

THE PREVENTION OF MOISTURE MIGRATION  
IN WINTER STORED WHEAT

by

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## INTRODUCTION

The agricultural progress of civilization is intimately related with man's ability to produce grain, consume what he needs, and store what is left for the future. To produce and to consume are achieved in man's desire to live. And problems of storing grain have appeared in history for centuries. The Peruvian Incas had large stone storage houses for their grain. The Bible makes mention of Egyptians storing grain. Chinese history also tells of developing elaborate warehouse systems for storage against famine. It was the foresight of the Incas, the Egyptians and the Chinese to build these storage places for some future benefit. Today with the tremendous production and availability of grain, and particularly of wheat in this country, the problem of storing grain is magnified. Consequent to storage are the problems of combating harmful effects of heating, molding and insect damage to grain.

The heat, mold, and insect damage to the quality of grain stored in bulk can be attributed to one or more of several causes. Excessive moisture content when grain is threshed and stored in non-ventilated bins is a major cause. Moisture in certain localities of the bin may accumulate because of leaky roofs and side walls, and ground dampness. Insect infestation may also cause areas to become damp. Finally damage within the grain itself can be due to a phenomenon called "moisture migration".

These movements and accumulations of excessive moistures are shown by the visible damages in the stored grain as seen by the naked eye. The main cause of damage in wheat is too high moisture content, which promotes mold growth and too rapid respiration of the grain with accompanying heating.

The mold and fungus growths and the hot moist spots created by the metabolic processes of insects infesting the grain are distinct signs of deterioration. The musty, rotten odor of the bin as a whole and the damp, warm feeling of the grain due to its increased respiration rates cause serious damage to grain when unchecked. Damage due to heat alone makes the bran more brittle, thereby making separation in milling more difficult. All these are visible evidences of the destruction caused by storing damp grain.

Except moisture migration, all the evidences mentioned can be prevented by careful handling, proper design and construction of the bins and the use of fumigants. Moisture migration or the moisture movement from one part of the bin to another then must be thoroughly understood before further methods of prevention can be applied.

In theory, moisture migration is the consequence of a differential in vapour pressures between the grain in different parts of the bin. Here, the equilibrium of the vapour pressures is disturbed by the differences in the temperatures set up within the different parts of the bin. The magnitude of the pressure difference determines the rapidity of the movement of moisture. The existence of both warm and cold grain during winter increases this differential, where warm grain having high vapour pressures will cause moisture to move towards the cool grain having low pressures. This is true of all hygroscopic materials where the laws of vapour pressures and their behaviours apply.

Cereal grains are hygroscopic in nature and their moisture content will vary with the conditions to which they are exposed. The moisture content of the wheat stored in dry regions is much lower than in sections where the relative humidity of the atmosphere is greater. In wheat, stored for a year

or more, complex temperature changes take place and large temperature gradients are established. This is particularly evident in relatively small three to five thousand bushel bins. Night and day and seasonal variations occur in stored wheat too. During winter, however, the differences become larger within the grain mass, thereby causing more changes in temperatures and moisture contents.

#### REVIEW OF LITERATURE

An extensive literature exists on how to prevent the spoilage of wheat but little has been written on the prevention of moisture migration. This study is an attempt to gather and select the written reports on moisture migration and on the tests of ventilation to prevent the damage caused by harmful moisture migration.

#### Equilibrium Moisture Content

In moisture migration, the equilibrium moisture content of grain and air is a basic element. Barre and Sammet (5) p. 319, define equilibrium moisture content as the grain moisture content when the vapour pressures are equal at identical temperatures of the air and the grain. These authors explained that when the internal vapour pressure of the grain which is dependent on moisture content of the grain and the atmospheric temperature, is greater than the partial vapour pressures of the air, the grain loses moisture to the air until the vapour pressures are equal. If the relations are reversed, then the grain will absorb moisture from the air. Oxley (29), writes that in a differentially heated vessel with grain, air flowing into the cool region continuously gives up water to the grain, while air entering

a hot region continuously absorbs water. These two processes continue until the grain in the cool region is wet, and in the hot region is dry. This exchange finally results in an equilibrium moisture content between the grain and air at a certain temperature and relative humidity. Fenton (18), states that grains hygroscopically gain or lose moisture when there is a vapour pressure difference between the grain and the surrounding atmosphere. He held that this phenomenon continues until an equilibrium moisture content is reached and held. Results of the work done by Fenton on the equilibrium moisture content of winter wheat is shown in Fig. 1. This figure represents the relative humidities of air at three different temperatures where there is no further exchange of moisture at the corresponding grain moisture content.

#### Reports on Moisture Migration

Of the work on this subject done in Russia, Kizel et al. (26) found that by using cool coils in grain flasks that stood for 30 days, moisture moved from a pocket of warm temperatures to one of cool temperatures. Anderson et al. (1) proved Kizel's method by employing a large box of dimensions 6' x 6' x 20". This box was cooled with ice on one end and heated with warm water on the other. After a year's observations, they found that the grain originally at 14 per cent moisture, assumed different moisture contents ranging from 29.6 per cent at the cool end to 10.9 per cent at the warm end. Fenton tells of damage done by moisture migration on wheat stored in Kansas by the Commodity Credit Corporation (11). Grain stored in June, 1940 to February, 1941 showed an increase of moisture from 12 to 20 per cent on the top of many bins causing excessive damage due to heating, molding, and insect



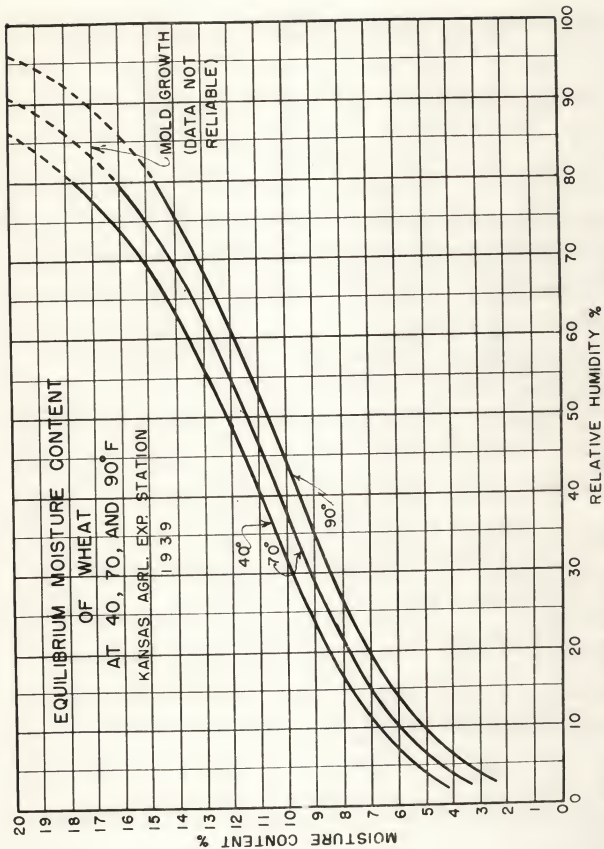


Fig. 1. Equilibrium moisture curves of wheat in Kansas from Fenton (16).

infestation. Work was done by Pratt (31) on the causes of moisture migration in stored grain. He used three columns of wheat in boxes of dimensions  $7\frac{3}{4}" \times 7\frac{3}{4}" \times 6'$ . One column was placed horizontally, heated at one end and cooled by a cooling tank at the other end. A second column, also vertically placed, was heated at the bottom and cooled at the top. Pratt found that the columns were favorable to moisture migration, and that moisture migration was most rapid in each column where steep temperature gradients existed. Oxley (29) claimed that moisture migration set up by temperature gradients is very important in any storage problem. He wrote that whenever a mass of grain is cool in one part and warm in another, there is a movement of water from the hotter to the cooler parts. Trouble is common he says, where warm grain comes into close contact with the cool surface or air currents. Anderson et al. (1) wrote about an accumulation of wheat in Canada that had to be immediately stored. Country elevators of dimensions  $60' \times 30' \times 20'$  high to the eaves were built and then filled with 30,000 bushels each. As winter progressed, damp wheat developed on the surface causing heavy visible damage.

