Broken Corn and Dust Generated During Repeated Handling

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FIELD shelling and heated-air drying have caused an increase in the brittleness and fragility of corn. Over 50 percent of the corn grown in the United States is moved from farms and subjected to many handlings as it is moved through the marketing system from producer to consumer.

Exported corn is moved from one container or storage structure to another many times before it reaches a consumer. It has been repeatedly alleged (USGAO 1976) that such corn is badly damaged and contained excessive amounts of fine material and broken kernels which we shall call "breakage."

Segregation of breakage is a problem that complicates the delivery of a uniform grade of grain to a consumer. When a bin is filled, the stream hits an inclined slope of deposited grain and fine particles remain near the point of impact, whereas larger whole kernels roll down the slope toward the wall (Jenike and Johanson 1971). Bins empty by mass flow or funnel flow. In mass flow, all the grain in a bin flows when the gate is opened, segregated materials are remixed in the hopper, and a first-in first-out flow pattern prevails. In funnel flow, material at the center of the bin flows fastest, and the core, which contains a greater amount of breakage than the other material in the bin, is the first grain to be removed. Segregation can become severe when a bin empties by funnel flow. The funnel-flow pattern is a last-in, first-out sequence.

High levels of breakage contribute to dust control problems as the grain is handled repeatedly in grain elevators. Dust is separated from grain during handling for reduction of fire and explosion hazards, environmental pollution, and labor required for housekeeping. The separated dust is frequently returned to the grain stream.

In this test, corn was moved from one bin to another 21 times. The objectives of the study were: (a) To determine the amount of breakage generated and the segregation caused by repeated handling, (b) to determine the amount and size characteristics of dust generated, and (c) to evaluate the effects of breakage on grain dustiness.

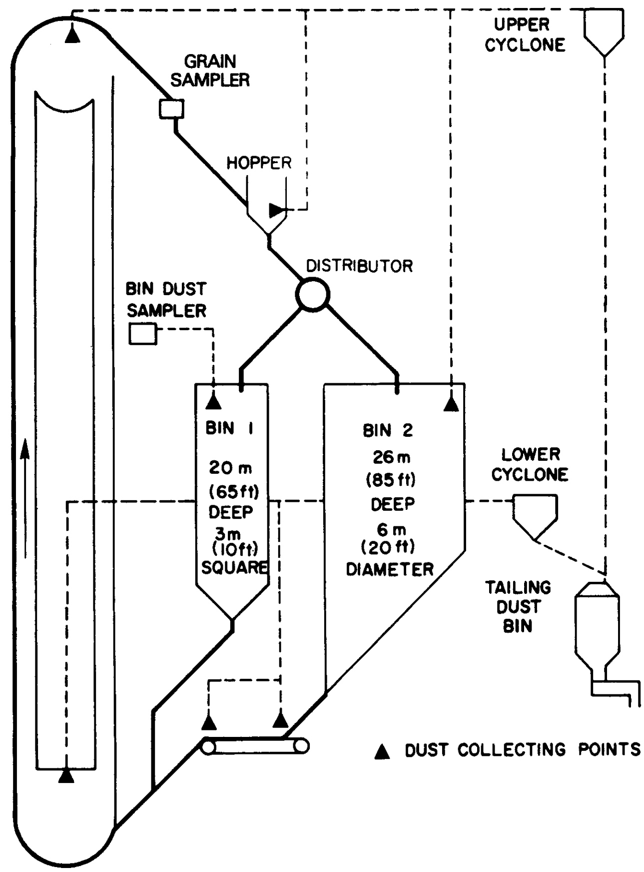

FIG. 1 Grain flow paths and dust collecting points for repeated handling test.

MATERIALS AND METHODS

Test Facilities

Fig. 1 is a schematic drawing of the grain handling system at the U.S. Grain Marketing Research Center (USGMRC) where the test was conducted. Corn was moved back and forth between bin 1 and bin 2. Both storage bins were of slip-formed concrete construction and had their grain inlets slightly off center. When the corn was moved from bin 1, it fell by gravity through spouts and entered the boot on the descending side of the bucket elevator. It was then elevated 53 m (174 ft) and discharged into another spout. It descended 3 m (10 ft) into and through an automatic grain sampler, descended 1.5 m (5 ft) to a hopper, and then continued 3 m (10 ft) to a distributor that directed the flow to bin 2. It then descended another 4.6 m (15 ft) to the point where it entered the receiving bin and fell to the bottom of the bin.

