空氣運送系에 있어서 옥수수의 損傷에 關한 硏究

Damage to corn in Pneumatic conveying

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I. 적 요

옥수수를 공기운송할때 옥수수 곡입에 주는 기계적인 손상량을 규명하기 위한 실험실 시험을 행하였다. 이 시험에 고려된 변수는 옥수수의 함수량, 곡입의 크기와 모양, 운송 공기 속도, 그리고 운송길이였다. 곡입의 크기 또는 모양은 작고 납작한 곡입, 크고 납작한 곡입, 크고 둥근 곡입이였다. 곡입의 수분함양은 12%와 20%였다. 공기속도는 3960, 5160, 6000, 7200 f.p.m 였으며 운송길이는 200, 800, 1600 ft였다.

기계적 손실은 파손입자 ($\frac{12}{64}$인치 둥근 구멍체를 통과하는 입자), 파손곡입, 큰구열 곡입, 작은 구열 곡입 등 네가지 종류로 분류하였다.

실험 결과에 의하면, 운송 속도가 높은것이 옥수수 손상을 증가시키는 가장 중요한 요인이였다. 높은 공기속도로 인한 손상은 함수량이 작을때 더욱 뚜렷하였다.

곡입의 크기와 형태에 관한 영향은 거의 없었다. 옥수수가 운송되는 거리에 대한 손상비율의 비는 첫 200ft.에서 일반적으로 높았고, 곡입손상은 운송거리가 증가됨에 따라 감소하였다.

좋지 못한 조건하에서 운송계를 작동하면 옥수수에 주는 손상은 대단히 클수 있으므로, 함수량에 따른 운송 공기속도의 범위를 기대되는 곡입손상과 대비시켜 표시하였다.

INTRODUCTION

Recently, farmers and grain-handling firms have become increasingly concerned about economic losses resulting from grain damage. Harvesting machinery probably is responsible for most of the mechanical damage to grain, but conveying methods and equipment certainly contribute(1)[1]

Segler (6), working with peas and wheat showed that in pneumatic conveying, the air velocity of the conveying system and the moisture content of the grain conveyed were the most critical factors in the amont of grain damage. Segler also showed that the grain-input rate, the conveyor-pipe diameter, and the temperature of the grain were relatively unimportant. Metzer (4) investigated seed viability loss resulting from various operating conditions of pneumatic conveyors. Pearson and Sørenson (5) studied the damage to germination of grain sorghum resulting from the high velocity conveying. They also investigated the influence of gran's moisture content in establishing a safe range of air velocity. A number of different methods have been used to evaluate damage to grain that is conveyed pneumatically. The standard germination and cold-soil emergence tests have been used to determine seed viability (4). The sieving method (7) is the U.S. Official Grain Standard means of measuring grain breakage. However, in evaluating the quality of commercial grain there is no acceptable method of determining the extent of broken or damaged kernels not separated by sieving. Recently, Kaminski (3) discussed the need for better standards to evaluate grain damage. Since few data have been available on the effect of handling equipment and various types of

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1) Underscored numbers in parentheses refer to Literature Cited, p. 26

conveyors on grain damage, little progress has been made on improved handling methobs and equipment that minimize grain damage.

This is a study of the damage to corn caused by a pneumatic conveyor under a variety of operating conditions. The conveying air velocity and the distance conveyed were the principal variables contributing to corn damage. The relationship of the corn kernel size, shape, and moisture content to the amout of mechanical damage in pneumatic conveying was also studied.

APPARATUS

The pneumatic conveying system used for the experimental work consisted of an air blower with a variable-speed power unit, a rotary air-lock feeder, coveying pipe,and a cyclone separator. Figurel shows a schematic diagram of the system.

The blower had the capacity to deliver air at maximum pressure of 10 pounds per square inch gage (p.s.i.g.) continuously.

A calibrated airflow meter (rotometer) was used to measure air volume and pressure gages used to measure static pressure. Corn was introduced into the system through a rotary drop-through airlock feeder. The amount of corn was metered by a cone orifice in a surge hopper located above the airlock feeder. The aluminum conveying pipe and elbows were 1.9-inch inside diameter. Total conveying length of the pipe from feeder to the cyclone separator was 200 feet. The conveying pipe included one 45-degree and 14 90-degree elbows, each with a 24-inch radius. The length of the line in elbows totaled 45.6 feet.

