MECHANICAL DAMAGE TO WHEAT IN A PNEUMATIC CONVEYING SYSTEM

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BURUGUPALLI VENKATESHWAR RAO

B. E. (Mech.), Osmania University, India, 1966

A MASTER'S REPORT

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Agricultural Engineering

KANSAS STATE UNIVERSITY

Manhattan, Kansas

1970

Approved by:

J O Hodges

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INTRODUCTION

The growing importance of pneumatic conveying systems for bulk materials is attributed to the economic advantages such systems frequently exhibit when compared to alternate methods. Some of these advantages are mechanical simplicity, ease of installation, low initial cost, flexibility, ease of maintenance, cleanliness, wide range of applicability and ease of automation to the degree desired.

The main disadvantages of a pneumatic system are the higher power requirements per unit weight of material conveyed, material limitations in abrasiveness and density and material breakage. High power requirements are due to either improper design of the system or to high conveying velocities. Also, velocity is the critical factor for the breakage of the material.

Lowered grain quality, due to substantial amounts of broken and cracked wheat kernels, causes significant economic losses throughout the grain industry. The importing nations at one time were increasingly critical of the poor quality of U. S. wheat. All this led to thorough investigations to find what caused the damage. Considerable improvements were affected in the design of combines, but that was not the end of the story.

Recent studies have revealed that climatic conditions before harvesting, growing location and variety are the major biological contributing factors to grain damage during handling. Considerable work is still to be done to evaluate all the factors which contribute to mechanical damage to grain.

OBJECTIVE

The purpose of this investigation was to evaluate the extent of mechanical damage to wheat in pneumatic conveying as affected by air velocity, conveying length, variety and climatic conditions in the year of growth and to provide information for corrective measures to minimize mechanical damage.

LITERATURE REVIEW

Pioneering and extensive work in the area of damage evaluation in a pneumatic conveying system was done by Segler (25). However, Gasterstadt (12) was first to point out the occurrence of damage to grain when it is conveyed with too high an air velocity. He found that grain which was handled repeatedly under unfavorable conditions (which would not have occurred in practice) was completely broken up.

The experiments carried out by Segler (25, 26) were designed to investigate the influence that air velocity, grain moisture content, grain temperature, pipe size and throughput have on grain damage. He carried out experiments with peas in a pipe line 4.44 inches in diameter and about 240 feet long with four 90 degree bends. He showed that damage increases as the throughput decreases and that grains conveyed one at a time are exposed to greatest danger of damage. He assumed that at higher throughputs individual grains collide with the wall less frequently because the denser stream of material acts as a cushion against the pipe wall.

To determine the influence of the pipe diameter on damage he used two pipe lines of 1.81 and 10.8 inches in diameter with identical arrangements and concluded that the grain was damaged more in the smaller pipe than in the larger one.

Segler regards air velocity as the most critical factor in determining whether or not damage will occur. His tests with peas of 15.4 percent moisture content showed that the incidence of damage increased approximately with the cube of the air velocity in the range of velocities from 50 to 100 feet per second. He suggested safe air velocities to avoid both blockage and grain damage for various rates of throughput.

In his work on conveying velocities, Alden (1) points out that for a given pipe diameter, the material handling capacity increases as the cube of the velocity. He recommends the range of conveying velocities for various materials, including grain. For wheat he recommends a range of 5,000 to 7,000 feet per minute. However, he adds that the velocities should be selected with consideration for the nature and subsequent use of the conveyed material. He also points out that dense materials require less air per pound than do lighter and bulkier substances.

According to Kleis (16), a conveying air velocity of 4,000 feet per minute is necessary and sufficient for satisfactory and continuous operation. Bilanski (2) and co-workers published the terminal velocities of various seed grain. For wheat the terminal velocity they gave was 29.5 feet per second. Person and Sorenson (21) found that the minimum air velocities ranged from approximately 3,000 fpm. to 4,700 fpm. depending on the grain capacity required. Fischer (9) recommends that for nearly all conveying systems involving material with bulk densities ranging from 25 to 60 pounds per cubic foot, a velocity of 5,000 feet per minute will be satisfactory.

Person and Sorenson (21) in their attempt to determine the air velocity at which damage to germination of sorghum grain occurred, could increase the velocity by only 800 fpm. over their suggested minimum air velocity. They had system limitations and at that maximum velocity they could not find any damage to germination. Chung (6), in his work with corn conveying, found that air velocity contributed to the highest mechanical damage, and he concluded that the range of conveying velocities proposed by Alden was too high for practical conveying purposes.

The moisture content of the grain was also shown by Segler to be a critical factor in grain damage by pneumatic conveying. Over the range of 17.1 to 15.5 percent moisture content, the percentage breakage of peas increased from 0.1 to 11.1 percent, showing that dry peas are more sensitive to damage than wet peas. But in the case of wheat he did not find any evidence of damage to normally dry wheat of 15.2 percent moisture content even at an air velocity of 130 feet per second; however, damp wheat (22.6 percent) and very dry wheat (10.3 percent) were badly damaged at this velocity. He concluded that liability to damage in conveying rises both with increasing and decreasing moisture. Least damage occurs at about normal dryness. Chung (6) reported higher damage to corn at 12 percent moisture content than at 20 percent moisture content and recommended an upper limit velocity of 90 feet per second for conveying 12 percent moisture corn.

Segler also investigated the effect of grain temperature on damage and found this factor insignificant in the range of 32 to 86 degrees F.

The design aspects of the pneumatic conveying system were studied by numerous investigators such as Vitunac (32), Kraus (17), Fischer (9), Uematsu and Co-workers (30), Kleis (16), Crane and Carleton (8), Puckett (22), Hudson (14) and Molyneux (20) and significant advances were made in that aspect.

Much work was done to make better use of pneumatic conveyors by Stoess (29), Hudson (15), Schultz (24), and Burrel (4). Their attempts were partially to reduce higher power consumption, the major disadvantage of these conveyors.

Leko (18) showed that considerable power reductions were possible by using air pipes of oval cross sections instead of circular ones.

Bilanski (3), in an attempt to determine some basic knowledge of the energies and forces involved in damaging grain during threshing, cleaning and conveying, predicted that the history of the grain kernel will affect its damage resistance. For example, the stage of maturity at which the grain was threshed and the storage conditions affect susceptibility to mechanical damage. Fischer (9) suggested that the physical characteristics, such as size, bulk density and degree of hygroscopicity of the material to be conveyed, should be taken into consideration before designing a pneumatic conveyor.

Milner and Shellenberger (19) used x-ray techniques to find internal fissures in weathered wheat. In their studies, changes in physical properties due to weathering, wetting and drying were discussed in terms of radiographical evidence of internal fissures.

Chung and Converse (5), in their radiographical examination of internal damage to wheat, observed significant effects of the year of growth and location, followed by variety and method of harvesting on internal damage. They found many internal cracks in wheat kernels already formed in the field before harvest. They also predicted that grains with many internal cracks were more susceptible to breakage in handling.

