Reducing Damage to Corn Handled through Gravity Spouts

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THE fragility of shelled corn has been and continues to be a major source of marketing problems. Brittle corn breaks easily when handled, and this brittleness often results in an excessive amount of broken corn that must be removed to meet market grades. The market value of corn screenings is nearly always less than that of whole kernels. The concentration of broken kernels in certain locations within a storage structure results in uneven aeration and delayed drying and is an open invitation to mold growth and insect invasion.

The problem is not new. Shelled corn has always contained broken kernels. The grade standards for the highest grade, U.S. No. 1, permit the presence of up to 2 percent broken corn and foreign material in the grain (USDA 1970). The most widely traded grade, U.S. No. 2, allows 3 percent. When corn was harvested with a corn picker and dried in a crib it usually contained few broken kernels. However, the corn combine and higher temperature grain dryer produce grain that is highly susceptible to breakage.

Modern grain elevator design has not aided in minimizing breakage. High grain flow rates and tall bins are the design norm, with no provisions for limiting stream velocities.

A few devices designed to reduce damage to grain flowing in spouts have been introduced in recent years. They are intended to reduce the velocity of the grain almost to zero and then allow the grain to reaccelerate. Two or more devices may be installed in a long spout. The velocity is usually reduced by impacting the grain stream on a mass of grain held within the device, since such an impact produces less broken grain than is produced when grain impacts upon steel (Foster and Holman 1973). The effectiveness of any flow control device depends on reducing the grain velocity without breaking the kernels.

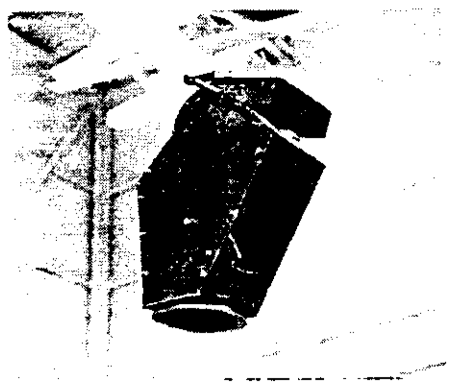

FIG. 1 Cushion box.

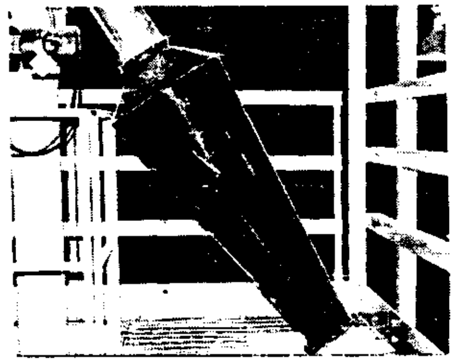

FIG. 2 Spout retarder.

The objectives of this study were: (a) to measure the effectiveness of commercial and experimental flow retarders in reducing handling damage to corn, and (b) to observe any fundamental principles that may be used to reduce damage to corn in commercial handling.

EQUIPMENT

Flow Retarders

One experimental and two commercial flow retarders were used in this study. The cushion box (Fig. 1), one of the commercial retarders used, is usually installed at the end of a spout and acts as an elbow and a flow retarder. A baffle in the box catches about 2 l of grain as the stream enters the box. Additional grain strikes the trapped grain, spills over the baffle at a low velocity, and falls into the bin below. A slot at the bottom of the baffle permits the trapped grain to drain out slowly but completely, eliminating the possibility of spoilage.

The spout retarder (Fig. 2), the second commercial retarder used, is usually installed at some point in the spout run, rather than at its end. It is about 1.3 m long, with the general appearance of a long, inverted cone that is topped by a short, upright cone, and is radially symmetric. Inside, just below its top, is a bucket that catches about 5 l of grain. This grain acts to cushion the impact of additional grain. The additional grain then spills over the edge of bucket and restarts down the spout, virtually from rest. This bucket is equipped with drains that serve the same purpose as the slot in the cushion box.

