PERFORMANCE OF EQUIPMENT FOR APPLYING CHEMICAL PRESERVATIVES TO GRAIN

by

MICHAEL SEWARD SIMS

B.S., Purdue University, 1972

A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Agricultural Engineering

KANSAS STATE UNIVERSITY
Manhattan, Kansas
1976

Approved by:

[signature]

Major Professor

ACKNOWLEDGEMENTS

Financial support and facilities for this study were provided by the U. S. Grain Marketing Research Center, North Central Region, Agricultural Research Service, U. S. Department of Agriculture.

I wish to express my gratitude to Mr. George Foster and Dr. Ted Hodges for their valuable suggestions during this study.

The assistance of Dr. David Sauer, Mrs. Rosemary Burroughs, Mr. Harry Converse, Mr. George Wyatt and Mr. Larry Shackleford was greatly appreciated. Dr. Fang Lai is gratefully acknowledged for his aid on the mixing of solids.

Gratitude and thanks are extended to Mrs. Sue Carter for her fine photography print work.

The author must not forget the great encouragement given him by his wife and his mother to succeed in graduate school.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

Agriculture continues to stride ahead with significant advances in technology. Advances are necessary to improve farm life and to feed the ever growing world population. The choices farmers have for storing their grain are becoming more numerous. All methods should be evaluated so that each farmer is able to choose the best alternative for him.

Storing corn at higher than normal moisture levels has become of great importance to farmers for three reasons. First, the feeding value is improved with high moisture grain. It is more palatable to farm animals according to research by Wilson (1973). Second, grain harvested when the kernels reach their maximum dry weight has the highest yield. Maturity occurs when the kernel moisture is about 30% (Sauer 1973b). Yields decrease after maturity is reached because of microbial growth, insect, bird, rodent and weather damage. Third, drying, one alternative to stop microbial growth and other forms of deterioriation, is facing limitations because petroleum products are becoming more expensive and less available.

Ensiling had been the only option open to farmers for storing high moisture grain until about 10 years ago when it was demonstrated that organic acids were effective preservatives of grain. Principle chemicals now being used for grain preservatives are propionic acid or a combination of propionic and acetic acids. Other chemicals that may be used are formic acid and isobutyric acid.

The organic acids kill fungi and related microorganisms and the effect lasts almost indefinitely (Campbell 1972). The acid also destroys seed viability and biological activity is stopped. The process is similar to preserving food by pickling.

The uniformity of application of the acid is very important (Young 1971). The majority of kernels being stored need to be treated with acid in order that all fungi are killed (Sauer 1973b). Part of the grain will mold if there are extensive pockets of untreated grain. The amount of acid may be reduced with uniform application. Therefore, this study was to examine the distribution of acid on treated grain by commercial applicators and to design an applicator with improved performance.

LITERATURE REVIEW

Acid treatment is a relatively new method for storing grain. Acid treatment will prevent mold growth and spoilage in grain stored at high moisture contents (Sauer 1973a). It is similar to the pickling process in the food industry (Campbell 1972).

For many years salts of propionic acid had been sold as mold inhibitors for preserving food products (Sauer 1973b). Only within the last five years have acids been used to preserve high moisture grain in the United States. The initial development of the acid preservative method was in Great Britain in 1960 (Campbell 1972).

Feeding Trials

Acid treated grain has been fed to livestock with favorable results. The livestock readily accept acid treated grain. The grain is softer at the higher moisture making it more palatable and digestible (Wilson 1973). Merrill (1971) reports a 6-10% improvement of feed conversion for cattle fed high moisture grain compared to dry grain. Wilson (1973) reports one trial with a 15% feed efficiency improvement for acid treated corn compared to dry corn, but states that the feeding value of acid treated corn is approximately the same as ensiled high moisture corn. According to Jones and associates (1974) milk production of cows fed high moisture corn, either ensiled or treated with propionic acid, increased compared that of cows fed dry corn. They also state that feed conversion by pigs is the same for acid treated high moisture as for dry corn.

Storage Tests

Many chemicals have been investigated as mold inhibitors. Propionic acid or a mixture of propionic and acetic acid are considered the best preservatives (Sauer and Burroughs 1974, Sauer et al. 1975, Tuite 1973).

The type of storage structure used for acid treated grain is an important consideration. The galvanized steel bin is, at present, the most widely accepted grain storage structure used on the farm. Corrosion problems develop when acid treated grain is stored in galvanized bins (Holmes et al. 1972). Teter (1974) studied the storage of acid treated corn in various kinds of structures. He found that treated grain in open storage should be covered to minimize wetting of the grain caused by rain and snow. Also treated grain should not come in contact with fresh concrete because the concrete neutralizes the acid.

Storing high moisture grain is difficult because of the free water it contains. Air within the storage area moves when temperature gradients exist and carries moisture from warmer to cooler areas in the grain bulk. Acid treatment of grain does not diminish the significance of moisture migration (Stewart 1973). Acid rates required for grain preservation increase with grain moisture content.

Economic Analysis

Costs vary from one farm situation to another because of the size of operation, type of operation, and facilities currently available. Farm grain storages vary in size from 5,000 to 100,000 bushels. Fixed costs generally drop with increased volume. Some farmers market their grain as a cash crop, while others use the grain for feeding livestock. Government regulations require that acid treated grain be used only for livestock feed.

In comparisons of acid application to other grain preservation methods, past work has studied only livestock feeding operations. The advantage of feeding high moisture acid treated grain to livestock has been documented. In addition the feed value improvement of acid treated grain can be subtracted from the cost of high moisture storage systems according to Sauer (1975). Cost analysis has also shown that there is at least one other method of storing and preserving grain that may be less expensive than using acid. Costs vary depending on the location of the farm and the arrangements that a farmer can make. For example, Hall and associates (1973) show that at a 5,000 bushel production level, it is less costly for a grain elevator to dry and store the grain than it is to try to preserve it on the farm. At the 50,000 bushel production level bin drying and storing the grain on the farm is the least expensive method. If a farmer owns a grain dryer it would likely be more economical for him to continue drying his grain.

Hicks and associates (1975) state that the major cost of acid preservation is the acid. If the price of acid decreases, then this will make the use of acid more feasible regardless of the volume of grain the farmer handles, according to Hall and associates (1973). As the use of acid increases, less expensive ways of producing it in volume will likely be implemented. If this occurs, acid preservatives might be the choice of many more farmers.

Mixing of Solids

The ideal acid applicator should apply an equal amount of acid to every kernel. To date, the practice has been to apply the acid non-uniformly and then to mix the treated kernels with untreated kernels. Applying acid at the correct bulk rate is not difficult with a proper pump and flowmeter. The distribution of treated and untreated kernels is a solids mixing problem. Even from early times, solving solids mixing problems has been mainly based on trial and error (Fan et al. 1970).

A mixer that produces a homogeneous distribution at any location within the bulk is defined as a perfect mixer (Fan et al. 1975). Uniform distribution permits bulk acid application rates to be reduced.

Acid Applicators

Acid application is very important in the storability of treated grain (Young 1971). A pocket of grain in storage that is untreated could cause extensive spoilage (Sauer 1973).

Hare (1971) stated "a tremendous amount of application research and development still has to be done on the use of organic acids in agriculture." There has been relatively little previous research on acid application methods and equipment.

OBJECTIVES

The objectives were as follows:

(1) Design and make an improved acid applicator

(2) Compare acid distribution capabilities of selected applicators

  (a) develop a method to determine which kernels were sprayed with acid

  (b) treat corn with acid using the applicators

  (c) run statistical analyses to compare applicators

MATERIALS AND METHODS

There are two different methods to obtain uniform acid treatment. One method is to treat some kernels of grain and mix them uniformly with untreated kernels. The second method is to attempt to treat every kernel with acid.

Description of Applicators Tested

Five different applicators were tested. A specific procedure was developed for comparing the applicators. A new applicator was designed to apply acid to more kernels.

Double Cone Acid Applicator

There were four factors used in the design criteria for the new applicator. First, the applicator needed a simple design. Second, the applicator must be economically feasible. Third, the applicator should be inside the bin when treating the grain. Last and most important, the grain is treated in a thin stream in an attempt to contact each kernel with acid.

The grain stream is spread thinly by passing it over the surface of a cone. As the thin layer leaves the cone it is sprayed with acid from a 120° hollow cone nozzle. The grain then passes through an inverted cone located immediately below the "spreading" cone. This arrangement trapped vapors within the treating chamber for more efficient application of acid.

The applicator was designed to match the output of the six-inch auger used to feed it. It's capacity was approximately 700 bushels per hour of 14% moisture corn. This capacity would be less with grain at higher moisture contents, as was true with all applicators tested. The applicator is shown in Figures 1 and 2. Dimensions could be enlarged to handle a higher capacities. But the clearance between the tube and the cone should be about 1½ inches in order to prevent clogging while spreading the stream enough to treat the maximum number of kernels.

The double cone applicator is referred to as Applicator A.

Static Mixer

The static mixer effects radical mixing by each element successively dividing the material in half. A spinning effect is accompalished by each element twisting 180°. The mixer used was six inches inside diameter and had six elements. The mixer can be seen in Figure 3 and is referred to as Applicator B. The grain was sprayed with acid as it entered the mixer by two full cone nozzles. The capacity of the static mixer was about 700 bushels per hour of 14% moisture corn.

Commercial Auger Applicators

Three auger applicators were tested. Each was approximately twelve feet long and used an auger to transfer and mix the treated grain.

One applicator used a six-inch auger and had three nozzles where the grain entered the auger. This auger had a capacity of 700 bushels per hour of 14% moisture corn. The applicator is shown in Figure 4 and is referred to as Applicator C.

THIS BOOK CONTAINS NUMEROUS PAGES WITH DIAGRAMS THAT ARE CROOKED COMPARED TO THE REST OF THE INFORMATION ON THE PAGE.

THIS IS AS RECEIVED FROM CUSTOMER.

