.

$F_k$ = the true average effect for the k treatment of conveying rate.

- all other terms are interactions of either the first or second order of the main effect.

1 ANOVA, SAS Institutes Inc.

$E_{ijkn}$ = the random error of total damage with the assumption of homogeneity of variance for all sample means.

Table 4 shows the analysis of variance for the damage resulting from the drag conveyors at a cumulative distance of 7.32m (24ft). The analysis of variance for the conveying distances of 14.64m (48ft), 21.96m (72ft), and 29.28m (96ft) are shown in Tables 5, 6, and 7, respectively, in Appendix II. The results of the analysis of variance were used to determine if any of the independent variables, or combination of these variables, had any significant effect on the amount of corn kernel damage resulting from the drag conveyors. The decision to claim significance was based on the tail probability - P-value.

We find that the P-value for the damage, 0.7049 for a cumulative distance of 7.32m (24ft), is greater than $\alpha=0.05$. This indicates that there is no significant difference in damage between the effects of the three independent variables or any combination of these variables.

Further analyses were performed on the average values of the data obtained with the replications of the tests. Table 8 shows the analysis of variance for the average damage resulting from the drag conveyors at a cumulative distance of 7.32m (24ft). The analysis of variance for the cumulative conveying distances of 14.64m (48ft), 21.96m (72ft), and 29.28m (96ft) are shown in Tables 9, 10, and 11, respectively, in Appedix II.

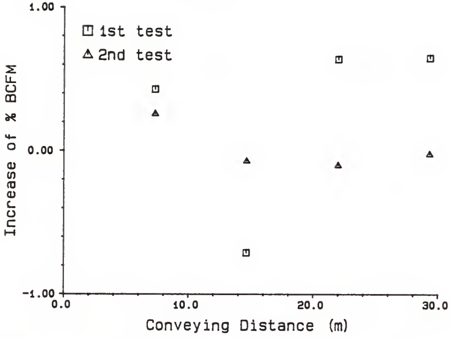


Figure 8. Percentage increase of BCFM for the flat conveyor, natural air dried corn, at $17.56 m^3/hr$ (500bu/hr).

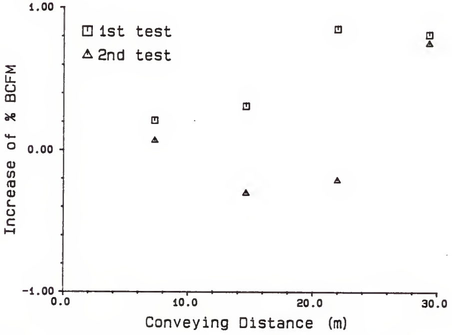


Figure 9. Percentage increase of BCFM for the U-trough conveyor, natural air dried corn, at $17.56 m^3/hr$ (500bu/hr).

Table 4. Analysis of variance for the difference between samples 1 and 2 at a cumulative distance of 7.32m (24ft) for all treatment combinations.

| Source of Variation | DF | SS | P-Value |
|---|---|---|---|
| Conveyor (C) | 1 | 0.1473 | 0.3899 |
| Grain (G) | 1 | 0.0008 | 0.9481 |
| Flow Rate (F) | 2 | 0.1143 | 0.7400 |
| C * G | 1 | 0.2321 | 0.2847 |
| C * F | 2 | 0.4932 | 0.3002 |
| G * F | 2 | 0.2116 | 0.5792 |
| C * G * F | 2 | 0.2620 | 0.5122 |
| Model | 11 | 1.4614 | 0.7049 |
| Error | 12 | 2.2211 | |
| Total | 23 | 3.6825 | |

The P-value for the average damage, 0.5743 for a cumulative distance of 7.32 m (24 ft), is greater than $\alpha$=0.05. This indicates, as did the analysis of the individual test data, that there is no significant difference in damage between the effects of the three independent variables or any interaction of two of these variables.

A comparison was also made between the amounts of damage resulting from the handling with the drag conveyors, the drop into the receiving pit and handling by the bucket elevator, and the drops into the holding bins. Table 12 shows the range of the

Table 8. Analysis of variance for the average difference between samples 1 and 2 at a cumulative distance of 7.32m (24ft) for all treatment combinations.

| Source of Variation | DF | SS | P-Value |
|---|---|---|---|
| Conveyor (C) | 1 | 0.0752 | 0.3935 |
| Grain (G) | 1 | 0.0007 | 0.9279 |
| Flow Rate (F) | 2 | 0.0581 | 0.6900 |
| C * G | 1 | 0.1220 | 0.3032 |
| C * F | 2 | 0.2569 | 0.3348 |
| G * F | 2 | 0.1058 | 0.5499 |
| Model | 9 | 0.6186 | 0.5743 |
| Error | 2 | 0.1293 | |
| Total | 11 | 0.7479 | |

damage occurring in the different zones of the system and the mean damage for each type of corn tested.

We can see that the least amount of damage occurs from the drop into the receiving pit and handling by the bucket elevator. The drag conveyors caused the second highest amount of damage and the drop into the holding bins caused the greatest amount of damage within the test system. An analysis of variance of the amount of damage occurring in the three zones, with respect to the two types of corn, natural air dried and artificially dried, was performed with the results summarized in Table 13. The results of the analysis of variance were used to determine if the different zones of the test system, the type of corn used for the tests, or their interaction had any significant effect on the amount of corn kernel damage. The decision to claim significance was based on a P-value of $\alpha \leq 0.05$.

