Grain Drying
and Conditioning
Investigations

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During some years, an important percentage of Oklahoma's wheat crop is harvested with excess moisture. This wheat is then susceptible to damage and quality deterioration during storage unless the excess moisture is removed soon after harvesting.

Grain sorghums are sometimes harvested during unfavorable fall weather, or after regrowth following drouth has produced green stems and heads. These conditions result in excess moisture in the grain and consequent deterioration in storage.

Other crops are occasionally harvested with excess moisture. Experimental studies have been conducted at the Oklahoma Agricultural Experiment Station on the selection of appropriate conditions and treatments for grain harvested with excess moisture.

These studies have included: (1) Experiments on batch-drying of grain sorghum, wheat and rye with forced circulation of air in field and laboratory size installations, (2) Field experiments on drying of grain with natural wind ventilation, and (3) Experiments on the use of conditioning powders for grain stored with excess moisture.

Batch Drying with Forced Air Circulation

The principal objective of the forced air drying experiments was the development of prediction equations for drying effect over various ranges of drying air temperatures, humidities, circulation rates, grain bed depths or column thicknesses, and grain moistures.

The authors acknowledge the assistance of Orville Stout, Agronomy Dept., and Dwight Stephens, Supt. of the Ft. Reno Experiment Station in providing grain and certain facilities for conducting the field experiments.

Field Experiments

The equipment used for the field experiments on forced-air circulation, batch drying of wheat, grain sorghum, and rye included a commercially-manufactured air heater and blower connected to the drying bin or chamber with a canvas duct. The unit included a six-bladed, 24-inch, propeller-type fan powered by a 3 HP electric motor. The air was heated by an oil-burner with interchangeable nozzles to provide variation in fuel burning rate. Fuel pressure could be manually adjusted to give some additional control of fuel rate. Nozzle sizes of 2.5 3.0 and 4.0 gal. per hour nominal capacity were used. The unit was

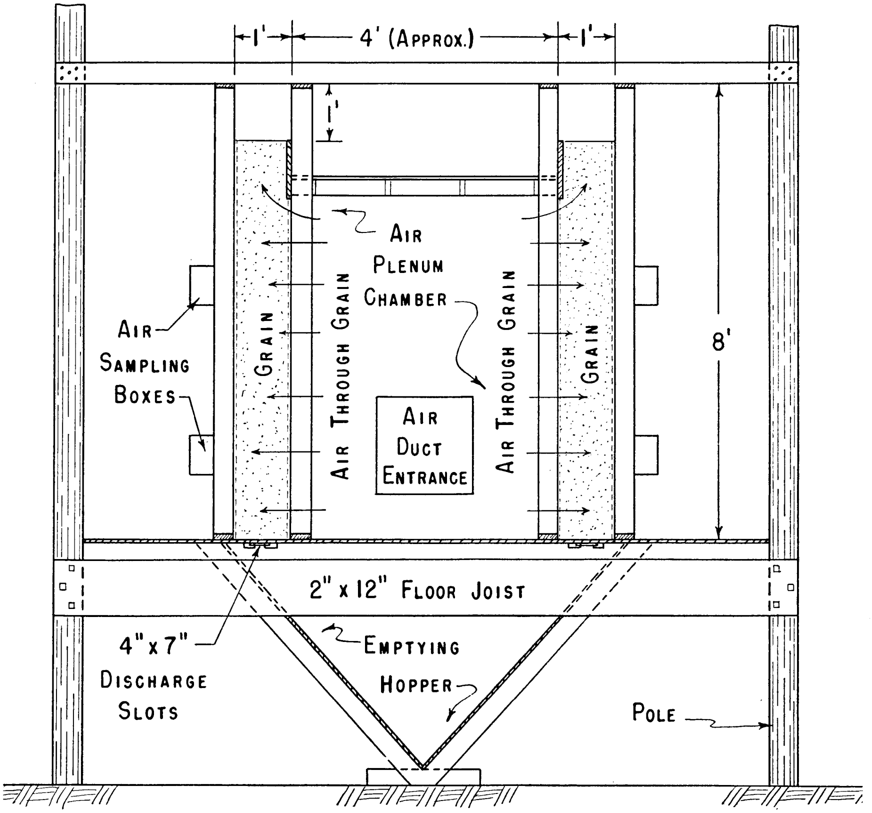

Figure 1. This cross section drawing shows the general arrangement of column type drying bins erected on the Oklahoma Experiment Station's Agronomy Farm west of Stillwater.

"direct heating"; i.e., the heated combustion gases were mixed with the air which was circulated through the grain to be dried.

Two different drying bin or chamber installations were used for containing grain to be dried. One, at the Ft. Reno Experiment Station, El Reno, Oklahoma, included a conventional 500-bushel cylindrical steel bin 9 feet 10 inches in diameter with a perforated steel floor over a relatively airtight plenum space. The air supply from the blower was introduced into the plenum space through an opening at the bottom of the bin wall. The other installation, on the Oklahoma Experiment Station's Agronomy Farm near Stillwater, was a "column-type" drying bin with two 12-inch wide grain chambers each enclosed with a 16-mesh screen over ¼-inch mesh screen. One column was located on each side of a plenum chamber approximately 6 feet 4 inchs high by 4 feet wide. The grain chambers were each 8 feet long by 7 feet high. Heated air was introduced at the end of the plenum chamber by a duct connection 1½ feet square. Figure 1 shows the general arrangement of this column-type drying bin.

Ambient air conditions were sampled with a hand aspirated psychrometer during each experiment. The air temperature entering the grain was measured with a thermocouple junction in the plenum space. Leaving air conditions were sampled with a hand-aspirated psychrometer held directly over the grain or in special exhaust air sampling boxes at the sides of the column-type drying bin. Air rate was determined either by anemometer traverses across the intake openings to the blower and heater unit, or by static pressure measurements with a U-tube manometer and a static pressure tube in the plenum chamber. These static pressure measurements were used with the data in Figure 7 of Ref. (1), extrapolated for air rates above 40 cfm/sq. feet. Drying effects were computed as the differences between entering and leaving humidities determined from psychrometric observations.

Laboratory Experiments

Experiments on drying small samples of grain sorghum with forced circulation of air through grain in a cup were conducted by Kolega (2). The objective of Kolega's experiments was to evaluate the feasibility of using small-sample laboratory data for developing a drying effect prediction equation valid for application to a prototype installation. The apparatus used is depicted in Figure 2. The essential parts of the apparatus included a compressed air flask for the air supply, a pressure regulator, a desiccant chamber, a heating chamber equipped with electrical resistance heaters and a plastic cup with a screened bottom for

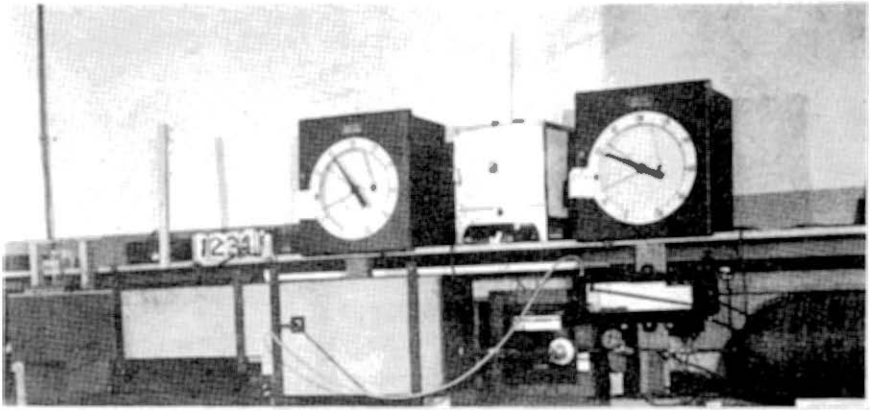

Figure 2. Experimental apparatus for small-sample drying studies. Air supply contained in flask at right, grain cup was clamped to chamber top at extreme left.

containing the grain supply. Instrumentation included recording thermometers with thermocouple sensing elements, a recording hygro-thermograph, and a millivoltmeter pyrometer for controlling air temperatures entering the grain cup. A precision manometer was used for gaging the air flow rate. The grain cup was cut from lucite tubing with an inside diameter of 2.73 inches. In use, it was affixed to a plywood base which was clamped over the discharge opening in the air chamber.