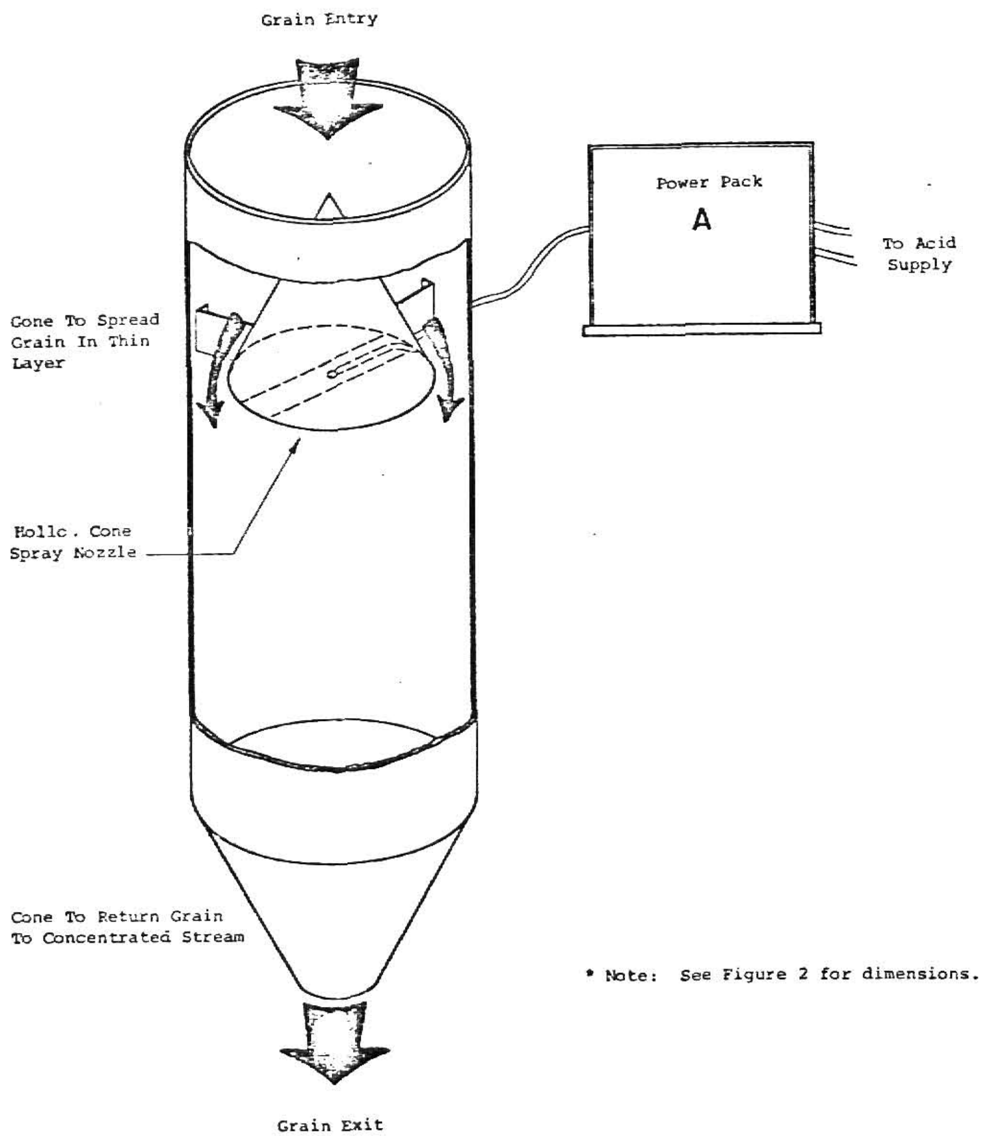


Figure 1. "Double Cone" (Applicator A)

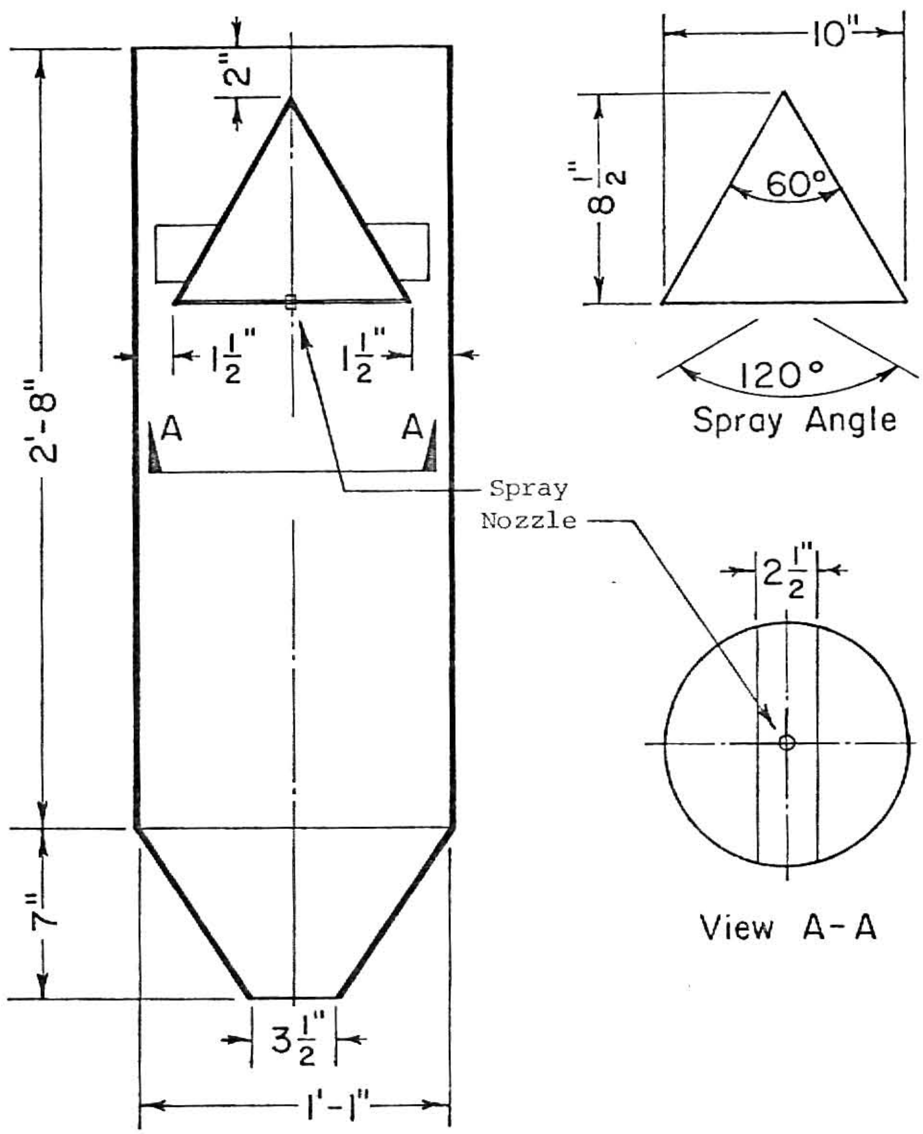


Figure 2. Internal dimensions of Applicator A

The other two applicators tested were modified or improved designs of auger applicators. Both designs used an eight-inch auger and a method of restricting the entering grain followed by a method of more fully exposing the grain to the acid spray. Each had an approximate capacity of 1,000 bushels per hour of 14% moisture corn.

One of the modified auger applicators employed a short section of a six-inch auger followed by an eight-inch auger. Since an eight-inch auger has nearly twice the capacity of a six-inch auger, the eight-inch section was only about half full when sprayed with acid using two full cone nozzles. This applicator is shown in Figure 5 and is referred to as Applicator D.

The other applicator was an eight-inch auger throughout its length but used a half-pitch flighting to restrict the entering grain, followed by full-pitch flighting. This arrangement had the same effect as decreasing the size of the entry auger for Applicator D. The grain was sprayed using three full cone nozzles located over the section that was half filled. This applicator is shown in Figure 6 and is referred to as Applicator E.

<u>Acid Measurement</u>

All applicators used a power pack to control operation and adjust the amount of acid applied to the grain. Two different power packs were used. Both had a pump to move the acid from its supply container to the grain.

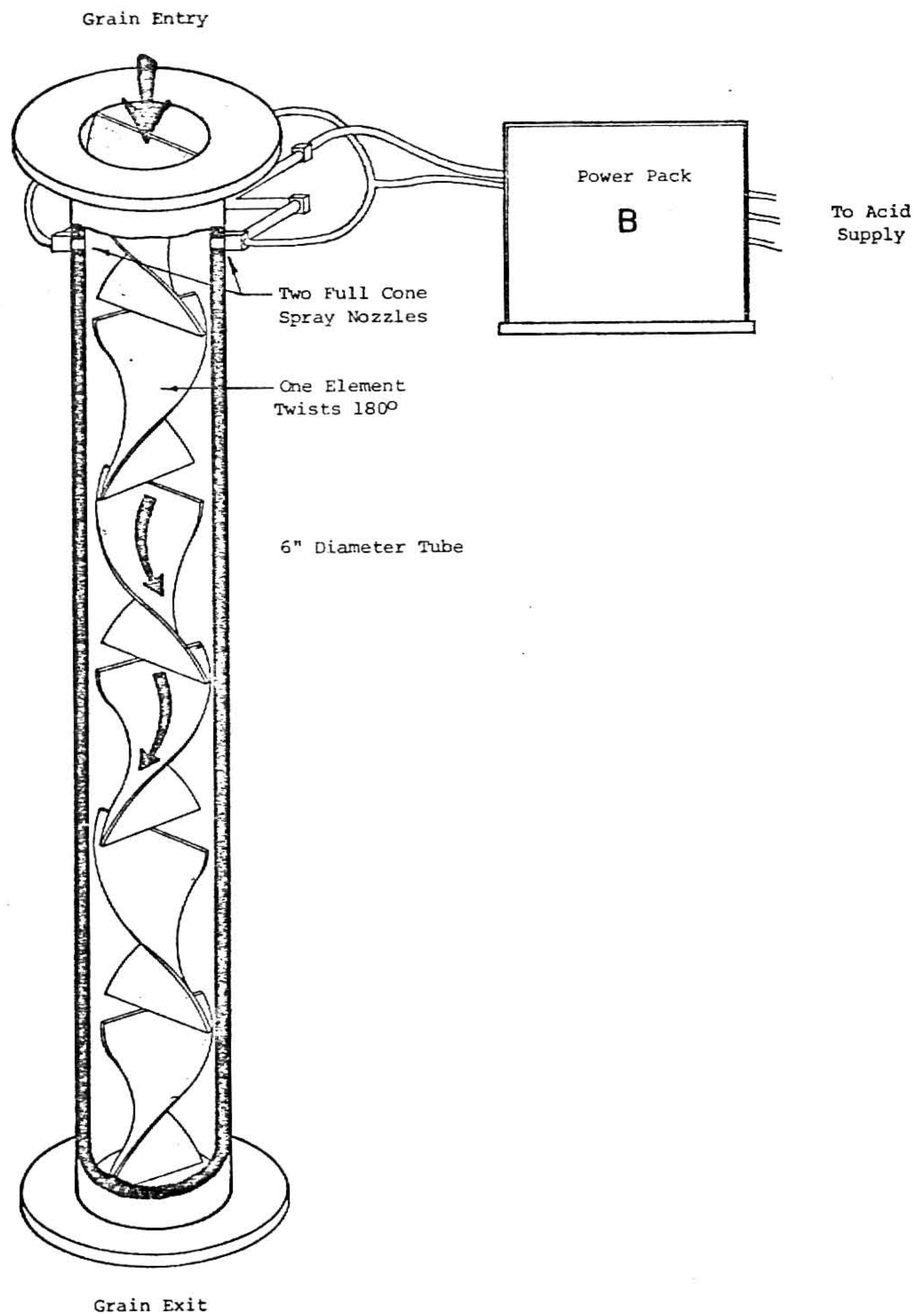


Figure 3. Static Mixer (Applicator B)