Various methods were developed to evaluate damage to pneumatically conveyed grain, depending on the conveyed material and its use after conveying. Official grain standards of the United States (31) defines damaged kernels as those kernels and pieces of kernels of wheat and other grains which are heat damaged, sprouted, frosted, badly ground damaged, badly weather damaged, moldy, diseased or otherwise materially damaged. This is obviously an ambiguous definition of damage. Shrunken and broken kernels are defined as those that pass readily through a 0.064 x 3/8 inch oblong hole sieve (31). Henderson and Perry (13) suggested the use of the Ro-Tap machine, using proper Tyler sieves, for classifying any granular material.

Only limited data are available on wheat damage caused in pneumatic conveying systems. All the factors that contribute to damage were never studied together; therefore this study was suggested to evaluate the effects of certain factors on wheat damage during pneumatic conveying.

EXPERIMENTAL METHOD

A. Equipment

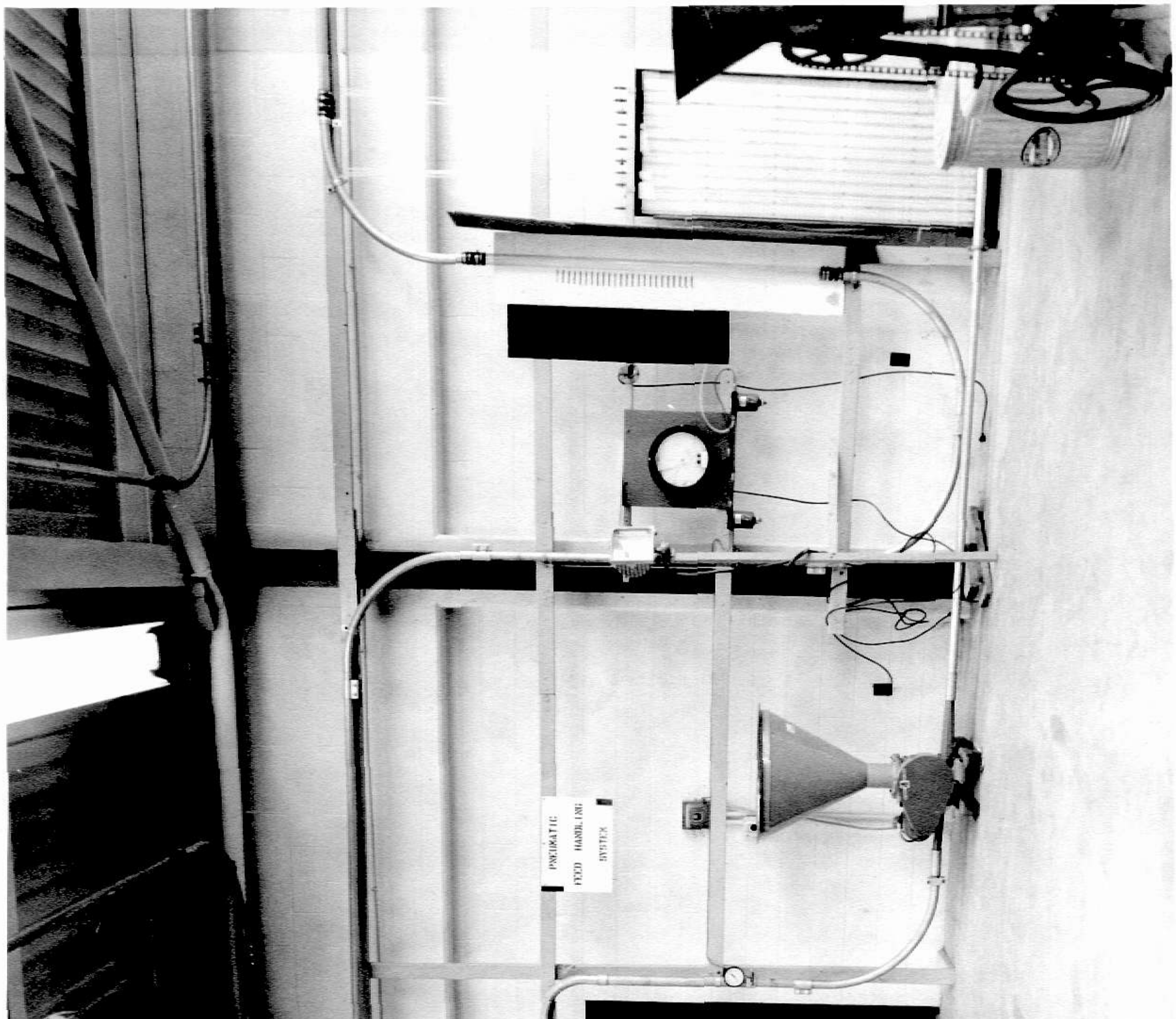
Experiments were conducted in a positive low-volume medium pressure conveying system. A positive displacement air blower with a maximum pressure of 10 psig., a rotary drop-through air lock feeder with a surge hopper over it and a cyclone separator were used in the system. The quantity of air was regulated by changing the blower speed until the test flow was indicated on a flowrator meter made by Fischer and Porter Company (10). The flowrator was calibrated to give 180 cubic feet of air per minute at 100 percent reading, at 2 psig. and 100 degrees F. A dial thermometer and a pressure gage were used in the line before the flowrator to correct flow rate calculations as suggested by the Fischer and Porter Company. A circular cone orifice fitted in the hopper maintained a constant feeding rate throughout the experiments.

The conveying lines were 1.9 inches in diameter, 200 feet long and had 14 90-degree elbows and one 45-degree elbow; all the elbows had a curvature of 24 inches radius. A photograph of the pneumatic conveying system is shown in Plate I.

For the purpose of evaluating the damage or fines after conveying through the system, a Ro-Tap machine was used with a set of Tyler sieves composed of screen numbers 5, 6, 7, 8, 10, 14, 28 and the pan.

PLATE I

Photograph of pneumatic conveying system used in the experiment.


PNEUMATIC
FEED HANDLING
SYSTEM

B. Materials

Two common varieties of winter wheat in Kansas (Scout and Ottawa) combine harvested in 1968 and 1969, were selected on the basis of their particle size or weight per thousand kernels, for the purpose of this investigation. The 1968 samples were harvested in the last week of June, 1968 from Kansas State University Experimental Field at Hutchinson in Reno County. The samples were stored in bags at room temperature until conveyed through the system.

The Scout variety of 1969 was harvested in the last week of June, 1969 in Stafford County, Kansas. The Ottawa variety of 1969 was harvested in the second week of July. The rainy weather conditions prevented combining during the first week of maturity. This Ottawa came from Geary and Saline counties. The varieties of 1969 were run through the system as they were procured. There was negligible variation in the moisture contents of each variety of wheat tested as shown in Table 1.

Table 1. Some physical and mechanical properties of test wheat.