The experimental flow retarder, called the "retro-air" retarder (Fig. 3) operated on the basis of aerodynamic drag, rather than impact, to slow the grain. A fan driven by 2.2 kW electric motor, attached to a special section of 23-cm-square spouting, forced air up the spout in the opposite direction from that of the grain flow. About 3 m above the point where the air was introduced into the spout, a duct was provided so the air could escape from the spout and return to the fan inlet. A deflector was installed on the bottom of the

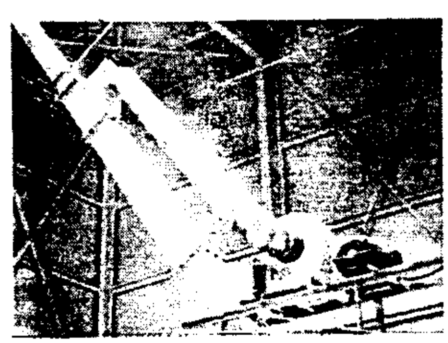

FIG. 3 Retro-air retarder.

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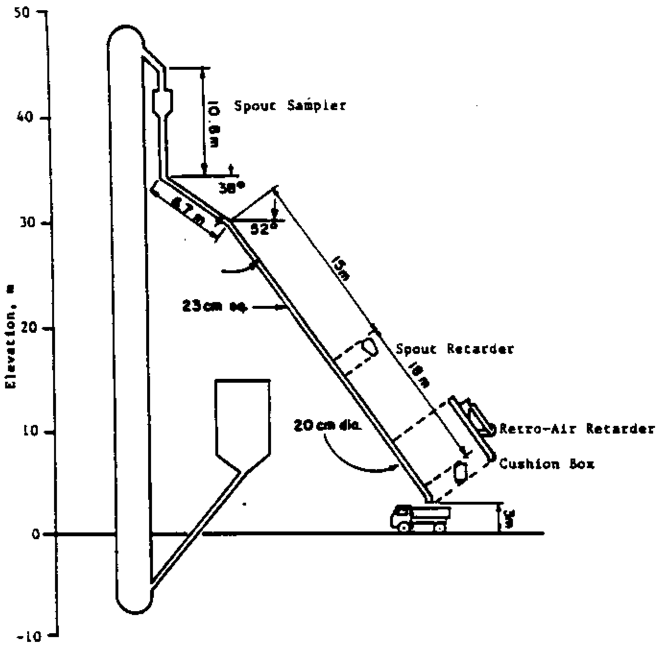

FIG. 4 Grain spout system.

spout, 2 m above the fan inlet to lift the grain stream into the airflow to increase the drag on the grain.

Grain Spout

The flow retarders were installed in a grain spout at the U.S. Grain Marketing Research Center in Manhattan, Kansas. A drawing of the spout system appears in Fig. 4. A round-to-square transition section was used to attach the retro-air retarder to the end of the spout.

The grain stream was discharged into a grain truck whose floor was 1.5 m above ground. The truck bed was covered by a polyethylene sheet and evacuated by a fan for dust control. The sheet was lifted around the grain spout to eliminate dust leakage into the laboratory.

Sample Cleaner

A 4.5-m-tall bucket elevator that discharged into a 10-cm-diameter spout delivered grain to a rotating-screen grain cleaner. The screen was perforated with 4.76-mm (12/64-in.) round holes. Material that passed through the holes, herein referred to as breakage, was conveyed to a scale cart for weighing. The cleaner and conveyor were supported about 2 m above the floor to clear the sides of the scale cart. Material too large to pass through the screen was discharged onto a belt conveyor and returned to the elevator headhouse. A valve was installed in the clean-grain discharge spout to collect samples.

MATERIALS AND METHODS— TEST SERIES I

The first series of tests was conducted to measure the effectiveness of the three flow retarders in reducing breakage. (In a second series of tests, to be discussed later, the performance of the experimental flow retarder was examined in more detail.) The flow retarders were used singly and in combination of a grain flow rate of 51 tons (2000 bu) per hour. The combinations tested were retro-air retarder, cushion box, spout retarder, and cushion box and spout retarder. In some tests no retarder was used and an elbow made of round spout was installed at the end of the spout.