Table 12. Means of percentage increase of BCFM for the three zones of the test system.

| Zone | Corn Type | Min. | Max. | Mean |
|---|---|---|---|---|
| 1 | Known Hist. | -0.71 | 0.82 | 0.0776 |
| 1 | CCC | -0.80 | 1.30 | 0.1975 |
| 2 | Known Hist. | -1.12 | 0.30 | -0.2050 |
| 2 | CCC | -1.53 | 2.04 | 0.0402 |
| 3 | Known Hist. | -0.28 | 1.34 | 0.3386 |
| 3 | CCC | 0.00 | 2.01 | 1.0528 |

Zone 1 --- Conveyor = Sample 2 - Sample 1
Zone 2 --- Elevator = Sample 3 - Sample 2
Zone 3 --- Holding Bin = Sample 1 - Sample 3

The P-value for the damage is 0.0001, as are the P-values for the main effects and their interaction. This leads to the conclusion that the effects of the zone and grain are very highly significant.

Further analysis of the difference in damage as an effect of zone and grain type was carried out in the form of a test of least significant difference. The least significant difference analysis shows whether or not there is a significant difference between the mean damage resulting from the different zones and types of grain. Table 14 shows the comparisons of the difference

Table 13. Analysis of variance for the amount of damage occurring in the three zones.

| Source of Variation | DF | SS | P-Value |
|---|---|---|---|
| Zone (Z) | 2 | 25.6940 | 0.0001 |
| Grain (G) | 1 | 7.0756 | 0.0001 |
| Z * G | 2 | 3.8912 | 0.0001 |
| Model | 5 | 36.6609 | 0.0001 |
| Error | 258 | 53.2781 | |
| Total | 263 | 89.9390 | |

between the means of the damage from the three different zones. Table 15 shows the comparisons of the difference between the means of damage for the two types of corn.

The analysis for least significant difference of damage reaffirms the conclusions drawn from the analysis of variance for the amount of damage occurring in a particular zone. The zones and types of corn have a significant effect on the amount of corn kernel damage.

Hall (1974) found the increase of fines for 15.6 percent moisture natural air dried corn in a 6-inch U-trough conveyor operating at 240 rpm and conveying 1016bu/hr to be 0.06 percent in 15.ft. This investigation found the increase in broken corn and foreign material for similar conditions of 13.05 percent moisture natural air dried corn in the U-trough conveyor conveying 35.12m$^3$ (1000bu/hr) to be 0.07 percent.

Table 14. Least significant difference of damage with comparison of zones.

| Comparison | Lower C.I. | Diff. Between Means | Upper C.I. | Significant at $\alpha$=0.05 |
|---|---|---|---|---|
| 1 - 2 | 0.0909 | 0.2201 | 0.3493 | Yes |
| 2 - 3 | -0.9176 | -0.7781 | -0.6386 | Yes |
| 3 - 1 | 0.4185 | 0.5580 | 0.6975 | Yes |

Table 15. Least significant difference of damage with comparison of types of corn.

| Comparison | Difference Between Means | Least Significant Difference | Significant at $\alpha$=0.05 |
|---|---|---|---|
| CCC - Known Hist. | 0.3274 | 0.1102 | Yes |

Realizing that negative values of grain damage are an impossibility, it can be deduced that the sampling of the corn was in error.

Most of the error in the model can be attributed to the problem of obtaining a representative sample of a lot of grain. Christensen (1974) accredits the problems of sampling grain to the fact of grain being a nonhomogeneous mixture and the problem of performance and accuracy of the sampling system. Studies have shown the performance of diverter-type samplers to be unaffected by spout angle or grain flow rate and, in general, sampling accuracy or variability were not significantly affected by slot widths and speeds. Pelican samplers have been found to have about the same accuracy as diverter-type samplers, but if the pelican overflowed before traversing the entire grain stream a bias in the sample could result if the grain was stratified.

While diverter-type samplers and pelican samplers have been shown to be reasonably accurate for grain trade purposes they may not provide samples accurate enough for investigations such as this one. The use of two different diverter-type samplers and a pelican sampler undoubtedly led to differences in sample accuracy and variability.

The nonhomogeneity of the grain flow could also lead to sampling error. During the tests it was noted that there was an extreme increase in broken corn and fines at the last part of the test lot as it flowed from the holding bin. It was also noted that there was an accumulation of corn and BCFM in the tail sections of each conveyor, as seen in Figures 3 and 5. These accumulations of grain are in contradiction to the claims that drag conveyors are self cleaning mechanisms. Part of these accumulations may have re-entered the grain stream during the tests and caused a higher value for damage than what was actually occurring. A further reaching problem of these accumulations is that of insect infestation and mold growth since they provide an ideal enviroment for such activity.

Power Requirement

The power requirements of the drag conveyors were evaluated by recording as many readings of the power meter as possible. The data recorded during the tests were averaged and are presented in Table 16. Figure 10 and 11 show the power requirements at different conveying rates for the flat bottom and U-trough conveyors, respectively. The power requirements of the two types of conveyors for natural air dried and artificially dried corn, at varying conveying rates, are shown in Figures 12 and 13, respectively.

The statistical design for this invesitgation was a factorial design with three factors. An analysis of variance computer program[2] was employed to analyze the following statistical model:

$$P_{ijkn} = C_i + G_j + F_k + CG_{ij} + CF_{ik} + GF_{jk} + E_{ijkn}$$

where $P_{ijkn}$ = a sample total power + the grand average of all $P_{ijkn}$.

$C_i$ = the true average effect for the i treatment of conveyor type.

$G_j$ = the true average effect for the j treatment of type of corn.

2 Ibid., pg. 24

$F_k$ = the true average effect for the k treatment of conveying rate.

- all other terms are interactions of the first order of the main effects:

$E_{ijkn}$ = the random error of total damage with the assumption of homogeneity of variance for all sample means.