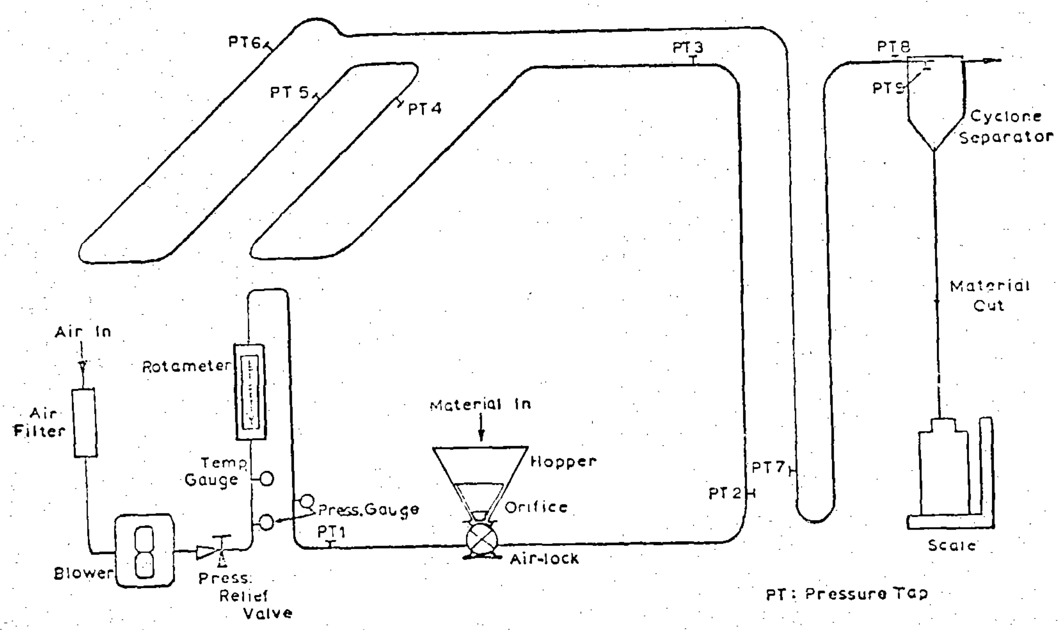

Figure 1. A schematic diagram of pneumatic conveying system.
Total Conveying Length: 200′ Pipe Diamter: 1.9″ID. Horizontal Length: 132′. Vertical Length 22.5′, Equivalent Elbow Length 45.6′

TEST VARIABLES AND PROCEDURE

In order to test the effect of the pneumatic conveying system on the damage to corn, four variables were studied: Kernel size and shape, corn moisture content, the air velocity of the conveying system, and the distance the corn was conveyed. The levels of the variables studied re given in table 1.

CORN KERNEL SIZE AND SHAPE

Corn kernels vary in size and shape; the size and shape distribution depends on the growing history and the variety of the corn. Data were obtained on eight sizes and shapes of corn kernels. However, the results reported here are for a weighted average of three size and shape categories; large-medium-flat, small-small-flat, and a mixture of large-round and medium-round. About 80 percent of the kernels in the corn lot used were in these three size-shape categories.

Table 1. Approxitmate Levels of Experimental Variables

Experimental Variables	Levels Tested			
	1	2	3	4
Size and shape	Small Small Flat	Large Medium Flat	Large and/or Medium Round	
Moisture Content(%)	12	20		
Air Velocity (f.p.m)	3960	5160	6000	7200
Distance Conveyed	200ft.	800ft.	1600ft.	

CORN MOISTURE CONTENT

Yellow corn at two moisture contents was tested. One test lot of corn, from the 1967 crop, had a moisture content (m.c.) of 12 percent. The other test lot, from the 1968 crop, had a 20 percent m.c. Both corn crops were harvested by a combine. The moisture contents of the corn crops at harvest were approximately 27 percent m.c. for the 1967 crop and 25 percent m.c. for the 1968 crop.