In the laboratory experiments, moisture removal from the grain was determined by removing and weighing the grain cup at regular intervals during each experiment.

The air flow rate was determined by adjusting the pressure regulator and valve after the compressed air flask to maintain the static pressure needed for the desired air flow rate. The setting was determined from calibration experiments. Air flow rates during calibration were determined by weighing the compressed air flask before and after a timed run, then converting the weight loss to equivalent cu. ft./min.-sq. ft. of cup area.

Data were collected with this apparatus on the drying rates of Redlan Kafir grain sorghum for air flow rates of approximately 17, 32, 44, and 55 cu. ft./min.-sq. ft. and for five temperature levels varying from room temperature to temperatures in the range 180 to 190 F. A curve of moisture loss versus elasped time was plotted for each drying run.

A computed grain depth in the cup of 0.114 ft. was used for all analyses. This grain depth was based on an average grain moisture content of 17.23 percent (dry weight basis) and a specific weight of the damp grain of 56 lb./bushel.

Field and Laboratory Data

A summary of the data from 13 drying experiments with heated air in the field installations and 20 experiments with the laboratory equipment is given in Table 1.

The general approach in developing the prediction equation for drying effect was: First, the selection of a set of pertinent variables based on a hypothetical model of the drying process and, second, the correlation of a set of dimensionless parameters formed from these pertinent variables. The correlation was partly based on a rational hypothesis for the drying effect prediction equation.

Model Drying Process

The model drying process is depicted in Figure 3, Page 10. The air supply is heated in the heating device from ambient temperature t_a at constant moisture to some temperature t_e entering the grain. In passing through the grain, moisture is added to the air at a constant wet bulb temperature corresponding to the entering wet bulb temperature. At point 3, the air leaves the grain after having been cooled to the temperature t_I and humidified to the equilibrium humidity corresponding to the moisture content of the grain at the beginning of the drying operation. This process, 2-3 (Cf. Figure 3) assumes that the grain bed is deep enough so that there will always be enough damp grain at the initial moisture content to permit the leaving air to closely approach equilibrium with the grain. Otherwise leaving humidity of the air would progressively drop as drying continued.

The drying process that occurs in practice may depart in some respects from the model. The drying air may not circulate through the grain at a constant wet bulb temperature. When grain temperature is lower than t_e, the circulated air will at first experience a decrease in enthalpy; or, if the grain is hotter than t_e at the beginning of the drying operation, the air will at first increase in enthalpy. Also, the leaving air humidity will start to decrease as soon as drying commences. For the batch depths and other conditions usually encountered in drying grain in farm storage, it appeared that this hypothetical model was

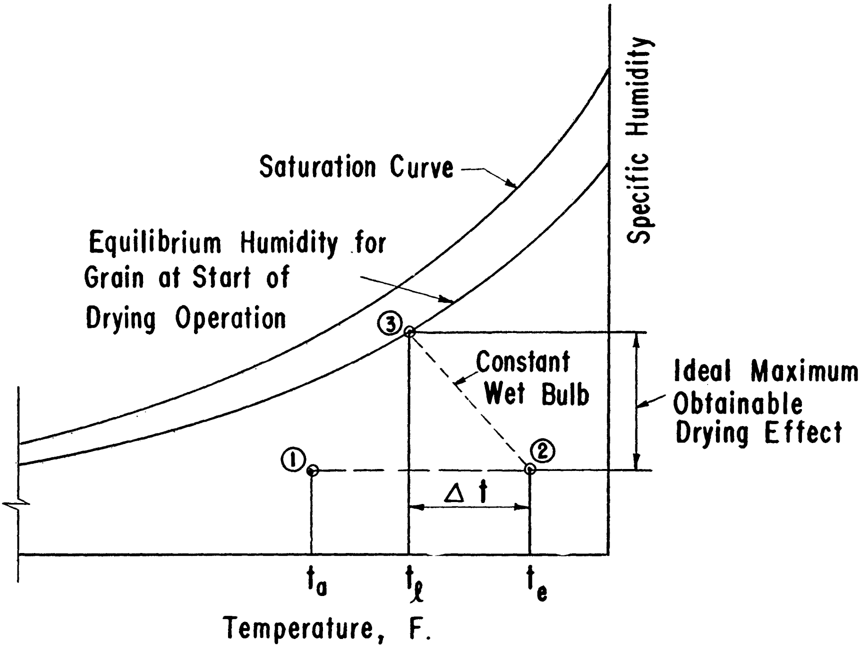

Figure 3. This graph depicts the model drying process in these experiments.

adequate as a basis for analyzing and correlating results from experiments. The model was used as the basis for selecting the following variables which characterize it:

1. E_a, average drying effect during elapsed time, Φ, since start of the drying operation — lb. moisture removed per lb. of dry air circulated during time Φ.
2. ΔM, difference, initial grain moisture minus equilibrium grain moisture, corresponding to entering air humidity—lb. moisture per lb. of dry grain. (Cf. Figure 4).
3. t_e, air temperature entering grain—deg. F. absolute.
4. Δt, difference, t_e — t_l, (Fig. 3) — deg. F.
5. Φ, elapsed time since start of drying process-minutes.
6. V, air circulation rate-cfm/sq. ft.
7. λ, grain bed depth or thickness-ft.

8. R, hydraulic radius of grain container in plane normal to direction of air flow-ft.

The air temperature entering the grain will establish the maximum grain temperature. The temperature difference Δt is one of the factors which will establish the theoretical maximum drying effect obtainable. Also, Δt is an index of the temperature difference which will result in heat transfer from the air to the grain, and hence in departure from the constant wet bulb air humidification process.

The elapsed time, Φ, during the drying process will influence the average drying effect because as time elapses, the grain batch will become progressively dryer and hotter.

The air circulation rate, V, will influence the rate of convective heat transfer from air to the grain, vapor conductance at the particle surface, and the moisture content of the air leaving the grain.

The bed depth or thickness, λ, will influence the time during which the circulated air is in contact with damp grain. The hydraulic radius, R will influence peripheral, or edge cooling in relation to the bin or container cross-section.

The Buckingham Pi theorem was used to correlate these variables. According to the Buckingham Pi theorem, the pertinent variables in a system can be combined into a set of dimensionless, parameters or pi terms equal in number to the total number of variables involved minus the number of independent dimensions involved. An adequate functional relationship among the pi terms will then describe or predict the behaviour of the system. The only restriction placed upon the pi terms is that they be dimensionless and independent.