#### Tests on Ventilation

Kelly (25) in summarizing the Illinois tests with forced ventilation indicated that ventilated air merely transferred moisture in the mass but did not remove moisture from the mass. Air forced through the moist wheat took up moisture and deposited it on the colder kernels. The Kansas Agricultural Experiment Station (Kelly, 25) in 1936 to 1938 gave a summary of experiments with three 1,000 bushel round steel bins to check the various methods of ventilation that could be suitable for storage. Forced ventilation methods were used during the first two years supplying air at 540 cubic feet per minute to



each bin. The blowers that were used operated continuously from June 30 to July 7, and then intermittently until July 11. In the 159 hours of ventilation, wheat moisture content was reduced from 15.4 per cent to 11 per cent. When the two bins were emptied in August, the wheat was found in excellent condition. North Dakota tests (26) used ventilation systems in which grain blowers forced air through eight feet of wheat. The results however, did not favor forced ventilations since heating developed.

Hukill (23) wrote of mechanical ventilators at Greene, a county of Iowa, using 10,000 bushel bins thirty feet in diameter, and 16 feet high up to the eaves. In the test done with these ventilators, he reported that insect infestation resulted, thereby raising the temperatures of the interior grain up to 100 degrees and 105 degrees F. But the experiments done by pushing a perforated flue through a hole in the bin and attached to a pneumatic grain conveyor to draw air out, resulted in greatly reduced temperatures. The pneumatic grain conveyor operated during the cold days for a week. It was useful in treating accumulations of moisture in the surface. Robinson et al. (34) in 1951 told of an investigation done by the Commodity Credit Corporation and the Iowa Agricultural Experiment Station on a 2740 bushel circular bin that was filled with corn up to nine and a half feet. Sisalkraft moisture-proof paper placed on the entire level surface was covered with another layer of corn up to a depth of three feet. The results were as follows: During winter and spring of the following year, there was no increase of moisture on the top but in May, the layer of corn three feet on the top of the paper was removed and the corn below the barrier removed. There was a big increase in moisture content adjacent to the bin wall below the moisture barrier. Here moisture was condensed from the air. This showed that during winter the

sides of the walls of bins became very cold thereby influencing the temperature differential within the bin. And as a result of this temperature differential, vapour pressure differences also occurred allowing moisture to increase and move.

Foster of Indiana (19) concluded that mechanical ventilation was effective in preventing moisture migration. Test done in a 25,000 bushel bin showed temperatures reduced from 54 to 22 degrees F in 71 hours of ventilation during winter. The average atmospheric temperature during ventilation was 17 degrees Fahrenheit.

Experiments done by other states using low-powered fans were discussed during the Grain Storage Conference (20) at Ames, Iowa, by grain specialists and USDA men. The following is a brief compilation of the conditions that existed in the states of Iowa, North Dakota and Indiana, and the results that these states had in experimenting with low-powered fans. The number bins and systems of ventilation were similar in all cases.

Iowa used dry corn with original moisture contents of about 10 per cent. The results of their experiments showed that grain when dry requires no ventilation for short time storage, and that small capacity fans prevented crusting adequately although moldiness still remained. Foster of Indiana reported that the original moisture content of the corn that they tested was 11.8 per cent. From October to January the check bins without any ventilation had moistures up to 17 per cent in the center of the mass of grain and about 22 per cent on the surface. HLs findings were that the higher capacity fans gave higher moistures than the lower capacity fans. Temperature reduction was slower in the small capacity fans. In the North Dakota tests, DeLong began with 10 per cent moisture content of wheat. All fans brought the temperatures

down to approximately five degrees F after four months of operation from October to January. This method of ventilation was more effective than the check bins without ventilators in keeping the temperatures down. In the use of non-powered wind ventilators, low temperatures were also attained. No moldy grain developed in the bins with low capacity fans.

### Objective of the Research Project

Tests conducted during the past showed that ventilated bins were preferable to non-ventilated bins. Since these tests disclosed conclusively that ventilation aided in the prevention of harmful moisture migration in winter stored wheat, a further research was done to exploit the feasibility of using low-powered fans ranging in capacities from 50 cubic feet per minute to 200 cubic feet per minute.

Terms of agreement were made by the Commodity Credit Corporation, Grains and Feeds Section (AMS), (10) and Kansas State College to determine the most economical methods of maintaining the quality of Commodity Credit Corporation stored wheat by means of low-powered fans and wind-ventilators, and to prevent harmful moisture migration.

### METHODS AND PROCEDURES OF THE RESEARCH PROJECT

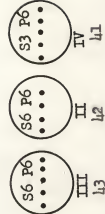
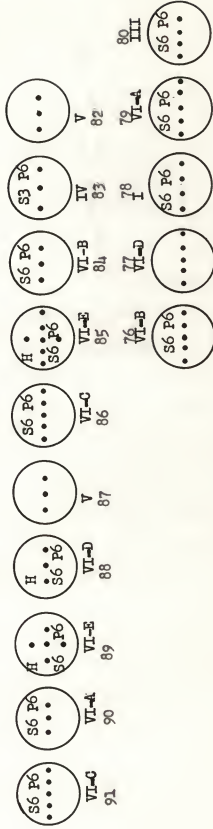
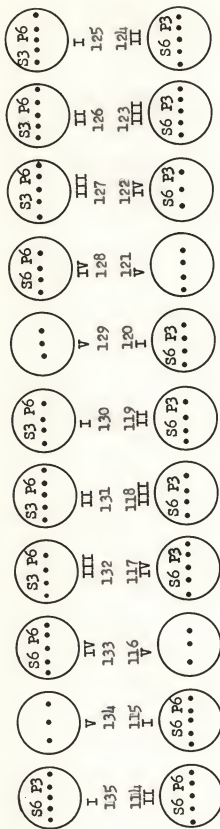
#### Methods

A binsite was provided by the Commodity Credit Corporation at Larned, Kansas. Forty bins with rows running from North to South, were filled with high grade wheat to a depth of approximately 12 feet. These bins were divided into six groups and numbered consecutively.

# EXPLANATION OF PLATE I

Larned, Kansas, Binsite diagram for forty bins in rows

- I - 50 CFM group drawing air out
- II - 100 CFM group drawing air out
- III - 200 CFM group drawing air out
- IV - "Eredicart" Wind Cupola group
- V - Check group
- VI - A. 50 CFM group blowing air in
  - B. 200 CFM group blowing air in
  - C. 50 & 100 CFM group blowing air in
  - D. 50 CFM group using horizontal flues
  - E. "Roots" Lobe type pumps using horizontal flues
- S - Length of solid tube in feet
- P - Length of perforated tube in feet
- H - Horizontal flues at the bottom
- ... - Position and number of thermocouples



SOUTH  $\longleftrightarrow$  NORTH





## PLATE II



Fig. 1



Fig. 2

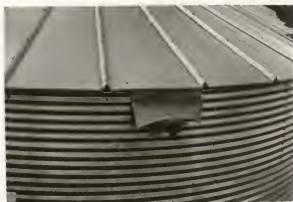


Fig. 3



Fig. 4



Fig. 5

### EXPLANATION OF PLATE III

#### Test and description of the wind ventilator

Fig. 1 - Test position of the "Breidert" wind cupola to the wind tunnel with the following descriptions:

1. Air duct with air supplied by the fan and in the direction of the arrow
2. Position of the "Breidert" wind cupola
3. Suction intake of the cupola
4. Damper handle to regulate the static pressures
5. Hook gage to measure the static pressure in inches of water and connected to 6
6. Small opening to insert a rubber tube attached to the Hook gage.