AIR VELOCITY IN CONVEYING PIPE

Pneumatic conveyor transports grain material in suspension along the pipe by means of the air stream. Tests were conducted using various sizes of corn kernels at different air velocities to determine the minimum velocity for cleanout of all kernels dropped into the system. This system (figure 1) used in these tests gave satisfactory horizontal and vertical transport flow at the lower average air velocity, 3960 f.p.m. The higher average air velocities were 5160, 6000, 7200 f.p.m. and were used to apply additional abrasion and impact pressures to the corn kernels.

PROCEDURE

The corn used for the tests was field-shelled and then aerated and dried in 140-bushel refrigerated bins which were used for non-related refrigerated storage tests(2). Here, the corn from both crop years was cooled to 35°—40° F and ventilated continuously using an upward airflow rate of 0.5 cubic feet per minute(c.f.m) per-bushel. The 1967 corn crop test lot used for the conveying test was taken from the refrigerated test bin after 150 days of aeration with refrigerated air. Its moisture content was about 12 percent. The 1968 corn crop test lot was taken from the refrigerated test bin after 28 days of aeration with refrigerated air. Its moisture content was about 20 percent.

After the breakage was removed by the dockage tester, the breakage was weighed and its percentage of the whole sample lot was calculated. The corn with the breakage removed was dyed green so that the chipped and cracked kernels could be distinguished visually from the sound ones. The damaged corn kernels were classified arbitrarily into four categories:

(1) breakage: fine pieces of kernels that passed through a 12/64-inch round-hole sieve of the dockage tester

(2) broken kernels: any kernels that were chipped or broken

(3) large cracks: cracks extending through the whole kernels

(4) small cracks: any mark of skin damage other than the large cracks

The separated fraction of damaged kernels, broken kernels, with large cracks, and small cracks were weighed and the percentage of each category of damage was calculated. The total damage was the sum of the four categories. Table 2 shows initial damage to each classified corn test lot before it was subjected to a pneumatic conveyor.

Table 2. Mechanical Damage in Percentage of Total Sample Weight of Each Classified Corn Sample before It was handled in a Pneumatic Conveyor[1)]

Type of Damage	Low-Moisture Corn (12%)			High-Moisture Corn (20%)		
	Large and/or: Medium Round:	Large: Medium Flat:	Small Small Flat:	Large and/or: Medium Round:	Large: Medium-Flat	Small-Small-Flat
	Percent	Percent	Percent	Percent	Percent	Percent
Large Cracks	3.25	3.35	2.16	2.65	2.01	0.59
Small Cracks	14.47	12.42	10.99	14.34	13.94	14.85
Broken	6.92	7.48	10.15	4.55	6.46	13.28

1) Average of six replications.

A 7-pound corn sample, with breakage removed, and at a given moisture content, kernel size and shape, was conveyed at a specified air velocity in the pneumatic conveyor. After it was conveyed the first 200 feet, the corn was passed through a dockage tester to evaluate the percentage of breakage. The corn with breakage removed was then passed through a Boerner sample divider to obtain three 100-gram samples for mechanical damage evalution by the dye-test method. After the three 100-gram samples were removed, the remaining breakage-free corn was conveyed an additional 600 feet, the breakage and damage again determind, and this amount added that from the 200 feet conveying test to give the value of damage from 800 feet conveying length. The corn was conveyed an additional 800 feet, using the same procedure.

A total of 144 conveying tests were made. There were 72 treatment combinations —3 (sizes and/or shapes)×2 (moisture contents)×4 (velocities) ×3(distances) for each replication. Two replications were for each treatment combination.

RESULTS AND DISCUSSION

The test data were analyzed statistically to determine the factors and interactions of factors that significantly contributed to mechanical damage during pneumatic conveying. For the 12 percent m.c. corn, size and shape though statistically significant, were practically negligible. For the 20 percent m.c. corn, size and shape contributed somewhat to the increase in damage; however, the damage increase was small in most of the tests. Therefore, the damage data of three size and shape classifications were combined. The damage data reported are the weighted averages of three size and shape classifications, based on the percentage of weight each classification is of the original sample weight.