Table 16. Drag Conveyor Power Consumption.

| Conveyor | Corn | Flow Rate ($m^3$/hr) | Avg. Power (W) |
|---|---|---|---|
| Flat | Known History | 17.59 | 568 |
| | | 35.12 | 759 |
| | | 70.23 | 1163 |
| | CCC | 17.59 | 592 |
| | | 35.12 | 794 |
| | | 70.23 | 1081 |
| U-trough | Known History | 17.59 | 775 |
| | | 35.12 | 935 |
| | | 70.23 | 1453 |
| | CCC | 17.59 | 894 |
| | | 35.12 | 1012 |
| | | 70.23 | 1420 |

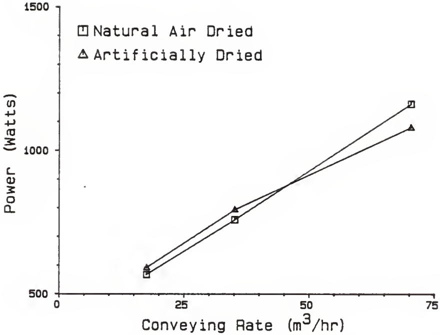


Figure 10. Power requirements for the flat bottom conveyor.

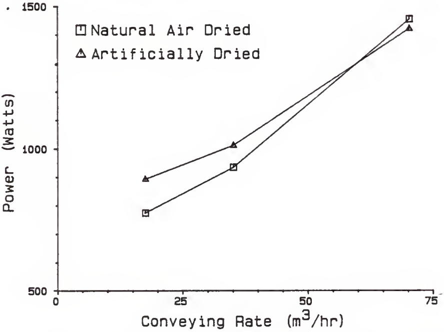


Figure 11. Power requirements for the U-trough conveyor.

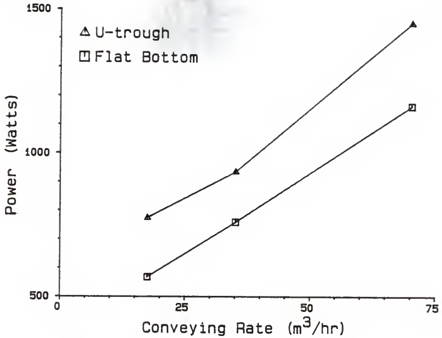


Figure 12. Power requirements for naturally air dried corn.

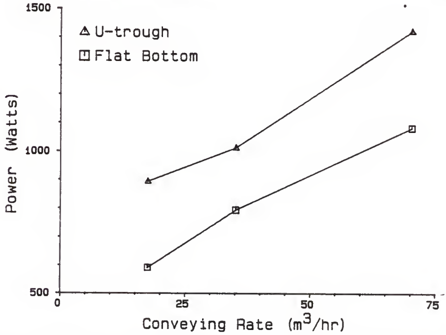


Figure 13. Power requirements for artificially air dried corn.

The results of the statistical analyses show that for the three main factors of the statistical model two factors, type of conveyor and conveying rate, were significant at $\alpha=0.05$. The only interaction that proved significant was between type of corn and conveying rate. The experimental effects of the main factors on power requirements are discussed individually.

The type of grain had no significant effect on the power requirements of the two conveyors tested. The plots of power requirements (Figures 10 and 11) illustrate that there is very little difference in power requirements between naturally air dried and artificially dried corn.

The U-trough conveyor had higher power requirements than the flat bottom conveyor for all conveying rates tested, as shown in Figures 12 and 13. This difference can be attributed to the differences in the mechanical efficiencies of the individual conveyors.

The minimum and maximum values of power requirements for both conveyors occurred with natural air dried corn at the extremes of the conveying rates tested. The minimum value for the flat bottom conveyor was 568 Watts and the maximum value was 1163 Watts. The minimum value for the U-trough conveyor was 775 Watts and the maximum value was 1453 Watts.

Conveying rate had the most significant effect of power requirements for both conveyors. The power requirement increased with an increase in conveying rate for both types of corn. The plots of power requirements (Figures 10, 11, 12, and 13) show that power requirements linearly increased with an increase in conveying rates.

The rates of increase in power requirements with respect to the grain flow rate were approximately 10 $W*hr/m^3$ for the flat bottom conveyor and approximately 12 $W*hr/m^3$ for the U-trough conveyor.

# CONCLUSIONS

Within the limits of this investigation the following conclusions were drawn:

1. Flat bottom and U-trough drag conveyors have no significant effect on the extent of corn kernel damage as a result of their design and mechanical differences.

2. Conveying rate of grain in drag conveyors has no significant effect on the extent of corn kernel damage.

3. The type of corn, natural air dried and artificially dried, had no significant effect on the extent of damage resulting from drag conveyors.

4. Within the test system the damage resulting from the drop into the receiving pit and handling by the bucket elevator was the least. The drag conveyors caused the second highest amount of damage and the damage resulting from the drop into the holding bins was the greatest.

5. The extent of damage experienced by the natural air dried corn was less than the damage experienced by the artificially dried corn, within the test system.

6. Increased conveying rates resulted in linearly increased power requirements. The rate of increase in power requirements with respect to grain flow rate were approximately 1Ø $W*hr/m^3$ for the flat bottom conveyor and

approximately 12 $W*hr/m^3$ for the U-trough conveyor.

7. The type of corn had no significant effect on the power requirements of the individual conveyors.

# SUGGESTIONS FOR FUTURE RESEARCH

## Corn Kernel Damage

Past studies of this nature, Fiscus, et al. (1969), Hall (1974), and Sands and Hall (1971), have screened the entire test lot to remove broken corn and foreign material. This, essentially, eliminated the sampling error which is apparent in the data obtained from this investigation.

Grain being used for tests of this nature should be handled as gently as possible. Methods similar to those employed by Fiscus, et al. (1969), Hall (1974), and Sands and Hall (1971) should be used. The amount of damage that is inherent to the testing system should be minimized so that any damage done by the particular piece of equipment being tested can be readily indentified.

A system that may be acceptable would be one where: (1) a clean lot of grain is placed in a holding bin, (2) the grain is passed through the equipment being tested into another bin, (3) the grain is taken from the second bin and passed through a cleaner, and (4) the grain is conveyed back into the original holding bin by means of a belt conveyor.