Fig. 2 - The performance curves of the cupola wind ventilator at different wind velocities supplied by the fan at the left end. The capacity in cubic feet per minute is the air movement that enters the wind ventilator.

PLATE III

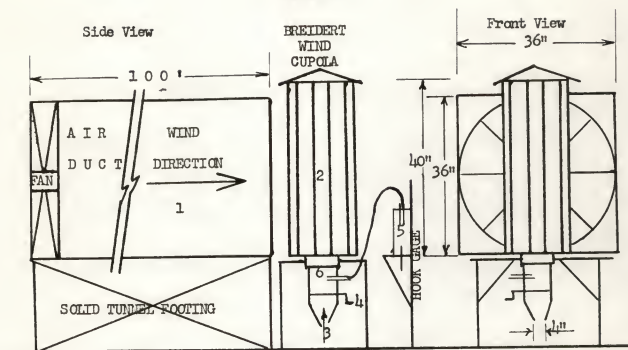


Fig. 1

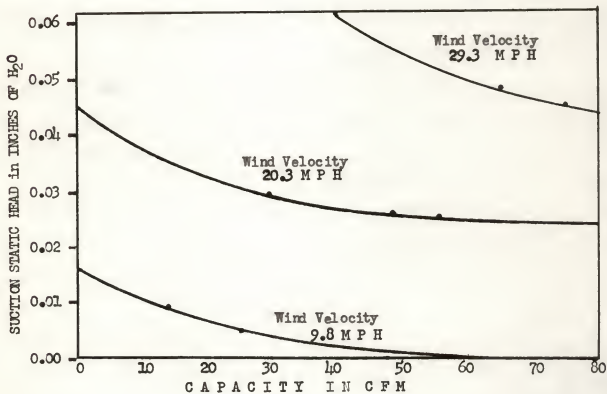


Fig. 2

#### EXPLANATION OF PLATE IV

Illustrations of the other systems of ventilation used including the wind ventilator type.

Fig. 1 - Position of the wind cupola at the top of the roof center

Fig. 2 - The vertical flue system connected to the suction intake part of the wind ventilator

Fig. 3 - Intermittently operated "Roots" Lobe type pump connected outside the bin and attached to a 4" horizontal flue at the bottom of the bin

Fig. 4 - 50 CFM fan attached to a 4" horizontal flue system at the bottom of the bin.

## PLATE IV



Fig. 1



Fig. 2



Fig. 3



Fig. 4

#### EXPLANATION OF PLATE V

A cross sectional view of the bin at the center, and the different types of pipes superimposed in the drawing.

Fig. 1 - Top view of the surface of the grain inside the bin showing the position of the thermocouples from each other

Fig. 2 - Side view of a cross section at the middle showing the depths of thermocouples and the systems of pipe installations

- 1 a. 6' solid vertical flue 8" in diameter
- 1 b. 6' perforated vertical flue 8" in diameter
2. 4" discharge pipe connected to the fan at the center
- 3 a. 6' horizontal flue 4" in diameter
- 3 b. 6' perforated horizontal flue 4" in diameter
4. Vertical attachment of the wind ventilator to 1 a & 1 b.





Three groups provided a volume rate of flow in the order of 50, 100, and 200 cubic feet per minute. In these systems of ventilation, air was drawn upwards from a central partially perforated flue extending into the bottom of the grain mass to a depth of nine to 12 feet. The air was discharged outside the bin (Plate II, Fig. 3). Perforations in the flue for the passage of air amounted to 10 per cent of the area of the section.

Group I had six bins placed at intervals of six through the rows of bins. Each bin from this group was ventilated by a fan delivering 50 cubic feet per minute (Plate II, Fig. 2). Group II followed group I in number and arrangement, but a fan delivery of 100 cubic feet per minute was used (Plate II, Fig. 4). Group III, basically like groups I and II, ventilated at the rate of 200 cubic feet per minute (Plate II, Fig. 5).

Group IV was ventilated by wind cupolas of the "Breidert" type (Plate IV, Fig. 1). These cupolas were connected to the flues at the center of six bins from the top of the roof. The flues contained the same amount of perforations that the others had (Plate IV, Fig. 2). The amount and direction of airflow through these cupolas were determined by a test done in a wind tunnel laboratory at Kansas State College and operated by ARS men of the USDA. The test made use of a three square-foot duct with a high capacity fan on one end delivering airflow rates of 10, 20 and 30 miles per hour respectively. The wind cupola was set at the other end of the 100 feet duct and equipped with gages to measure amount of airflow, direction of flow, and suction static pressures for different airflow rates (Plate III, Fig. 1 & 2). The cupola as tested, created suction in the flues and discharged air into the atmosphere.

Unlike the previous groups, Group V with six bins had no ventilation system. This group was intended to serve as the check bins that would deter-

mine the comparative success of the ventilation methods. Fans and flues were absent in this group.

The last and most complex group, Group VI, comprised ten out of the 40 bins. Six bins were equipped with vertical flues, and 50 and 100 cubic feet per minute capacity fans. The remaining four had flues in a horizontal position. In this system, two, 50 cubic feet per minute fans and two, intermittently operated "Roots" Lobe type pumps were connected at the outside ends of the horizontal tubes (Plate V).

A summary and table of all the groups including their sub-divisions, amount and systems of airflow are included in the following Table.

Table 1. Summary of groups and types of ventilation for each group.

Group No. :	Number of bins :	Capacity of Fan & Type of ventilation :	Description of airflow for the ventilated groups :	Flues S' - P' :
I	2 bins	50 CFM	Air sucked vertically upwards	3' - 6'
	2 bins	" "	" " " "	6' - 3'
	2 bins	" "	" " " "	6' - 6'
II	2 bins	100 CFM	Air sucked vertically upwards	3' - 6'
	2 bins	" "	" " " "	6' - 3'
	2 bins	" "	" " " "	6' - 6'
III	2 bins	200 CFM	Air sucked vertically upwards	3' - 6'
	2 bins	" "	" " " "	6' - 3'
	2 bins	" "	" " " "	6' - 6'
IV	2 bins	Wind Cupola	Air sucked vertically upwards	3' - 6'
	2 bins	" "	" " " "	6' - 3'
	2 bins	" "	" " " "	6' - 6'
V	6 bins	No Ventilation	Check bins	
VI	2 bins	50 CFM	Outside air forced vertically down	6' - 6'
	2 bins	100 CFM	Outside air forced vertically down	6' - 6'

Table 1 ( cont. )

Group	Number	Capacity	Description of airflow for the ven-	Flues
No.	of bins	of Fan & Type	tilated groups	S' - P'
:	:	of ventilation:	:	:
VI	1 bin	50 CFM	Inside air forced vertically down*	6' - 6'
	1 bin	100 CFM	Inside air forced vertically down*	6' - 6'
	2 bins	50 CFM	Outside air forced horizontally into the grain mass at the bottom	6' - 6'
	2 bins	"Roots" pumps	Outside air forced horizontally into the grain mass at the bottom and operated intermittently during cold spells of the weather	6' - 6'

\* - Inside air means that the pump sucked the atmospheric air above the grain and immediately below the roof the bins.

#### Materials and Procedures

In this experiment, the type of grain used had the following qualifications: Quality of wheat - High quality of the Hard Winter Wheat variety commonly found in Kansas; Grade of wheat - Grade number one was designated to the wheat used in the experiments; Wheat was harvested in 1952 and the weight per bushel ranged from 61 to 63 pounds per bushel; Initial moisture content - ranging from 9 to 10 per cent, indicating very dry wheat and perfectly storable.

Preliminary survey of the materials and the position of bins at the bin-site was necessary before the experiment. Most of the equipment used was furnished by the Commodity Credit Corporation. Installations of the equipment were done during the months of September and October.