The present analysis is based on eight variables with three basic dimensions that include length, time, and temperature. Thus, 5 pi terms are required to express the relationship. These pi terms may be written, by inspection, as follows:

$$\Pi_1 = E_a \qquad \Pi_4 = \lambda/V\Phi$$

$$\Pi_2 = \Delta M \qquad \Pi_5 = R/\lambda$$

$$\Pi_3 = \Delta t/t_e$$

Prediction Equation for Drying Effect

The value of each pi term was computed for each of the experiments tabulated in Table I with the results shown therein. In order to evaluate these pi terms, data on equilibrium relative humidity of grain were required. For this analysis, the data of Table 5 of Ref. (1) were used to plot equilibrium relative humidity curves for hard red winter wheat, rye, and sorghum. The equilibrium data were given for room temperatures, of approximately 77 F. These data together with the curve for 90 F replotted from Figure 4 of Ref. (1) are shown in our Figure 4. Usually, the dry bulb temperatures corresponding to the air

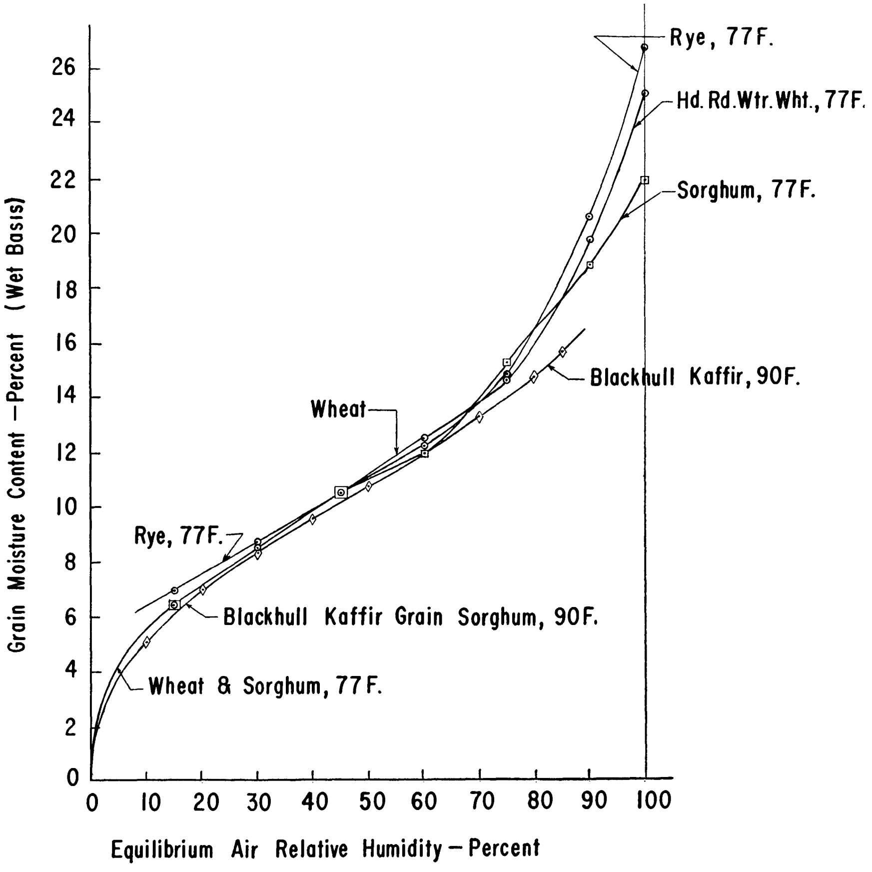

Figure 4. Equilibrium relative humidity of grain. Replotted from data in Ref. 1.

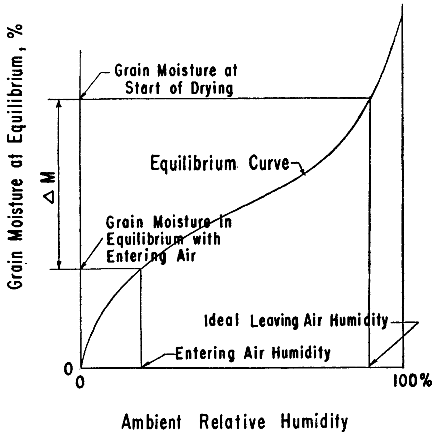

Figure 5. Schematic diagram showing computation of ΔM.

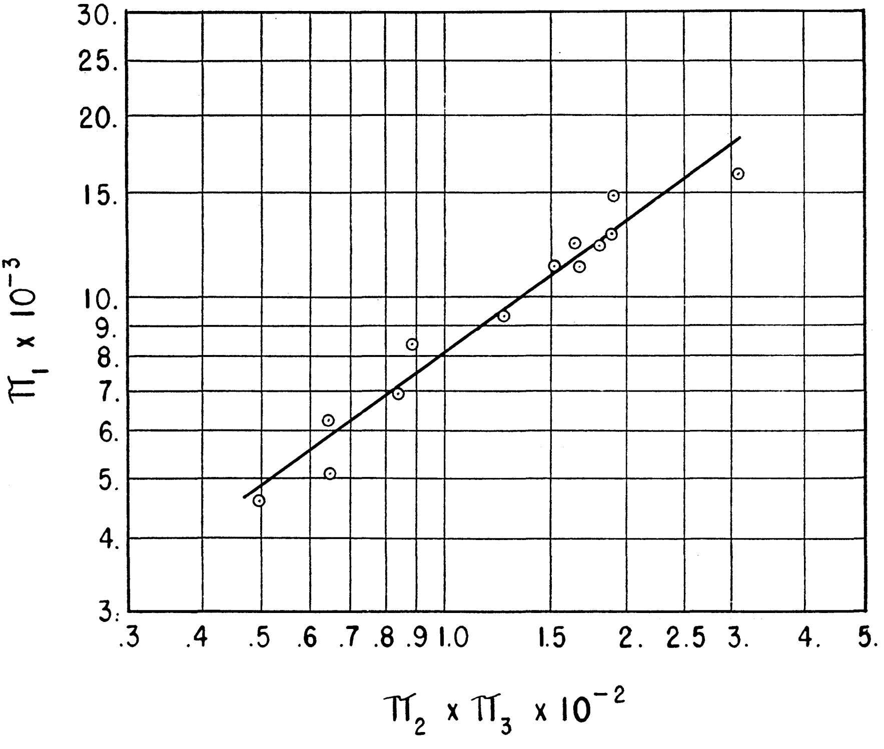

Figure 6. Dimensionless plot of pi_1 versus pi_2 x pi_3 for field experiments.

wet bulb temperature and equilibrium relative humidity for the initial grain moisture were close to or within the range 77 to 90 F. For air relative humidities less than about 10 percent, it was necessary to extrapolate the original data of Ref. (1) to pass through the origin. The schematic diagram, Figure 5, indicates the manner in which ΔM was determined for each experiment for the equilibrium relative humidity curve.