Variety	Location	Moisture content wet basis 1/	Weight per thousand kernels 1/	Test weight per bushel 1/	Compressive strength 2/	Percentage fines before handling 3/
		percent	grams	lb/bu	pounds	percent
Scout 1968	Hutchinson	10.13	33.4143	62.50	20.065	0.087
Ottawa 1968	Hutchinson	10.07	25.9320	62.15	19.84	0.064
Scout 1969	Stafford county	12.75	31.9233	60.03	17.58	0.079
Ottawa 1969	Geary and Saline counties	10.55	24.1185	57.10	17.06	0.333

1/ Average of 3 replications
2/ Average of 40 kernels
3/ Average of 12 replications

C. Experimental Design

A factorial design with 4 levels of conveying air velocity, 4 levels of conveying length, 2 levels of variety and 2 levels of age or year of growth of the wheat was used. There were 64 (4 x 4 x 2 x 2) treatment combinations for each replication. Three replications were made for each treatment combination. The levels of each variable studied are summarized in Table 2.

The air velocities were determined after applying three types of corrections to the flow indicated by the flowrator. First, when grain was introduced into the system, the air flow was reduced and a lower flowrator reading was recorded. The second correction was applied to account for the temperature and pressure variations of the air for test conditions. These correction factors were taken from the instruction booklet of the flowrator manufacturer (10). The third correction was to account for the air loss through the feeder. The loss of air in the air-lock due to positive displacement was a component of this. After a detailed analysis on the same system, Chung (6) found that there was an average air loss of 6.5 percent of actual air flow through the system. The actual air flows were obtained after applying the above three corrections, and from them a range for each velocity was obtained accounting for the variation in the cross-sectional area of the pipes in the system as shown in Table 3. For comparison purposes the air velocities used were 96, 102, 110 and 120 feet per second. The conveying lengths, given in Table 2, were obtained by conveying the same wheat repeatedly through the 200 feet system.

Table 2. Levels of the experimental variables.

Variables	Levels				
	1	2	3	4	Total levels
Air velocity, fps.	96	102	110	120	4
Conveying length, ft.	1,000	2,000	3,000	4,000	4
Variety	Scout	Ottawa			2
Year of growth	1968	1969			2
Replications					3

Treatment combinations for each replication = 4 x 4 x 2 x 2 = 64.

Replications for each treatment combination = 3.

Table 3. Air velocity calculations.

Flowrator reading air only	Flowrator reading air & grain	Average static pressure	Pressure correction factor 1/	Average tempera-ture	Temp-correction factor 1/	Corrected airflow to conveyor pipe	Corrected air-flow with 6.5% loss through feeder	Air velocity range	
percent	percent	lb/sq.in		°F		cu.ft/min	cu.ft/min	ft/min	ft/sec
72	70.0	4.0	1.06	126.5	0.978	121.54	113.6	5774-5928	96-98
78	75.0	4.50	1.075	137.5	0.969	129.60	121.2	6157-6321	102-105
86	81.5	5.50	1.10	140.0	0.967	137.91	129.0	6553-6727	109-112
96	91.0	6.80	1.13	156.5	0.954	151.94	142.0	7219-7411	120-123

1/ From Fischer and Porter Co. Instruction Bulletin 10A9020, Revision - 2 for the flowrator application.

D. Procedure

Five hundred grams of dockage free wheat sample were used for each test run throughout the experiments. The samples contained a few broken kernels before conveying through the system.

The criterion used for evaluating the damage in this investigation was based on the percentage of the broken kernels by weight passing through the No. 10-mesh Tyler screen sieve when the Ro-Tap machine was run for five minutes for each test sample with 5, 6, 7, 8, 10, 14, 28 sieves and pan. This percentage by weight of broken kernels and particles of wheat passing through the No. 10 sieve with an opening size of 0.065 inches was taken as the criterion for the damage and was called "percentage fines". Henceforth, in all the analysis of damage the terms, "percentage fines" and "damage" will be used interchangeably with the same meaning. The average of percentage fines before handling is recorded in Table 1.

The feeding rate was maintained constant for all the runs. The temperature and pressure of air in the pipe before the flowrator were observed and corrections were applied for the air flow. For each test run the weight of wheat retained on each sieve was recorded but the percentages were calculated only for the fines. The data of percentage fines after conveying are recorded in Tables 4 through 7 in Appendix I.

ANALYSIS OF PERCENTAGE FINES (WHEAT DAMAGE)

The analysis of variance tables of percentage fines for Scout and Ottawa varieties of both 1968 and 1969 are shown in Tables 8 through 12 in Appendix II.

As the quantities of percentage fines obtained were small for the purpose of analysis of variance, they were converted into angles by means of Arcsine transformation (27) which would ensure a normal distribution.

The standard analysis of variance program (N-Way ANOVA) (28), stored in the computer-360, was used to obtain the F - test values. Throughout the analysis a 5 percent confidence interval was used. For the purpose of making decisions, the critical F-values were taken from the standard F-distribution tables (11).

Mathematical Model for Analysis of Variance

A mathematical model may be formed for the analysis of variance of percentage fines of Scout and Ottawa of both 1968 and 1969, as an extension of the standard model given in any text on Experimental Statistics (11) with the usual general meaning of each term.

$$
\begin{aligned}
X_{ijklm} = \mu &+ (V)_i + (L)_j + (VL)_{ij} + (W)_k + (VW)_{ik} + (LW)_{jk} \\
&+ (VLW)_{ijk} + (A)_l + (VA)_{il} + (LA)_{jl} + (VLA)_{ijl} \\
&+ (WA)_{kl} + (VWA)_{ikl} + (LWA)_{jkl} + (VLWA)_{ijkl} + E_{ijklm}
\end{aligned}
$$

where i, j, k, l and m represent the levels of conveying velocity, V; conveying length, L; variety, W; year of growth or age, A; and replication, R, respectively. X is a sample data of transformed percentage fines; μ is the grand mean; and E is the random error in percentage fines which is assumed to be normally independently distributed.

RESULTS

A graphical presentation of the results is shown in figures 1 through 4 in Appendix III. The average values of the percentage fines were used in drawing these graphs.

Table 8 shows the analysis of variance on the basis of percentage fines for the Scout and Ottawa varieties of 1968 with the three factors, velocity, conveying length and variety having 32 treatment combinations for each replication. It is seen that variety has the highest significant effect, followed by conveying length and velocity. The first order interactions are also found to have highly significant effects on mechanical damage.

In Table 9 the percentage fines of Scout and Ottawa varieties grown in 1969 are analysed with the same factors as above, and it is again seen that variety has the highest significant effect, followed by the conveying length and velocity. The first order interactions also have highly significant effect on the damage.

In Table 10, the data of percentage fines of Scout variety of 1968 and 1969 are analysed with the three factors, velocity, conveying length and year of growth or age. In this case, conveying length has the highest significant effect on mechanical damage, followed by the velocity and the year of growth. In the first order interactions, velocity x conveying length has higher significant effect on the damage than that of velocity x year of growth and conveying length x year of growth.

In Table 11, mechanical damage to Ottawa variety of 1968 and 1969 is analysed with the same three factors as above. In this case, the year of growth is seen to have very highly significant effect on mechanical damage. Year of growth is followed by conveying length and velocity in significance. The effects of the first order interactions are also highly significant.