## Power Requirements

The data taken for the power requirements of the conveyors showed some interesting trends that should be further investigated. The absence of available literature concerning the power requirements for drag conveyors moving grain indicates a need for study in this area.

Investigation could be made into the difference in power requirements for natural air dried and commercial corn. The difference in types of conveyors would also be interesting but much attention would have to be focused on the mechanical similarity of the conveyors. Any strict investigation into the power requirements of drag conveyors would have to involve accurate monitoring of the conveyor throughput or conveying rate.

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# APPENDIX I

Percentages of broken corn and foreign material
for the complete investigation.

Table 2. Percentage of BCFM resulting from the test system with the flat bottom conveyor.[1]

| Corn Type | Conveying Rate Ideal ($m^3$/hr) | Conveying Rate Actual ($m^3$/hr) | Conveying Distance (m) | Sample Loc. | Moist. (%) | BCFM (%) |
|---|---|---|---|---|---|---|
| Known History | 17.56 | 16.54 | 7.32 | 1 | 12.35 | 1.12 |
| | | | | 2 | 13.00 | 1.55 |
| | | | | 3 | 12.85 | 1.25 |
| | | 16.47 | 14.64 | 1 | 13.10 | 2.59 |
| | | | | 2 | 13.20 | 1.88 |
| | | | | 3 | 12.95 | 1.37 |
| | | 16.40 | 21.96 | 1 | 13.05 | 1.54 |
| | | | | 2 | 12.95 | 2.18 |
| | | | | 3 | 13.00 | 1.73 |
| | | 16.33 | 29.28 | 1 | 12.95 | 1.97 |
| | | | | 2 | 13.05 | 2.62 |
| | | | | 3 | 12.90 | 1.75 |
| | | 16.15 | 7.32 | 1 | 12.85 | 1.50 |
| | | | | 2 | 13.00 | 1.76 |
| | | | | 3 | 12.90 | 1.34 |
| | | 16.33 | 14.64 | 1 | 13.05 | 1.63 |
| | | | | 2 | 12.90 | 1.56 |
| | | | | 3 | 12.85 | 1.55 |
| | | 16.36 | 21.96 | 1 | 12.90 | 2.05 |
| | | | | 2 | 13.00 | 1.95 |
| | | | | 3 | 12.90 | 1.93 |
| | | 16.36 | 29.28 | 1 | 12.95 | 2.42 |
| | | | | 2 | 12.75 | 2.40 |
| | | | | 3 | 12.95 | 1.94 |

Table 2. --- continued

| Corn Type | Conveying Rate Ideal ($m^3$/hr) | Actual | Conveying Distance (m) | Sample Loc. | Moist. (%) | BCFM (%) |
|---|---|---|---|---|---|---|
| Known History | 35.12 | 34.24 | 7.32 | 1 | 12.95 | 1.05 |
| | | | | 2 | 12.65 | 0.74 |
| | | | | 3 | 12.95 | 0.85 |
| | | 33.75 | 14.64 | 1 | 12.75 | 1.13 |
| | | | | 2 | 12.80 | 1.04 |
| | | | | 3 | 12.90 | 1.02 |
| | | 33.36 | 21.96 | 1 | 12.95 | 1.23 |
| | | | | 2 | 12.75 | 1.48 |
| | | | | 3 | 12.85 | 1.74 |
| | | 33.12 | 29.28 | 1 | 12.85 | 1.46 |
| | | | | 2 | 12.80 | 1.48 |
| | | | | 3 | 12.75 | 1.41 |
| | | 33.29 | 7.32 | 1 | 12.95 | 1.47 |
| | | | | 2 | 13.05 | 1.48 |
| | | | | 3 | 12.95 | 1.12 |
| | | 33.78 | 14.64 | 1 | 13.10 | 1.50 |
| | | | | 2 | 12.95 | 1.41 |
| | | | | 3 | 12.95 | 1.46 |
| | | 33.82 | 21.96 | 1 | 13.10 | 1.76 |
| | | | | 2 | 13.00 | 1.69 |
| | | | | 3 | 13.05 | 1.63 |
| | | 33.82 | 29.28 | 1 | 12.95 | 2.69 |
| | | | | 2 | 13.05 | 2.20 |
| | | | | 3 | 13.10 | 1.90 |

Table 2. --- continued

| Corn Type | Conveying Rate Ideal ($m^3$/hr) | Actual | Conveying Distance (m) | Sample Loc. | Moist. (%) | BCFM (%) |
|---|---|---|---|---|---|---|
| Known History | 70.23 | 70.09 | 7.32 | 1 | 12.65 | 1.08 |
| | | | | 2 | 12.75 | 1.90 |
| | | | | 3 | 12.55 | 0.78 |
| | | 70.16 | 14.64 | 1 | 12.70 | 1.35 |
| | | | | 2 | 12.70 | 1.20 |
| | | | | 3 | 12.40 | 1.42 |
| | | 69.53 | 21.96 | 1 | 12.50 | 1.60 |
| | | | | 2 | 12.70 | 1.46 |
| | | | | 3 | 12.50 | 1.65 |
| | | 68.76 | 29.28 | 1 | 12.60 | 1.78 |
| | | | | 2 | 12.80 | 2.43 |
| | | | | 3 | 12.45 | 1.79 |
| | | 67.28 | 7.32 | 1 | 12.75 | 1.47 |
| | | | | 2 | 12.80 | 1.58 |
| | | | | 3 | 12.90 | 1.48 |
| | | 68.27 | 14.64 | 1 | 12.80 | 1.93 |
| | | | | 2 | 12.85 | 1.73 |
| | | | | 3 | 13.00 | 2.00 |
| | | 69.18 | 21.96 | 1 | 13.00 | 1.95 |
| | | | | 2 | 12.85 | 2.50 |
| | | | | 3 | 12.90 | 2.01 |
| | | 67.18 | 29.28 | 1 | 12.85 | 2.23 |
| | | | | 2 | 12.90 | 2.30 |
| | | | | 3 | 13.00 | 2.55 |