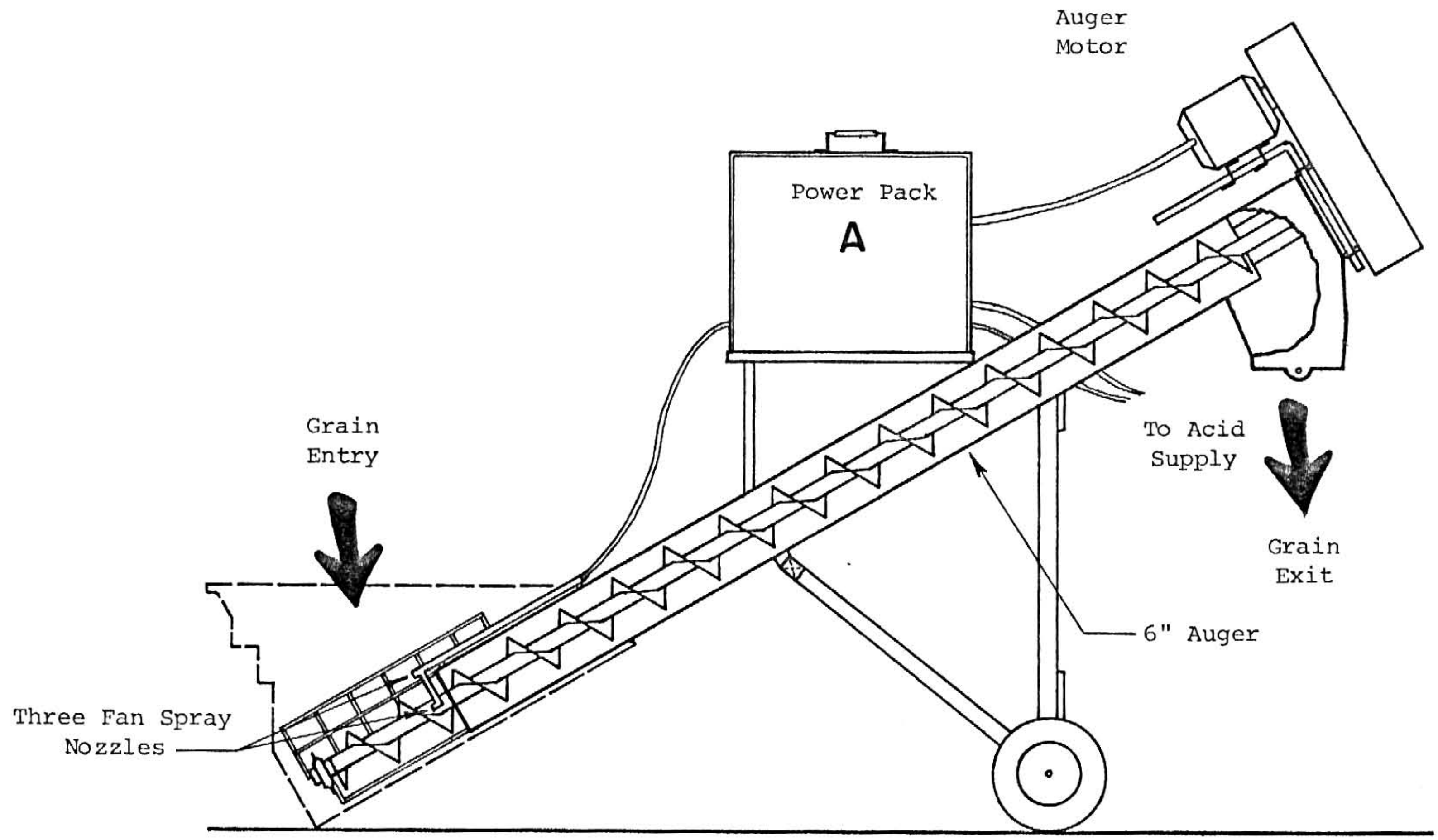


Figure 4. Commercial six-inch auger (Applicator C)

One of the power packs used a flowmeter and valve to obtain the correct acid rate. It had two pressure gages. One pressure gage indicated that the system was at operating pressure and the other pressure gage indicated clogged nozzles. This power pack is referred to as Power Pack A in previous figures and is shown in Figure 7.

The other power pack used a pressure gage and valve to obtain correct acid rate. This worked in combination with two special spray nozzles that had return lines from the nozzles. The pressure gage also indicated clogged nozzles. Another pressure gage indicated that the system was at operating pressure as it did in Power Pack A. This power pack is referred to as Power Pack B in previous figures and is shown in Figure 8.

Other Materials Used

Corn.

The grain used in the research was yellow corn with 14% moisture content, wet basis. Although acid treatment would not be required to preserve corn at this low moisture content, the corn was suitable for studying applicator performance.

Acid Mixture.

One tenth of one percent by weight of ethyl violet dye was mixed with pure propionic acid before applying in order to facilitate visual evaluation of acid coverage of kernels. This was adequate to stain the grain purple upon contact.

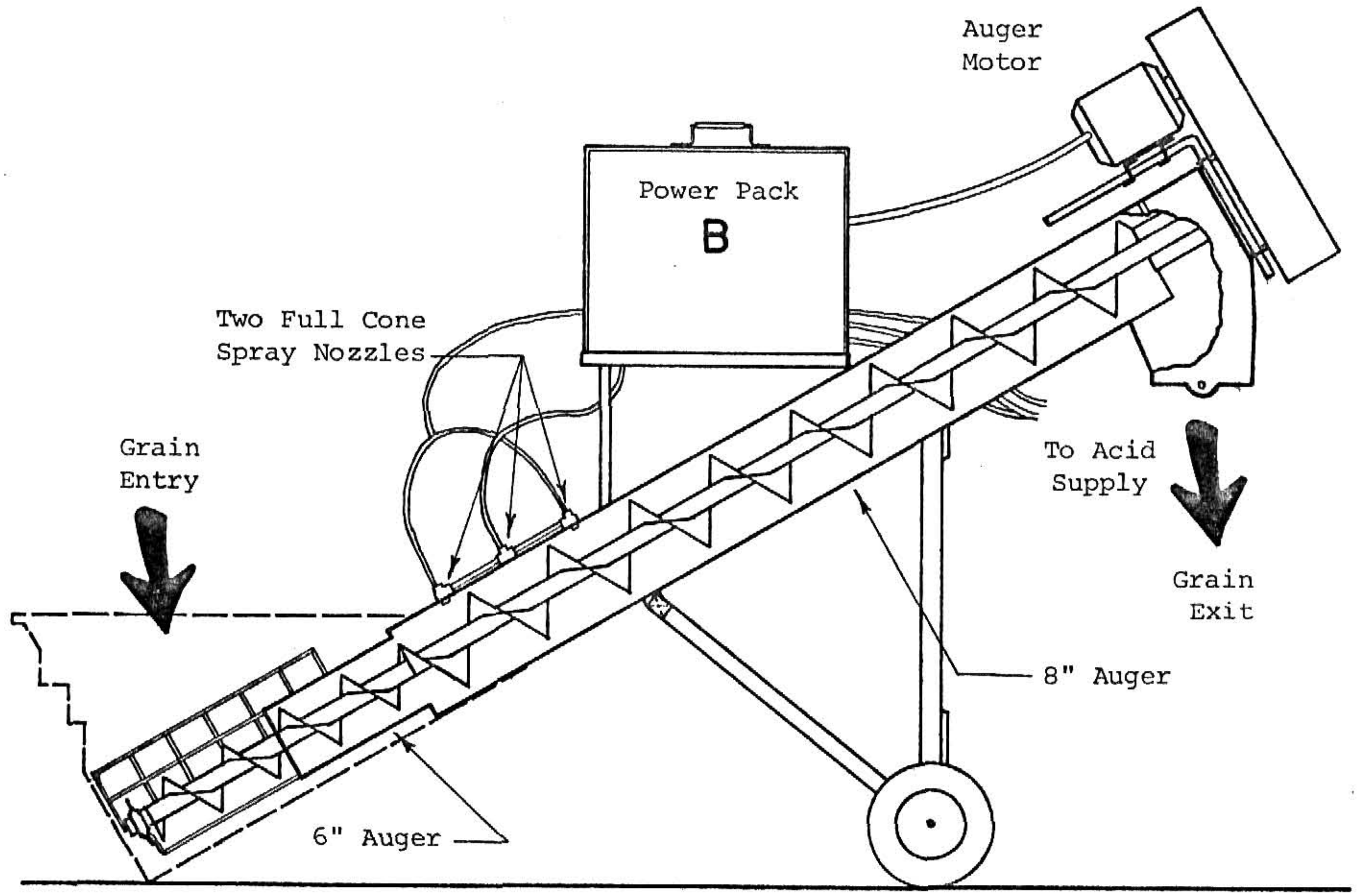


Figure 5. Improved commercial auger (Applicator D)