Trial plotting of the data collected during the field experiments indicated that the relationship among Π, Π_2 and Π_3 was linear on a graph of log Π_1, as a function of log $(\Pi_2\ \Pi_3)$, as shown in Figure 6. The values of $\Pi_4 = \lambda/(V\Phi)$ corresponding to these data ranged from 1.48×10^{-4} to 3.00×10^{-4} with a mean value of 2.24×10^{-4}. The slopes or regression coefficients of log Π_1, on log $(\Pi_2\Pi_3)$ were computed for the field data and for each of the sets of the laboratory data, at a relatively constant Π_4. The two mean values obtained from the analysis of the field and laboratory data, respectively, were averaged to give an average regression coefficient of 0.774. This was considered an appropriate value of the exponent "n" in the expression

$$\Pi_1 = f\ [(\Pi_2\Pi_3)^n]$$

for constant Π_4.

To obtain a functional relationship for Π_1 that included Π_4 as well as Π_2 and Π_3, it was hypothesized that as Π_4 increased, due to increased bed depth, decreased air circulation rate, or shorter elapsed time, drying effect increased and approached a maximum drying effect. Also, when Π_4 approached zero (very thin bed depth, or air circulation rates or elapsed times that increased to very large values) Π_1 must also become zero. Therefore, the characteristic equation with Π_2 and Π_3 constant is analogous to a growth equation, such as for transient current in an R—L direct current electrical circuit upon which a constant emf is suddenly impressed. Such a characteristic equation for the grain drying system is:

$$\Pi_1 = C\ (\ 1 - e^{-C_2\pi_4})$$

The complete prediction equation for Π_1, was therefore hypothesized to be:

$$\Pi_1 = [f_1\ (\Pi_2\ \Pi_3)]\ [f_2(\Pi_4)]$$

where

$$f_1\ (\Pi_2\ \Pi_3) = k_1\ (\Pi_2\ \Pi_3)^n$$

and

$$f_2\ (\Pi_4) = (k_2)\ (1 - e^{-C_2\pi_4})$$

The complete expression can be written

$$\Pi_1 / (\Pi_1\Pi_3)^{n} = C_1\ (1 - e^{-C_2\pi_4})$$

where ^{n}, C_1, and C_2 are dimensionless constants to be determined by experiments. C_1 is an index of the maximum or asymptotic value of Π_1 that could be attained with the prevailing values of Π_2 and Π_3.

It appeared that because of differences in peripheral cooling of the grain cup or bin wall associated with differences in Π_5, different constants C_1 and possibly C_2 existed for the laboratory data as compared to the field data.

To evaluate C_1 and C_2, the two equations

$$y = C_1\ (1 - e^{-C_2x})$$

and

$$dy/dx = C_1\ C_2\ e^{-C_2x}$$

where $y \equiv \Pi_1/(\Pi_2\ \Pi_3)^{0\cdot774}$

$x = \Pi_4.$

were solved simultaneously for C_1 and C_2 at the mean x and y of the experimental data, and dy/dx equal to the slope of linear regression of y on x.

This procedure resulted in a prediction equation for a curve passing through the mean values of x and y; with a tangent slope at that point equal to the slope of a straight line fitted to the data by least squares.

The values obtained for the constants were:

for field data,

$$C_1 = 30.8 \times 10^{-2}$$

$$C_2 = 1.0620 \times 10^{4},$$

and for laboratory data

$$C_1 = 12.2 \times 10^{-2}$$

$$C_2 = 1.2420 \times 10^{4}.$$

The prediction equations obtained were, for the field data,

$$\Pi_1 = 30.8 \times 10^{-2} \; (\Pi_2 \; \Pi_3)^{\,0 \cdot 774} \, (1 - e^{-10{,}620\pi_4})$$

and for the laboratory data,

$$\Pi_1 = 12.2 \times 10^{-2} \, (\Pi_2 \; \Pi_3)^{\cdot 0774} \; (1 - e^{-12{,}420 \; \pi 4}).$$

The graphs corresponding to these two equations are shown in Figure 7, next page.

It is evident that the maximum drying effectiveness of the circulated air in the laboratory apparatus was only about 40 percent of that with larger, field-size bins. It is believed that this difference was due mainly to larger cooling losses at the periphery of the small grain cup corresponding to smaller values of Π_5. The overall effect of these peripheral cooling losses would be minimized in a 10 ft. diameter or larger grain bin. It appeared that differences in performance between a small and large grain container due to differences in Π_5 could be largely eliminated by a well-insulated grain cup, so that peripheral cooling would be minimized. Then the performance of prototype drying installations might be evaluated by small-scale, laboratory tests.

The instantaneous value of drying effect may be obtained directly from the expression for E_a, the average drying effect. Let E_i denote the instantaneous effect at time Φ. Then

$$\begin{aligned} E_i &= \partial/\partial\phi \; (E_a \; \Phi) \\ &= (\Pi_2 \; \Pi_3)^{\,0 \cdot 774} \; C_1 \; [1 - (C_2\lambda/V\Phi+1) \; e^{\,-C_2\lambda/V\Phi}] \end{aligned}$$

At the start of the drying operation, ($\Phi=0$), the instantaneous drying effect is $(\Pi_2 \; \Pi_3)^{0.774}$ C_1. As elapsed time becomes very large E_i approaches zero.

A graph of experimentally observed drying effect versus drying effect, E_a, computed by the prediction equation is shown in Figure 8 on log-log co-ordinates. If perfect agreement had existed between observed and predicted values, all points would fall on a line with a slope of 45 degrees and passing through 1.0, 1.0. It appeared that the prediction equation was an adequate representation of the data.

The experimental data were obtained under non-uniform conditions, and, in the case of the field experiments, with relatively crude instrumentation. Differences in drying behaviour doubtless occurred be-

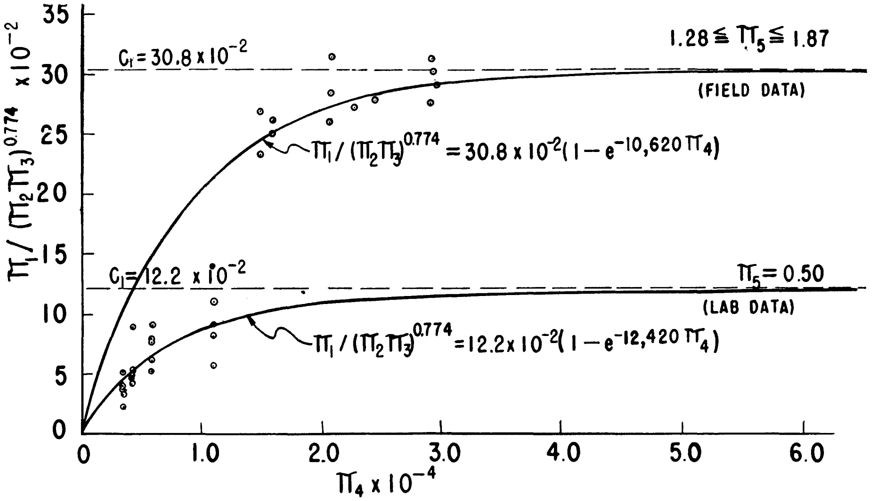

Figure 7. Graphs of prediction equations and experimental data on which equations were based.

cause of uncontrolled variations in amount of foreign material in the grain, grain density, grain size, and other natural differences between batches of grain over the three-year period covered by the experiments.

Application of Results

The prediction equation can be used to investigate the effects of changes in drying air temperature, air humidity, grain moisture content, grain bed depth, and air circulation rate on performance of a grain drying system.

