Corn Dust Emissions with Repeated Elevator Transfers After Selected Drying Treatments

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ABSTRACT

Six high moisture corn lots of about 26t(1000 bushel) were combine harvested at about 25% moisture (wet basis) from one field of yellow dent (Pioneer 3377) hybrid. The identity preserved test lots were dried by a different method and to a different moisture content. After drying treatment, each test lot was moved into a concrete elevator storage bin until the grain elevator transfer impact tests were conducted. Physical properties determined on the corn samples were: test weight, moisture content, and broken corn and fine material (BCFM). During elevator handling and impact transfers, the smallest dust emissions were observed for the natural air dried corn at 12% moisture. Measured dust emission was the most for heated air dried corn to 10.6% moisture. Key factors to the difference in dust emissions were the drying air temperature, drying method, and the moisture content of the test lot at the time of repeated transfers.

INTRODUCTION

The Occupational Safety and Health Adminstration (OSHA) has established grain handling safety standards (Federal Register, 1987) which include rules about dust control and requirements for housekeeping programs to manage grain dust emissions. All off-farm grain handling facilities are required to develop and implement a written housekeeping program—to reduce accumulations of fugitive grain dust on ledges, floors, equipment, and other exposed surfaces. Fugitive grain dust means combustible dust particles emitted from the grain handling system and of a size less than 400 microns. The "action level" established by OSHA for priority housekeeping areas requires immediate removal of fugitive grain dust accumulations whenever they exceed a thickness of 3.175 mm (1/8 in.). The standards require prompt correction of malfunctioning pneumatic dust collection systems. Employees are to be trained in recognition and preventive measures for hazards related to grain dust accumulation and common ignition sources.

Mechanical field-shelling of corn followed by high-temperature, rapid drying can result in broken kernels, damaged kernels, thermal stress cracks, fine material, and degradation in the physical properties relative to handling and end-use. Chowdhury and Buchele (1978) found that combine-shelling produced grain with less than 75% whole, sound kernels by weight. Laboratory analysis (Martin et al., 1987) of corn samples using a green dye and visual separation of the degrees of mechanical damage to new harvest yellow and white corn have confirmed that optimum machine shelling might produce 80% whole, sound kernels. Soft and hard starches of the endosperm become exposed to the air and cause deterioration of the broken kernels; further damage occurs from grain augers and mechanical and penumatic conveying (Chung et al., 1973; Thompson and Foster, 1963).

Typical physical damage to corn by various handling techniques used in commercial grain handling facilities was determined by Fiscus et al. (1971) and Foster and Holman (1973). Corn breakage caused by commercial elevator handling was measured during tests conducted by Cargill, Inc. in which the breakage from the entire test lot was removed and weighed; therefore, sampling was not involved. Drop height was the most significant test variable in the free-fall and spouting tests. There was consistently less breakage at 15% moisture level than at 13% moisture content. There was less breakage when the corn temperature was above 20° C than when it was below 10° C (Foster and Holman, 1973).

Martin and Stephens (1977) found that the flow characteristics of shelled corn from hopper bottomed bins can cause broken corn and foreign material (BCFM) to segregate, and the degree of segregation increased with repeated transfer handling. They also found that the pattern of segregation flowing from a small rectangular bin was different from the pattern flowing from a larger round bin, a difference related to bin size and shape. The corn from the same field, yellow dent hybrid (Pioneer 3377), was used by Eckhoff et al., 1988 in evaluation of the effects of moisture content and grain temperature on breakage susceptibility (BrSu) values as determined by breakage test instruments. A significant interaction between moisture content and temperature was observed. Therefore, the repeated transfer impact tests at the elevators were conducted within the same temperature range (10° C ±4° C) for the corn and ambient air.

Article was submitted for publication in January 1989; reviewed and approved for publication by the Food and Process Engineering Div. of ASAE in September 1989. Presented as ASAE Paper No. MCR 88-125.

Mention of firm names or trade products does not constitute endorsement by the U.S. Department of Agriculture over others not mentioned. Contribution No. 89-109-J of the Kansas Agricultural Experiment Station. The project was partly supported by the Federal Grain Inspection Service under contract No. 54-6395-6-40 with Kansas State University.

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Acknowledgment: The authors wish to acknowledge the contributions of George Wyatt, Engineering Technician, USGMRL, L. G. Obaldo, Graduate Research Assistant, and Marty Criswell, Research Assistant.

The objective of this analysis was to determine the amount of dust emissions during multiple elevator transfers of the same lot of corn and to evaluate the effect of six different grain drying treatments on these emissions.