Table 12 shows the analysis of variance on the basis of percentage fines using all four factors, velocity, conveying length, variety and the year of growth, for the Scout and Ottawa varieties of both 1968 and 1969. The highest significant effect on the mechanical damage is seen to be due to the first order interaction of variety x year of growth, followed by conveying length and velocity and then by the year of growth. The varietal effect is seen to be comparatively less. Among the first and second order interactions velocity x conveying length, velocity x year of growth, velocity x variety x year of growth and conveying length x variety x year of growth are found to have highly significant effects on the mechanical damage.

Discussion of the Results

From the above results it is seen that all four factors, (velocity, conveying length, variety and the year of growth), have significant effects on the extent of mechanical damage caused in the pneumatic conveying system. The effects of the factors, year of growth and variety were more pronounced on the damage. Between the two, velocity and conveying length, conveying length had more significant effect on the mechanical damage than velocity.

In figures 1 through 4 it is seen that percentage fines generally increased with increasing length and/or velocity. The damage caused to Scout variety compared to Ottawa variety, 1968 crop, is twice as much under the same conditions of treatment. This is shown in figures 1 and 2. For 1969 samples the order is reversed. Twice as much damage occurred to Ottawa as to Scout. This is shown in figures 3 and 4. From the figures 1 and 3, and figures 2 and 4, it is seen that the Scout variety of 1968 suffered as much as twice the damage for a given treatment compared to the same variety of 1969. In the case of Ottawa the order was reversed.

As explained in the materials section, the two varieties of 1969 which were not procured from the same location, probably introduced the factor of location. The different soil and climatic conditions at harvest time have significant effects on the internal damage to wheat, which would contribute to further damage in handling. Although the two varieties, Scout and Ottawa, were selected partially on the basis of size of the kernels or weight per thousand kernels, a definite relation could not be established. After conveying 1968 wheat samples it was thought that the bigger kernels were more susceptible to damage, but this idea was proved baseless after conveying 1969 wheat when the order was reversed.

The extent of damage was maximum in the Ottawa variety of 1969. As mentioned earlier, this involved a delay factor of two weeks in harvesting after maturity. The bad weather conditions probably introduced more internal cracks in the wheat. The percentage fines of this variety before conveying, which was due to weathering and combining, was also three to four times higher than for all other varieties tested. Another significant difference in this variety (Table 1) was that the test weight per bushel was only 57 pounds compared to more than 60 pounds for the other samples. The weight per thousand kernels and the compressive strength were also least in the case of this variety.

It was observed that the percentage fines increased abruptly at the conveying velocity of 120 feet per second in all the varieties tested. That was probably because of the increased abrasion, collision forces and impacts in the pipe that would tend to break the kernels. It was as expected that the farther the wheat was conveyed, the greater the damage caused to it, since the kernels were subjected to abrasion and impacts so many more times.

CONCLUSIONS

The following conclusions were drawn from the results of this investigation:

1. Year of growth, variety, conveying length and velocity all had a significant effect on the mechanical damage in decreasing order.

2. The damage generally increased with increasing air velocity and conveying length for a given variety and year of growth.

3. Year of growth has to do with the climatic conditions of a given location over the period of growth until harvesting is done. This had the most significant effect on the damage as revealed in this investigation. Unfavorable weather conditions like excessive heat and rain contribute to damage in handling.

4. The variety with the least test weight per bushel and compressive strength was more susceptible to damage.

5. Different varieties are susceptible to damage in conveying in different ways. An intensive search in this field might result in varieties less susceptible to mechanical damage.

6. It is advisable to keep the conveying air velocity as low as possible without blockage in the conveying pipe in order to have minimum damage and minimum power consumption.

7. In general, to keep the percentage fines less than one percent for the type of the conveying system used, a conveying velocity of less than 100 feet per second is suggested. If the limit of the percentage fines acceptable is three percent, the velocity of air may be increased by ten percent.

8. It should be noted that the pipe diameter of the conveying system was 1.9 inches, which is smaller than generally used for grain. The range of diameters generally is three to eight inches and the susceptibility to damage in a wider pipe is less because the kernels will have less impact with the pipe wall due to the higher leaps possible. In the system used, the wheat conveyed was subjected to many elbows for the distance conveyed (75 elbows for each 1,000 feet), increasing the possibility of damage occurrence. Further, the grain was conveyed only intermittently and it is known that in continuous conveying the denser stream of material acts as a cushion and reduces the damage. In the light of the above mentioned points, damage is apt to be less in a practical system than indicated here.

9. United States Department of Agriculture specification does not give a true representation of mechanical damage as it also includes sound kernels. The method used in this investigation might be worthwhile for determining mechanical damage.

RECOMMENDATIONS

To gain further understanding of the problem the following additional work is suggested:

1. Study the effect of moisture content of the wheat on mechanical damage in conveying.

2. Study the effect of varying the feeding rate, the diameter of the pipe and the cross-section of the pipe on mechanical damage.

3. Compare the extent of damage to wheat with no internal damage and wheat with known levels of internal damage, as determined by the radiographical examination for various conveying procedures.

ACKNOWLEDGEMENTS

The author wishes to express his sincere appreciation to his major adviser, Dr. Teddy O. Hodges, for his excellent guidance in preparing this report; to Dr. Do Sup Chung, for his advice in analyzing the data; to Dr. George H. Larson, Head of Agricultural Engineering Department, for his counselling; to Dr. Alley H. Duncan, Professor, Mechanical Engineering, for his encouragement in the course of this work.

The author is deeply thankful to Mr. Harry H. Converse, for his helping spirit and encouragement throughout this work; to Dr. Ray Waller, Department of Statistics and Computer Science, for his guidance in analyzing the data on the computer. He also wishes to thank Mr. Chang Joo Chung and Mr. Dee Hattan for their help in procuring the data.

And finally, the author wishes to express his deep appreciation to his wife, Swarajya Laxmi, for her sacrifices through separation during this work.

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APPENDIX I

Data of percentage fines after conveying through the system for Scout and Ottawa varieties of wheat grown in 1968 and 1969.

Table 4. Percentage fines of Scout variety of wheat grown in 1968.

Air velocity	Conveying length	Replication No. 1	Replication No. 2	Replication No. 3	Average percentage fines
ft/sec	ft	percent	percent	percent	percent
96	0	0.082	0.074	0.062	0.072
	1,000	0.289	0.322	0.338	0.316
	2,000	0.582	0.521	0.620	0.607
	3,000	0.900	0.931	0.939	0.922
	4,000	1.212	1.213	1.219	1.210
102	0	0.098	0.098	0.110	0.102
	1,000	0.335	0.341	0.361	0.345
	2,000	0.633	0.635	0.677	0.644
	3,000	0.994	1.015	1.067	1.021
	4,000	1.319	1.348	1.417	1.357
110	0	0.090	0.092	0.088	0.090
	1,000	0.519	0.519	0.495	0.511
	2,000	0.984	0.984	0.994	0.987
	3,000	1.495	1.469	1.470	1.477
	4,000	2.049	1.999	2.018	2.021
120	0	0.090	0.084	0.080	0.084
	1,000	0.702	0.706	0.719	0.709
	2,000	1.502	1.532	1.544	1.526
	3,000	2.465	2.484	2.520	2.489
	4,000	3.574	3.639	3.627	3.612

Table 5. Percentage fines of Ottawa variety of wheat grown in 1968.