Certain applications to operating drying installations are apparent. In order to accomplish drying without wasting heat and power, a relatively high value of Π_4 should be maintained. To achieve an effectiveness of 0.9 of the maximum, i.e., $e^{-C_2\pi_4}=0.1$, Π_4 must have a value of approximately 2.1 x 10^{-4}, at least. As elapsed time increases, air circulation rate might be decreased proportionately or bed depth increased proportionately to maintain constant effectiveness.

The results of the present study may also be applied in planning experimental investigations of grain drying systems. It appears feasible to perform grain drying experiments with relatively small samples of grain in an appropriate arrangement of laboratory equipment. If the grain container is adequately insulated so that peripheral effects are minimized, a prediction equation based on the laboratory data should

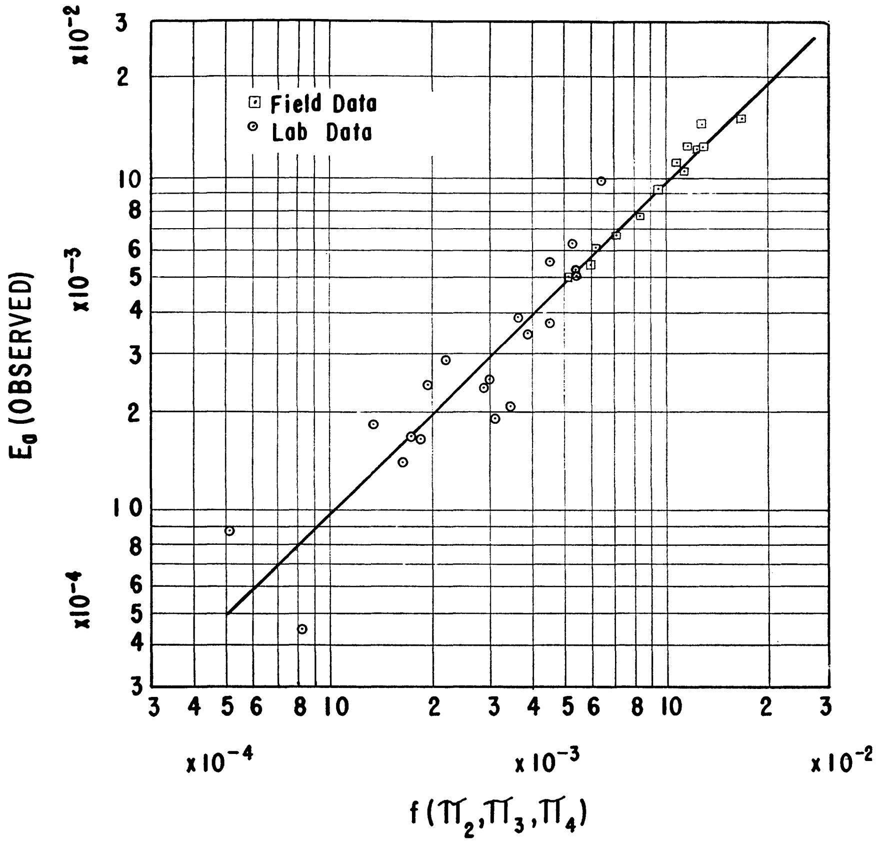

Figure 8. Observed versus predicted values of drying effect.

be valid for full-size systems. In the present study, predicted values of Π_1 from the laboratory results were approximately 40 percent of those from field results for the same values of Π_4. This difference appeared to have been caused by lack of insulation of the grain cup which resulted in excessive peripheral cooling of the cup and grain compared to a 10 ft. diameter grain bin.

Summary and Conclusions

1. The prediction equation

$$E_a = C_1 (\Delta M \ \Delta t / t_e)^n \ (1 - e^{-C_2 \lambda / v\Phi})$$

was found to be adequate for predicting the performance of batch grain drying systems using forced circulation of air. A value of "n" of 0.774 was found to be appropriate to the experimental data. The value of C_1, the maximum drying effect obtainable for specified grain moisture and entering air temperatures, was found to be quite different for drying grain in a small cup as compared to a 10 ft. diameter bin or 7′ by 8′ columns. For the small cup installation, C_1 was found to be approximately 12.2×10^{-2}, but for the 10 ft. bin, it was evaluated as 30.8×10^{-2}. These values were in roughly the same proportion as the mean values of $\Pi_5 = R/\lambda$, for the field and laboratory experiments, respectively, where R is hydraulic radius and λ is grain bed depth. The values of C_2 were 10,620 for the prototype installations and 12,420 for the small laboratory installation. These values differ from the mean by approximately 8 percent.

The approximate ranges of values covered by the experiments were:

$0.5 \times 10^{-3} \leqq E_a \leqq 15 \times 10^{-3}$,

$0.5 \times 10^{-2} \leqq \Delta M \Delta t/t_e \leqq 5 \times 10^{-3}$,

$0.3 \times 10^{4-} \leqq \lambda/V\Phi \leqq 1.1 \times 10^{-4}$ for laboratory experiments,

$1.5 \times 10^{-4} \leqq \lambda/V\Phi \leqq 3.0 \times 10^{-4}$ for field experiments,

$0.50 = R/\lambda$ for laboratory experiments,

$1.28 \leqq R/\lambda \leqq 1.87$ for field experiments.

2. Correlations and prediction equations for performance of grain drying systems appear to be amenable to development by experiments with small-size laboratory apparatus at a considerable saving in time and cost compared to experiments with large batches of grain in full-size installations. Care is needed to prevent distortion of the results due to dissimilar peripheral cooling between model and prototype as seems to have occurred in the present study. Validation should be accomplished by a few experiments with prototype installations.

3. Below a Π_4 value of about 2.0×10^{-4}, drying effectiveness was found to drop below 90 percent of the maximum. Above a Π_4 value of about 3.0×10^{-4}, improvement in drying effectiveness by increasing Π_4 was found to be slight.

Performance of Wind Ventilated Column Driers

The use of corn cribs for drying corn by natural ventilation is a familiar practice. To test the efficiency of similar wind ventilated drying systems for drying small grains, three column driers were constructed in 1953. These driers, or drying bins, were designed to function for small grains in much the same manner as corn cribs are used to dry ear corn, exposing a wall of grain to natural wind movement. The driers were constructed to give maximum exposure of the grain surface to the wind. The depth, or thickness, of the grain column is the limiting factor in such drying systems since normal wind pressures must provide sufficient air movement through the grain to remove excess moisture. The three driers were constructed with three different thicknesses, or wall spacings. In this way, the optimum wall spacing, giving maximum storage and adequate drying, could be determined.

Equipment Used

The driers were pole-frame structures using four pressure preservative treated poles with the floor and roof framed to the poles. Details are shown in Figure 9. The wood floors of the bins were elevated 36 inches above the ground and constructed with 3 sliding trap doors so the bins could be emptied into an elevator hopper by opening the sliding plywood doors. The roofs of the driers were constructed to project well out from the walls of the drier, to provide protection for the stored grain, and were hinged to allow the bins to be filled from the top and to facilitate sampling of the grain. All walls were semi-free standing so the spacings of the walls, and the capacity of the drying bins, could be varied with minimum effort.