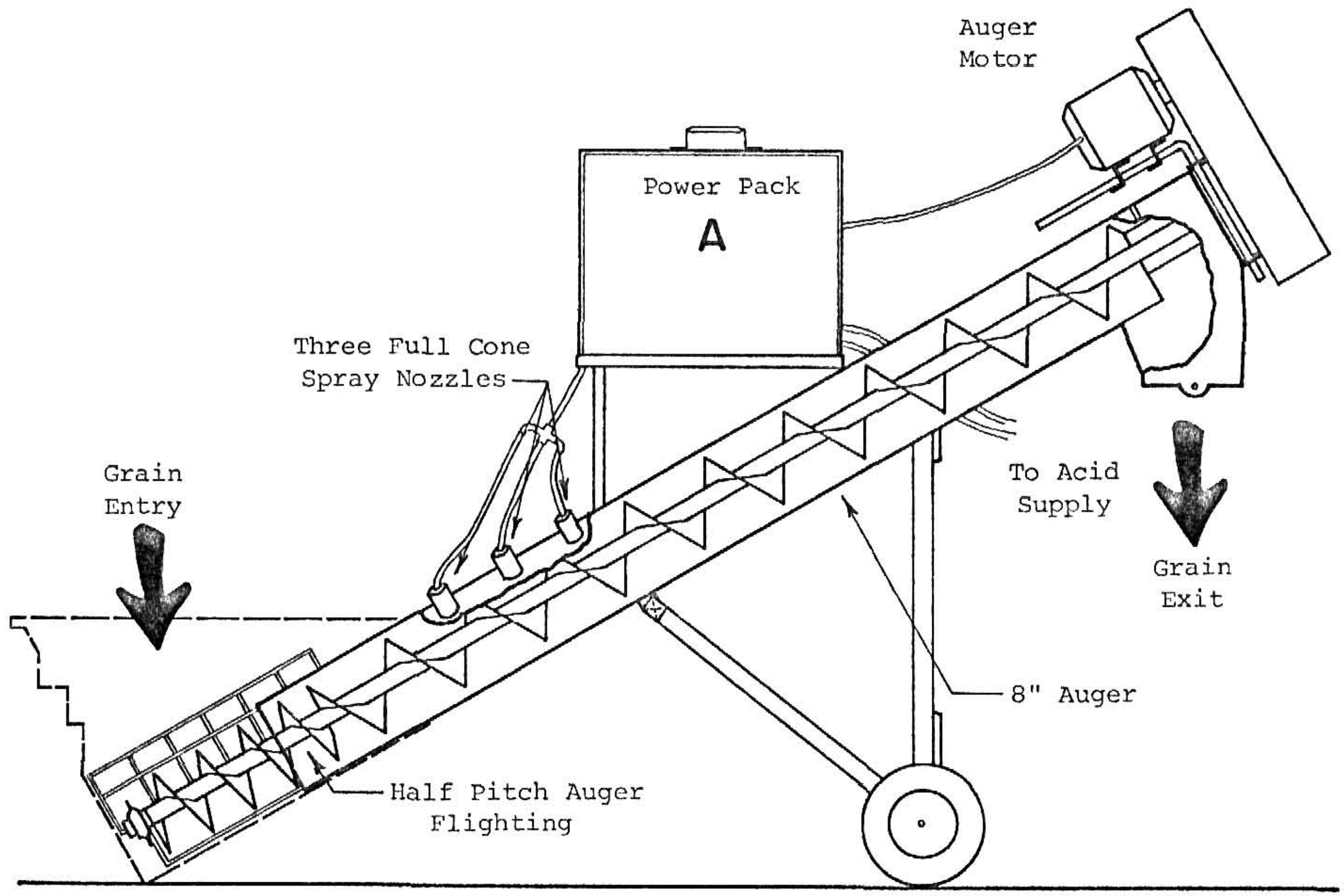


Figure 6. Improved commercial auger (Applicator E)

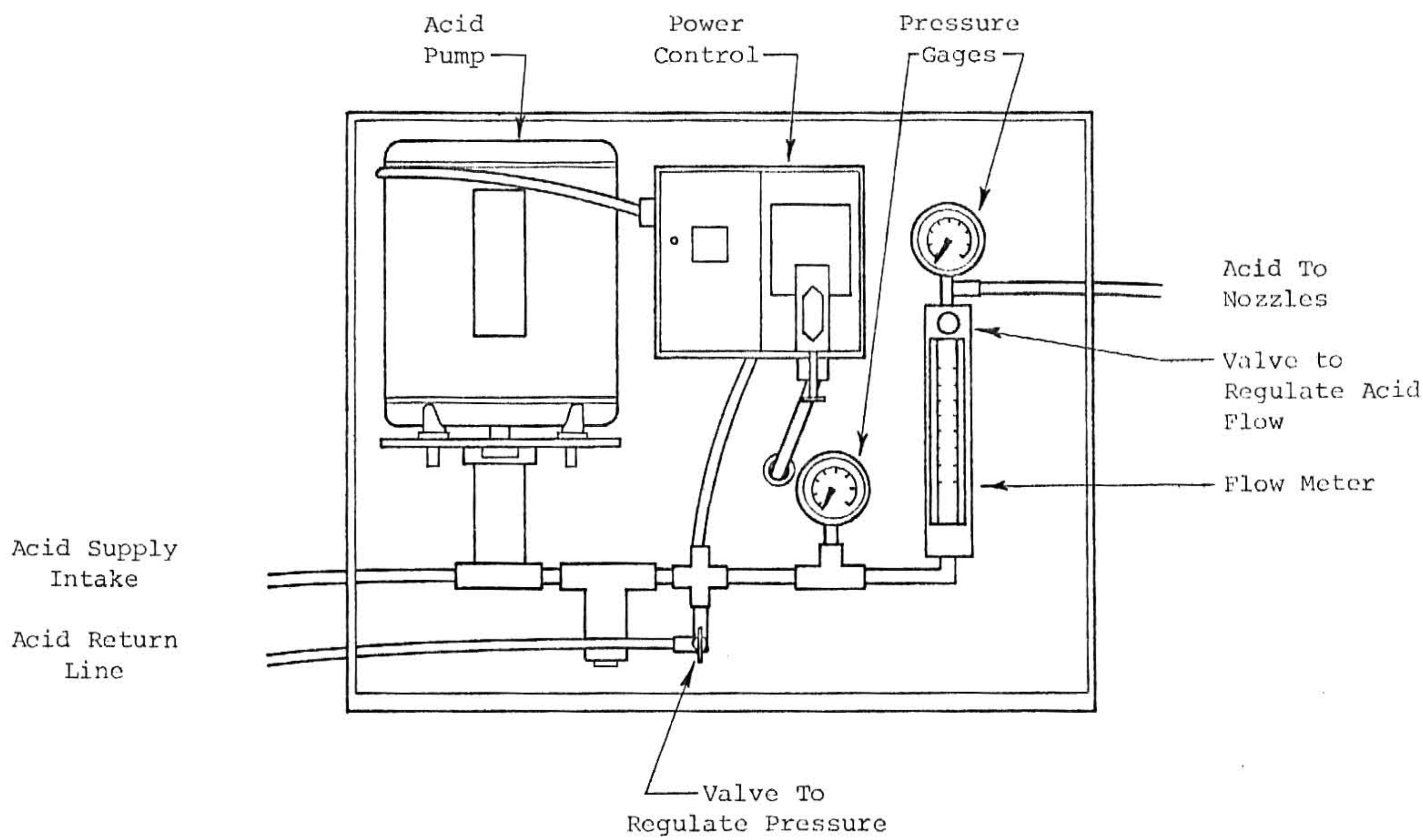


Figure 7. Power Pack A

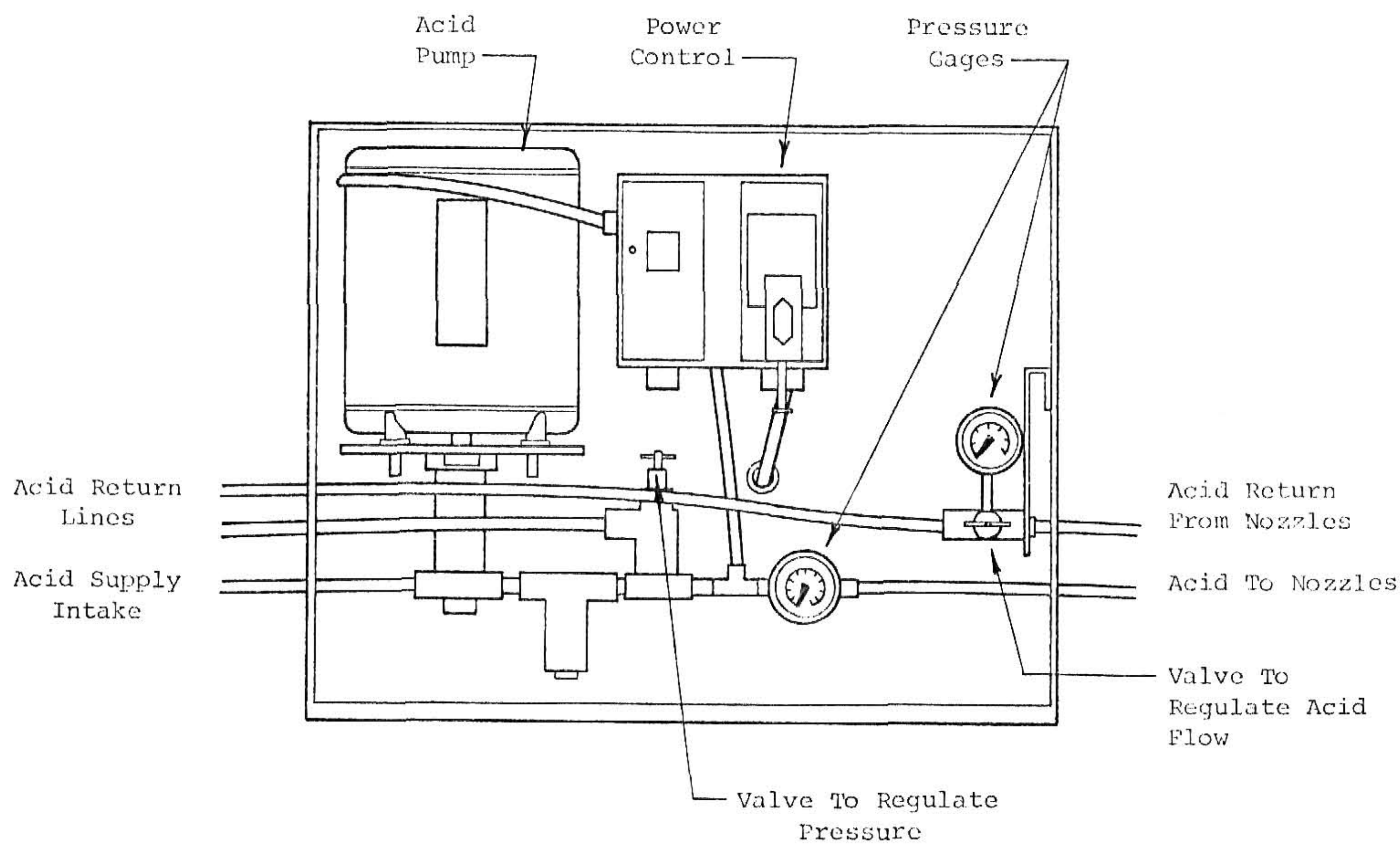


Figure 8. Power Pack B

Stained grain, a mixture of ethyl violet dye and propionic acid, and propionic acid without the added dye are shown in Figure 9.