METHODS AND PROCEDURES

The yellow dent corn used for these elevator transfer tests was combine harvested from a selected field of Pioneer Hybrid No. 3377 located about 16 miles east of Manhattan, Kansas. The farm owner and his operators cooperated with labor, trucks, combine, and in-bin heated-air grain drying. The field-shelling machine was an Allis-Chalmers Model L2 Gleaner with a six-row corn head. A DICKEY-john GAC II moisture meter with printer was used with field sampling to determine when the average moisture content of grain reached 25%. The first two 26-t (1000/bushel) test lots were harvested in early September for in-bin layer drying treatments. Two more (1000/bushel) test lots were harvested the next week for cross-flow recirculating batch dryer treatments. In the third week, two 26-t (1000/bushel) test lots were harvested for in-bin heated-air and ambient air drying treatments.

Test Lot — Grain Drying Treatments

Six drying procedures were employed to produce corn lots with different levels of breakage susceptibility (BrSu). The test lots were numbered in the sequence of harvesting. Lot 1 was transported to the U.S. Grain Marketing Research Laboratory (USGMRL) elevator headhouse, where it was dumped, elevated, sampled by the automatic diverter-type (D/T) spout sampler, and gravity spouted into a load-out bin. The next day, Lot 1 was moved by truck and a 15-cm (6-in.) diameter transport grain auger into a 5.486-m (18-ft) diameter in-bin dryer and dried with natural air plus 2° C to 5° C of temperature rise using a 7.00 kW vane-axial fan. Moisture content was reduced 12.5 points with 133 hours of fan operation with an airflow of 5 m^3/min per m^3 of grain.

Lot 2 was transported to the cooperator's on-farm 7.315-m (24-ft) diameter in-bin grain dryer equipped with a 9.00 kW in-line centrifugal fan, a 293 kW (1,000,000 Btu/h) propane burner, and with a Shivvers circulator. This corn was exposed to heated air at a temperature of 105° C and dried to a moisture content of 15%. It was then unloaded and transported to the USGMRL elevator, where it was weighed, elevated, automatic D/T-spout sampled, and gravity spouted into a concrete storage bin.

Corn lots 3 and 4 transported to a commercial elevator for drying with a Gilmore & Tatge, 12.7 t (500/bushel) recirculating batch dryer equipped with a 8.00 kW axial fan and a 880 kW (3,000,000 Btu/h) burner. Lot 3 was subjected to heated air at 100° C and dried down to 10.6% moisture. Lot 4 was dried with heated air at 70° C to a moisture content of 13.6%. After drying, each lot was transported to the USGMRL elevator, weighed, elevated, automatic sampled, and spouted into separated concrete storage bins.

Lots 5 and 6 were transported to the cooperator's in-bin dryer (same as for lot 2), where both lots started a combination heated-air drying procedure to remove about 5 points of moisture using a controlled air temperature of 80° C. Then lot 5 was unloaded and transported to the USGMRL, weighed, elevated, sampled, and transferred to a in-bin layer dryer equipped with a 11.00 kW centrifugal fan, where ambient air was used to achieve a final moisture content of 12.5%. Lot 5 was unloaded and transferred to a concrete storage bin. Then lot 6 was transferred from the cooperator's in-bin, heated-air dryer to the in-bin, ambient air dryer at the USGMRL (same as for lot 5) and dried to a final moisture content of 13%.

TABLE 1. Grain elevator corn cleaning data before transfer rotations

Drying Treatment Lot No.	Average Moisture Percent	Cleaned Corn Weight Tonnes	Bushels	Removed by Cleaning BCFM Percent
1 In-bin layer Natural heat	12.0	20.95	825	3.15
2 In-bin 105° C air	15.0	23.64	930	3.88
3 Batch Dryer 100° C	10.6	22.04	868	5.79
4 Batch Dryer 70° C	13.6	24.33	958	2.68
5 In-bin* 80° C + then Ambient air	12.5	25.45	1002	2.06
6 In-bin* 80° C + then Ambient air	13.0	24.97	983	2.30

* Two-stage combination heated air first then transferred to a different in-bin drying system

Repeated Handling Procedure

Prior to the repeated handling operations, each test lot of corn was transfer-elevated and passed through a Continental Grain Cleaner, Mark II-B, adjusted and set for corn with a fine sieve size openings of 5.16-mm (13/64-in.) diameter round holes and a scalper screen to remove foreign material. This cleaning operation removed more broken corn and fine material (BCFM, Table 1) than would be measured by the official Carter dockage tester procedure (USDA, 1988).