The dimensions of the drier walls were 4′0″ wide by 6′0″ high. Depths, or inside to inside wall spacings, were 9″, 12″ and 15″ respectively. The 4 feet by 6 feet north and south walls consisted of wood framing with ½ inch hardware cloth and #16 insect screen, attached to the inner face of the studs. The screen provided adequate openings for free circulation of air, yet was small enough to retain the grain. The heavier hardware cloth provided strength and support to the insect screen. This provided maximum exposure of the grain to the wind with adequate strength to prevent failure of the bin walls. The narrow end walls of the bins were framed with solid shiplap lumber.

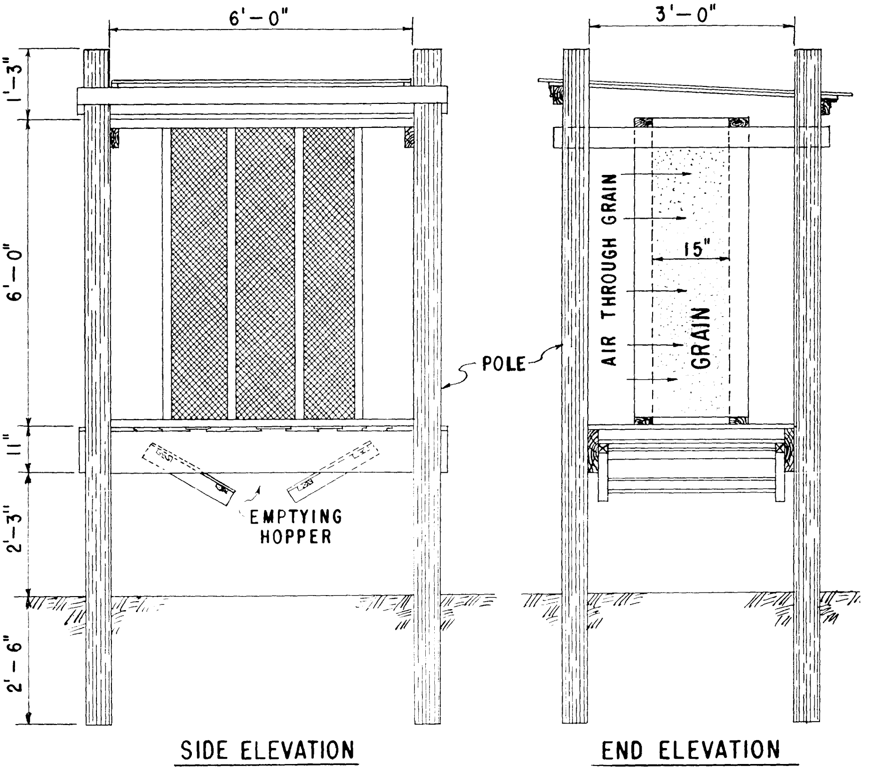

Figure 9. Construction details of wind ventilated column driers for grain. All walls were free standing so wall spacing and bin capacity could be varied.

Location of Driers

The three column driers were located in an open pasture and were oriented east and west to assure maximum exposure to the prevailing southerly wind. They were located in an east-west line about 6 feet apart so all would have the same exposure (see Figure 10). Rains from the south occasionally drove in under the overhanging roof and wet the grain on the surface of the screen wall but this did not prove to be a problem. What rain did strike the grain penetrated but a short distance and the grain soon dried out after the rain ceased. Some of the grain on the surface of the south wall was also exposed to direct sunlight and some fading was noted.

Experimental Procedure

Grain samples were obtained from the grain stored in the drying bins at the time of filling, once daily for the first two weeks after fill-

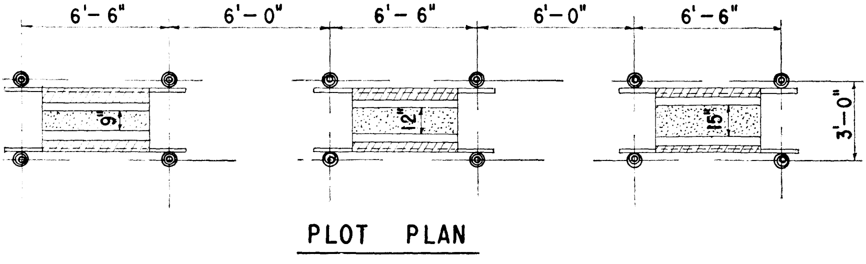

Figure 10. Column driers were located in an east-west line about 6 feet apart so all bins would have uniform exposure to prevailing southerly winds.

ing, then every other day for the duration of the drying period. The samples were taken with a standard grain probe at 9 locations in each bin: At three locations at either end and in the middle of the bins, next to the front and back screen wall, and at the center between walls. Samples of the grain were stored in sealed metal containers from the time they were obtained until they were testd for moisture content. Moisture content of the grain was determined with a Steinlite moisture tester.

Grain temperatures were taken with a standard probe type thermometer each time grain samples were obtained. Both wheat and grain sorghum were dried in the column driers in 1953 and wheat was dried in 1954. For the 1954 tests, the width of the 9 inch bin was increased to 18 inches. Initial moisture content of the grain introduced into the bins varied slightly due to the time of harvesting. Grain harvested early in the morning usually had a higher moisture content than that harvested later in the day. Once the grain had been placed in the bin, the mass effect decreased its rate of moisture loss and subsequent cooling. Therefore, the longer the grain stood before harvesting the lower the grain moisture content when combined.

Results of Experiments

The first grain dried in the column driers was wheat, placed in the bins June 13, 1953. The average moisture content of the wheat when placed in the three bins was 12% for the 9 inch bin, 11.1% for the 12 inch bin, and 11.0% for the 15 inch bin. The wheat was actually dry enough for storage at the time it was placed in the driers but additional drying did take place. Most grain dried an additional 1.5% to 2%, but heavy rains and humid conditions caused a rise in moisture content during the latter part of June. Final moisture content of the grain, taken on July 13, one month after storage in the column driers, was 11.1% for the 9 inch bin, 11.2% for the 12 inch bin, and 12.2% for the 15-inch bin, an average increase of approximately 0.1% moisture content for the grain.

Grain sorghum was placed in the column driers on September 25, 1953. The moisture content of the sorghum was well above the safe storage level at the time of harvesting, the average moisture content being 16.8% for the grain in the 9 inch bin, 17.4% for the grain in the 12 inch bin, and 17.9% for the grain in the 15 inch bin. By October 20, 1953, the average moisture content of the sorghum in the bins was down to 11.0%, 11.3% and 11.6% respectively, an average decrease of 6% moisture content. The grain was left in the bins until November 13, 1953, at which time the average moisture content of the grain was 12.7%.