Storage Containers.

The treated grain was stored in fifty-five gallon steel barrels until it was sampled.

Test Procedure

First, each applicator was calibrated in order that the grain flow rate could be established and the amount of acid needed could be calculated. Next, the necessary flow adjustments were made and the applicator was primed.

After this step, an initial run was made to check the calibration. A barrel was weighed empty, filled and then weighed again. The acid applied was also weighed. This was necessary to check the actual acid application rate under test conditions.

A test run consisted of filling one barrel. (See Figures 10, 11, 12). The empty barrel after being weighed was centered under the applicator. The applicator was stopped at the discretion of the operator when the barrel was full. The acid, which had been weighed before the test, and the barrel were reweighed. The location where the filling auger (sometimes same as application auger) went over the lip of the barrel was also recorded for determining sample location, as described later.

THIS BOOK CONTAINS SEVERAL DOCUMENTS THAT ARE OF POOR QUALITY DUE TO BEING A PHOTOCOPY OF A PHOTO.

THIS IS AS RECEIVED FROM CUSTOMER.

THIS BOOK CONTAINS NUMEROUS PICTURES THAT ARE ATTACHED TO DOCUMENTS CROOKED.

THIS IS AS RECEIVED FROM CUSTOMER.

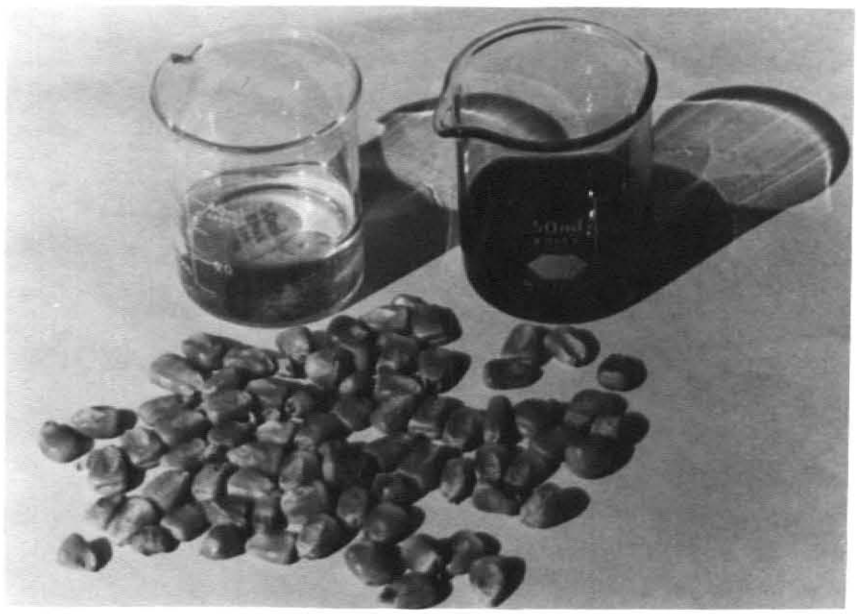


Figure 9. Beakers of propionic acid with and without ethyl violet dye plus treated corn kernels.

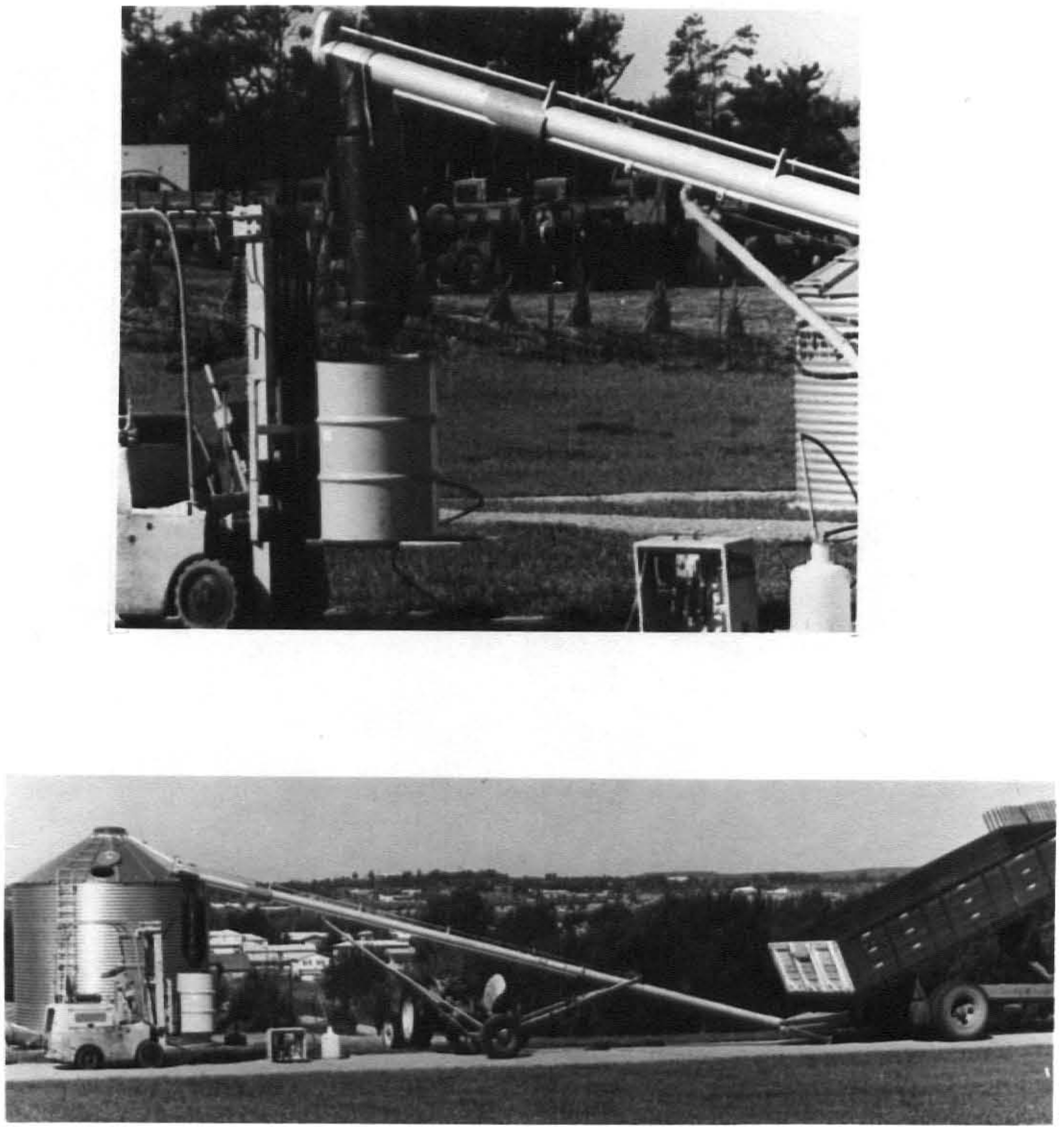


Figure 10. Applicator A set up for test.

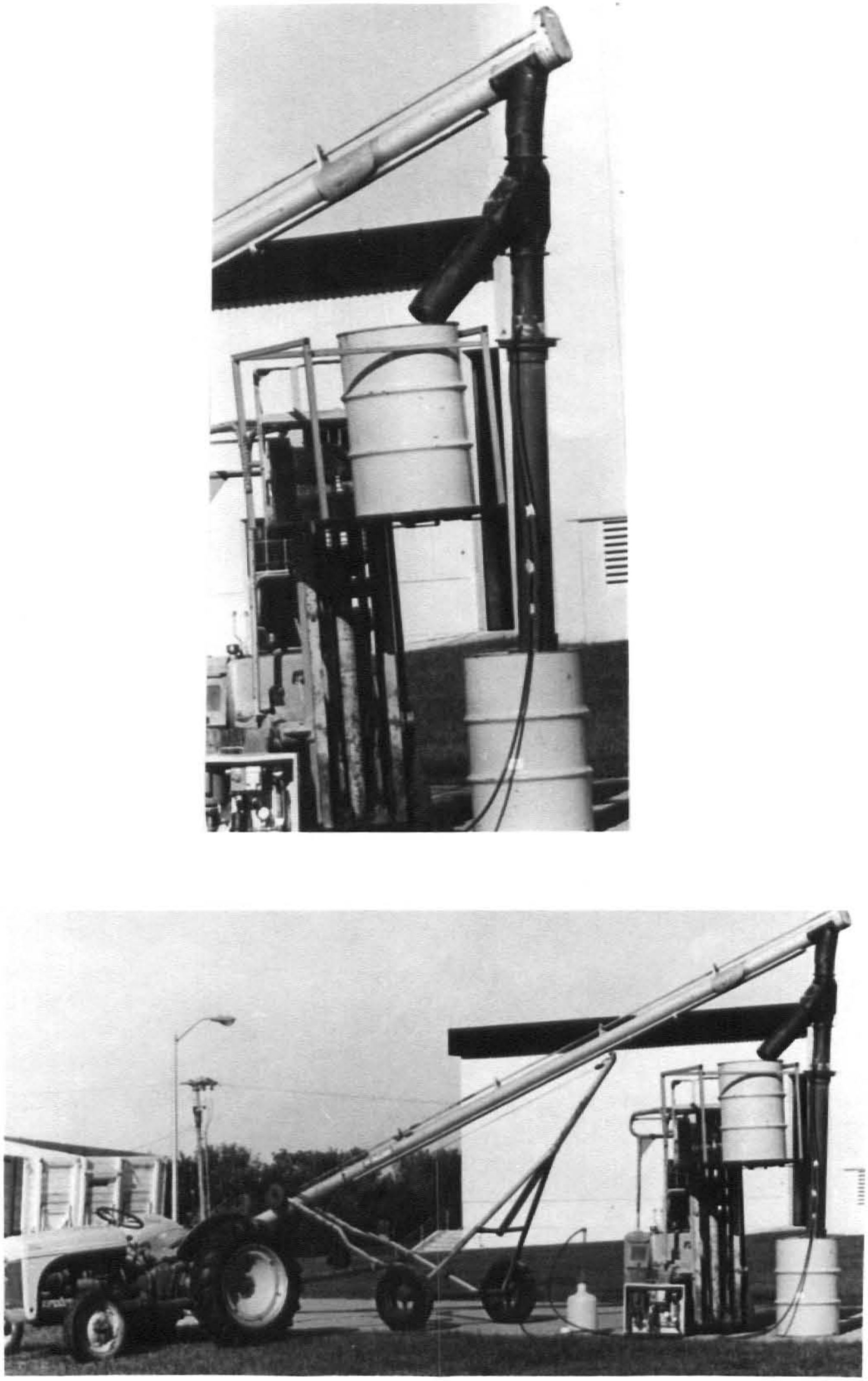
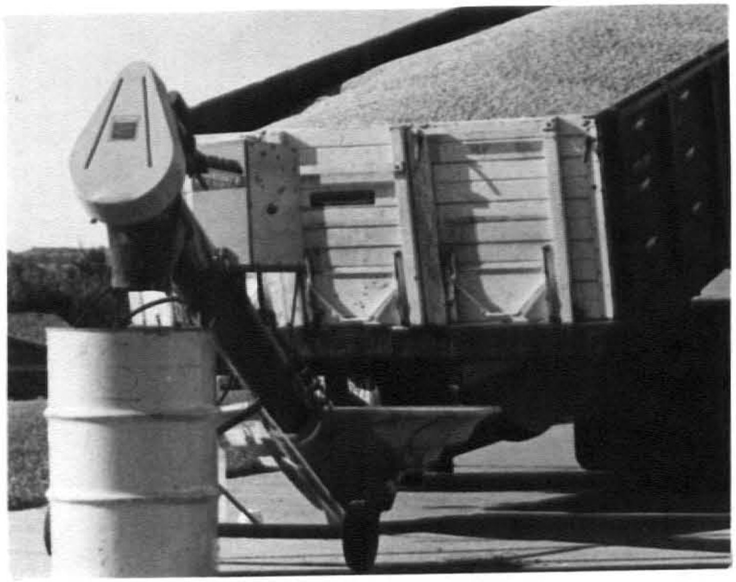


Figure 11. Applicator B set up for test.