After the cleaning operation, the test lot was transfer-elevated for automatic scale weighing to determine starting lot weight before the repeated elevator handling tests. Data collected for the first transfer-rotation included any breakage from the weighing operation. Cyclone dust collectors separated airborne particulate during the weighing operation, adding to the first transfer-rotation dust measurement.

A schematic (Fig. 1) of the test elevator facilities shows the general grain flow plan. Vertical grain elevating distance was 54.9 m (180 ft) followed by gravity spouts with an automatic D/T spout sampler, diverter grain gates, and a distributor plus spouting into the bins. The handling tests consisted of moving the test lot from the bottom bin into the leg and up over the head into gravity spouting, the sampler, and the top bin A, then allowing 7.6 m (25 ft) free-fall through bin A1 into the lower bin, A2. Hang-up grain, dust, and BCFM on the hoppered bin bottoms were manually removed and returned to the

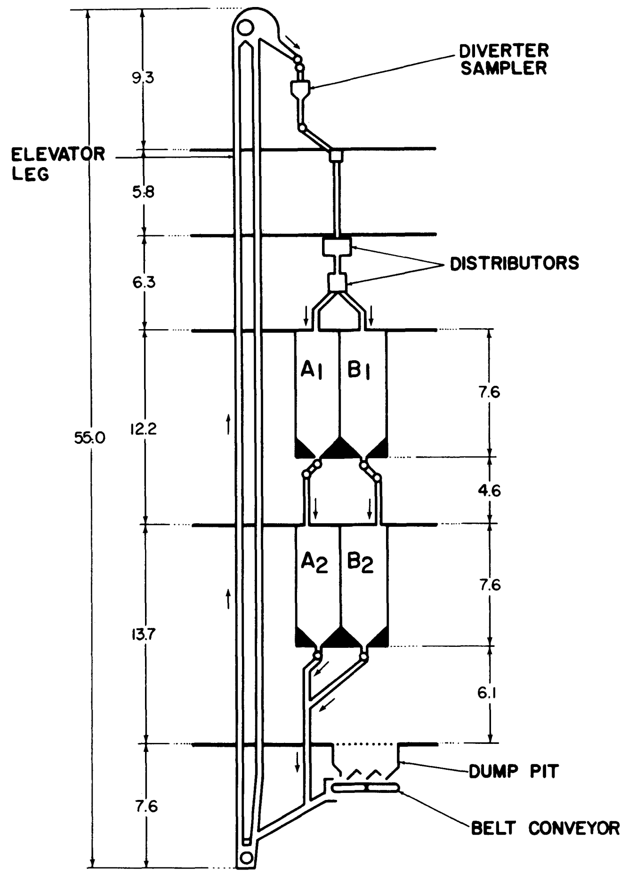

Fig. 1—Schematic of grain flow in the concrete grain elevator headhouse at U.S. Grain Marketing Research Laboratory, Manhattan, KS. (All dimensions in meters)

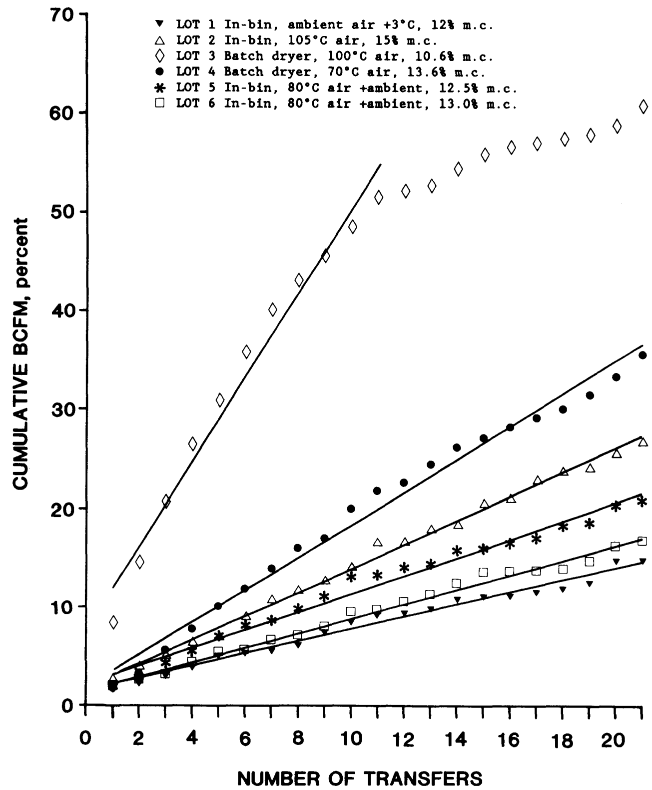

Fig. 2—Cumulative percent broken corn and fine material as a function of the number of transfer passes for each corn lot exposed to different drying treatment.