Yellow dent shelled corn grown near Wamego, Kansas, and harvested with a corn combine in 1973, was dried by three methods to determine any effect that drying might have on the performance of the flow retarders. The first lot was dried at a local elevator in a batch dryer at air temperatures of 90-100 °C (190-210 °F). The second lot was dried on the farm in a batch-in-bin dryer at air temperatures of 50-60 °C (120-140 °F). The third lot was allowed to dry in the field to 15 percent moisture content before harvest.

A test lot weighing 3054 kg (120 bu) was withdrawn from one of the bulk lots. The corn was weighed on a 382-kg (15-bu) batch scale as it entered a grain cleaner. It was cleaned over a screen with 5.16 cm (13/64 in.) diameter holes and the breakage that passed through the screen was collected and weighed. The remaining corn was thereafter kept as a separate, identified, test lot. After the test lot was cleaned, it was moved to a temporary holding bin.

Grain moisture contents ranged from 11.1 to 13.7 percent and temperatures from 4 to 11 °C (40 to 52 °F).

For a test, the corn was elevated by the bucket elevator at 51 tons (2000 bu) per hour and and discharged into the grain spout previously described. The time of flow was recorded for later computation of the actual flow rate. The automatic sampler took samples from the grain stream every 15 sec. This sample was screened on a hand sieve with 4.76 mm (12/64 in.) diameter holes. The percent of sample passing through the screen was recorded as the "before handling" breakage content of the corn. This percentage ranged from 0.4 to 8.8 percent.

The test lot collected in the truck was unloaded and cleaned by the rotary screen, and its breakage content was computed. Because some breakage remained in the cleaned grain, it was sampled and screened on the hand sieve and its breakage content was computed. The sum of these two percentages was recorded as the "after handling" breakage content of the corn. The differences between the "after handling" and the "before handling" breakage content was recorded as the increase in breakage for each handling test. The cleaned grain was weighed on the batch scale previously described as it was returned to the temporary holding bin.

The first handling was followed by a second and third handling in which the same corn and test procedure were used as for the first handling.

After the third handling, the corn was weighed into another storage bin and was not reused. Then the same series of three tests was repeated with the next lot of corn.

When a test lot from each of the three supply lots had been run through a flow-control device, another device was installed and the entire sequence of nine tests was repeated.

Motion pictures were taken at 1000 frames per second to measure the grain discharge velocity at the point where grain exited the spout.

RESULTS—TEST SERIES I

The flow retarders were relatively

TABLE 1. BREAKAGE INCREASE PER HANDLING BY FLOW RETARDER TYPE

Corn lot	Handling number	Breakage increase per handling by flow retarder type, percentage points					
		None	Cushion box	Spout retarder	Retarder and box	Retro-air	Average
	1	5.00	4.22	4.97	4.16	5.13	4.70
Dried at high temperature	2	7.52	5.24	6.56	5.10	6.70	6.22
	3	7.32	6.21	6.93	5.86	7.14	6.69
	Average	6.61	5.22	6.15	5.04	6.32	5.87
	1	1.79	1.97	2.25	1.92	2.47	2.08
Dried at low temperature	2	2.02	2.32	2.88	2.07	3.22	2.50
	3	3.44	2.88	3.15	2.76	4.72	3.39
	Average	2.42	2.39	2.76	2.25	3.47	2.66
	1	1.25	0.57	0.76	0.81	1.28	0.93
Field dried	2	1.10	0.99	0.73	0.55	1.11	0.90
	3	1.22	1.03	0.79	0.63	1.02	0.94
	Average	1.19	0.86	0.76	0.66	1.14	0.92

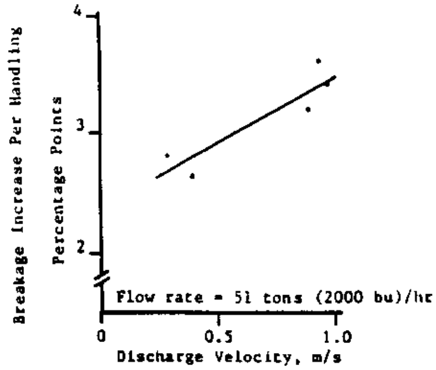

FIG. 5 Added breakage per handling versus discharge velocity for five flow retarders.

ineffective in reducing breakage. The mean increases in breakage per handling, averaged across the three corn drying treatments and the three repetitions, for each flow retarder were as follows:

Flow retarder	Breakage increase per handling (percentage points)
Retro-air	3.64
No retarder	3.41
Spout retarder	3.22
Cushion box	2.83
Spout retarder and cushion box	2.65

The drying treatment had a greater effect on the breakage level than did the type of flow retarder. The mean increases in breakage per handling, averaged across the five flow-retarder types and the three repetitions, for each drying treatment were as follows:

Drying treatment	Breakage increase per handling (percentage points)
High temperature	5.87
Low temperature	2.66
Field drying	0.92

The three repetitions of filling the truck were not true replicates, as breakage increased with each handling. The mean increases in breakage per handling, averaged across the five flow-retarder types and the three drying treatments, for each handling were as follows:

Handling	Breakage increase per handling (percentage points)
First	2.57
Second	3.21
Third	3.67

This is *not* the accumulated breakage, since all breakage was removed by the rotary screen and was not returned to the test lot.

Table 1 presents the increase in breakage for each of the handling tests in this series, as well as averages across flow-retarder types and handling numbers. Both the high-temperature and low-temperature drying treatments produced grain that became more susceptible to breakage with each handling. The field-dried corn showed no detectable change in breakage increase with increasing numbers of handling.

The velocities recorded by the motion pictures were well correlated with the increase in breakage, even though the velocities measured were not necessarily the impact velocity. The correlation coefficient between velocity and breakage was +0.92. Fig. 5 illustrates this relationship.

MATERIALS AND METHODS—TEST SERIES II

Because the experimental flow retarder was unable to effectively handle the flow rate used in the first phase of testing, a series of tests was conducted to determine the range of flow rates over which it would be effective in reducing breakage.

The supply of corn used in the first test series had been exhausted, so other supplies were used. No single lot of sufficient size was available to complete the tests, so three different lots were used. A corn lot that had been dried at air temperatures of 18-21 °C (65-70 °F) was used at flow rates of 12.7 tons (500 bu) and 20.4 tons (800 bu) per hour. A lot that had been dried at air temperatures of 0-10 °C (32-50 °F) was used at 20.4 tons (800 bu), 28 tons (1100 bu) and 35.6 tons (1400 bu) per hour. A lot obtained from Commodity Credit Corporation stocks, of unknown history, was used at 35.6 tons (1400 bu) and 43.3 tons (1700 bu) per hour. Each time the corn type was changed, the previous flow rate was repeated to help assess the relative effects of flow rate and past history of the test corn on breakage increase.

Grain moisture contents ranged from 10.8 to 13.5 percent and temperature from 21 to 30 °C (70-86 °F).

The same sequence of weighing, cleaning, sampling, and other procedures, used in the first test series was repeated in this phase of testing. Three tests were made with one test lot with the retarder fan operating, after which the test lot was discarded. Three more tests were made with a second lot of the same type of corn at the same flow rate, but with the retarder fan off, after which this test lot was discarded. The six tests were then repeated at another flow rate or with another type of corn, in the order given above.

RESULTS—TEST SERIES II

Table 2 presents the increase in breakage for all the tests with the retro-air retarder at the various grain flow rates with the three types of corn and with the fan operating and not operating. The ratio of breakage caused with the fan off to that which occurred when it was on is a measure of the effectiveness of the retro-air retarder for reducing breakage. A ratio greater than one indicates that the retarder reduced the breakage. The average ratio is an overall measure of performance, and the results indicate that the retro-air retarder was effective at flow rates up to 20 to 25 tons (800 to 1000 bu) per hour, but not beyond. Fig. 6 presents the ratios obtained across the range of flow rates.