Table 2. --- continued

| Corn Type | Conveying Rate Ideal | Conveying Rate Actual ($m^3$/hr) | Conveying Distance (m) | Sample Loc. | Moist. (%) | BCFM (%) |
|---|---|---|---|---|---|---|
| CCC | 17.56 | 15.84 | 7.32 | 1 | 13.35 | 3.80 |
| | | | | 2 | 13.30 | 4.01 |
| | | | | 3 | 13.15 | 4.14 |
| | | 16.05 | 14.64 | 1 | 13.25 | 4.84 |
| | | | | 2 | 13.25 | 5.15 |
| | | | | 3 | 13.30 | 5.67 |
| | | 16.19 | 21.96 | 1 | 13.25 | 6.16 |
| | | | | 2 | 13.45 | 7.01 |
| | | | | 3 | 13.35 | 6.52 |
| | | 16.33 | 29.28 | 1 | 13.40 | 7.41 |
| | | | | 2 | 13.25 | 8.22 |
| | | | | 3 | 13.25 | 8.26 |
| | | 15.66 | 7.32 | 1 | 13.15 | 4.89 |
| | | | | 2 | 13.00 | 4.96 |
| | | | | 3 | 13.15 | 5.48 |
| | | 15.77 | 14.64 | 1 | 13.15 | 6.39 |
| | | | | 2 | 13.15 | 6.09 |
| | | | | 3 | 13.00 | 6.40 |
| | | 16.01 | 21.96 | 1 | 13.20 | 7.70 |
| | | | | 2 | 13.15 | 7.49 |
| | | | | 3 | 13.30 | 8.05 |
| | | 16.12 | 29.28 | 1 | 13.30 | 8.39 |
| | | | | 2 | 13.05 | 9.14 |
| | | | | 3 | 13.20 | 9.37 |

Table 2. --- continued

| Corn Type | Conveying Rate Ideal ($m^3$/hr) | Conveying Rate Actual ($m^3$/hr) | Conveying Distance (m) | Sample Loc. | Moist. (%) | BCFM (%) |
|---|---|---|---|---|---|---|
| CCC | 35.12 | 31.99 | 7.32 | 1 | 13.15 | 4.73 |
| | | | | 2 | 13.40 | 4.26 |
| | | | | 3 | 13.45 | 4.83 |
| | | 32.34 | 14.64 | 1 | 13.40 | 6.84 |
| | | | | 2 | 13.65 | 6.29 |
| | | | | 3 | 13.30 | 6.22 |
| | | 32.83 | 21.96 | 1 | 13.40 | 7.67 |
| | | | | 2 | 13.55 | 7.97 |
| | | | | 3 | 13.30 | 7.44 |
| | | 33.12 | 29.28 | 1 | 13.55 | 8.87 |
| | | | | 2 | 13.35 | 9.24 |
| | | | | 3 | 13.30 | 9.04 |
| | | 30.87 | 7.32 | 1 | 12.85 | 4.13 |
| | | | | 2 | 12.90 | 4.43 |
| | | | | 3 | 13.05 | 4.40 |
| | | 31.64 | 14.64 | 1 | 13.05 | 5.58 |
| | | | | 2 | 13.05 | 5.20 |
| | | | | 3 | 13.10 | 5.46 |
| | | 32.06 | 21.96 | 1 | 13.10 | 7.02 |
| | | | | 2 | 13.00 | 6.45 |
| | | | | 3 | 13.35 | 8.49 |
| | | 32.03 | 29.28 | 1 | 13.35 | 8.49 |
| | | | | 2 | 13.35 | 7.89 |
| | | | | 3 | 13.20 | 8.06 |

Table 2. --- continued

| Corn Type | Conveying Rate Ideal ($m^3$/hr) | Conveying Rate Actual ($m^3$/hr) | Conveying Distance (m) | Sample Loc. | Moist. (%) | BCFM (%) |
|---|---|---|---|---|---|---|
| CCC | 70.23 | 62.09 | 7.32 | 1 | 13.45 | 3.91 |
| | | | | 2 | 13.25 | 3.85 |
| | | | | 3 | 13.35 | 4.25 |
| | | 63.21 | 14.64 | 1 | 13.10 | 5.08 |
| | | | | 2 | 13.35 | 5.52 |
| | | | | 3 | 13.30 | 5.17 |
| | | 63.35 | 21.96 | 1 | 13.30 | 6.70 |
| | | | | 2 | 13.45 | 6.46 |
| | | | | 3 | 13.60 | 6.63 |
| | | 64.54 | 29.28 | 1 | 13.50 | 7.27 |
| | | | | 2 | 13.45 | 8.57 |
| | | | | 3 | 13.60 | 7.01 |
| | | 60.82 | 7.32 | 1 | 12.75 | 4.52 |
| | | | | 2 | 12.95 | 4.54 |
| | | | | 3 | 13.30 | 4.57 |
| | | 63.10 | 14.64 | 1 | 13.00 | 5.70 |
| | | | | 2 | 13.05 | 4.90 |
| | | | | 3 | 13.15 | 6.14 |
| | | 64.16 | 21.96 | 1 | 13.00 | 6.63 |
| | | | | 2 | 13.05 | 7.04 |
| | | | | 3 | 13.20 | 7.37 |
| | | 62.54 | 29.28 | 1 | 13.15 | 8.34 |
| | | | | 2 | 13.25 | 9.43 |
| | | | | 3 | 13.20 | 8.98 |

1./ Actual damage by the drag conveyor is BCFM of the sample taken at location (2) minus the BCFM of the sample taken at location (1).