test lot after using the bin for no more than three transfer rotations to keep segregated material within the test lot grain. A normal loading of 75% was used for the elevator leg. With the grain handling bucket elevator leg and dust control system running, the grain bin draw-off gate was manually adjusted to obtain the same corn flow rate (volume/h) at the start and during each handling-transfer period. The handling and flow rates ranged from 55.8 t/h to 60.2 t/h (2,200 bu to 2,370 bu/h) for 120 test periods. The range in cumulative elevator and dust control running time for 20 transfer-rotations of one corn lot was from 7.9 h to 9.2 h.

A composite corn sample was obtained from the D/T spout sampler during each test run of approximately 30 min with the sampler timer set for 45 s to 50 s between diverter cuts. The 20 kg composite sample was reduced in size by the official type Boerner divider to 5 kg and 1 1/2 kg duplicate corn samples for BCFM analysis, moisture content determination, and breakage susceptibility tests. Twenty samples for each corn drying test lot were used to determine broken corn generation (Fig. 2).

BCFM and Moisture Content Determination

The amount of BCFM in the sample from each handling (rotation) was determined for two samples following the grain inspection procedure (USDA, 1988) using a Carter dockage tester, Style XT2, with the 4.76-mm (12/64-in.) round hole sieve.

The moisture content of about 100 g from each sample was determined by the whole kernel, air oven method (103° C for 72 hours) (ASAE, 1986). Moisture levels were expressed on a wet basis (w.b.).

Pneumatic Dust Emission — Control Operations

Cyclone centrifugal dust collectors were used for both the pneumatic dust control systems and the grain cleaning operations. Ventilation and emission control for all the upper spouting, distributors, and bin filling areas involved pulling about 5 m^3/s (11,000 CFM) of air (total) from transfer points and exhausting it through a 2.74-m (9-ft) diameter low pressure cyclone, while the ground level dust control system exhausted about 5.5 m^3/s (12,000 CFM) of air through twin 2.24-m (7 1/3-ft) diameter low pressure cyclones. All of the separated grain dust was gravity spouted into one hopper- bottom steel dust bin. The dust bin was emptied into a weigh-buggy four times for each corn test lot, making either five or six transfer-rotations per dust weight measurement.

Two Breakage Susceptibility Measurement Methods

Four replicate evaluations of BrSu were made on representative sample portions drawn from the BCFM-free sample left after Carter dockage tester determinations. The Stein corn breakage test (SBT) procedure, AACC Method 55-20 (1983), was followed with a Stein CK-2M tester in which 100-g samples were processed for a 2-min period.

The second method used to determine BrSu was the Wisconsin breakage test (WBT), following the procedure employed by Gunasekaran and Paulsen (1985). A 200-g sample size and a 200-g/min feed rate were used for four samples.

After the breakage tester runs, each sample was sieved for 30 cycles on a Gamet-or-Strand shaker using a 4.76-mm round hole precision sieve. The material left on the sieve was removed and weighed. The difference between starting sample weight and ending (overs) weight was used to calculate the percentage of the sample passing through the sieve and the BrSu value.

RESULTS AND DISCUSSION

The repeated elevator transfers of the six corn lots were completed within a 7-week time period (2 Feb. to 20 March) while ambient air and handling facilities were at a day time normal temperature of about 10° C ±5° C.Initial test lot corn temperatures were in the 8 to 10° C range before handling and were in the 11° C range ±3° C after the repeated transfer tests.

Rate of Broken Corn Generation

The amounts of BCFM measured after each transfer-rotation for each test lot are shown in Fig. 2. The experimental data for a given corn lot fit a linear model for the BCFM increase. In the handling tests for Lot 3, the transfer-rotation procedure was changed after 10 rotations because the breakage and fine material caused a spout flow problem, along with hopper bottom bin flow and the segregation of material around the bin bottom outlet. The free-fall through the upper bin was changed to a normal grain on grain filling of the upper bin followed by full spout flow into the bin below. This procedure caused a change in the rate of BCFM increase for Lot 3, which was the lowest in moisture content (10.6%) (Table 2). In general, the rate of breakage increased with the use of high temperatures in the drying treatments (Gustafson et al., 1978). The rate was lowest for in-bin, layer drying with natural air. Lot 2 had a lower rate than Lot 4 because of the type of dryer used and the higher average moisture content of 15% after drying. The high-temperature recirculating batch dryer exposed the kernels to higher air temperatures for a longer period than did the in-bin layer dryer.