Air velocity	Conveying length	Replication No. 1	Replication No. 2	Replication No. 3	Average percentage fines
ft/sec	ft	percent	percent	percent	percent
96	0	0.060	0.064	0.058	0.060
	1,000	0.106	0.110	0.104	0.106
	2,000	0.226	0.228	0.226	0.226
	3,000	0.332	0.334	0.326	0.330
	4,000	0.456	0.451	0.451	0.452
102	0	0.062	0.060	0.062	0.061
	1,000	0.196	0.188	0.184	0.189
	2,000	0.356	0.278	0.356	0.353
	3,000	0.497	0.431	0.500	0.499
	4,000	0.638	0.578	0.649	0.644
110	0	0.056	0.060	0.056	0.057
	1,000	0.233	0.220	0.208	0.220
	2,000	0.513	0.488	0.502	0.500
	3,000	0.780	0.757	0.767	0.767
	4,000	1.065	1.042	1.050	1.051
120	0	0.076	0.074	0.078	0.076
	1,000	0.331	0.336	0.339	0.335
	2,000	0.707	0.694	0.734	0.711
	3,000	1.081	1.066	1.118	1.087
	4,000	1.496	1.485	1.543	1.506

Table 6. Percentage fines of Scout variety of wheat grown in 1969.

Air velocity	Conveying length	Replication No. 1	Replication No. 2	Replication No. 3	Average percentage fines
ft/sec	ft	percent	percent	percent	percent
96	0	0.078	0.072	0.080	0.076
	1,000	0.184	0.180	0.182	0.182
	2,000	0.329	0.323	0.333	0.328
	3,000	0.484	0.454	0.496	0.478
	4,000	0.615	0.587	0.637	0.613
102	0	0.909	0.084	0.084	0.086
	1,000	0.263	0.270	0.266	0.266
	2,000	0.515	0.502	0.508	0.508
	3,000	0.778	0.715	0.751	0.748
	4,000	1.074	0.980	1.032	1.028
110	0	0.080	0.060	0.070	0.070
	1,000	0.300	0.280	0.290	0.290
	2,000	0.581	0.521	0.551	0.551
	3,000	0.874	0.787	0.834	0.831
	4,000	1.158	1.061	1.118	1.111
120	0	0.080	0.090	0.080	0.083
	1,000	0.491	0.486	0.491	0.489
	2,000	0.936	1.001	0.996	0.994
	3,000	1.566	1.622	1.598	1.595
	4,000	2.368	2.445	2.420	2.410

Table 7. Percentage fines of Ottawa variety of wheat grown in 1969.

Air velocity	Conveying length	Replication No. 1	Replication No. 2	Replication No. 3	Average percentage fines
ft/sec	ft	percent	percent	percent	percent
96	0	0.350	0.310	0.340	0.330
	1,000	0.513	0.472	0.483	0.489
	2,000	0.898	0.836	0.857	0.863
	3,000	1.244	1.161	1.192	1.198
	4,000	1.571	1.497	1.519	1.528
102	0	0.360	0.300	0.320	0.326
	1,000	0.663	0.633	0.643	0.646
	2,000	1.159	1.068	1.108	1.111
	3,000	1.618	1.516	1.546	1.559
	4,000	2.059	1.976	1.965	1.999
110	0	0.400	0.410	0.390	0.400
	1,000	0.704	0.774	0.723	0.733
	2,000	1.343	1.464	1.331	1.378
	3,000	1.935	2.067	1.903	1.967
	4,000	2.572	2.656	2.520	2.580
120	0	0.310	0.270	0.250	0.276
	1,000	1.085	1.045	1.104	1.078
	2,000	2.092	2.001	2.060	2.051
	3,000	3.193	3.112	3.171	3.158
	4,000	4.601	4.468	4.556	4.541

APPENDIX II

Analysis of variance of percentage fines for Scout and Ottawa of 1968 and 1969.

Table 8. Analysis of variance based on percentage fines for Scout and Ottawa varieties of 1968.

Source of variation	Sum of squares	Degrees of freedom	Mean squares	F - Test	Critical F at $\alpha = .05$	Decision
V	106.22059	3	35.40686	5303.57118*	2.79	Reject H_o: All $(V)_i = 0$
L	158.27335	3	52.75778	7902.55469*	2.79	Reject H_o: All $(L)_j = 0$
V x L	12.02042	9	1.33560	200.05896#	2.07	Reject H_o: All $(VL)_{ij} = 0$
W	96.58088	1	96.58088	14466.78749*	4.03	Reject H_o: All $(W)_k = 0$
V x W	4.26935	3	1.42312	213.16789#	2.79	Reject H_o: All $(VW)_{ik} = 0$
L x W	6.99840	3	2.33280	349.42877#	2.79	Reject H_o: All $(LW)_{jk} = 0$
V x L x W	1.13302	9	0.12589	18.85711+	2.07	Reject H_o: All $(VLW)_{ijk} = 0$
Error	0.42727	64	0.00668			
Total	385.92327	95				

* Very highly significant
\# Highly significant
\+ Significant

Table 9. Analysis of variance based on percentage fines for Scout and Ottawa varieties of 1969.

Source of variation	Sum of squares	Degrees of freedom	Mean squares	F - Test	Critical F at $\alpha = .05$	Decision
V	133.09464	3	44.36488	4483.65972*	2.79	Reject H_o: All $(V)_i = 0$
L	187.64858	3	62.54953	6321.45963*	2.79	Reject H_o: All $(L)_j = 0$
V x L	17.60123	9	1.95569	197.64870#	2.07	Reject H_o: All $(VL)_{ij} = 0$
W	134.40300	1	134.40300	13583.20676*	4.03	Reject H_o: All $(W)_k = 0$
V x W	1.90340	3	0.63447	64.12138#	2.79	Reject H_o: All $(VW)_{ik} = 0$
L x W	4.28781	3	1.42927	144.44675#	2.79	Reject H_o: All $(LW)_{jk} = 0$
V x L x W	0.30847	9	0.03427	3.46386+	2.07	Reject H_o: All $(VLW)_{ijk} = 0$
Error	0.63327	64	0.00989			
Total	479.88040	95				

* Very highly significant
\# Highly significant
\+ Significant

Table 10. Analysis of variance based on percentage fines for Scout variety of 1968 and 1969.