Table 3. Percentage of BCFM resulting from the test system with the U-trough conveyor.[1]

| Corn Type | Conveying Rate Ideal ($m^3$/hr) | Conveying Rate Actual ($m^3$/hr) | Conveying Distance (m) | Sample Loc. | Moist. (%) | BCFM (%) |
|---|---|---|---|---|---|---|
| Known History | 17.56 | 16.22 | 7.32 | 1 | 12.85 | 1.55 |
| | | | | 2 | 12.80 | 1.30 |
| | | | | 3 | 12.65 | 1.43 |
| | | 16.15 | 14.64 | 1 | 12.85 | 1.59 |
| | | | | 2 | 12.75 | 1.96 |
| | | | | 3 | 12.85 | 1.54 |
| | | 16.15 | 21.96 | 1 | 12.85 | 2.03 |
| | | | | 2 | 12.65 | 1.89 |
| | | | | 3 | 12.95 | 1.96 |
| | | 16.19 | 29.28 | 1 | 12.85 | 2.07 |
| | | | | 2 | 12.80 | 2.22 |
| | | | | 3 | 12.70 | 2.32 |
| | | 16.19 | 7.32 | 1 | 12.85 | 1.47 |
| | | | | 2 | 13.00 | 1.13 |
| | | | | 3 | 12.90 | 1.15 |
| | | 16.19 | 14.64 | 1 | 12.80 | 1.53 |
| | | | | 2 | 12.65 | 1.40 |
| | | | | 3 | 13.10 | 1.49 |
| | | 16.08 | 21.96 | 1 | 12.85 | 1.70 |
| | | | | 2 | 12.90 | 1.59 |
| | | | | 3 | 12.80 | 1.73 |
| | | 16.15 | 29.28 | 1 | 12.95 | 2.09 |
| | | | | 2 | 12.85 | 2.14 |
| | | | | 3 | 12.75 | 1.92 |

Table 3. --- continued

| Corn Type | Conveying Rate Ideal ($m^3$/hr) | Actual | Conveying Distance (m) | Sample Loc. | Moist. (%) | BCFM (%) |
|---|---|---|---|---|---|---|
| Known History | 35.12 | 34.06 | 7.32 | 1 | 12.90 | 1.61 |
| | | | | 2 | 12.95 | 1.91 |
| | | | | 3 | 13.00 | 1.12 |
| | | 33.64 | 14.64 | 1 | 12.95 | 1.48 |
| | | | | 2 | 12.90 | 1.51 |
| | | | | 3 | 13.10 | 1.35 |
| | | 33.26 | 21.96 | 1 | 12.75 | 1.48 |
| | | | | 2 | 12.80 | 1.87 |
| | | | | 3 | 13.00 | 1.77 |
| | | 33.15 | 29.28 | 1 | 12.85 | 2.01 |
| | | | | 2 | 12.90 | 2.41 |
| | | | | 3 | 12.85 | 1.71 |
| | | 34.38 | 7.32 | 1 | 13.20 | 1.01 |
| | | | | 2 | 13.10 | 1.01 |
| | | | | 3 | 13.00 | 1.31 |
| | | 34.20 | 14.64 | 1 | 13.15 | 2.05 |
| | | | | 2 | 13.10 | 1.75 |
| | | | | 3 | 13.35 | 1.36 |
| | | 33.96 | 21.96 | 1 | 13.35 | 1.53 |
| | | | | 2 | 13.25 | 1.56 |
| | | | | 3 | 13.40 | 1.47 |
| | | 33.75 | 29.28 | 1 | 13.15 | 2.03 |
| | | | | 2 | 13.10 | 1.77 |
| | | | | 3 | 13.10 | 1.78 |

Table 3. --- continued

| Corn Type | Conveying Rate Ideal ($m^3$/hr) | Conveying Rate Actual ($m^3$/hr) | Conveying Distance (m) | Sample Loc. | Moist. (%) | BCFM (%) |
|---|---|---|---|---|---|---|
| Known History | 70.23 | 70.41 | 7.32 | 1 | 12.95 | 2.06 |
| | | | | 2 | 13.10 | 1.41 |
| | | | | 3 | 12.75 | 0.95 |
| | | 70.27 | 14.64 | 1 | 12.80 | 1.46 |
| | | | | 2 | 12.90 | 1.71 |
| | | | | 3 | 12.95 | 1.34 |
| | | 69.07 | 21.96 | 1 | 12.70 | 1.59 |
| | | | | 2 | 13.05 | 1.99 |
| | | | | 3 | 13.00 | 1.44 |
| | | 68.20 | 29.28 | 1 | 12.85 | 1.74 |
| | | | | 2 | 12.90 | 2.47 |
| | | | | 3 | 12.85 | 1.76 |
| | | 69.11 | 7.32 | 1 | 13.10 | 1.00 |
| | | | | 2 | 13.20 | 1.14 |
| | | | | 3 | 13.25 | 1.05 |
| | | 69.60 | 14.64 | 1 | 13.20 | 1.32 |
| | | | | 2 | 13.10 | 1.30 |
| | | | | 3 | 13.20 | 1.28 |
| | | 68.72 | 21.96 | 1 | 13.05 | 1.59 |
| | | | | 2 | 13.20 | 1.64 |
| | | | | 3 | 13.15 | 1.63 |
| | | 67.60 | 29.28 | 1 | 13.20 | 1.79 |
| | | | | 2 | 13.05 | 1.73 |
| | | | | 3 | 13.25 | 1.77 |