Wheat was again placed in the column driers on July 1, 1954. The moisture content of the wheat was well above the safe storage level at the time it was placed in the driers. The average moisture content was 18.1% for the 12 inch bin, 19.0% for the 15 inch bin, and 19.9% for the 18 inch bin. By July 23, 1954, the moisture content for the wheat in the three bins was down to 8.8%, 9.8%, and 10.4% respectively, well below the safe storage level for wheat. This was an average reduction

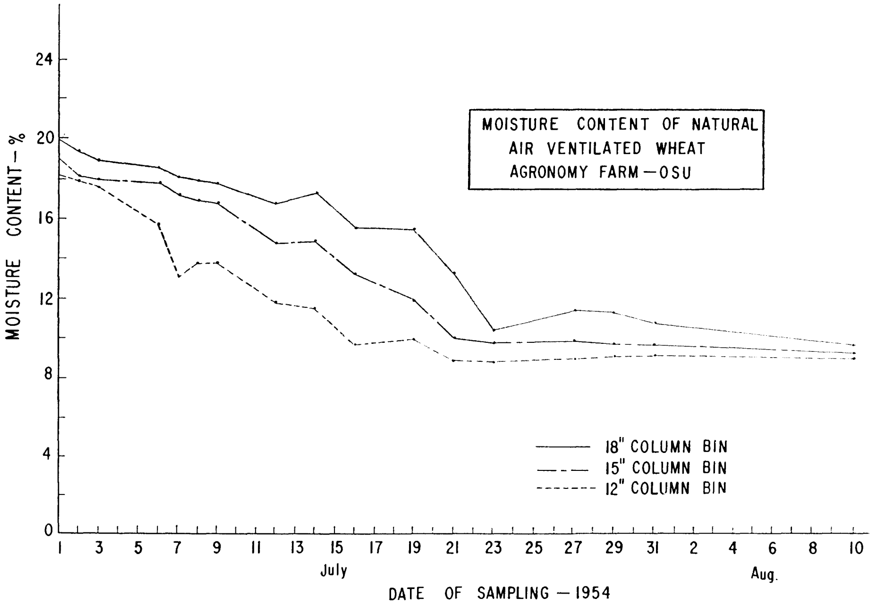

Figure 11. Moisture content of natural air-ventilated wheat stored in 3 column driers of varying thickness. Safe storage level of moisture was reached by July 23.

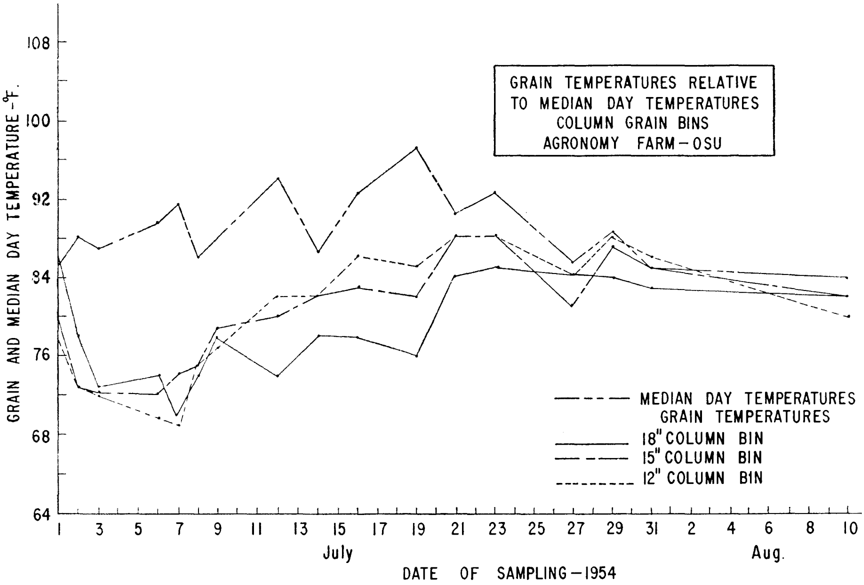

Figure 12. Grain temperatures in column driers relative to median day temperatures. Grain temperatures fluctuated with median day temperatures.

of 9.3% moisture content. The moisture content of the wheat during storage is shown in Figure 11, previous page.

Grain temperatures in all tests dropped immediately after the grain was placed in the column driers and continued to drop for about a week. This was due to the evaporation of the moisture from the grain. Grain temperatures then increased slowly, as the drying rates of the grain decreased, until they reached the median outdoor air temperature. Grain temperatures then fluctuated with median day temperatures. This tendency is shown in the graph on Figure 12.

In all tests, the grain on the south wall of the column drier, the side exposed to the prevailing wind and the sun, dried the fastest. This grain was also the first to show an increase in moisture content after a rain or during humid weather. The grain on the north side of the column driers was the last to show an increase or decrease in moisture content as the moisture had to migrate through the drier from south to north, or front to back, to be exhausted from the drier. The moisture content of the grain in the center of the bin was usually the average of the moisture content of the two surfaces of the bin and could therefore be used to obtain the average moisture content of the entire contents of the drying bin.

Conclusions

The results of drying in all tests were satisfactory. Grain stored in the bins remained clean and in good condition. This type grain storage structure would not replace mechanical drying but could be used as a low-cost method of drying small quantities of grain. It might be useful for drying and storage of seed wheat, storing it from harvesting time in June to planting time in September. Due to the large exposure of the grain, plus the eveness of drying, no heating was encountered.

The column driers, shown in Figures 13 and 14, are an experimental type. Permanent installations of this type could be much larger, could be grouped under a roof or used as a wall of an open machinery shelter, or could be incorporated into a similar covered structure. This method of construction would further reduce the cost of the drying bins. Filling and emptying facilities could be improved, and protection should be provided against birds. Insects were not a problem in the experimental driers since the grain was dry and clean at all times. Birds, however, used the bins regularly as feeding stations since they were not made bird proof.

Figure 13. Column driers were constructed for loading from top.

Figure 14. Roof overhang did not shade grain in column drier completely.

Performance of Grain Preservatives

Chemical formulations have been sold as powdered admixtures to help prevent or reduce damage to farm-stored grain binned with excess moisture. If such powders were effective, they might be used when drying facilities were not available, or in lieu of drying.

Experiments

High-moisture grain—Fifteen bushels of 20.5 percent moisture (wet basis) grain sorghum were placed in a compartment in a 10 ft. diameter metal bin, on November 8, 1950. Two and one-eighth pounds of a commercially-formulated "preservative" powder for excess moisture grain was thoroughly mixed with the grain. According to the label, the ingredients included sodium bicarbonate, calcium phosphate, sodium bicarbonate, and calcium hydroxide. The manufacturer's recommended rate for 19 percent to 20 percent moisture corn, oats, barley, and rye was 5 lbs. per ton. The rate used in this trial corresponded to this application rate. Fourteen days later, there were indications of molding, heating, and a sour odor in the grain. By December 6, the grain was badly caked and molded, with temperatures above 100 F. near the surface.

Medium-moisture grain—The following year, an experiment was conducted with the use of preservative powders for medium moisture grain sorghum. Four hundred and twelve bushels of grain sorghum were harvested October 8 through October 11 at the Ft. Reno Experiment Station.

The grain was binned in 4 identical wooden-walled bins in a large granary and treated October 12 at the rate of 5 lbs. of preservative powder per ton of grain. The powder was added at the intake to the grain auger used for filling the bins, in order to help assure thorough and uniform mixing of the powder with the grain. The control bin was untreated. The other three bins were treated with sodium bicarbonate and two different commercial formulations respectively.

The bins were sampled periodically during the ensuing storage season for moisture content, temperature in the bin, and germination. Temperatures were measured at four depths and five positions in each bin with a thermocouple junction mounted on a probe.

The results of these observations are shown in Tables II, III, and IV. In these tabulations, treatments 2 and 3 were commercial formulations. Treatment 4 was sodium bicarbonate. The control bin was untreated.