Source of variation	Sum of squares	Degrees of freedom	Mean squares	F - Test	Critical F at α = .05	Decision
V	123.84151	3	41.28050	6865.78026*	2.79	Reject H_o: All $(V)_i = 0$
L	180.26014	3	60.08671	9993.63196*	2.79	Reject H_o: All $(L)_j = 0$
V x L	16.50285	9	1.83365	304.97299#	2.07	Reject H_o: All $(VL)_{ij} = 0$
A	39.02775	1	39.02775	6491.10204*	4.03	Reject H_o: All $(A)_k = 0$
V x A	3.16111	3	1.05370	175.25219#	2.79	Reject H_o: All $(VA)_{ik} = 0$
L x A	3.22202	3	1.07401	178.62896#	2.79	Reject H_o: All $(LA)_{jk} = 0$
V x L x A	0.27167	9	0.03019	5.02042+	2.07	Reject H_o: All $(VLA)_{ijk} = 0$
Error	0.38480	64	0.00601			
Total	366.67185	95				

* Very highly significant
\# Highly significant
\+ Significant

Table 11. Analysis of variance based on percentage fines for Ottawa variety of 1968 and 1969.

Source of variation	Sum of squares	Degrees of freedom	Mean squares	F - Test	Critical F at α = .05	Decision
V	113.47000	3	37.82333	3582.32054*	2.79	Reject H_o: All $(V)_i = 0$
L	165.24531	3	55.08177	5216.90012*	2.79	Reject H_o: All $(L)_j = 0$
V x L	12.98041	9	1.44227	136.59994#	2.07	Reject H_o: All $(VL)_{ij} = 0$
A	230.23718	1	230.23718	21806.20452*	4.03	Reject H_o: All $(A)_k = 0$
V x A	5.01535	3	1.67178	158.33790#	2.79	Reject H_o: All $(VA)_{ik} = 0$
L x A	8.48068	3	2.82689	267.74043#	2.79	Reject H_o: All $(LA)_{jk} = 0$
V x L x A	1.30821	9	0.14536	13.76700+	2.07	Reject H_o: All $(VLA)_{ijk} = 0$
Error	0.67573	64	0.01056			
Total	537.41287	95				

* Very highly significant
\# Highly significant
\+ Significant

Table 12. Analysis of variance based on percentage fines for Scout and Ottawa varieties of 1968 and 1969.

Source of variation	Sum of squares	Degrees of freedom	Mean squares	F - Test	Critical F at α = .05
V	236.33156	3	78.77719	9507.93312*	2.67
L	345.28537	3	115.09512	13891.28992*	2.67
V x L	28.98887	9	3.22099	388.75361#	1.95
W	1.55880	1	1.55880	188.13804#	3.91
V x W	0.97995	3	0.32665	39.42478+	2.67
L x W	0.22007	3	0.07336	8.85383+	2.67
V x L x W	0.49439	9	0.05493	6.62998+	1.95
A	39.83985	1	39.83985	4808.43073*	3.91
V x A	2.98366	3	0.99455	120.03663#	2.67
L x A	0.63656	3	0.21219	25.60950+	2.67
V x L x A	0.63278	9	0.07031	8.48588+	1.95
W x A	229.42507	1	229.42507	27690.22781*	3.91
V x W x A	5.19280	3	1.73093	208.91342#	2.67
L x W x A	11.06614	3	3.68871	445.20560#	2.67
V x L x W x A	0.94710	9	0.10523	12.70098+	1.95
Error	1.06053	128	0.00829		
Total	905.64352	191			

* Very highly significant
\# Highly significant
\+ Significant

APPENDIX III

Graphical presentation of mechanical damage.

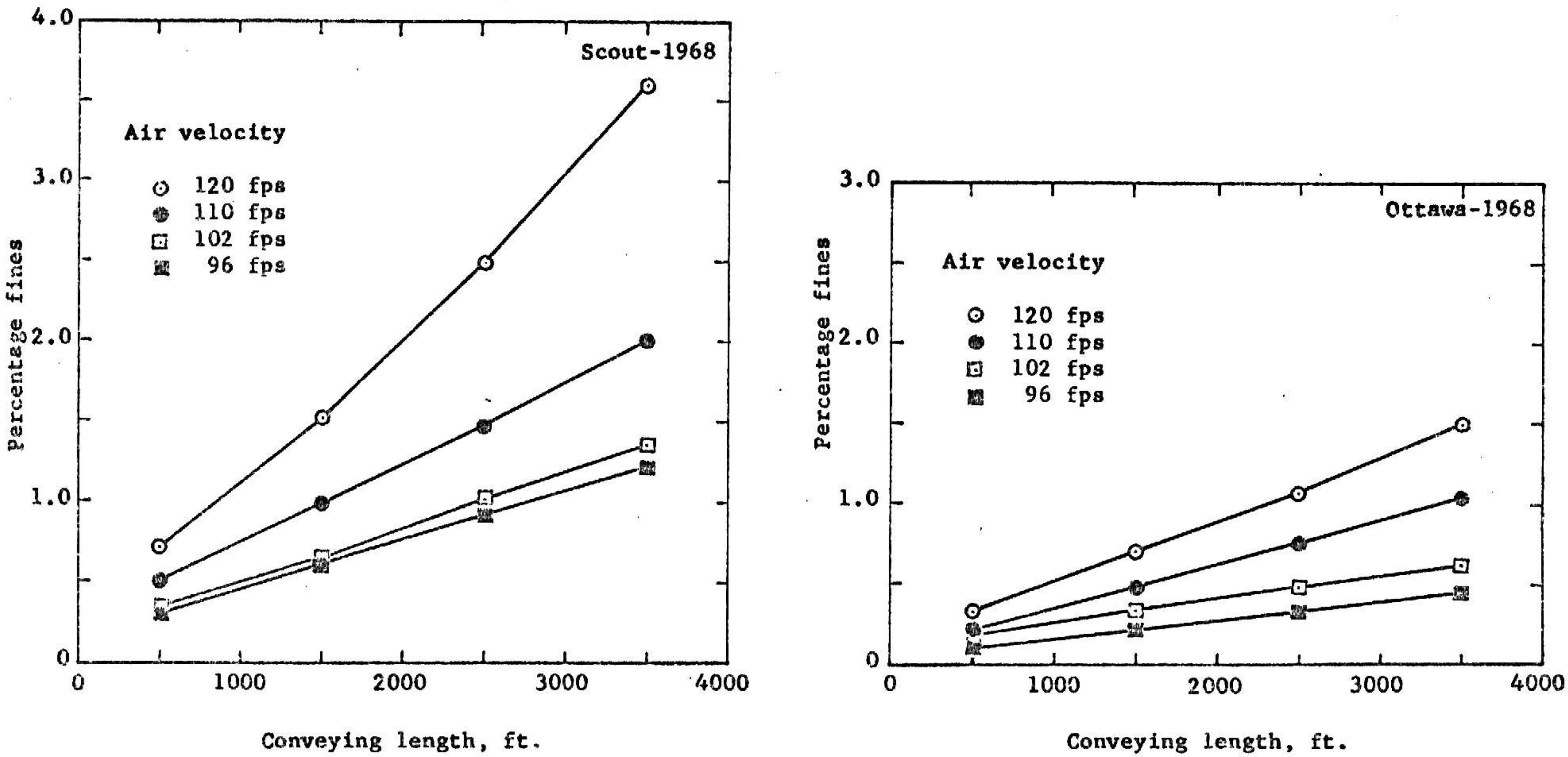

Fig. 1. Percentage fines versus conveying length for four conveying velocities.