Bin 2 was about 26 m (85 ft) deep

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and 6 m (20 ft) in diameter. It had a sloping bottom that discharged at the side of the bin onto a belt conveyor. From the belt, the grain descended 3 m (10 ft) to enter the elevator boot. The flow path from the bucket elevator to bin 1 was similar to the path described above. Bin 1 was about 20 m (65 ft) deep and 3 m (10 ft) square and had a hopper bottom that discharged from its center.

The USGMRC headhouse was equipped with two conventional dust control systems in which cyclone separators were used to separate dust from the air. One system served the upper and one the lower parts of the handling system. Both cyclone separators discharged tailings into a common dust bin. Ducts in each system connected the many dust collecting points to the appropriate cyclone. Valves located at dust collecting points controlled the amount of air flowing into the dust collection system. The efficient performance of cyclone separators required that most valves be open; however, dust was collected only where grain was flowing.

Dust collecting points and respective cyclone separators were located as indicated in Fig. 1. A hood arrangement covered or surrounded the dust generating points where grain was loaded onto and discharged from the conveyor belt. Surrounding air was drawn through the hoods and entrained the suspended dust. There were dust collecting points located at the boot and head pulley covers of the bucket elevator. Air that was entrained in the grain entered the elevator boot and air from an outside vent entered the head cover. A dust collecting duct that was connected to the hopper drew air from above and entrained the dust suspended within the hopper. The overspace of bin 2 drew air from an outside vent while a dust collecting duct was evacuating air from the top of the bin. Bin 1 was not vented and the dust collection was handled separately as described below.

Test Procedure

The corn used in this test was grown near Wamego, Kansas, in 1973 and harvested with a corn combine. The farmer used an in-bin counter-flow dryer operating at an air temperature of 50 to 58 °C (122 to 136 °F) to dry the grain from 25 to 13 percent moisture content. Corn was loaded into a truck with an auger, hauled to the USGMRC headhouse, and elevated into storage where it remained until used for this test.

A 63.5-ton (2500-bu) lot of this corn was weighed into storage bin 1. The corn was transferred alternately between bins 1 and 2 a total of 21 times at an average flow rate of 71.2 t/h (2800 bu/hr). Each transfer was labeled alphabetically from A through T. An automatic spout sampler took samples from the grain stream at 2-1/2-min intervals. The samples were numbered serially in the order of their collection.

During the test, we set the air control valves in the upper dust control system to control the airflow to the cyclone separator at 4.7 m^3/s (10,000 ft^3/min), and we set the lower system valves to control the airflow to the separator at 7.1 m^3/s (15,000 ft^3/min). The material discharged to the dust bin was removed by an auger under the bin hopper. This dust was collected in barrels for weighing and sampling after each transfer. A 2.3 kg (5.0 lb) sample was removed from each barrel by nine full-depth corings. During transfers Q and R (one cycle of transferring grain from bin 1 to bin 2 and back to bin 1), upper and lower dust control system tailings were collected separately.

We used a commercial vacuum cleaner to collect dust samples from the top of bin 1 as it was filled. The bin's dust control system valve was closed while the vacuum cleaner removed air at 0.03 m^3/s (63 ft^3/min). Since bin 1 was not vented, the air removed was the amount of air displaced by the grain plus the amount of air entrained in the grain flowing into the bin. The dust from bin 1 was weighed after each collection.

Sample Analysis Procedure

We screened each of the samples collected with a 4.75-mm (12/64-in.) round-hole screen on a Strand shaker* for 20 sec to determine breakage. We determined breakage segregation by comparing the breakage levels from samples taken consecutively during each transfer. To compare different transfers that had unequal numbers of samples, we normalized breakage levels into 20 time-weighted values. Then, we obtained the segregation patterns from transfers A, C, etc. (from bin 1 to bin 2) and B, D, etc. (from bin 2 to bin 1) by averaging each of 20 time-weighted values.

We determined coarse particle sizes of each cyclone dust sample after 20 min of sieving on a Fisher-Wheeler sieve shaker, using a U.S. Standard set of No. 20-, 35-, 45-, 60-, 80-, and 120-mesh sieves. We extracted oil from 30-g samples with petroleum ether before the dust was sieved to reduce aglomeration of dust particles and to improve accuracy of size separation. Particles that passed through the 120-mesh sieve were called fine dust.

*Reference to a company or product does not imply approval to recommendations of the product by the U.S. Department of Agriculture to the exclusion of others that may be suitable.

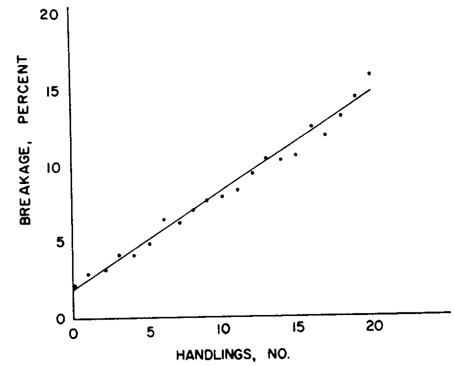

FIG. 2 Breakage accumulated from repeated handling.