The effects of air velocity and conveying length on breakage for the two corn moisture content levels are shown in figure 2. For corn with a 12 percent m.c., the increase in air velocity and conveying length caused breakage to increase rapidly; while for the corn with a 20 percent m.c., the increase in breakage was small.

Figure 3 shows the broken damage increase in 12 and 20 percent m.c. corn when it is conveyed at air velocities varying from 3960 to 7200 f.p.m. and for conveying lengths of 200, 800, and 1600 feet. Note that the data shown in figure 3 exclude the broken damage (8.20 and 6.93 percent broken damage in original 12 and 20 percent m.c. corn, respectively) in the original sample caused by harvesting and/or drying. At either moisture level, an increase in air velocity and conveying length increased the broken kernels.

Pneumatic conveying of corn at 20 percent m.c. caused less than 5 percent broken damage even at the highest air velocity (7200 f.p.m.) and the longest conveying distance (1600 ft.). However, pneumatic conveying of low moisture corn at 12 percent m.c. under the same conditions 7200 f.p.m. of air velocity and 1600 ft. caused about 70 percent broken damage to the corn kernels.

The results indicate that for corn at both moisture contents the number of small cracks in kernels generally increased proportionally with the increase in air velocity and conveying length.

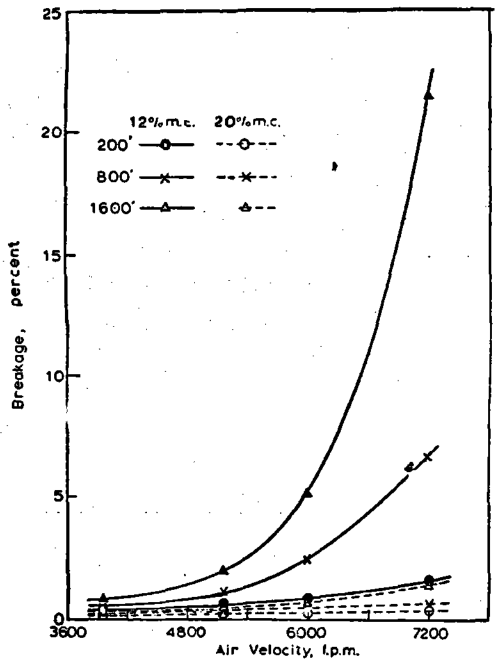

Figure 2. Breakage, material passed through 12/64 inch round hole sieve, versus air velocity at three conveying lengths (200, 800, and 1600 tf.) for corn with 12 and 20 percent m.c.

For low-moisture corn (12 percent m.c.) at the highest air velocity (about 7200 f.p.m) the number of small cracks rapidly decreased after four repeated runs (800 ft. of conveying); the decrease in small cracks were in direct proportion to the increase in broken kernels. For corn with either moisture content, large cracks accounted for only a small percentage of the total damage.

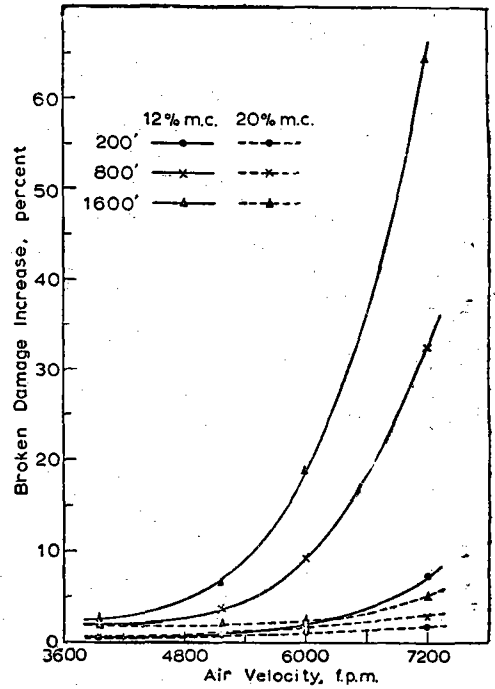

Figure 3. Broken damage increase versus air velocity at three conveying lengths (200, 800, and 1600 ft.) for corn with 12 and 20 percent m.c.