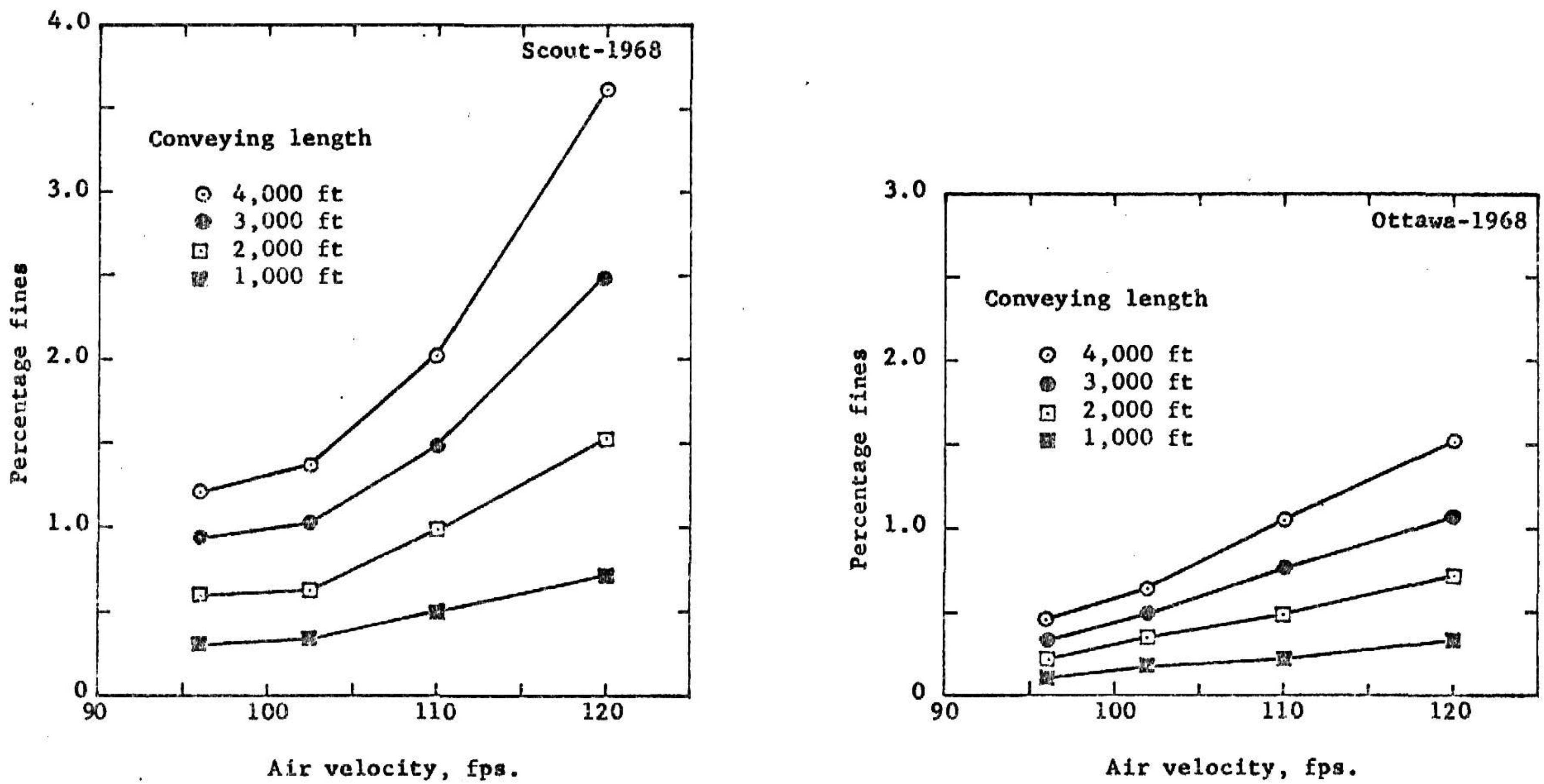

Fig. 2. Percentage fines versus conveying air velocity for four conveying lengths.