Thermocouples for each bin were specified to take the temperatures at different locations and depths in the grain. A cross sectional view of the bins with the position of the thermocouples is shown in Plate V. For reasons

of simplicity, henceforth thermocouples will be designated as couples. Each couple is comprised of two different metal wires, copper and constantan, soldered together at their ends. One copper and constantan wire was placed at each three feet depth, where a temperature reading was desired. The theory explained by Rhodes (32) in the use of couples can be summarized in a few words:

If one junction is at a higher temperature than the other, an electromotive force is produced and current flows. This current can be measured and represents the isothermal property of the space or object around the junction.

All the couples were installed inside the bins by means of specially made  $1\frac{1}{4}$ " x 3' long tubes screwed together in workable lengths. These tubes were used to guide the insertion of the couples into the wheat mass. They were pulled out and unscrewed at every three feet section. The depth of penetration in the grain mass was approximately 12 feet.

Next in the order of equipments installed were the flues. Hydraulic jacks, chains, and manual labor were used to drive the flues vertically down through the center of the grain mass. In some instances the pipe sections collapsed because of the pressures exerted and the resistance offered by the wheat mass. An improvised vacuum cleaner with a conical container was used to suck the wheat from inside the flues that were being inserted. Care in selecting the right lengths of solid and perforated tubes was emphasized to conform to the specifications. Table I and Plate I give the length and size of flues used. Adaptors and reducers were used to fit the four inch round discharge pipes to the fan. In turn the fan fit the eight inch intake flue that was inserted through the grain mass (Plate II). Electricity was provided for the performance of the fans and pumps.

## EXPLANATION OF PLATE VI

Illustrations of the instruments used for taking temperatures and for determining the moisture content of wheat.

Fig. 1 - Potentiometer for measuring the temperatures in the thermocouple

Fig. 2 - Diagram of how a potentiometer works

AB - uniform slide wire

R - variable resistance

B - battery

SC - standard weston cell

G - galvanometer

K - tapping key

Fig. 3 - Tools used in taking moisture samples: sample prober, combined grain collector and paper bag disposer

Fig. 4 - Tag-Hepenstahl moisture meter machine to determine the moisture content of the grain directly on the wet basis.



## PLATE VI



Fig. 1

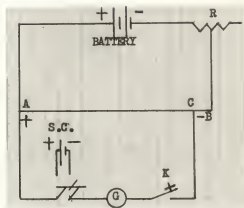


Fig. 2



Fig. 3



Fig. 4

Minor details such as the surface levelling of the grain in all the bins prior to the start of the experiment, and the use of boards or planks were attended to to least disturb the surface layer while the experimental data was taken.

#### EXPERIMENT

The experiment officially began on November 1, 1953. Temperatures at every couple were taken about the beginning of every month up to and including July, 1954. The arrangements of couples, including the position and depth of penetration inside the grain mass are illustrated in Plate V. All the bins had at least three couples in a row for sufficient temperature data of the grain mass. Others had more than three depending on the need of taking additional data. The general pattern of lining the couples went from North to South for all bins. For the bins using horizontal system of flues two additional couples were lined East to West. These couples were considered pertinent since the flues were inserted from East to West, a position which influenced the variations in temperatures.

The usual method of measuring two potentials without the passage of appreciable current is by means of a potentiometer (Plate VI, Fig. 1). This method was used to measure the temperatures of the couples. Figure 2 of Plate VI illustrates the theory of a potentiometer. The potential drop along the slide wire from A to B was accurately calibrated by setting AC to the potential of a Weston Cell and adjusting the resistance on closing the key. This placed the instrument in balance, and an accurate reading of the temperature was made. Two electrodes of the couple to be measured were inserted in place of the Weston Cell, and once more the distance AC was ad-

justed until the galvanometer showed no deflection on the closed position of the key. The potential drop from A to C was the differential in potentials of the two electrodes or couple, or the calibrated temperature of the couple.

Several minor adaptations of the potentiometer were made to suit the particular needs of the experiments.

The percentage of moisture was also desired at depths in the grain of six inches and one foot. The distribution pattern of taking samples was around one and one-half feet radius from the center and also five feet radius from the center. To guard against possible pollution or rapid evaporation of the grain samples, special moisture sample bags were used. Other devices facilitated the routine of taking moisture samples for all the forty bins (Plate VI, Fig. 3). The use of the Tag-Hopenstahl moisture meter machine gave readings of the moisture content of the grain directly on a wet basis (Plate VI, Fig. 4).

The climatological data at the binsite was obtained for every month and correlated with the monthly temperatures and moisture records of the grain inside the bins. The effect of condensation on the roof, dust blown in after several severe duststorms, and snow after a snowstorm were also recorded.

## RESULTS

The monthly temperatures of the grain inside the bins were averaged from all the monthly couple readings. However, the records of the couples right beside the bin walls and those at the surface that were exposed to the outside air were excluded because outside atmospheric conditions rather than the actual grain temperatures strongly influenced these couples. Hence, only the center couples and those at 3.5 feet from the center were considered in the

averaging of temperatures. In comparing the performances of each group, it was necessary to correlate the differences in weather conditions that existed at the binsite. Daily maximum and minimum temperature records and the relative humidities every six hours were obtained and averaged into months (Plate IX, Fig. 2).

Plate VIII illustrates the average grain temperatures of each group. The order of groups from the highest to the lowest temperatures are: the check bins, those with wind ventilators, and those with the 50, 100 and 200 cubic feet per minute fans respectively. The groups with 100 and 200 cubic feet per minute fan delivery had the lowest temperature curves. As the outside temperature decreased during the winter months, grain in the ventilated bins cooled. The sudden drop in temperatures started immediately after the start of the experiment. By January the temperatures dropped from 72 degrees F to about 40 degrees F. February marked the change in slope of the gradient to higher temperatures and continued as the warmer months came.

Plate IX, Fig. 1 shows the distribution of the moisture content averaged for the top foot of each group. The original moisture content ranged from 9.7 to 9.9 per cent. With ventilation there was a slight increase of moisture as the winter months progressed, although below the safe storage limits. The check bins represented by curve 5 showed a slight increase of moisture during the colder and more humid months. The rise of all curves during December closely followed the rise in the relative humidity for that month (Plate IX, Fig. 2).

Since considerable air movement was caused by the ventilation systems at and around the center of the bins, the resulting temperatures and moisture contents of each group were averaged for the center and for the distance 3.5 feet from the center respectively.

## EXPLANATION OF PLATE VII

Illustrations of dust accumulations and removal of dust from the surface of the wheat by means of a suction cleaner.

- Fig. 1 - Picture of dust on the wheat surface dark colored
- Fig. 2 - Picture of a 50 CFM fan filled with dust after a duststorm
- Fig. 3 - Round nozzle used for removing the dust on the surface and within the top 6 inch layer of the grain, attached to a suction cleaner and screened with very fine wire to prevent wheat from entering inside the cleaner
- Fig. 4 - Straight nozzle attached to the suction cleaner to remove the surface dust alone
- Fig. 5 - Dust coming out from the round nozzle
- Fig. 6 - Dust coming out from the straight nozzle.

## PLATE VII

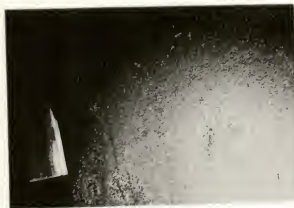


Fig. 1



Fig. 2



Fig. 3

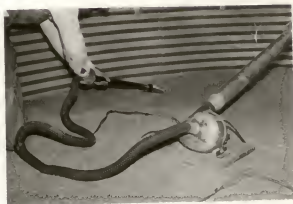


Fig. 4



Fig. 5



Fig. 6



### EXPLANATION OF PLATE VIII

Grain temperature curves representing the different groups with and without ventilation. Temperatures were averaged and combined for the center and 3.5 feet from the center. The curve represented by the broken lines show part of the monthly average atmospheric temperature curve of Fig. 2, Plate IX.