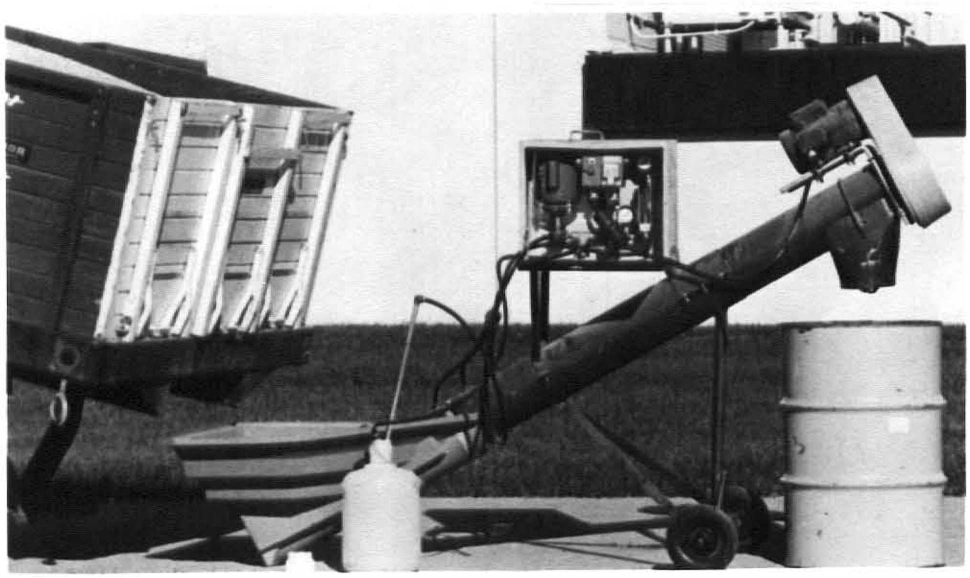


Figure 12. Applicator E set up for test.

Two test runs at two different acid rates were made with each applicator. The acid was applied at a rate of 0.5 and 0.9% of the grain by weight. Unless the acid applied, as determined by the weighing procedure described, was within .05% of the acid rate desired, the test was rerun.

A template was used to locate sampling locations in each barrel. The template was placed in a fixed position with respect to the position of the applicator. Five holes were made in the template for sampling; the template is shown in Figure 13.

Sampling of the grain was done by using a five-foot sectional grain probe; the probe is shown in Figure 13. The center of each section of the grain probe is six inches from the center of the next section.

The probe was pushed down vertically through the template and six sectional cells of the probe were filled. This was done for each of the five holes in the template, making thirty samples per barrel.

Five applicators each were used at two acid rates and each run was duplicated, so twenty barrels were used. A total of six hundred grain samples were taken for evaluation. Each sample was placed in a polyethlene bag until the kernels were in a sample. The kernels in each sample were divided into three classifications.

The classes were: kernels with no visible dye, those with germs partially covered with dye, and those with germs

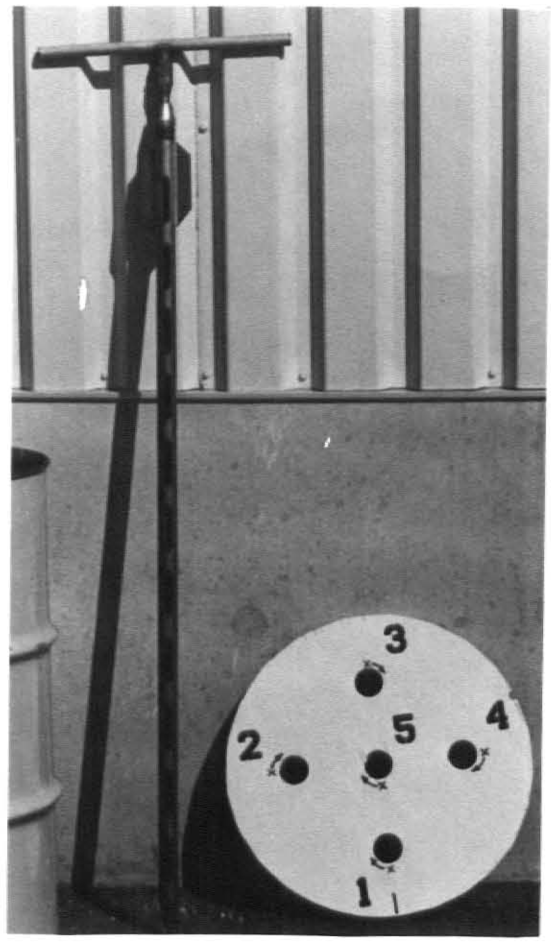


Figure 13. Grain probe and template used in tests.

fully covered (see Figure 14). Broken kernels were discarded.

The data were summarized by taking the eighteen values at each hole (referred to here after as horizontal locations) on the template (six samples, each divided into three classifications) and averaging the values of each classification. This gave three classification values at each horizontal location. The sum of the percentages at each horizontal location equalled 100.

For analysis, two different sets of weighting factors were assigned to classes of kernels dependent on the degree of acid coverage on each kernel. One set of weighting factors multiplied the percentage of kernels with no dye visible by zero, the partially covered germs of the corn kernels by one-half, and the full covered germs by one (0-½-1). These weighting factors were chosen on the basis of surface coverage. On the average, the partially coated germs of the corn kernels had half their surface areas coated with dye. The second set of weighting factors multiplied the percentage with no visible dye by zero and both percentages of the partially and fully visible dye-covered germs by one (0-1-1). This set of weighting factors was chosen on the assumption that any kernel treated, partially or fully, would not develop mold.

Percentages for the horizontal locations of the four test runs for each applicator were then averaged so that there were three percentage classification values for each applicator. Then the percentages were multiplied by their respective

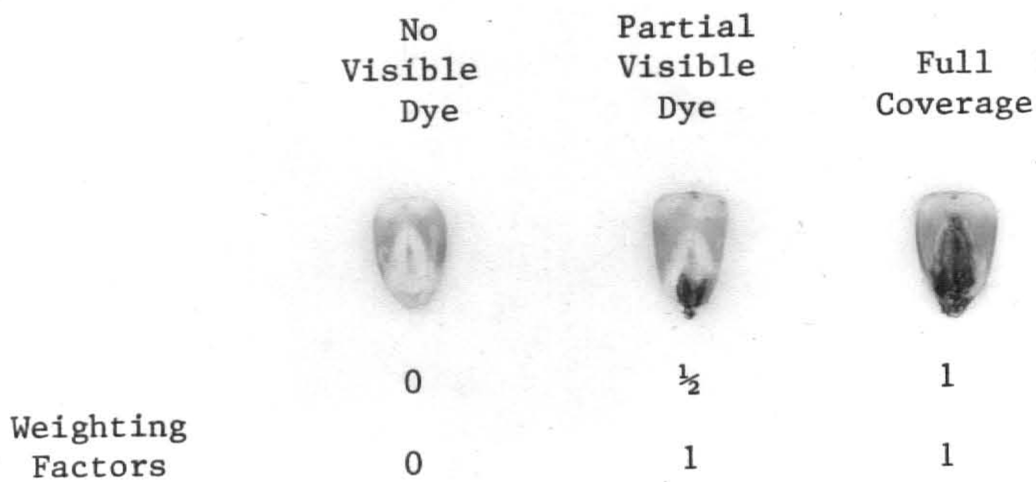


Figure 14. Classification of acid coverage of corn kernels.

weighting factors and then summed into one value for each applicator. This was done twice, once for each set of weighting factors. Next an analysis of variance was conducted to determine which factors that made up the tests (rates, replications, horizontal locations, etc.) had significant differences.

RESULTS AND DISCUSSION

Experimental data for percentages of kernels in each coverage category for the five horizontal sample collection locations are given in the appendix. Each unweighted value given represents lumped data for all vertical locations at one horizontal probe port.

The three classification values and sums of the values using the two sets of weighting factors are shown in Table 1. Applicator C was clearly inferior to the other four applicators. A least significant difference (LSD) test with a 95% confidence interval varified this. The LSD test was run on the values from both sets of weighting factors and the same results were observed.

Changing the weighting factors (0-½-1) to (0-1-1) increased the coverage indicated by applicators A and D. This was due to the large number of kernels with partial coverage.

Further comparisons can be made from the analysis of variation. Since two sets of weighting factors were used, two analyses of variance were made. The results are shown in Tables 2 and 3.

There was a significant difference in the number of kernels treated using different acid applicators, as discussed in the second paragraph of this section. Also, there was a significant difference in the two acid treatment rates. A higher percentage of the kernels in the test lot were treated at the higher acid rate.

A significant difference was found in the interaction of acid applicators and horizontal locations. The weighted percentages of the acid applicators at the horizontal locations are shown in Tables 4 and 5. These data are important because they show how the treated grain was distributed by the applicators. The applicator that provided the most uniform value in all five locations was judged to be the best of the four applicators, Applicators A, B, D, and E. Applicator A had the most uniform distribution using either set of weighting factors; the coefficient of variation of the five locations for each applicator is shown in the last line of Tables 4 and 5.