RESULTS AND DISCUSSION

Breakage

The amount of accumulated breakage in the corn increased with each transfer from one bin to another. The level, initially 2.0 percent, increased about 0.6 percent with each handling, reaching a levl of 15.7 percent during the 21st handling (Fig. 2). Individual points shown in Fig. 2 are averages of the 18 to 25 samples taken during each transfer.

Corn breakage caused by commercial handling methods has been related to such variables as free fall height, impact surface, and corn moisture content and temperature (Foster and Holman 1973). Corn that fell 12 m (40 ft) onto corn in the commercial handling study, a fall similar to the average 16-m (52-ft) free fall in filling bins 1 and 2, caused the following breakage: 4.3 percent breakage for 12.6 percent moisture corn at -3.8 °C (25 °F) and 0.25 percent breakage for 15.2 percent moisture corn at -5.0 °C (23 °F). Also, breakage of corn handled decreased at higher grain temperatures. By comparison, the corn used in our tests had a moisture content of about 13

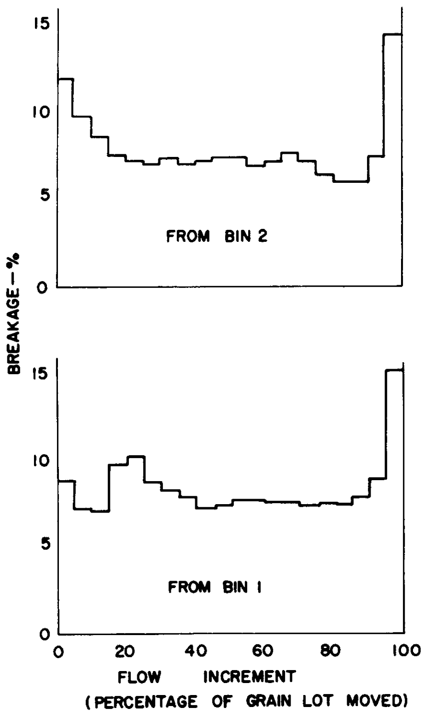

FIG. 3 Profiles of average breakage in grain flowing from bin 1 and bin 2.

percent and a temperature of 11 °C (52 °F), conditions which were within the range of those reported for corn by Foster and Holman (1973). The level of breakage we observed was also within the range reported by Foster and Holman (1973), considering the effect of the temperature and moisture differences in the two tests. A constant increase in breakage during four repeat handlings was also observed by Foster and Holman (1973) in the commercial handling study.

Breakage Segregation

The highest levels of breakage appeared near the start and at the end of the grain flow from the bins (Fig. 3). The segregating process that occurred may be explained as follows: During filling, small broken particles remained near the point of impact as they sieved into the stationary pile while whole kernels rolled down the slope. When the bins were emptied, funnel flow developed. The core of corn removed first in funnel flow had a high level of breakage that was transferred to the hopper of the second bin. When the corn was transferred again, high breakage levels in the bottom of the bin were the last to be removed, and accordingly, were deposited on the surface of the first bin. As the corn was transferred repeatedly, segregation continued and the breakage level increased in the bottom and top of the grain in the bins.

The test lot filled bin 2 to the relatively shallow depth of 5.3 m (17 ft). This depth allowed the surface breakage concentration to reach the flowing stream sooner than it was reached in bin 1. The depth of grain in bin 1 was 19.6 m (64 ft), and the breakage in the surface grain appeared in the flowing stream after 15 to 25 percent of the grain volume had been removed. A change from mass flow at the beginning of the bin-emptying process to funnel flow later in the process could also have caused this delay. In any event the pattern of segregation flowing from bin 1 was different from that flowing from bin 2, a difference related to bin size and shape.

Dust Generation

The weight of dust collected during each transfer increased as shown in Table 1. The average amount of dust removed per transfer was 0.088 percent of the corn weight. When bin 1 was being filled (transfers B, D, etc.), 28 percent more dust was collected than when bin 2 was being filled (transfers A, C, etc.). Two more dust pickup points were involved when bin 1 was filled than when bin 2 was filled. A more detailed breakdown of dust collection was obtained during the cycle when the dust from the upper and lower dust systems was collected separately. These results (Table 2) show that more dust was collected from the upper part of the handling system than from the lower part.