Table 3. --- continued

| Corn Type | Conveying Rate Ideal ($m^3$/hr) | Actual | Conveying Distance (m) | Sample Loc. | Moist. (%) | BCFM (%) |
|---|---|---|---|---|---|---|
| CCC | 17.56 | 15.49 | 7.32 | 1 | 13.40 | 3.48 |
| | | | | 2 | 13.05 | 4.03 |
| | | | | 3 | 13.35 | 4.23 |
| | | 15.66 | 14.64 | 1 | 13.35 | 5.29 |
| | | | | 2 | 13.35 | 5.65 |
| | | | | 3 | 13.20 | 5.58 |
| | | 15.91 | 21.96 | 1 | 13.20 | 6.39 |
| | | | | 2 | 13.55 | 6.81 |
| | | | | 3 | 13.35 | 7.11 |
| | | 16.08 | 29.28 | 1 | 13.25 | 8.07 |
| | | | | 2 | 13.40 | 8.54 |
| | | | | 3 | 13.50 | 8.10 |
| | | 15.91 | 7.32 | 1 | 13.40 | 5.10 |
| | | | | 2 | 13.30 | 5.25 |
| | | | | 3 | 13.20 | 5.10 |
| | | 16.01 | 14.64 | 1 | 13.05 | 6.18 |
| | | | | 2 | 13.35 | 6.80 |
| | | | | 3 | 13.40 | 7.06 |
| | | 16.26 | 21.96 | 1 | 13.20 | 7.63 |
| | | | | 2 | 13.40 | 7.90 |
| | | | | 3 | 13.40 | 8.18 |
| | | 16.33 | 29.28 | 1 | 13.40 | 9.05 |
| | | | | 2 | 13.35 | 9.58 |
| | | | | 3 | 13.30 | 9.75 |

Table 3. --- continued

| Corn Type | Conveying Rate Ideal | Conveying Rate Actual | Conveying Distance (m) | Sample Loc. | Moist. (%) | BCFM (%) |
|---|---|---|---|---|---|---|
| | ($m^3$/hr) | ($m^3$/hr) | | | | |
| CCC | 35.12 | 31.43 | 7.32 | 1 | 13.30 | 4.55 |
| | | | | 2 | 12.90 | 3.85 |
| | | | | 3 | 13.20 | 4.25 |
| | | 31.53 | 14.64 | 1 | 13.25 | 5.09 |
| | | | | 2 | 13.20 | 5.91 |
| | | | | 3 | 13.00 | 5.64 |
| | | 31.96 | 21.96 | 1 | 13.25 | 7.06 |
| | | | | 2 | 13.40 | 7.05 |
| | | | | 3 | 13.50 | 7.13 |
| | | 32.31 | 29.28 | 1 | 13.40 | 7.66 |
| | | | | 2 | 13.40 | 8.81 |
| | | | | 3 | 13.25 | 7.99 |
| | | 31.82 | 7.32 | 1 | 13.30 | 4.21 |
| | | | | 2 | 13.40 | 5.02 |
| | | | | 3 | 13.30 | 4.87 |
| | | 32.38 | 14.64 | 1 | 13.15 | 5.86 |
| | | | | 2 | 13.40 | 5.08 |
| | | | | 3 | 13.30 | 6.04 |
| | | 32.66 | 21.96 | 1 | 13.25 | 7.22 |
| | | | | 2 | 13.30 | 7.11 |
| | | | | 3 | 13.30 | 7.03 |
| | | 32.87 | 29.28 | 1 | 13.15 | 8.17 |
| | | | | 2 | 13.20 | 8.18 |
| | | | | 3 | 13.35 | 8.32 |

Table 3. --- continued

| Corn Type | Conveying Rate Ideal ($m^3$/hr) | Conveying Rate Actual ($m^3$/hr) | Conveying Distance (m) | Sample Loc. | Moist. (%) | BCFM (%) |
|---|---|---|---|---|---|---|
| CCC | 70.23 | 61.31 | 7.32 | 1 | 13.35 | 3.61 |
| | | | | 2 | 13.45 | 3.28 |
| | | | | 3 | 13.25 | 3.35 |
| | | 62.54 | 14.64 | 1 | 13.25 | 4.94 |
| | | | | 2 | 13.40 | 5.86 |
| | | | | 3 | 13.30 | 4.94 |
| | | 62.40 | 21.96 | 1 | 13.20 | 6.64 |
| | | | | 2 | 13.35 | 6.39 |
| | | | | 3 | 13.40 | 6.35 |
| | | 63.70 | 29.28 | 1 | 13.40 | 7.66 |
| | | | | 2 | 13.65 | 9.03 |
| | | | | 3 | 13.30 | 7.50 |
| | | 61.74 | 7.32 | 1 | 13.25 | 4.65 |
| | | | | 2 | 13.10 | 4.48 |
| | | | | 3 | 13.20 | 4.29 |
| | | 63.25 | 14.64 | 1 | 13.40 | 5.60 |
| | | | | 2 | 13.10 | 6.16 |
| | | | | 3 | 13.35 | 5.76 |
| | | 63.39 | 21.96 | 1 | 13.30 | 6.83 |
| | | | | 2 | 13.10 | 6.57 |
| | | | | 3 | 13.25 | 6.65 |
| | | 64.16 | 29.28 | 1 | 13.15 | 8.27 |
| | | | | 2 | 13.15 | 8.31 |
| | | | | 3 | 13.30 | 9.15 |

1./ Actual damage by the drag conveyor is BCFM of the sample taken at location (2) minus the BCFM of the sample taken at location (1).

# APPENDIX II

Analysis of variance for

percentage of BCFM caused by drag conveyors.