As shown in Tables 4 and 5, a trend can be seen in the auger applicators (C, D, and E). The high value occurs approximately the same horizontal location for Applicators C, D, and E. The lowest value for Applicator C is 90 away from those of Applicators D and E's values because Applicators D and E had flow restrictions. Applicator C ran nearly full and would be expected to have a slightly different pattern.

One reason that Applicators D and E did a satisfactory job, when evaluated against Applicator C, is the increase in the surface area sprayed. Applicator A (the newly designed applicator) increased the surface area sprayed, obtaining a uniform distribution.

Applicator A had treated the grain with a speckled

Table 1. Percent of kernels with no acid coverage, partial coverage, and full coverage and sums for two sets of weighting factors.[1]

Applicator	None	Partial	Full	Weighting[2] (0-½-1)	(0-1-1)
A	7.9	66.9	25.2	58.6	92.1
B	12.7	40.5	46.8	67.0	87.3
C[3]	51.7	36.7	11.6	29.9	48.3
D	8.0	58.9	33.1	62.5	92.0
E	23.6	40.9	35.5	55.9	76.4

[1] Each coverage value is an average for two replications and two acid rates. Classification: None - no visible dye; Partial - germ partly covered; Full - germ fully covered.

[2] The weighting of (0-½-1) was applied to the data this way. For Applicator A, 7.9 was multiplied by zero, 66.9 by one-half and 25.2 by one. These products were added together to obtain a sum of 58.6. The same procedure was followed for the other applicators and for the other set of weighting factors (0-1-1).

[3] The LSD test at a 95% C.I. detected a significant difference between Applicator C and the other four applicators.

Table 2. Analysis of variance of kernel acid coverage using weighting factors (0-½-1).[1]

Source	Degrees of Freedom	Mean Square	F-Value	Tested Against Error	Significant at $\alpha = 0.05$
Applicator (A)	4	0.422	5.36	A	*
Rate (R)	1	1.591	20.23	A	*
A * R	4	0.040	0.51	A	
Replication (REP)	1	0.177	2.24	A	
A * REP	4	0.077	0.97	A	
R * REP	1	0.116	1.47	A	
A * R * REP	4	0.047	0.59	A	
Error A	10	0.079	8.43	B	*
Location (L)	4	0.029	3.09	B	*
A * L	16	0.023	2.45	B	*
R * L	4	0.002	0.21	B	
A * R * L	16	0.003	0.32	B	
REP * L	4	0.002	0.21	B	
A * REP * L	16	0.010	1.07	B	
R * REP * L	4	0.007	0.75	B	
A * R * REP * L	16	0.011	1.17	B	
Error B	40	0.009			
Corrected Total	99	0.052			

[1] Weighting factors: 0, no acid coverage; ½, partial acid coverage; 1, full acid coverage of kernel germ.

Table 3. Analysis of variance of kernel acid coverage using weighting factors (0-1-1).[1]

Source	Degrees of Freedom	Mean Square	F-Value	Tested Against Error	Significant at α=0.05
Applicator (A)	4	0.680	6.87	A	*
Rate (R)	1	1.351	13.65	A	*
A * R	4	0.113	1.14	A	
Replication (REP)	1	0.469	4.73	A	
A * REP	4	0.069	0.70	A	
R * REP	1	0.117	1.18	A	
A * R * REP	4	0.032	0.32	A	
Error A	10	0.099	4.74	B	*
Location (L)	4	0.062	2.98	B	*
A * L	16	0.035	1.68	B	*
R * L	4	0.005	0.25	B	
A * R * L	16	0.006	0.29	B	
REP * L	4	0.016	0.76	B	
A * REP * L	16	0.018	0.86	B	
R * REP * L	4	0.034	1.62	B	
A * R * REP * L	16	0.022	1.05	B	
Error B	40	0.021			
Corrected Total	99	0.073			

[1] Weighting factors: 0, no acid coverage; 1, partial acid coverage; 1, full acid coverage of kernel germ.

pattern. In the other applicators, the grain spent more time in the applicator. The kernels rubbed against each other and did not appear as speckled.

Table 4. Horizontal distribution of kernel acid coverage using weighting factors $(0-\frac{1}{2}-1)$.[1]

Applicator	Location 1	2	3	4	5	Mean $\bar{X}$	Variance S	Coefficient of Variation $S/\bar{X}$
Double Cone - Applicator A	.595	.583	.571	.597	.587	.587	.010	.018
Static Mixer - Applicator B	.584	.679	.657	.761	.669	.670	.063	.094
Six-Inch Auger - Applicator C	.460	.445	.239	.162	.191	.299	.143	.476
Six to Eight-Inch Auger - Applicator D	.615	.581	.493	.514	.595	.560	.053	.095
Half to Full Pitch Auger - Applicator E	.713	.632	.569	.603	.608	.625	.054	.087

[1] Weighting factors: 0, no acid coverage; $\frac{1}{2}$, partial acid coverage; 1, rull acid coverage of kernel germ.

Table 5. Horizontal distribution of kernel acid coverage using weighting factors (0-1-1).[1]

Applicator	Location 1	2	3	4	5	Mean $\bar{X}$	Variance S	Coefficient of Variation $S/\bar{X}$
Double Cone - Applicator A	.956	.914	.917	.913	.904	.921	.020	.022
Static Mixer - Applicator B	.848	.872	.826	.939	.878	.873	.042	.049
Six-Inch Auger - Applicator C	.701	.718	.379	.281	.334	.483	.210	.435
Six to Eight-Inch Auger - Applicator D	.826	.782	.685	.737	.789	.764	.054	.071
Half to Full Pitch Auger - Applicator E	.969	.929	.861	.914	.926	.920	.039	.042

[1] Weighting factors: 0, no acid coverage; 1, partial acid coverage; 1, full acid coverage of kernel germ.

CONCLUSIONS

Based on differences among acid applicators as judged by percentage of kernels treated and uniformity of treated kernels in the storage container, the following conclusions are made.

1. Applicator C was significantly inferior to the other four applicators.
2. Applicator A (the newly designed applicator) was equal to Applicators B, D, and E in the percentage of kernels treated and was superior to them in uniformity of acid application at different horizontal locations in the storage containers filled by the applicators.
3. The pattern of the treated kernels in the container filled by the auger applicators (C, D and E) was similar but the distribution was not entirely uniform.

SUGGESTIONS FOR FUTURE WORK

The following suggestions are recommended for future work:

1. Rerun tests using different grains.
2. Run storage tests on high moisture grain treated with the applicators compared in this study.
3. Conduct on-the-farm tests using new applicator.
4. Study possibility of lower acid rates using newly designed applicator.
5. Conduct controlled experiments to determine the importance of uniform acid coverage on grains.

REFERENCES

Campbell, Joseph K. 1972. Preserving grain with organic acids - from an engineering viewpoint. Paper No. NA72-108. St. Joseph, Michigan. American Society of Agricultural Engineers.

Fan, L. T., S. J. Chen, and C. A. Watson. 1970. Solids mixing. Industrial and Engineering Chemistry. 62(7):53.

Fan, L. T., F. Lai, and R. H. Wang. 1973. Cereal grain handling system - storing, transporting, blending, separating, and sampling. Unpublished Review. Department of Chemical Engineering, Kansas State University, Manhattan, Kansas.

Hall, G. E., L. D. Hill, E. E. Hatfield, and A. H. Jensen. 1973. Propionic-acetic acid for high moisture corn preservation. Paper No. 73-312. American Society for Agricultural Engineers. St. Joseph, Michigan.

Hall, J. H. 1971. Sees increase in use of organic acids for damp grain preservation. Feedstuffs. 71(1):19-35.

Hicks, D. R., H. G. Johnson, H. A. Cloud, C. M. Christensen, and R. A. Meronuck. 1975. Preservation and storage of high-moisture grain with propionic acid. Fact Sheet, Agronomy No. 29. Agricultural Extension Service, University of Minnesota, St. Paul, Minnesota.

Holmes, J. W., H. R. Clark, and F. H. Theakston. 1972. Prevention of corrosive attack on galvanized steel by acid treated feed grain. Paper No. 72-201. Canadian Society of Agricultural Engineers. Charlottetown, Prince Edward Island, Canada.

Jones, G. M., D. N. Mowat, J. I. Elliot, and E. T. Moran, Jr. 1974. Organic acid preservation of high moisture corn and other grains and the nutritional value: A review. Canadian Journal of Animal Science. 54(4):499-517.

Merrill, W. G. 1971. Feeding high moisture grain silages. Proceedings International Silage Research Conference. Washington, D. C.

Sauer, D. B. 1973a. Grain Preservatives. Mimeographed proceedings. Kansas Formula Feed Conference.

Sauer, D. B. 1973b. Grain preservatives for high moisture feed grains. A report from the U.S. Grain Marketing Research Center, Agricultural Research Service, Manhattan, Kansas. 9 pgs.

Sauer, D. B. 1975. Economics of chemical grain preservative systems. Unpublished data. U.S. Grain Marketing Research Center, Agricultural Research Service, Manhattan, Kansas.

Sauer, D. B., and Rosemary Burroughs. 1974. Efficacy of various chemicals as grain mold inhibitors. Transactions of American Society of Agricultural Engineers. 17(3):557-559.

Sauer, D. B., T. O. Hodges, Rosemary Burroughs, and H. H. Converse. 1975. Comparison of propionic acid and methylene bis propionate as grain preservatives. Transactions of American Society of Agricultural Engineers. (In press).

Stewart, J. A. 1973. Moisture migration during storage of high moisture grains. Paper No. 73-3512. American Society of Agricultural Engineers. St. Joseph, Michigan.

Teter, N. C. 1974. Nebraska trials on storage of acid treated corn. Paper No. 74-3107. American Society of Agricultural Engineers. St. Joseph, Michigan.

Tuite, John. 1973. Preservation of high moisture shelled corn by treatment with organic acid. Unpublished paper. Agricultural Experiment Station, Purdue University, West Lafayette, Indiana.

Weidenbaum, S. S. 1958. Mixing of solids. Advances of Chemical Engineering. 11:211-324.

Wilson, L. L. 1973. Organic acid preserved grain, from a feeding viewpoint. Grain Quality Proceedings, Department of Animal Science, University of Illinois, Urbana-Champaign, Illinois. 64-79.

Young, B. A. 1971. Harvesting and storage of high moisture grain. Free Press Weekly. April 10.