Curve 1 - 1 : 50 CFM group drawing air out

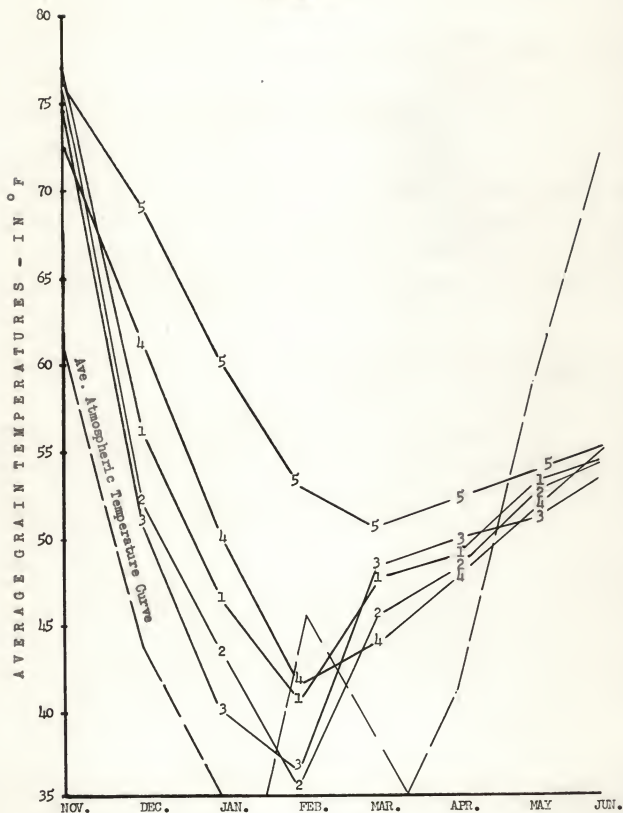
Curve 2 - 2 : 100 CFM group drawing air out

Curve 3 - 3 : 200 CFM group drawing air out

Curve 4 - 4 : The wind cupola ventilator group

Curve 5 - 5 : Check bins without ventilation.

PLATE VIII



## EXPLANATION OF PLATE IX

Fig. 1 - Grain moisture contents of each group at the top foot.

These were taken at 1.5 and 3.5 foot radii from the center and averaged together.

Curve 1 - 1 : 50 CFM group drawing air out

Curve 2 - 2 : 100 CFM group drawing air out

Curve 3 - 3 : 200 CFM group drawing air out

Curve 4 - 4 : The wind cupola ventilator group

Curve 5 - 5 : Check bins without ventilation

Fig. 2 - Atmospheric temperatures of the Larned Weather Bureau

Station showing the maximum and minimum temperatures for the months from November to May; and the averaged relative humidities of the Dodge City Weather Bureau Station represented by the line with small circles. Broken lines average the minimum and maximum temperatures.

PLATE IX

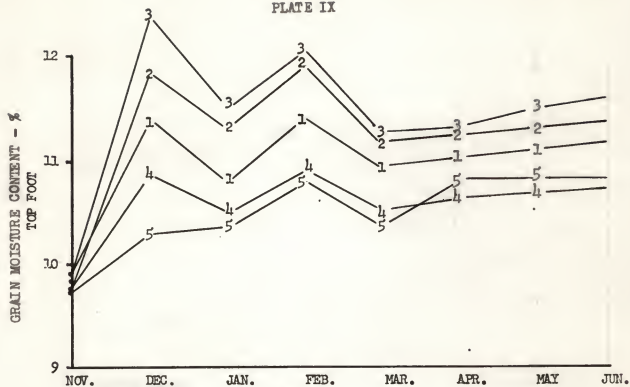


Fig. 1

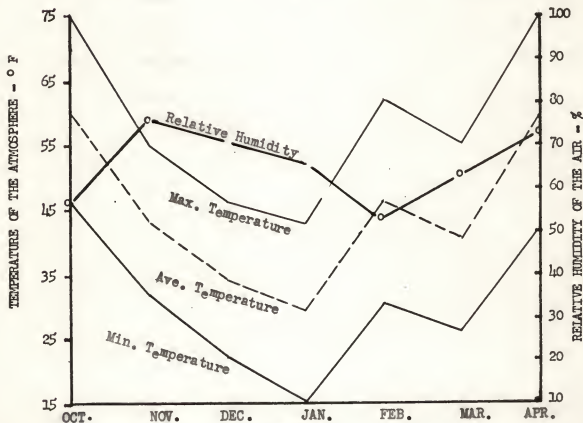


Fig. 2

#### EXPLANATION OF PLATE X

Temperature curves representing the average grain temperatures of each group at the center of the bin alone. The curve represented by the broken lines show part of the average monthly temperature of the atmosphere taken from Fig. 2, Plate IX.

Curve 1 - 1 : 50 CFM group drawing air out

Curve 2 - 2 : 100 CFM group drawing air out

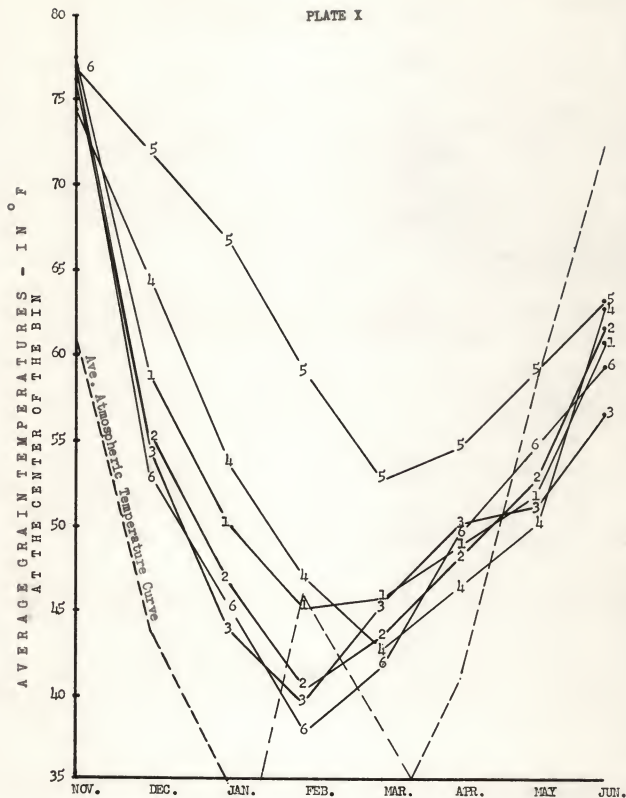
Curve 3 - 3 : 200 CFM group drawing air out

Curve 4 - 4 : The wind cupola ventilator group

Curve 5 - 5 : Check bins without ventilation

Curve 6 - 6 : The group representing four bins using the horizontal flue systems and supplied by two, 50 CFM fans and two, intermittently operated large capacity pumps ("Roots" Lobe type pumps).

PLATE I



### EXPLANATION OF PLATE XI

Temperatures represented by the curves are the average grain temperatures of each group at a distance of 3.5 feet from the center of the bin. The curve represented by the broken lines is the atmospheric temperature curve taken from Fig. 2, Plate IX.