At low flow rates the breakage increased more rapidly for each handling with the fan off than it did with

TABLE 2. INCREASE IN BREAKAGE IN THE RETRO-AIR RETARDER TESTS CONDUCTED AT VARIOUS GRAIN FLOW RATES

Flow rate	Drying air temperature	Fan	Breakage increase per handling by handling number, percentage points 1	2	3	Avg.
12.7 tons/hr (500 bu/hr)	18-21 °C	Off	2.66	3.23	3.61	3.16
		On	2.70	2.40	2.84	2.65
		Ratio	0.99	1.35	1.27	1.20
20.4 tons/hr (800 bu/hr)	18-21 °C	Off	3.09	3.85	4.70	3.88
		On	2.95	2.13	2.84	2.64
		Ratio	1.05	1.81	1.65	1.50
20.4 tons/hr (800 bu/hr)	0-10 °C	Off	0.86	1.33	1.66	1.28
		On	0.80	1.29	1.32	1.14
		Ratio	1.08	1.03	1.26	1.12
28 tons/hr (1100 bu/hr)	0-10 °C	Off	1.18	1.94	2.44	1.85
		On	1.66	1.73	1.94	1.78
		Ratio	0.71	1.12	1.33	1.05
35.6 tons/hr (1400 bu/hr)	0-10 °C	Off	1.51	1.74	2.14	1.80
		On	1.62	1.69	1.83	1.71
		Ratio	0.93	1.03	1.17	1.04
35.6 tons/hr (1400 bu/hr)	Unknown	Off	2.79	3.35	3.28	3.14
		On	3.35	3.25	3.46	3.35
		Ratio	0.83	1.03	0.95	0.94
43.3 tons/hr (1700 bu/hr)	Unknown	Off	2.59	3.06	3.06	2.90
		On	2.57	2.86	3.16	2.86
		Ratio	1.01	1.07	0.97	1.02

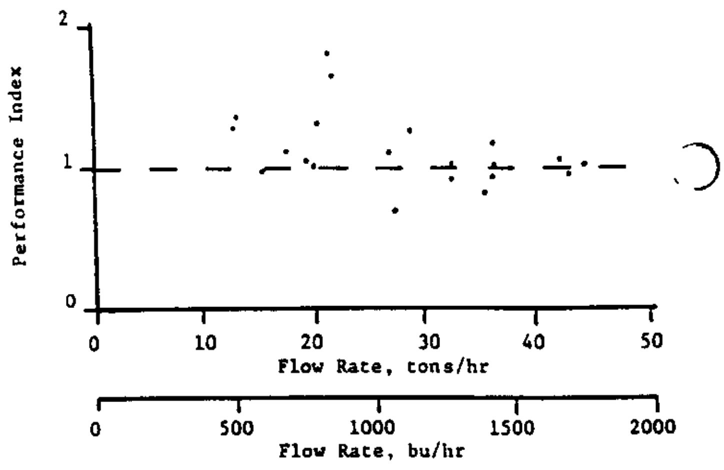

FIG. 6 Performance ($\frac{\text{Breakage with fan off}}{\text{Breakage with fan on}}$) of retro-air flow retarder versus grain flow rate.

the fan on. Thus, the effectiveness of the retarder tended to increase slightly each time the corn was handled.

DISCUSSION OF RESULTS

The flow retarders, except for the retro-air retarder, reduced the amount of breakage increase in shelled corn at the flow rate of 51 tons (2000 bu) per hour, but by a relatively small amount. The spout flow retarder reduced the amount of breakage increase in these tests by an average of only 0.2 percentage points compared to tests with no flow-retarding device. A cushion box at the end of the spout was more effective; the amount of breakage increase was reduced by an average of 0.6 percentage points. Breakage increase in the lot of corn dried at low temperatures was greater with the spout retarder than without it. Even the best combination allowed an average of 2.65 percentage points breakage increase in corn moved through the spout. This amount of added breakage from one pass through the spout would lower the market grade of corn from one to three grades, depending on how near the initial level was to the limit for a given grade.

The number of flow-retarding devices required to prevent excessive breakage in a spout of given length and drop was not determined in these tests. Obviously, one flow retarder in a spout 55 m long, with a drop of 43 m, was not adequate. Since the velocity at impact, or the resulting impact stress, is the principal cause of grain breakage (Foster and Holman 1973), the middle of a spout run should be near optimum placement for a single flow retarder. Evidence exists that, for a given lot of corn, there is a threshold of impact velocities below which the amount of breakage increase in small, and above which breakage increase is proportional to the velocity at impact (Foster and Holman 1973). This hypothesis is corroborated to a degree by the data in Table 1. The breakage increase with the spout retarder and cushion box was only 55 percent as great as with no flow retarding devices in tests with field-dried corn; but was 76 percent and 93 percent as great in the two tests with corn that had been artificially dried. It seems reasonable to assume that the different lots of corn reached equal velocities in a given combination of flow retarders. With the spout retarder and cushion box in use the velocity reached was below the breakage threshold of the field dried corn but was above the threshold velocity of the two artificially dried lots.