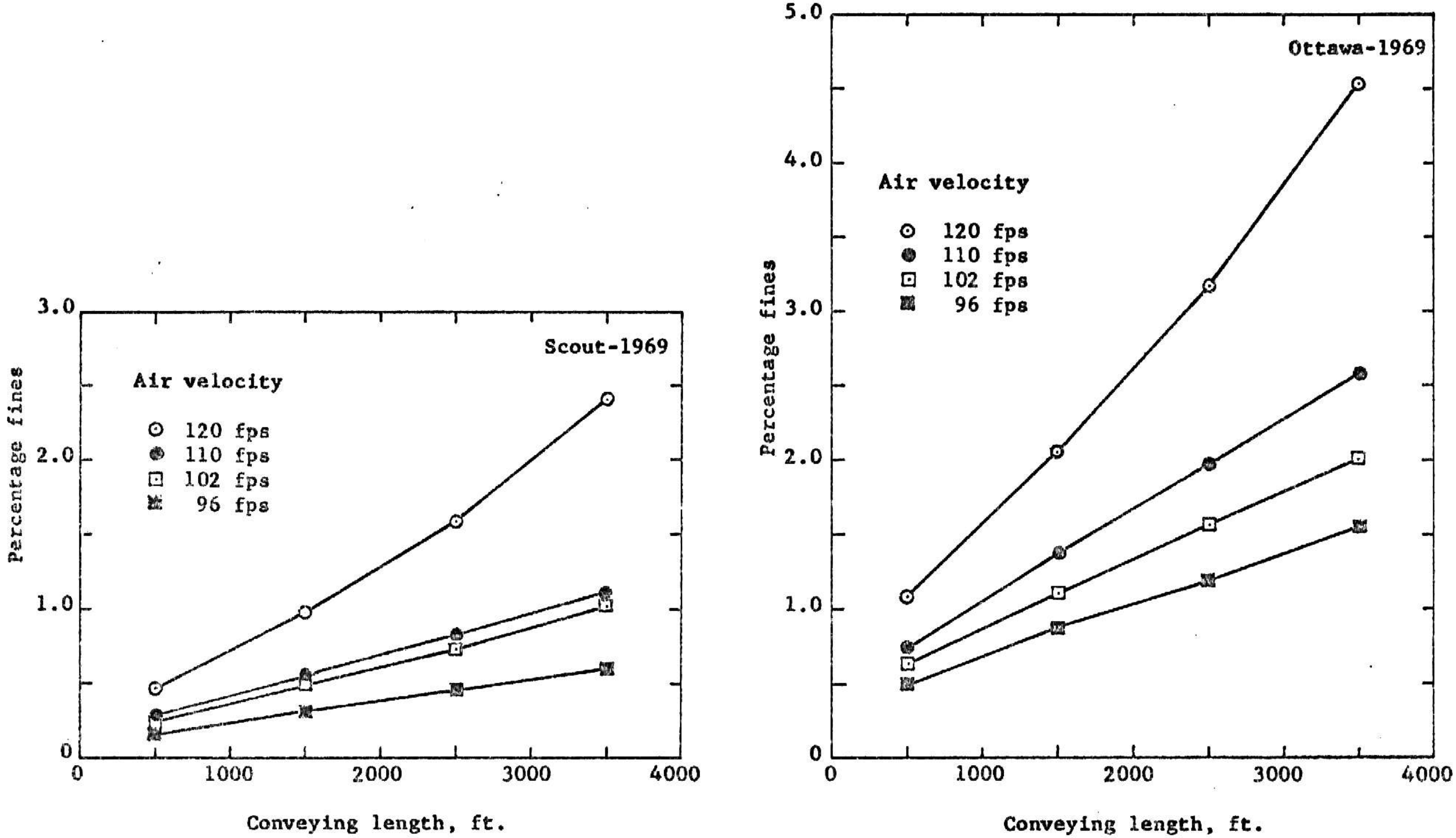

Fig. 3. Percentage fines versus conveying length for four conveying velocities.

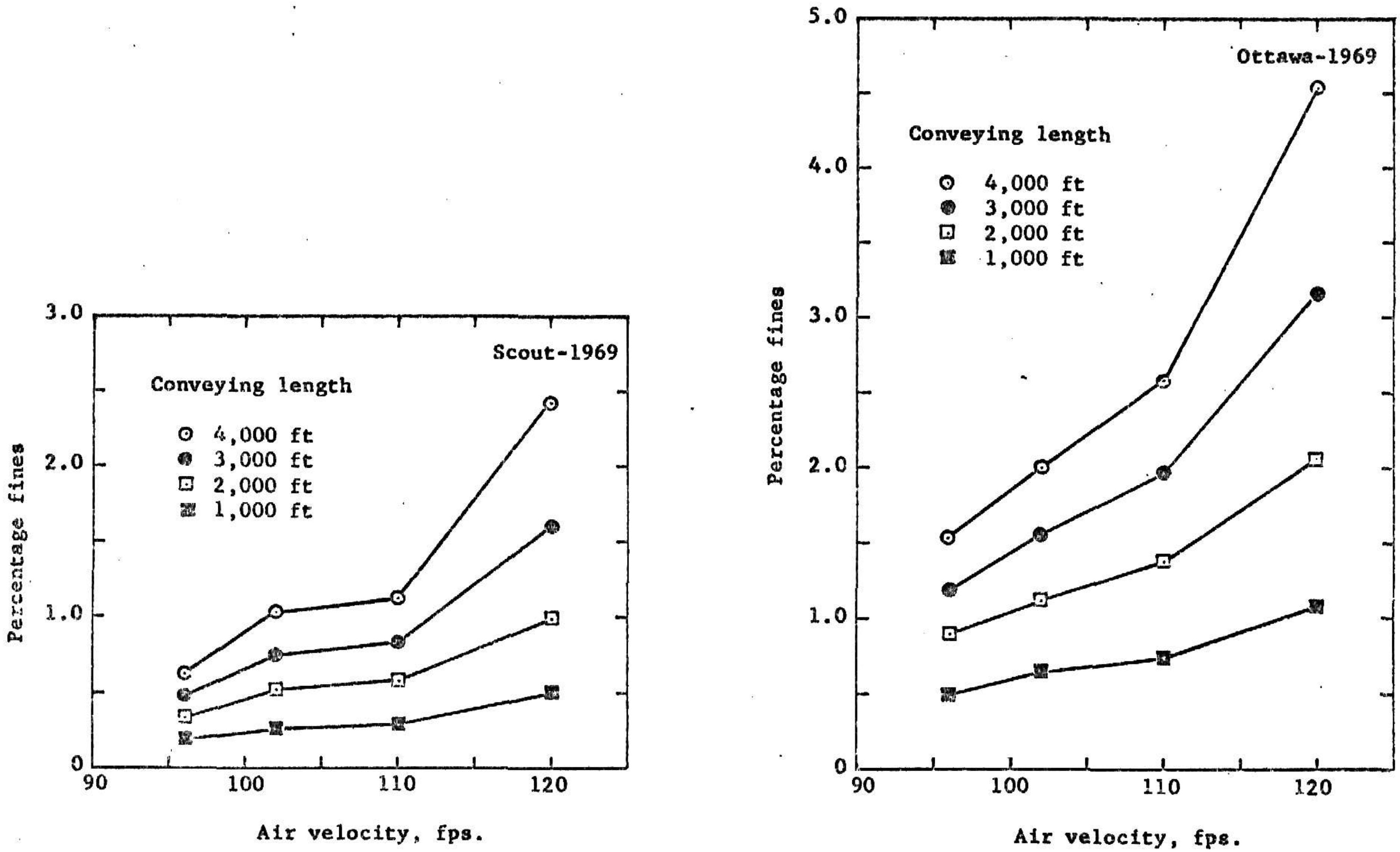

Fig. 4. Percentage fines versus conveying air velocity for four conveying lengths.

MECHANICAL DAMAGE TO WHEAT IN A PNEUMATIC CONVEYING SYSTEM

by

BURUGUPALLI VENKATESHWAR RAO

B. E. (Mech.), Osmania University, India, 1966

AN ABSTRACT OF A MASTER'S REPORT

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Agricultural Engineering

KANSAS STATE UNIVERSITY

Manhattan, Kansas

1969

This investigation was to study the effects of air velocity and conveying length on mechanical damage during pneumatic conveying to Scout and Ottawa Hard Red Winter Wheat grown in Kansas in 1968 and 1969. A factorial design was used with four levels of air velocity and four levels of conveying length having 32 treatment combinations for each replication and three replications for each treatment combination. A 500-gram sample of wheat was used for each test run and the feeding rate was kept constant. The moisture content of all the wheat samples tested ranged from 10 to 13 percent, wet basis. The experiments were conducted in a pneumatic conveying system having 1.9 inches inside diameter pipes. The pipe length was 200 feet and contained 14 90-degree elbows and one 45-degree elbow.

The statistical analysis of the data showed that the year of growth or age and the variety of the wheat, and their combined interaction effect, were the most significant factors contributing to the mechanical damage. The percentage fines generally increased with increasing air velocity and conveying length for a given variety and year of growth. Unfavorable weather conditions before harvesting were found to contribute to mechanical damage in handling. It was suggested that the conveying air velocity be always kept near to that minimum limited by the blockage in the pipe; however, it may be increased to an extent such that the damage caused by that velocity is within an acceptable limit.

A new criterion for evaluating the mechanical damage was developed in terms of percentage fines, which is percent by weight of broken kernels passing through the number 10 Tyler sieve when the sieve set is run in a Ro-Tap machine exactly for 5 minutes. This criterion was recommended for future work in evaluating the mechanical damage in handling the wheat.