Curve 1 - 1 : 50 CFM group drawing air out

Curve 2 - 2 : 100 CFM group drawing air out

Curve 3 - 3 : 200 CFM group drawing air out

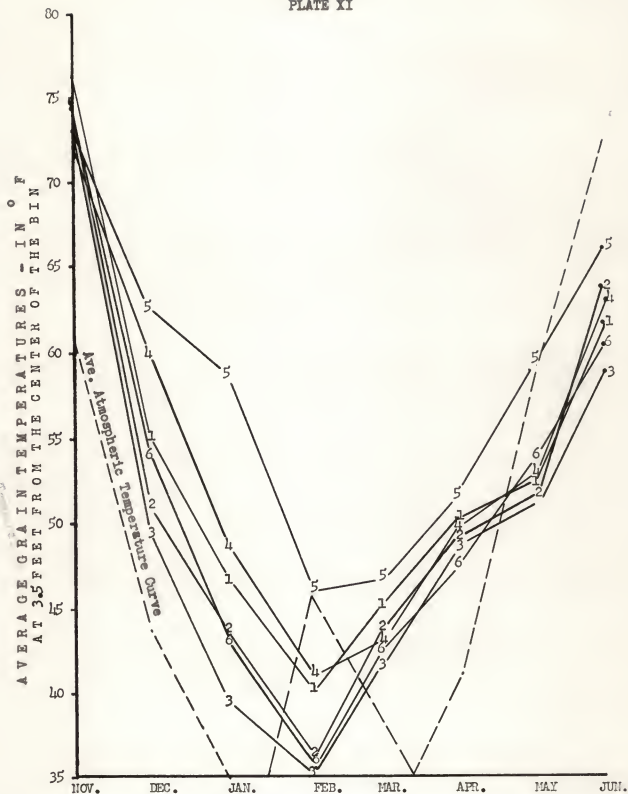
Curve 3 - 3 : The wind cupola ventilator group

Curve 5 - 5 : Check bins without benefit of ventilation

Curve 6 - 6 : The group representing the four bins with the horizontal flue systems and supplied by two, 50 CFM fans and two, intermittently operated large capacity fans ("Roots" Lobe type pumps).



PLATE XI



### EXPLANATION OF PLATE XII

Fig. 1 - Grain moisture content in per cent at 1.5 feet radius from the center of the bin

Fig. 2 - Grain moisture content in per cent at 3.5 feet radius from the center of the bin.

Explanation of the curves in Figures 1 and 2:

Curve 1 - 1 : 50 CFM group drawing air out

Curve 2 - 2 : 100 CFM group drawing air out

Curve 3 - 3 : 200 CFM group drawing air out

Curve 4 - 4 : The wind cupola ventilator group

Curve 5 - 5 : Check bins without ventilation

Curve 6 - 6 : The group representing the four bins with the horizontal flue systems and supplied by two, 50 CFM fans and two, intermittently operated large capacity pumps ("Roots" Lobe type pumps).

## PLATE XIII

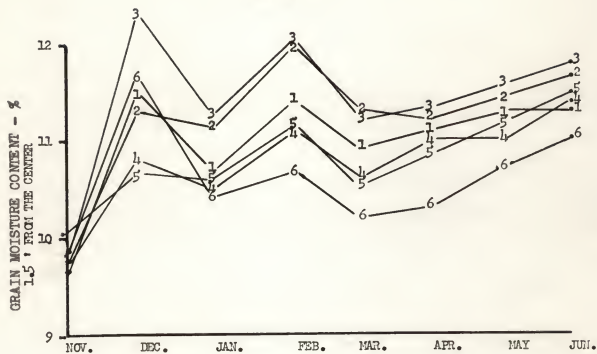


Fig. 1

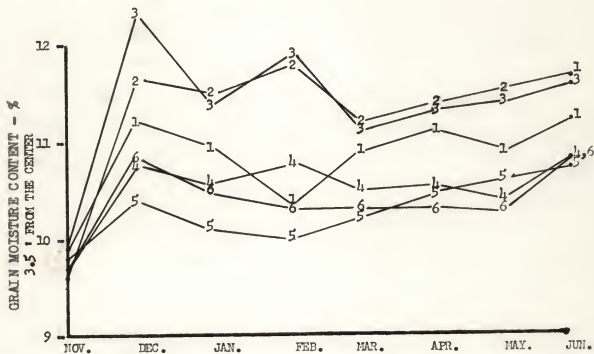


Fig. 2

Plate XI, shows the average temperatures of the grain mass 3.5 feet from the center. Plate X shows the isothermal behaviours of each group at the center of the bin. Temperature conditions at 3.5 feet from the center were found slightly cooler than those at the center. Group I with 50 cubic feet per minute capacity fans averaged about 5 degrees F cooler, Group II also 5 degrees, and Group III about 4 degrees F. The wind ventilator group cooled less away from the center. The check groups indicated by curve 5 in both plates X and XI consistently stayed above the other curves. Significantly, curve 6 represented by the system described partly in Group VI, as having the horizontal flues, outcooled the others at the center but was warmer at the distance of 3.5 feet from the center. This curve is the average of four bins that were ventilated at the bottom by two, 50 cubic feet per minute fans and two, intermittently operated "Roots" Lobe type pumps.

The behaviour of the top foot moistures at 1.5 feet and 3.5 feet radii from the center in each group is illustrated in Plate XII, Fig. 1 and 2. Except for curve 6 which represents the bins horizontally ventilated at the bottom, the pattern follows closely the average of each group in Plate IX, Fig. 1. Curve 6 maintained the lowest moisture curve at the center (Plate X) and almost parallel curve 5 away from the center (Plate XI). The higher capacity fans assumed slightly higher moistures than the lower capacity fans.

Table 2 is a compilation of the maximum differences in grain temperatures attained inside a bin representative for each group. This table shows how temperature differences in the experiment induced such small pressures that there was no actual harmful moisture migration. The maximum temperature that occurred within the representative bins of each group, as well as the

Table 2. Maximum grain temperature differences inside a representative bin for each group at different locations of the bin. ( $^{\circ}\text{F}$ )

GROUP	BIN	LOC.	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL
NO.	NO.	:	:	:	:	:	:	:	:	:	:

Maximum temperature difference throughout the bin

I	125	Max.	75	69	63	56	53	55	55	69	86
		Min.	49	26	39	30	25	26	30	56	13
II	126	Max.	71	62	56	47	57	53	58	72	85
		Min.	48	23	41	21	38	18	28	19	52
III	127	Max.	69	62	54	40	54	50	58	73	90
		Min.	32	37	34	28	36	18	26	14	31
IV	128	Max.	71	68	58	51	49	50	57	70	86
		Min.	52	19	44	24	42	16	34	17	39
V	129	Max.	80	78	74	65	55	56	55	78	94
		Min.	56	24	45	33	46	19	40	15	44
VI	88	Max.	83	59	46	40	55	54	60	68	86
		Min.	65	18	41	18	32	14	29	11	46

Maximum temperature difference at the center of the bin  
between the top and the next 3 ft. depth

I	125	Top	69	46	44	40	40	49	52	69	86
		3 ft.	79	10	51	4	36	4	52	0	61
II	126	Top	67	44	41	37	35	45	52	72	86
		3 ft.	81	14	48	4	43	2	36	1	35
III	127	Top	67	42	38	36	31	49	52	63	84
		3 ft.	80	13	51	9	42	4	35	1	52
IV	128	Top	54	48	46	48	39	49	54	70	86
		3 ft.	66	12	64	16	52	6	42	6	48
V	129	Top	59	50	50	50	41	53	54	67	92
		3 ft.	79	20	78	28	75	25	65	15	54
VI	88	Top	70	56	42	40	55	54	55	63	84
		3 ft.	83	13	56	0	42	0	35	5	55

Maximum temperature difference at 3.5 ft. from the center  
between the top and the next 3 ft. depth

I	125	Top	71	48	44	40	44	50	52	1	69
		3 ft.	84	13	52	4	50	6	33	7	52
II	126	Top	69	44	42	40	36	48	50	1	48
		3 ft.	83	14	46	2	44	2	32	8	53
III	127	Top	65	39	40	40	31	49	52	2	56
		3 ft.	78	13	51	12	38	2	37	3	50
IV	128	Top	63	44	46	36	44	47	51	2	60
		3 ft.	73	10	55	11	51	5	34	2	49
V	129	Top	56	48	46	46	41	51	52	1	54
		3 ft.	72	16	69	21	62	16	53	7	50
VI	88	Top	65	52	44	37	43	53	55	1	64
		3 ft.	76	11	59	7	46	2	33	4	49

minimum temperatures can be read from the first part of the table. The difference between these two extremes gave the maximum temperature difference of 14 degrees F during July in bin number 129. The second part illustrates the temperature differences of the bin center that occurred at the surface layer and the next 3 feet depth of the grain. The results indicate that the ventilated bins have less temperature differences than the check bins. Hence, moisture migration dependent on vapour pressure differences due to temperature differentials was prevented by reducing the temperature differences at the center to nil during the months of April and May. Group V represented by bin number 129 in the second part of the table shows clearly that large temperature differences existed since the start of the experiment but was reduced when the warmer months came and equalled the temperatures inside the bin. Part three of this table shows the temperature differences at 3.5 feet radius from the center between the top and the next 3 feet depth. Results are similar to the second part although some increase in temperature difference occurred in the bin represented by the 200 cubic feet per minute fan.