Breakage Susceptibility

Changes in the measured breakage susceptibility percentage as a result of the repeated handling were found to be relatively small but generally increased with handling. The magnitude of the BrSu measured by the WBT was found to be almost twice that measured by the SBT for the low breakage test lots 1, 5, and 6 (Eckhoff et al., 1988).

TABLE 2. Corn breakage – cumulative BCFM after elevator transfer – rotations

No. of Transfers	Breakage Percent					
	Lot 1	Lot 2	Lot 3	Lot 4	Lot 5	Lot 6
2	0.91	2.43	12.18	3.57	2.44	1.24
5	3.91	6 40	27.27	9.76	6.25	3.66
10	7.11	14.01	43.01	19.77	11.49	7.86
15	9.12	18.47	48.05*	26.19	14.77	11.81
20	12.87	24.03	52.13*	33.57	19.21	14.84
Transfer Average	0.64	1.20	4.30†	1.68	0.96	0.74

* Handling rotation procedure was changed after the 10th transfer
† Transfer average for the first 10 rotations for Lot 3

TABLE 3. Corn dust emissions separated by pneumatic dust control systems

Drying Treatment Lot No.		Average Moisture Percent	Centrifugal Cyclone Separator Tailings: Transfer Rotations 22 Elevations Lot Weight Loss (%)	Dust Emissions Per Handling: Weight Loss Percent	Dust Emissions Per Handling: Parts per Million (ppm)
1	In-bin layer Natural heat	12.0	1.84	0.08	836
2	In-bin 105° C air	15.0	4.66	0.21	2119
3	Batch Dryer 100° C	10.6	4.45	0.20	2020
4	Batch Dryer 70° C	13.6	4.38	0.20	1991
5	In-bin 80° C Ambient air	12.5	3.39	0.15	1539
6	In-bin 80° C Ambient air	13.0	3.00	0.14	1363

Moisture Content

No significant changes in corn moisture content were measured in any test lot as it was being transfer-rotated. The mean moisture contents were 12.0%, 15.0%, 10.6%, 13.6%, 12.5%, and 13.0% for lots 1 through 6, respectively, as shown in Table 1. The standard deviation in moisture content for individual lots varied from 0.04% to 0.18%.

Characteristics of the Corn Dust Emissions

One of the values in conducting these repeated handling tests with shelled corn of known history is the knowledge gained about the amount or quantity of combustible dust that might be emitted into the air as pollution or contamination within work areas. On the basis of the weight of dust separated by the dust control systems, the total percent of dust emissions was calculated for an average amount per transfer-rotation and evaluated in parts per million (ppm) average per transfer-handling (Table 3). In these tests, nearly all the dust emissions were drawn through the fans and out through the cyclone dust separators, with only the very small particulates (less than 10 microns) being transferred to the atmosphere in an amount estimated to be less than 100 ppm.

The amount of dust emissions determined by the weight of airborne particulate captured by the two pneumatic dust control systems remained nearly the same during all of the transfer-impact tests with one given test lot. Since the airborne emissions were removed during each test, there was no measured or observed build-up nor decrease in dust emissions even though each test lot had a continued cumulated BCFM increase for every transfer period.

CONCLUSIONS

1. The cumulative broken corn and fine material produced by repeated handling appeared to be linearly related to the number of transfer-rotations the corn made in a concrete grain elevator.
2. The rate of broken corn generation and dust emissions increased with the severity of heated-air drying treatment and with the degree of over-drying to low moisture contents.
3. The breakage susceptibility values increased only slightly during 20 transfer-rotations of a test lot and are functions of the drying procedure.
4. Dust emissions were highest for the corn lots that had been exposed to air temperatures of 100° C to 105° C during in-bin and heated-air batch drying and for the test lots having the higher breakage (BCFM) level.
5. Based on the U.S. corn marketing grading system, the elevator transfer-rotation procedure was more severe than expected and caused more breakage than would be practical in handling corn for marketing under the U.S. grain grading standards. All drying treatment lots became sample grade with 10 or less repeated elevator transfers.

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