Total damage increase (the sum of the breakage, the broken kernels and the large and small cracked kernels) was compared for the four different conveying air velocities (3960, 5160, 6000, and 7200 f.p.m.), and three conveying lengths (200, 800, and 1600 ft.) and two corn moisture levels (12 and 20 percent m.c.). The results are shown in figure 4. Note also that the results in figure 4 exclude the broken damage and cracked kernels in the original sample that were caused by harvesting and/or drying (23.5 and 23.0 percent broken and cracked damage in original 12 and 20 percent moisture corn, respectively). For each test condition, the total damage increase in the 12 percent m.c. corn was much higher than damage increase in the 20 percent m.c. corn. At the higher moisture content (20 percent m.c.), the increase in total damage could be kept below 20 percent, even for the highest air velocity (7200 f.p.m.) and the longest distance conveyed (1600 ft.).

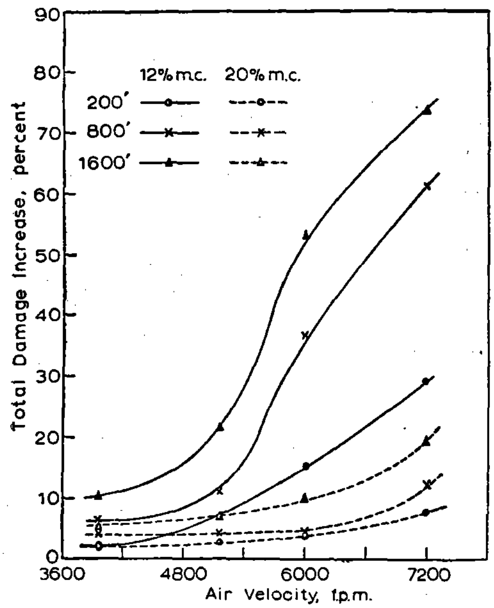

Figure 4. Total damage increase versus air velocity at three conveying lengths for with 12 and 20 percent m.c.

To obtain information on sources of damage in pneumatic conveying, the total damage versus conveying-length curves and total damage versus air-velocity curves were graphically differentiated. For a given moisture content, in the first stage of conveying length (200 ft.) the total damage increase was generally high but the total damage decreased rapidly as the conveying length increased.

Graphical differentiation of total damage versus air velocity revealed a difference in damage characteristics for the two moisture levels. For high moisture corn, the total damage rate increased almost proportionally with the increase in velocity regardless of conveying length, and the total damage rate was comparatively low even at the high air velocity; therefore, successive handling of high moisture content corn with a pneumatic conveyor set at the highest air velocity (7200 f.p.m.) would not cause excessive damage. But for low moisture content corn, each curve showed a maximum point at about 5700 f.p.m. when damage rate increased sharply. Based on these tests, the upper limit of air velocity for conveying low moisture corn should be around 5400 f.p.m. to avoid excessive damage to the corn.