#### INTERPRETATION OF RESULTS

Regardless of the methods of ventilation used, the weather conditions were basic factors in influencing the temperatures and the moisture contents of the grain. The wheat stored was good quality wheat. The winter was unusually mild and dry, and no trouble directly occurred due to moisture migration. Ventilation was noticeable at the under surface of the roof causing slight increases in the surface moistures. Dust blown in during severe duststorms was not serious although it made the work of taking temperatures and moisture samples very inconvenient. Plate VII illustrates



how the dust can be removed by the use of suction cleaner devices with different nozzles.

Plate IX, Fig. 2 shows the maximum, minimum and average curves of the atmospheric temperatures at the binsite. The average relative humidity curve for the months of October to May is also shown. In February the temperature curves stopped coming down and started to rise. This also happened to the grain temperatures. The higher ventilation of the 200 cubic feet per minute capacity gave lower minimum temperatures since a greater amount of cold air was introduced.

Figure 2 shows the moisture contents and vapour pressures of wheat at temperatures from 40 to 90 degrees F. At 13 per cent moisture content, grain temperature of 40 degrees F has a vapour pressure of 0.07 pounds per square inch. At 70 degrees F the vapour pressure is 0.22 pounds per square inch. This means that a temperature difference of 30 degrees F produces a vapour pressure difference of 0.015 pounds per square inch. Taking any ventilated group in Table 2 where temperatures ranged between 40 and 70 degrees F, one can see that temperature differences were reduced by ventilating during winter. Hence it can be said, that since large vapour pressure differences were prevented by the reduced temperature differences, winter ventilation also greatly reduced the migration of moisture.

Table 2 indicates that the check group had the greatest temperature difference during the winter months, as a result of the cold surface and the warm grain at three feet depth. January was the coldest month. Warmer days in the succeeding months led to the increase of temperatures. By March all fans were turned off to prevent the warmer air from increasing the grain temperature differences, and also to prevent the possibility of condensation



MOISTURE CONTENT  
AND  
VAPOUR PRESSURE

OF  
WHEAT  
AT -  $40^{\circ}$  -  $50^{\circ}$  -  $60^{\circ}$  -  $70^{\circ}$  -  $80^{\circ}$  -  $90^{\circ}$  F.

DEPT. OF AGRIC. ENG.  
KANSAS STATE COLLEGE  
F. C. FENTON

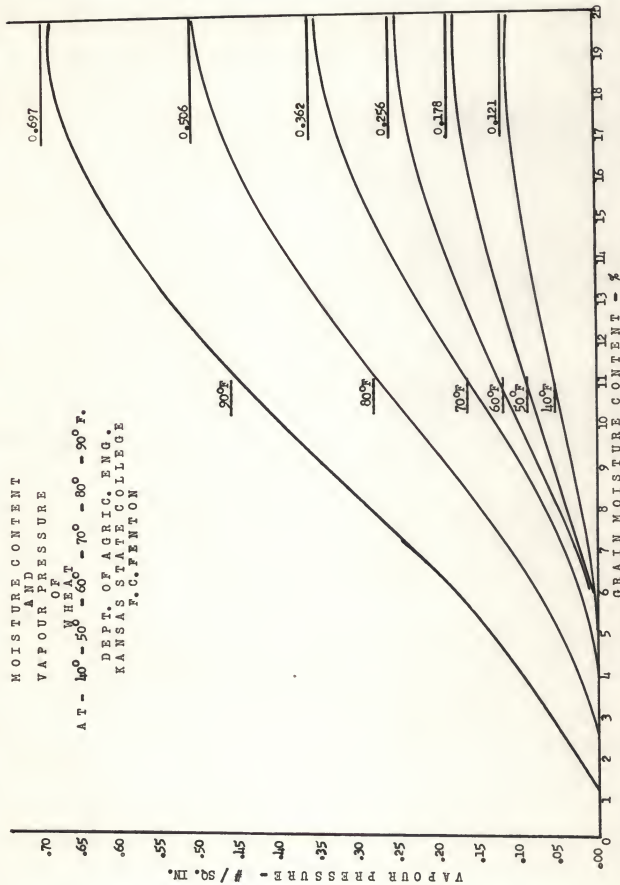


Fig. 2. Moisture Content and Vapour Pressure of Wheat at Different Temperatures by F. C. Fenton.

when warm air comes in contact with the cold grain.

Plates IX and X definitely indicated that winter ventilation kept the grain cool when the air turned warmer. Negatively harmful moisture migration was prevented by cooling the grain to a point where heating within the grain mass was stopped, temperature differences were reduced, and insects could not perform their destructive processes.

The use for small capacity fans in stored bins is economical and practical since temperature differences were greatly reduced and steep minimum temperatures were established (Plate X and XI). In vertically installed flue systems, the small fans were higher in the temperature values. Slow introduction of cold air accounted for this. Small capacity fans in the horizontal system of flues not only reduced temperatures more than the high capacity fans but also accumulated less moisture in the grain mass (Plate XII, Fig. 1 and 2).

The performance of the wind ventilator also indicated that this system of ventilation would be feasible depending on the intensity of the wind. High winds occur during low vapour pressure periods. Economy could give wind ventilators an advantage although reducing the moisture migration from stored grain was less satisfactory with the wind ventilators. Plate III and Plate IV show the position, attachments and performance curves of the wind ventilators.

#### CONCLUSIONS

Ventilation during winter was a means of cooling the grain mass. If dry air was available safe storage was assured. In the light of cold and dry air ventilation, the use of thermostats and humidistats would be invaluable. Ther-

mostats control the type of air desirable for storage, namely cool air. Humidistats on the other hand guarantee the humidity of air introduced into the grain mass. Dry air is the desirable quality. With cool and dry air introduced by the fans, controlled by thermostats and humidistats, any amount of moisture in the grain that is excessive will tend to move from the grain to the air and out into the atmosphere as the flow of air continues. In lowering the grain temperatures to about 45 degrees F, dormancy of insects occurs. Entomologists further point out that below 45 degrees F, the insects gradually starve and die.

Experience has shown that 12 per cent is the moisture content favored for storage. If it is impossible to store at or below this safe moisture content, then ventilation methods are indispensable for storing. The tests all show that mechanical ventilation is more effective than natural wind ventilation. Where electric power is available, it is desirable to use systems involving the electric fans for the aeration of grain. Where electric power is not available, then the wind ventilators should be installed to provide necessary ventilation for the grain. Motor driven fans are also practical if the power unit and the fuel costs are not expensive.

In considering the vapour pressure differences set up by large temperature gradients one should note that vapour pressures are large if the temperatures are far apart. But in the relation of moisture contents of the grain to vapour pressures, Figure 2 shows that at low temperatures, the differences in moisture content even up to 15 per cent produce small vapour pressures. Hence, applying this fact to the effect that ventilation by the low-powered fans reduced the temperature differences at moisture contents below 13 per cent, it can be concluded that the use of small capacity, low-powered fans is practical

Negative prevention of harmful moisture migration can only be gathered since no visible destruction of the wheat surface developed. The surface layers are still dry and the moisture contents are within the safe storage limits. In several bins condensation and dripping from the roof increased the surface moistures slightly. Sprouting developed where condensate fell. But the warm months of June and July dried the little pockets which germinated in the surface of the grain mass. A proper design and construction of bins should exclude dripping due to the rains. Condensation might have been due to the contact of the cold roof surface and the warm air leaving the grain mass consequent to ventilation. Proper design can prevent snow and dust from entering the bin.