Dust Characteristics

The percentage of particles smaller than 125 μm (5×10^{-3} in.) decreased slightly during repeated handling (Table 1). Overall, 70 percent of the dust collected was fine dust. All of the bin 1 dust collected was fine, as expected, since larger particles were not suspended long enough to reach the dust pickup point at the top of the bin. The amount of fine dust collected by the upper system was about equal for transfers Q and R (Table 2). The dust collected by the lower system during transfers Q and R contained a higher percentage of coarse dust than that collected by the upper system.

We used the ratio of coarse dust to fine dust from each sieve analysis to estimate the amount of coarse and fine particles in the dust collected from each transfer. To eliminate the effect of flow path differences, we added the coarse and fine particle estimates for pairs of transfers to make complete handling cycles. These results are shown in Fig. 4. Coarse dust increased about 1.1 kg (2.4 lb) per transfer,

TABLE 1. DUST COLLECTED DURING REPEATED HANDLING TESTS.

Filling bin 2	Dust collected	Particles smaller than 125 μm*	Filling bin 1	Dust collected	Particles smaller than 125 μm*	Dust from bin 1‡
Transfers	Kilograms†	Percent	Transfers	Kilograms	Percent	Kilograms
A	35.0	78	B	51.8	70	1.7
C	45.5	77	D	59.5	74	1.5
E	52.2	75	F	60.0	70	1.6
G	49.1	77	H	63.2	73	1.3
I	50.9	72	J	62.7	69	1.3
K	49.1	73	L	63.6	67	1.2
M	53.6	71	N	64.1	63	1.2
O	51.3	69	P	66.8	66	1.0
Q	56.8	67	R	67.7	62	1.0
S	43.2	72	T	65.9	63	0.8
Total	496.7			625.3		12.6

*5×10^{-3} inches.
†Kilograms times 2.2 equals pounds.
‡Collected separately. All dust particles were smaller than 125 μm.

TABLE 2. DUST COLLECTION AT SELECTED POINTS IN THE DUST CONTROL SYSTEM DURING TRANSFER CYCLE Q + R.

Dust source	Amount collected	Particles smaller than 125 μm*
	Kilograms†	Percent
Upper System		
Transfer Q	51.8	68
Transfer R	47.7	72
Lower System		
Transfer Q	5.0	56
Transfer R	20.0	38
Total for cycle Q + R	124.5	

*5×10^{-3} inches.
†Kilograms times 2.2 equals pounds.
Q from bin 1 to bin 2.
R from bin 2 to bin 1.

whereas fine dust decreased slightly after an initial buildup. As noted previously, bin 1 overspace dust (fine dust) decreased during the test (Table 1).

The amount of oil extracted from the dust samples increased from an initial 1.7 percent to a final 2.5 percent. This increase suggests that dust stickiness increased. Also, as the breakage level in the grain increased, the total surface area of the material handled increased. Any fine dust sticking to whole kernels and broken material during handling would not have been collected at the dust control points.

Effects of Breakage Level on Grain Dustiness

Each transfer of grain generated 0.6 percent of additional breakage, whereas a comparatively small 0.002 percent of additional dust was collected. Nearly all of this additional dust was made up of particles larger than 125 μm (5 x 10^{-3} in.). In grain elevators, fine dust causes more problems than is caused by coarse dust. Fine dust, which is easily suspended and carried by air, pollutes the environment and, in critical concentrations, can be very explosive. A return of the cyclone tailing dust to the corn in these tests would have increased grain dustiness about 0.09 percent per handling.

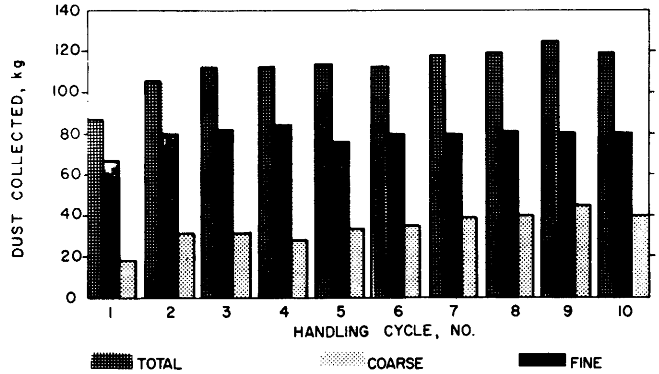

FIG. 4 Dust collected from repeated handling.

CONCLUSIONS

1 Repeated handling of dry shelled corn produces a continuous increase in breakage content during 20 handlings.

2 The flow characteristics of storage bins can cause broken grain to segregate from whole kernels, the degree of segregation increasing with repeated handlings.

3 The handling treatment affects the total amount of dust collected to a greater degree than does breakage content.

4 After an initial buildup, fine dust emission remained constant during repeated handling, even though breakage increased.

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