Thus, the breakage susceptibility of the principal grains being handled determined the number and spacing of flow-retarding devices needed in spouts.

The effect of high-temperature, rapid drying on the breakage susceptibility of shelled corn is clearly displayed here and confirms earlier reports (Thompson and Foster 1963, White and Ross 1972). The data from these tests indicate that reducing the stresses created by drying was more effective in reducing subsequent breakage than were the attempts at reducing impact damage from handling.

The two types of corn dried with heated air became more susceptible to breakage with each handling, whereas the corn that dried in the field showed a constant breakage increase per handling through three handlings.

Three independent variables, drying treatment, type of flow retarder, and number of handlings, were used in an analysis of variance of the data in Table 1. Since the repeated handling of each test lot was not a true replicate, the third-order interaction variance was used as the error variance. Based on this analysis, each of the three independent variables and the first-order interaction between drying treatment and type of flow retarder, and the interaction between drying treatment and number of handlings were statistically significant at the 1 percent level. According to Duncan's New Multiple Range Test (Steele and Torrie 1960) the difference between the mean breakage increase per handling by flow retarder types were significant at the 5 percent level, except for the following:

Spout retarder plus cushion box vs cushion box alone

Spout retarder vs no retarder

Retro-air retarder vs no retarder

Even the statistically significant differences were small. The breakage increases related to the three drying treatments and to the numbers of handlings were also significantly different at the 5 percent level.

Although the correlation between discharge velocity and breakage increase (Fig. 5), was good, a low discharge velocity does not always imply low breakage increase. The velocity measured at the end of a spout may not reflect the velocities reached at impacts at other points within the spout. At low flow rates the discharge velocity may be quite low, but a high percentage of kernels will impact steel, rather than grain, and cause a large increase in breakage.

The retro-air flow retarder was effective only at low grain-flow rates and its effectiveness varied from one test to another. As shown in Fig. 6, at flow rates up to 25 tons (1000 bu per hour, the performance index is greater than one for most of the observations, indicating a reduction in breakage. Thus, under the conditions of these tests, the minimum power input to the retro-air retarder required to effect breakage reduction in grain spouts is about 2.2 kW (3 hp) per 1000 bu (25 tons) per hour of flow rate.

SUMMARY

The use of flow retarding devices to limit grain velocities reduced handling damage, but by a relatively small amount. The correlation between velocity and breakage and the reduction in breakage as more retarding devices were installed indicated that high velocities and the impact forces that result from them contribute to grain breakage. The use of aerodynamic drag as a decelerating force shows potential usefulness as a flow retarder, though the design tested may not be optimum.

The difference in breakage increase per handling between heat-dried and naturally dried corn was much greater than were differences related to the flow retarders used. Reducing stresses in the drying process appears to be the most effective method of preventing handling damage in corn.

The increase in breakage observed with each successive handling indicated that reducing the number of handling operations between harvest and consumption will provide the consumer with a higher quality corn than does the present marketing system. Containerization of grain, for example, would greatly reduce the number of handling operations.

References

1 Foster, G. H. and L. E. Holman. 1973. Grain breakage caused by commercial handling methods. Marketing Research Report No. 968, U.S. Department of Agriculture, Agricultural Research Service.

2 Steel, R. G. D. and J. H. Torrie. 1960. Principles and procedures of statistics. McGraw-Hill Book Co., Inc. New York. 481 p.

3 Thompson, R. A. and G. H. Foster. 1963. Stress cracks and breakage in artificially dried corn. Marketing Research Report No. 631. U.S. Department of Agriculture, Agricultural Marketing Service.

4 U.S. Department of Agriculture. 1970. Official grain standards of the United States. Agricultural Marketing Service.

5 White, G. M. and I. J. Ross. 1972. Discoloration and stress-cracking in white corn as affected by drying temperature and drying rate. TRANSACTIONS of the ASAE 15(3): 504-507.