This dry and mild year was conducive to the storage of wheat. Different temperatures and humidity conditions may prevail next year. Whether or not changes not discernible from the standard tests may have occurred during this year's storage experiment, chances are that they might occur during the second year. Thus, it was decided that the experiments be continued for the next year to ascertain further the results of using low-powered fans in preventing heat, mold and insect damage to occur and preventing harmful moisture to migrate.

Moisture migration is a problem that man will always encounter in the storage of grain. The progress of being able to store grain efficiently lies in man's ability to control the harmful forces that destroy grain. Simple ventilation methods that are economical and practical can be a means of preventing harmful moisture migration especially in winter ventilation. Ventilation alone is not a permanent guarantee of a lifetime storage of grain since all grains live, perform metabolic processes and germinate. Prevention of harmful moisture migration is one useful function in the storage of grain.

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Thanks are also due to the Commodity Credit Corporation (USDA) for making possible this research project in supplying the grain and the binsite, and to Mr. Albert Graf, project leader of the CCC.

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THE PREVENTION OF MOISTURE MIGRATION  
IN WINTER STORED WHEAT

by

JUANITO L. CRDOVEZA

B. S. C. E., University of the Philippines, 1953

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AN ABSTRACT OF A THESIS

submitted in partial fulfillment of the  
requirements for the degree

MASTER OF SCIENCE

Department of Agricultural Engineering

KANSAS STATE COLLEGE  
OF AGRICULTURE AND APPLIED SCIENCE

1954

The heat, mold, insect damage to the quality of grain stored in bulk can be attributed to one or more of several causes. Excessive moisture content when grain is threshed and stored in non-ventilated bins is a major cause. Moisture in certain localities of the bin may accumulate because of leaky roofs and side walls, and ground dampness. Insect infestation may also cause local areas to become damp. Finally damage within the grain itself can be due to a phenomenon called "moisture migration" or the transfer of moisture from one part of the bin to another within the grain mass.

In theory, moisture migration is the consequence of a differential in vapour pressures between the grain in different parts of the bin. Here, the equilibrium of the vapour pressures is disturbed by the differences in the temperatures set up within the different parts of the bin. The magnitude of the pressure difference determines the rapidity of the moisture movement. The existence of both warm and cold grain during winter increases this differential, where warm grain having high vapour pressures will cause moisture to move towards the cool grain having low vapour pressures. This is true of all hygroscopic materials where the laws of vapour pressures and their behaviours apply. In wheat, stored for a year or more in small three to five thousand bushel bins, complex temperature changes take place and large temperature differences occur.

In moisture migration, the equilibrium moisture content of grain is a basic element. Equilibrium moisture content is defined as the grain moisture content when the vapour pressures are equal at identical temperatures of the air and the grain. When the internal vapour pressure of the grain, which is dependent on moisture content of the grain and the atmospheric temperature, is greater than the partial vapour pressures of the air, the grain loses mois-

ture to the air until the vapour pressures are equal. If the relations are reversed, the grain will absorb moisture from the air.

### Objective of the Research Project

Tests conducted during the past showed that ventilation of grain stored in bins has aided in the prevention of harmful moisture migration. The purpose of this research was to exploit the feasibility of using low-powered fans and wind ventilators. Terms of agreement were made by the Commodity Credit Corporation, Grains and Feeds Section (AMS) and Kansas State College to determine the most economical methods of maintaining the quality of Commodity Credit Corporation stored wheat by means of low-powered fans and wind ventilators and to prevent harmful moisture migration.

### Procedure

A binsite was provided by the Commodity Credit Corporation at Larned, Kansas. Forty bins with rows running from North to South were filled with high grade quality wheat to a depth of approximately twelve feet. These bins were divided into six groups and numbered consecutively from one to six.

Three groups provided a volume rate of flow in the order of 50, 100, and 200 cubic feet per minute. Group I had six bins placed at intervals of six through rows of bins. Each bin was ventilated by a fan delivering 50 cubic feet per minute. Group II followed group I in number and arrangement, but a fan delivery of 100 cubic feet per minute was used. Group III followed group II but was ventilated at the rate of 200 cubic feet per minute. In these systems of ventilation, air was drawn upwards from a central partially perforated flue in each bin extending into the bottom of the grain mass to a

depth of 12 feet. Perforations in the flue for the passage of sucked air amounted to 10 per cent of the area of the section. The air was discharged outside the bin.

Group IV was ventilated by wind cupolas of the "Breidert" type and connected to six bins. Each cupola was attached to a flue at the center of the bin from the top of the roof. The cupola created suction in the flues and discharged air into the atmosphere.

Group V also with six bins had no ventilation system. This group was intended to serve as the check bins that would determine the comparative success of the ventilation methods. Fans and flues were absent in this group.

Group VI comprised ten out of the 40 bins. Six bins were equipped with vertical flues using two fans each of 50, 100 and 200 cubic feet per minute that blew air down into the grain mass. Four others had flues in the horizontal position with two, 50 cubic feet per minute fans and two, intermittently operated large capacity fans that were connected at the outside exposed ends of the horizontal flues. These horizontal flues were inserted at the bottom of the bins.

### Results

Provisions were made in order that temperatures and moisture content records could be taken at the center and 3.5 feet away from the center of each bin. Regardless of the methods of ventilation used, the weather conditions were basic factors in influencing the temperatures and the moisture contents of the grain. The higher ventilation fans gave lower minimum temperatures after three months of winter ventilation since a greater amount of cold air was introduced.

Below 13 per cent moisture content, temperatures ranging from freezing to 75 degrees F would have vapour pressures ranging from 0.1 to 0.2 pounds per square inch. All the bins used had grain moisture contents below 13 per cent throughout the eight months of operation. Computed temperature differences of the surface and the next three feet depth of grain became smaller as winter progressed which meant that vapour pressure differences were also small. With these small differences in vapour pressures, moisture migration could hardly be expected. The dry state of the grain further diminished vapour pressure differences.

The use of small capacity fans not only reduced temperature differences but also established steep minimum temperatures. In vertically installed flue systems, the small fans were inferior to the higher capacity fans in bringing the temperatures down. In the horizontal system of flues the small fans gave lower minimum temperatures and moisture contents.

Wind ventilators, depending on the intensity of wind, was desirable where electricity was absent. Economy gave wind ventilators an advantage although keeping the harmful moisture migration from stored grain was less satisfactory.

All the check bins assumed higher maximum temperatures than the ventilated bins and the greatest temperature differences as a result of the cold surface and the warm grain at 3 feet depth.

### Conclusions

The past winter was unusually mild and dry, and no trouble directly due to migration of moisture occurred. Ventilation cooled the grain mass and no moisture could be seen on the surface. Condensation at the under surface of the roof caused small amounts of drips but hardly influenced the moisture con-



tent of the surface grain. Dust blown inside the bins during severe duststorms was no serious threat although it made the work of taking temperatures and moisture samples inconvenient. This year was conducive to the storage of wheat. Different temperatures and humidity conditions may prevail next year, and conditions which might be favorable for harmful moisture migration. Thus, it was decided that the experiments be continued for the next year to ascertain further the efficacy of low-powered fans in preventing harmful moisture migration.

In considering the vapour pressures set up by big temperature differences it is to be noted that at low temperatures moisture contents even up to 14 per cent produce small vapour pressures. Hence, it would seem that ventilation by the small capacity fans, in reducing the temperatures of the grain to around the freezing point and still had moisture contents below 13 per cent, was practical and safe for the storage of grain.

Harmful moisture migration on the surface of the grain mass did not occur since no visible destruction of wheat by this cause developed. The surface layers are still dry and the moisture contents are within the safe storage moisture content of 13 per cent.