APPENDIX

PERCENT OF ACID COVERAGE OF KERNELS AT HORIZONTAL LOCATIONS FOR ACID APPLICATOR A

Acid Rate[1]	Replication	Location	None[2]	Partial	Full	Weighting Factors[3] (0-½-1)	(0-1-1)
0.9%							
	I	1	0.2	87.3	12.6	56.2	99.8
		2	3.0	84.6	12.5	54.8	97.0
		3	2.3	83.1	14.6	56.2	97.7
		4	0.6	84.0	15.4	57.4	99.4
		5	11.3	84.7	4.0	46.3	88.7
	II	1	0.0	29.9	70.1	85.1	100.0
		2	0.0	34.0	66.0	83.0	100.0
		3	0.9	69.1	30.0	64.5	99.1
		4	0.6	38.7	60.8	80.1	99.4
		5	0.0	20.5	79.5	89.7	100.0
0.5%							
	I	1	0.6	92.9	6.6	53.0	99.4
		2	0.3	83.7	16.0	57.9	99.7
		3	0.1	66.3	33.6	66.7	99.9
		4	0.0	76.4	23.6	61.8	100.0
		5	0.0	80.4	19.6	59.8	100.0
	II	1	16.8	78.7	4.5	43.9	83.2
		2	31.2	62.6	6.2	37.5	68.8
		3	29.9	58.6	11.5	40.8	70.1
		4	33.5	53.1	13.4	39.9	66.5
		5	27.0	67.8	5.2	39.1	73.0

1 Rate of acid applied to grain on a weight percentage.

2 Classification of acid coverage in percentage values: None - no visible dye, Partial - partial coverage of germs of kernels, Full - full coverage of germs of kernels.

3 Two sets of weighting factors were used. Each was multiplied by the three classification percentages and summed. See Table 1.

APPENDIX CONTINUED
PERCENT OF ACID COVERAGE OF KERNELS AT HORIZONTAL LOCATIONS FOR ACID APPLICATOR B

Acid Rate[1]	Replication	Location	None[2]	Partial	Full	Weighting Factors[3] (0-½-1)	(0-1-1)
0.9%							
	I	1	0.6	42.8	56.5	77.9	99.4
		2	0.6	18.2	81.2	90.3	99.4
		3	3.5	37.5	59.0	77.8	96.5
		4	0.0	21.6	78.4	89.2	100.0
		5	0.2	26.4	73.5	86.6	99.8
	II	1	7.2	58.7	34.1	63.4	92.8
		2	8.2	38.7	53.1	72.5	91.8
		3	6.3	26.9	66.8	80.2	93.7
		4	3.6	19.2	77.3	86.9	96.4
		5	19.1	42.1	38.9	59.9	80.9
0.5%							
	I	1	15.3	56.4	28.3	56.5	84.7
		2	9.5	57.0	33.5	62.0	90.5
		3	6.6	30.6	62.7	78.1	93.4
		4	2.7	37.6	59.7	78.5	97.3
		5	6.1	42.0	52.0	73.0	93.9
	II	1	37.8	52.9	9.2	35.7	62.2
		2	33.1	40.1	26.8	46.8	66.9
		3	53.2	39.9	6.9	26.8	46.8
		4	17.8	64.9	17.3	49.8	82.2
		5	23.4	56.9	19.7	48.2	76.6

1 Rate of acid applied to grain on a weight percentage.

2 Classification of acid coverage in percentage values: None - no visible dye, Partial - partial coverage of germs of kernels, Full - full coverage of germs of kernels.

3 Two sets of weighting factors were used. Each was multiplied by the three classification percentages and summed. See Table 1.

APPENDIX CONTINUED
PERCENT OF ACID COVERAGE OF KERNELS AT HORIZONTAL LOCATIONS FOR ACID APPLICATOR C

Acid Rate[1]	Replication	Location	None[2]	Partial	Full	Weighting Factors[3] (0-½-1)	(0-1-1)
0.9%							
	I	1	0.3	58.0	41.6	70.7	99.7
		2	10.9	69.9	19.2	54.2	89.1
		3	55.2	37.8	7.0	25.9	44.8
		4	27.0	65.8	7.3	40.2	73.0
		5	1.2	90.3	8.6	53.7	98.8
	II	1	26.7	49.8	23.6	48.5	73.3
		2	17.6	46.4	36.0	59.2	82.4
		3	27.4	54.4	18.2	45.4	72.6
		4	82.5	12.1	5.3	11.4	17.4
		5	76.0	16.5	7.5	15.8	24.0
0.5%							
	I	1	7.5	73.4	19.0	55.7	92.5
		2	3.2	92.2	4.6	50.7	96.8
		3	88.1	9.3	2.6	7.2	11.9
		4	93.6	4.0	2.3	4.3	6.4
		5	93.5	4.8	1.7	4.1	6.5
	II	1	85.2	11.4	3.4	9.1	14.8
		2	81.3	9.9	8.8	13.8	18.7
		3	77.6	11.0	11.4	16.9	22.4
		4	84.3	13.4	2.3	9.0	15.7
		5	95.7	3.4	0.9	2.6	4.3

[1] Rate of acid applied to grain on a weight percentage.

[2] Classification of acid coverage in percentage values: None - no visible dye, Partial - partial coverage of germs of kernels, Full - full coverage of germs of kernels.

[3] Two sets of weighting factors were used. Each was multiplied by the three classification percentages and summed. See Table 1.

APPENDIX CONTINUED
PERCENT OF ACID COVERAGE OF KERNELS AT HORIZONTAL LOCATIONS FOR ACID APPLICATOR D

Acid Rate[1]	Replication	Location	None[2]	Partial	Full	Weighting Factors[3] (0-½-1)	(0-1-1)
0.9%							
	I	1	1.2	43.7	55.1	77.0	98.8
		2	2.4	54.4	43.2	70.4	97.6
		3	11.9	48.4	39.7	63.9	88.1
		4	3.7	58.7	37.6	67.0	96.3
		5	1.7	55.4	42.9	70.6	98.3
	II	1	0.1	14.9	85.0	92.4	99.9
		2	2.9	42.5	54.6	75.9	97.1
		3	4.4	54.8	40.8	68.2	95.6
		4	2.6	49.3	48.2	72.8	97.4
		5	2.0	59.3	38.7	68.4	98.0
0.5%							
	I	1	7.2	75.2	17.6	55.2	92.8
		2	10.3	72.1	17.6	53.6	89.7
		3	28.3	61.9	9.8	40.7	71.7
		4	21.5	67.4	11.1	44.8	78.5
		5	16.0	68.1	16.0	50.0	84.0
	II	1	4.0	70.5	25.5	60.7	96.0
		2	12.9	68.6	18.5	52.8	87.1
		3	10.9	68.3	20.8	54.9	89.1
		4	6.6	73.7	19.7	56.6	93.4
		5	10.1	71.2	18.8	54.4	89.9

1 Rate of acid applied to grain on a weight percentage.

2 Classification of acid coverage in percentage values: None - no visible dye, Partial - partial coverage of germs of kernels, Full - full coverage of germs of kernels.

3 Two sets of weighting factors were used. Each was multiplied by the three classification percentages and summed. See Table 1.

APPENDIX CONTINUED
PERCENT OF ACID COVERAGE OF KERNELS AT HORIZONTAL LOCATIONS FOR ACID APPLICATOR E

Acid Rate[1]	Replication	Location	None[2]	Partial	Full	Weighting Factors[3] (0-½-1)	(0-1-1)
0.9%							
	I	1	1.6	18.9	79.5	88.9	98.4
		2	0.1	29.0	70.9	85.4	99.9
		3	2.6	37.5	59.9	78.6	97.4
		4	0.7	42.6	56.8	78.0	99.3
		5	1.1	20.9	78.0	88.4	98.9
	II	1	0.7	56.1	43.3	71.3	99.3
		2	5.0	46.3	48.6	71.8	95.0
		3	8.6	53.8	37.6	64.5	91.4
		4	4.6	65.1	30.3	62.8	95.4
		5	8.5	39.4	52.1	71.8	91.5
0.5%							
	I	1	13.4	60.9	25.7	56.2	86.6
		2	23.7	53.9	22.4	49.4	76.3
		3	42.2	41.6	16.2	37.0	57.8
		4	36.4	42.6	21.0	42.3	63.6
		5	27.7	51.0	21.3	46.8	72.3
	II	1	54.0	32.9	13.0	29.5	46.0
		2	58.3	31.5	10.2	26.0	41.7
		3	72.4	21.3	6.3	16.9	27.6
		4	63.7	28.0	8.4	22.3	36.3
		5	47.0	44.0	8.9	30.9	53.0

[1] Rate of acid applied to grain on a weight percentage.

[2] Classification of acid coverage in percentage values: None - no visible dye, Partial - partial coverage of germs of kernels, Full - full coverage of germs of kernels.

[3] Two sets of weighting factors were used. Each was multiplied by the three classification percentages and summed. See Table 1.

PREFORMANCE OF EQUIPMENT FOR APPLYING
CHEMICAL PRESERVATIVES TO GRAIN

by

MICHAEL SEWARD SIMS

B.S., Purdue University, 1972

AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the
requirements for the degree

MASTER OF SCIENCE

Department of Agricultural Engineering

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1976

ABSTRACT

The purposes of this study were to design and construct a new acid applicator and to compare its preformance with other applicators.

Previous research with acid treated grain has dealt with economic analysis, storage tests and feeding trials, but not with application methods and equipment.

The newly designed acid applicator utilizes gravity to move grain through it. The applicator is mechanically simple and inexpensive. The design uses two cones, one to spread the grain into a thin layer for spraying with acid, and a second cone to return the grain to a stream.

Five applicators were studied. Three of them were commercially manufactured auger-type applicators. One was a static mixer and the fifth applicator was the newly designed double cone model. Ethyl violet dye was added to propionic acid to stain the grain for visual determination of acid coverage on grain kernels. Each applicator was used to fill 55-gallon barrels at two different acid-to-corn levels, .5% and .9% by weight.

The twenty barrels were sampled with a sectional grain probe at five horizontal locations each. These horizontal locations were relative to the applicator's position when filling the barrels in order that every barrel was sampled at fixed locations. There were approximately six cells filled in the probe at every horizontal location and each

cell was an individual sample containing approximately 120 kernels. Each sample was examined and each kernel was classified in one of three divisions: no acid visible, germ partially covered, and germ fully covered.

An analysis of variance showed that the difference in applicators was a significant variable. This analysis showed that the six-inch commercial auger-type applicator did not do an adequate job when compared to the other four applicators.

More important was the difference in the interaction of applicators and horizontal locations. The newly designed applicator had the least coefficient of variance between the values of the horizontal locations.

The three auger applicators had approximately the same localized distribution pattern of treated kernels. Mixing action was not homogeneous.