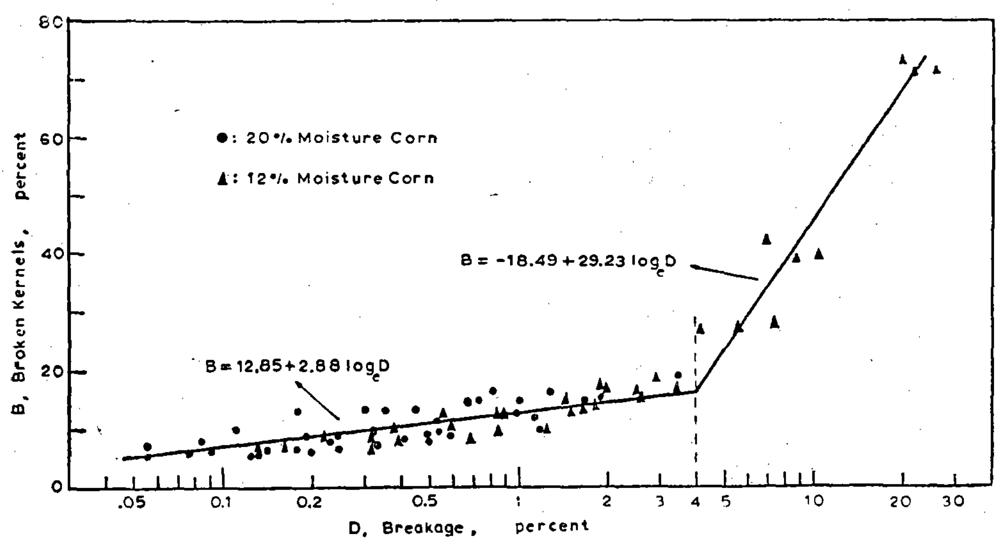

Figure 5. Relation between the percentage of actual broken damage (broken kernels over 12/64 inch round hole sieve) and breakage (broken kernels under 12/64 inch round hole sieve) for a pneumatic conveyor.

By using the dockage tester with the 12/64-inch round hole sieve, an attempt to predict the relation between total damage and breakage was made, but total damage for a given breakage varied so widely that a reasonable prediction was not possible. In figure 5, the broken damage was plotted against breakage on semi-logarithmic graph paper and showed a linear relation between two distinct trends.

A relationship between B(the percentage of broken damage) and D (the percentage of breakage) for pneumatic conveying was obtained.

The regression lines for the two distinct trends in figure 5 are:

$$B=12.85+2.88\log_e D,\ 0.05\% < D < 4\% \quad (1)$$

$$B=-18.49+29.23\log_e D,\ 4\% < D < 25\% \quad (2)$$

where B is the estimated broken damage in percent, and D is the breakage in percent that passed through 12/64 inch round hole sieve in the dockage tester. The broken damage to corn resulting from pneumatic conveying can be approximated by equations 1 or 2 and figure 5, with the known breakage value determined by the dockage tester having 12/64-inch round hole sieve.

If breakage is two percent (the maximum limit allowable for U.S. Grade No. 1 corn), by using equation 1 or figure 5 the broken damage can be estimated to be 13 percent.

In operating a system similar to the one used in this investigation one can choose an appropriate operating condition for a certain limit of damage allowable. Table 3 shows the estimated limit of operating conditions for conveying breakage-free corn to satisfy a certain grade requirement.

Table 3. The Limits of Operating Conditions for Certain Grade Requirements

Grade	Maximum Allowable Breakage	High Moisture(20%)		Low Moisture (12%)	
		Conveying: Length:	Air Velocity	Conveying: Length:	Air Velocity
	Pct.	Ft.	F.p.m	Ft.	F.p.m.
		< 800	7200	< 200	7200
1	2	<1600	6000	< 400	6000
		> 1600	5160	<1400	5160
				> 1600	3960
		<1400	7200	< 300	7200
2	3	> 1600	6000	< 700	6000
				<1600	5160
				> 1600	3960

If the total damage is more important, as for a specific use, i.e. export market, the appropriate operating condition could be chosen from table 4 which shows a certain limit of the increase in total damage resulting from pneumatic conveying.

If operated under adverse conditions, a pneumatic grain conveyor can cause serious damage to corn. In the interest of conserving energy and maintaining reasonable operating costs, farmers and grain-handling firms should use the lowest practical air velocity for conveying corn that is consistent with the desired rate of transfer (quantity per hour). To avoid excessive damage to dry corn, air velocity should not exceed 5400 f.p.m

Table 4. The Limits of Operating Conditions for the Increase in Total Damage Allowable

Increase in Total Damage Allowable	High Moisture (20%		Low Moisture (12%)	
	Convey ing: Length:	Air Velocity	Convey ing: Lenth:	Air Velocity
Pct.	Ft.	F.p.m.	Ft.	F.p.m.
	500	7200	*	7200
10	1600	6000	*	6000
			600	5160
			1400	3960
	1600	7200	*	7200
20	1600	6000	300	6000
			1400	5160
			1600	3960

* Not to be conveyed.

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