The data on grain moisture, germination, and temperature were subjected to statistical analysis. The effect of treatment on moisture change, Table II, was non-significant (variance ratio of 0.74). The analysis of effect of treatment on germination, Table III, produced a variance ratio of 1.52, with an associated confidence level of approximately 7 percent. It should be noted that the lowest germination percentages were obtained with the sodium bicarbonate (treatment 4) and one of the commercial power treatments (treatment 3). Analysis of variance of the temperature data, Table IV, produced a variance ratio for the effect of treatment on grain temperature with an associated confidence level above 99 percent. Further analysis revealed that the effect of the powder treatments compared to the control (no treatment) on temperature rise had a variance ratio with a confidence level above the 99 percent level. It should be noted that the means of the temperatures in the treated bins were consistently higher than in the untreated bin.

These foregoing analyses were applied to the data obtained during the period 12 October through 10 January. After the 10 January sampling the grain in bins with treatment 3 (commercial powder) and treatment 4 (sodium bicarbonate) had heated and otherwise deteriorated to such an extent that it was necessary to empty these two bins.

Conclusions

On the basis of the foregoing results, it was concluded that neither sodium bicarbonate nor the two commercial powders used were effective to a significant degree in preventing heating, preventing loss in viability, or producing appreciable drying effect when applied at a rate of 5 lb. of powder per ton of grain sorghum stored with an initial moisture content of 14.4 percent to 15.3 percent (wet basis) in relatively small, 100-bushel bins.

LIST OF REFERENCES

1. Engineering data on grain storage. In Agricultural Engineers Yearbook, pp. 97-106. 2nd ed. American Society of Agricultural Engineers. St. Joseph, Michigan 1955.
2. Kolega, John V. Development of a laboratory apparatus for grain drying studies. Master of Science thesis. Library, Oklahoma State University. 1952.

Table I—Summary Data for Drying Experiments

				Air Entering Grain Bed			λ	Φ
Experiment No. F=Field, L=Lab.	**Bin or Container for Grain**	**Kind of Grain**	**Initial Grain Moisture Lb./Lb. Dry Matter**	**Wet Bulb Temp. F.**	**Dry Bulb Temp. F.**	**V Air Rate Cfm./Sq. Ft.**	**Bed Depth or Thickness Ft.**	**Duration of Expmt. Minutes**
3F	Round	Sorghum	0.1605	81	163	52	1.92	123
4F	Round	Sorghum	0.1608	72	124	48	1.67	151
5F	Round	Sorghum	0.1644	74	141	46	1.67	146
6F	Round	Sorghum	0.1494	66	109	46	1.81	133
7F	Column	Sorghum	0.3008	87	163	36	1.00	188
8F	Column	Sorghum	0.1834	87	163	36	1.00	188
9F	Column	Sorghum	0.1616	79	136	40	1.00	85
10F	Column	Sorghum	0.1189	79	136	40	1.00	85
11F	Column	Sorghum	0.1579	82	168	45	1.00	139
12F	Column	Sorghum	0.1019	81	155	45	1.00	139
17F	Column	Wheat	0.1527	89	194	40	1.00	119
18F	Column	Wheat	0.1344	89	194	40	1.00	119
19F	Column	Rye	0.2315	85	149	40	0.96	115
1L	Cylindrical Cup, 2.73 inch Diameter	Grain Sorghum (Redlan Kafir)	0.219	56	82	17	60 Minutes All Experiments	0.1135 Ft., Avg. for all experiments
2L			0.248	58	80	32		
3L			0.217	55	74	44		
4L			0.250	59	77	55		
5L			0.180	64	115	17		
6L			0.198	67	116	32		
7L			0.210	68	117	44		
8L			0.211	66	116	55		
9L			0.250	70	139	17		
10L			0.315	73	140	32		
11L			0.299	74	141	44		
12L			0.235	75	146	55		
13L			0.198	78	164	17		
14L			0.315	79	165	32		
15L			0.199	79	165	44		
16L			0.250	79	164	55		
17L			0.220	85	187	17		
18L			0.220	84	184	32		
19L			0.221	85	189	44		
20L			0.315	85	183	55		

Table I—(Contd.):Summary Data for Drying Experiments

Experiment No. F=Field L=Lab.	Pi TERMS (Dimensionless)				
	π_1 E_a x 10^{-3}	π_2 ΔM	π_3 $\Delta t/t_e$ x 10^{-2}	π_4 $\lambda/V\Phi$ x 10^{-4}	π_5 R/λ
3F	12.30	0.1401	11.88	2.997	1.28
4F	6.94	0.1058	7.97	2.300	1.47
5F	9.38	0.1224	10.26	2.482	1.47
6F	6.25	0.0968	6.67	2.957	1.36
7F	16.00	0.2526	12.21	1.478	1.87
8F	12.70	0.1352	13.97	1.478	1.87
9F	8.35	0.1090	8.17	2.941	1.87
10F	4.60	0.0663	7.49	2.941	1.87
11F	11.25	0.1370	12.27	1.599	1.87
12F	5.10	0.0815	7.97	1.599	1.87
17F	14.74	0.1323	14.47	2.101	1.87
18F	11.30	0.1140	13.55	2.101	1.87
19F	12.16	0.1789	10.08	2.087	1.87
1L	1.682	0.1507	4.339	1.113	0.501, All Experiments
2L	1.860	0.1750	3.892	0.592	
3L	0.892	0.1277	3.000	0.429	
4L	0.450	0.1535	3.354	0.344	
5L	1.928	0.1554	8.006	1.113	
6L	2.430	0.1542	7.470	0.592	
7L	1.705	0.1662	7.891	0.429	
8L	1.412	0.1757	8.252	0.344	
9L	5.430	0.2317	11.360	1.113	
10L	3.727	0.2946	11.007	0.592	
11L	3.085	0.2786	11.189	0.429	
12L	2.903	0.2146	11.394	0.344	
13L	6.470	0.1879	13.631	1.113	
14L	5.230	0.3049	13.769	0.592	
15L	2.430	0.1889	13.449	0.429	
16L	2.460	0.2399	13.470	0.344	
17L	10.040	0.2150	15.234	1.113	
18L	5.710	0.2150	15.071	0.592	
19L	3.910	0.2160	15.572	0.429	
20L	3.500	0.3100	15.251	0.344	

Table II—Effect of Chemical Powder Treatment on Grain Sorghum Moisture in Bins, 1951

Date Sampled	Gain Moisture, Percent			
	Control	Treatment 2	Treatment 3	Treatment 4
12 October	14.8	14.4	14.8	15.3
4 December	14.8	14.6	14.8	15.4
10 January	14.5	14.2	16.1	15.2
26 March	13.0	12.8	---	---

Table III—Effect of Chemical Powder Treatment on Grain Sorghum Germination in Bins, 1951

Date Sampled	Germination, Percent			
	Control	Treatment 2	Treatment 3	Treatment 4
12 October	22	21	22	24
4 December	63	74	59	37
10 January	70	82	20	26

Table IV—Effect of Chemical Powder Treatment on Temperatures in Binned Grain Sorghum, 1951

Date Sampled	Mean Temperatures, Degrees F			
	Control	Treatment 2	Treatment 3	Treatment 4
12 October	78	76	76	76
23 October	65	67	67	66
4 December	54	58	69	61
10 January	46	59	91	65
26 March	54	53	--	--
11 June	94	93	--	--

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