Table 5. Analysis of variance for the difference between sampler 1 and 2 at a cumulative distance of 14.64 m (48 ft) for all treatment combinations.

| Source of Variation | DF | SS | P-Value |
|---|---|---|---|
| Conveyor (C) | 1 | 1.1660 | 0.0442 |
| Grain (G) | 1 | 0.2262 | 0.3417 |
| Flow Rate (F) | 2 | 0.3743 | 0.4675 |
| C * G | 1 | 0.2147 | 0.3539 |
| C * F | 2 | 0.1579 | 0.7171 |
| G * F | 2 | 0.2828 | 0.5580 |
| C * G * F | 2 | 0.1245 | 0.7681 |
| Model | 11 | 2.5463 | 0.4946 |
| Error | 12 | 2.7699 | |
| Total | 23 | 5.3162 | |

Table 6. Analysis of variance for the difference between sampler 1 and 2 at a cumulative distance of 21.96 m (72 ft) for all treatment combinations.

| Source of Variation | DF | SS | P-Value |
|---|---|---|---|
| Conveyor (C) | 1 | 0.0408 | 0.6168 |
| Grain (G) | 1 | 0.0551 | 0.5618 |
| Flow Rate (F) | 2 | 0.1373 | 0.6520 |
| C * G | 1 | 0.0000 | 0.9878 |
| C * F | 2 | 0.0978 | 0.7349 |
| C * G * F | 2 | 0.1540 | 0.6201 |
| Model | 11 | 0.8676 | 0.8629 |
| Error | 12 | 1.8574 | |
| Total | 23 | 2.7250 | |

Table 7. Analysis of variance for the difference between sampler 1 and 2 at a cumulative distance of 29.28 m (96 ft) for all treatment combinations.

| Source of Variation | DF | SS | P-Value |
|---|---|---|---|
| Conveyor (C) | 1 | 0.0000 | 0.9937 |
| Grain (G) | 1 | 1.2150 | 0.0505 |
| Flow Rate (F) | 2 | 1.3372 | 0.1155 |
| C * G | 1 | 0.0033 | 0.9122 |
| C * F | 2 | 0.7551 | 0.2691 |
| G * F | 2 | 0.0836 | 0.8519 |
| C * G * F | 2 | 0.1830 | 0.7079 |
| Model | 11 | 3.5772 | 0.3457 |
| Error | 12 | 3.0879 | |
| Total | 23 | 6.6651 | |

Table 9. Analysis of variance for the average difference between sampler 1 and 2 at a cumulative distance of 14.64 m (48 ft) for all treatment combinations.

| Source of Variation | DF | SS | P-Value |
|---|---|---|---|
| Conveyor (C) | 1 | 0.5808 | 0.0504 |
| Grain (G) | 1 | 0.1160 | 0.1955 |
| Flow Rate (F) | 2 | 0.1901 | 0.2497 |
| C * G | 1 | 0.1008 | 0.2161 |
| C * F | 2 | 0.0798 | 0.4422 |
| G * F | 2 | 0.1345 | 0.3200 |
| Model | 9 | 1.2020 | 0.2061 |
| Error | 2 | 0.0633 | |
| Total | 11 | 1.2653 | |

Table 10. Analysis of variance for the average difference between sampler 1 and 2 at a cumulative distance of 21.96 m (72 ft) for all treatment combinations.

| Source of Variation | DF | SS | P-Value |
|---|---|---|---|
| Conveyor (C) | 1 | 0.0217 | 0.5305 |
| Grain (G) | 1 | 0.0310 | 0.4633 |
| Flow Rate (F) | 2 | 0.0743 | 0.5077 |
| C * G | 1 | 0.0001 | 0.9687 |
| C * F | 2 | 0.0491 | 0.6098 |
| G * F | 2 | 0.1977 | 0.2794 |
| Model | 9 | 0.3738 | 0.5680 |
| Error | 2 | 0.0767 | |
| Total | 11 | 0.4505 | |

Table 11. Analysis of variance for the average difference between sampler 1 and 2 at a cumulative distance of 29.28 m (96 ft) for all treatment combinations.

| Source of Variation | DF | SS | P-Value |
|---|---|---|---|
| Conveyor (C) | 1 | 0.0000 | 1.0000 |
| Grain (G) | 1 | 0.5985 | 0.0693 |
| Flow Rate (F) | 2 | 0.6725 | 0.1209 |
| C * G | 1 | 0.0016 | 0.8683 |
| C * F | 2 | 0.3826 | 0.1947 |
| G * F | 2 | 0.0396 | 0.7002 |
| Model | 9 | 1.6949 | 0.2127 |
| Error | 2 | 0.0925 | |
| Total | 11 | 1.7874 | |

# DAMAGE TO SHELLED CORN
# DURING TRANSPORT IN DRAG CONVEYORS

by

RICHARD SHANNON JOHNSON

B. S., Kansas State University, 1982

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AN ABSTRACT OF A MASTER'S THESIS

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ABSTRACT

The purposes of this investigation were: (1) to study the effects of grain conveying rates on corn kernel damage and drag conveyor power requirements; (2) to study effects of different conveyor cross-sections on corn kernel damage and conveyor power requirements; and (3) to study effects of conveyor length on corn kernel damage.

Three main factors were studied: (1) grain conveying rates ($17.56m^3/hr$, $35.12m^3/hr$, and $70.23m^3/hr$); (2) type of drag conveyor (flat bottom and U-trough); and (3) type of corn (natural air dried and artificially dried). Corn kernel damage was measured by determining the difference of broken corn and foreign material in samples taken at the inlet and outlet of the drag conveyor. Samples were evaluated with a Carter Dockage Tester.

Tests were carried out with the grain handling facilities at the U.S. Grain Marketing Research Laboratory in Manhattan, Kansas. Corn flow rates were controlled with an orifice on the inlet side of the drag conveyor. A seperate test lot of $5.27m^3$ was used for each test.

The results showed that none of the main factors had a significant effect on the amount of corn kernel damage in drag conveyors. The type of conveyor and grain conveying rates had a significant effect on power requirements of the conveyors. The U-trough conveyor required more power than the flat bottom

conveyor and increases in conveying rates resulted in linearly increased power requirements. The rate of increase in power requirements with respect to grain flow rate were approximately 10 $W*hr/m^3$ for the flat bottom conveyor and approximately 12 $W*hr/m^3$ for the U-trough conveyor.

Within the test system, the damage resulting from the drop into the receiving pit and handling by the bucket elevator was the least. The drag conveyor caused the second highest amount of damage and the drop into the holding bins caused the greatest amount of damage.