Relationship of final moisture content and temperature of wheat under artificial conditions of drying using forced draft and supplemental heat

by Arthur F Shaw

A THESIS Submitted to the Graduate Faculty in partial fulfillment of the requirements for the degree of Master of Science in Agronoagr
Montana State University

Abstract:
The rate of airflow-through clean grain at.- varying depths and at a nearly constant static pressure was studied, A uniform straight-line reduction was found to exist as the grain depth in the drying chamber during separate operations was increased by twice the previous amount. At a static pressure of 0,90 to 1.0 inch of water the maximum depth at which grain may effectively be dried is 4 feet.

In the ten individual experiments the actual time required for drying by forced draft varied with the grain depth, the initial moisture percentage of the grain, the temperature of the introduced air and the rate of air flow. Drying at the shallower depths and the higher heater temperatures naturally was most rapid, however, it may not necessarily be more economical due to increased cost of handling.

The setup was inadequate to determine a relationship between the final grain temperature and moisture percentage. The design of the experiment overlooked the necessity of having two lots of grain, when dried at equal depths and at a single heater temperature* at a nearly equal initial moisture percentage. Temperature and moisture percentage determinations should have been at a uniform time throughout each individual pair of comparisons. Further study on this particular relationship seems advisable.

The germination of the wheat was not affected by the applied heater temperature nor the time of exposure to the heat at any of the various depths, This would indicate that the 140°F heater temperature would be satisfactory for drying if variety, test weight or other conditions are not factors influencing germination.

The actual required drying time for a particular lot of wheat can be reduced from that given in the experiment, if mixing of the grain in the upper and lower levels is accomplished. This method would be especially designed for a portable-type drying unit.

RELATIONSHIP OF FINAL MOISTURE CONTENT AND TEMPERATURE OF WHEAT UNDER ARTIFICIAL CONDITIONS OF DRYING USING FORCED DRAFT AND SUPPLEMENTAL HEAT

by

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ABSTRACT

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INTRODUCTION

Cool, wet harvest conditions during recent years in Montana have emphasized the necessity of special techniques in the harvest and storing of grain crops. Wheat harvested on thousands of acres, in both the dryland and irrigated regions of the state in 1951, was unfit to enter commercial channels as a result of too high a moisture content during or following harvest. Consequently, this necessitated storing on the farm grain with a high moisture content which resulted in rapid deterioration of grain quality. Much of this grain had to be utilized or sold as livestock feed. In the irrigated valleys of western Montana many fields remained unharvested in the fall of 1951. All of this has resulted in a serious financial loss to farmers.

There are three principal factors responsible for the damage caused by moisture in the storage of small grains on the farm:

1. Climatic conditions during harvest frequently necessitates threshing of grain containing too much moisture for safe storage.
2. Storage facilities are not designed to provide adequate ventilation and, consequently, grain cannot dry out before going "out of condition".
3. Insufficient farm storage facilities, glutted country

elevators and grain terminals, and a lack of railroad cars during the peak of harvest necessitates the piling of grain on the ground for weeks before being moved into adequate storage or commercial channels.

Such losses as have occurred recently, create a demand for information on methods of correction. The introduction of artificial grain drying techniques offers the most satisfactory solution to the problem. However, numerous questions have been raised concerning their feasability for use on the farm. Modifications necessary so that present storage bins may be equipped with forced air drying equipment, size and type of heater and blower, operating temperatures, time requirements and cost per bushel for drying are all issues at stake.

Many of the above factors have been carefully studied by research personnel and additional literature is being published annually. Much of the essential information is now available on grain drying methods. This paper presents the results of a study conducted on the "final grain temperature-moisture" relationships at varying levels of grain in a bin using forced draft with air heated at 110° F and 140° F.

LITERATURE REVIEW

The problem of handling high-moisture grains in storage has faced farmers for generations. Over the years, different techniques have been offered or advocated to prevent spoilage or to reduce the moisture content of stored grains to a safe level. Of all methods, forced draft with or without heated air, has proven to be most successful. However, one cannot fully appreciate the necessity of "conditioning" grain without an understanding of the biological processes involved in its deterioration.

Respiratory activity is a normal function of "living" materials but its rate is governed by factors of environment. Bailey and Gurjar (2)[1/] define respiration, "...as the release of energy through the biochemical oxidation of organic compounds as accelerated by certain enzymes. Carbon dioxide and water are the characteristic chemical end products". It is this phenomenon which is in part responsible for the heat energy which is released in a mass of damp grain.

According to Milner (1), whenever the critical moisture content of a grain is exceeded a sharp increase in respiratory activity with a resultant heating tendency is noted. For cereal grains the critical moisture range is between 14 and 15 percent.

The germ or embryo, according to Bailey and Gurjar (2), is the center of greatest respiratory activity in the wheat kernel since it possesses a greater proportion of the enzymes than the endosperm or the remainder of the kernel structure. However, Leach (9) and Oxley (12)

1/ Figures in parentheses refer to "Literature Cited", page .

have presented evidence that the removal of the embryo from the kernel caused no appreciable reduction in the respiratory activity. The latter evidence emphasizes the fact that heating of grains in commercial or farm storage is the result of microflora growth rather than from embryonic activity.

Spontaneous heating of stored grain is largely the result of accumulating heat generated by respiratory activity of molds growing on the grain (10). Since grain is a poor conductor of heat (2) the reduction of temperature in critical areas is low. Certain mold spores germinate on or within the seed coat and mycelial development begins at a rather well-defined humidity level in equilibrium with the critical moisture content.

According to Milner (10) the heating of grains occurs in two stages. The initial stage of heating caused by fungi development under favorable atmospheric conditions, together with increased respiratory rate, proceeds until a temperature of 54° to 55° C (129° to 131° Fahrenheit) is reached within the grain. At this point heating slackens and respiration is inhibited. The fungi responsible for the heating are killed by their own action or the accumulated heat, which they produced. Then, under very high moisture conditions favorable for the growth of thermophilic bacteria, the initial stage of heating may reach 68° to 70° C (154° to 158° F).

The second stage of heating which produces high levels of heat and carbon dioxide production, is the result of chemical oxidation. This latter stage is non-biological in nature.

James and Lejeune (7) obtained evidence, in their study of microflora responsible for the heating of grain, that the mesophilic species of bacteria are the ones primarily associated with heating and bin-burning of damp grain in storage. The thermophilic species are probably the result rather than the cause of higher temperatures in isolated pockets in a mass of grain since most of the heat has been dissipated under natural storage conditions.

A lowering of the vitality of viability of seed which has undergone self-heating in storage has been shown to result according to information presented by Bailey(1).

Other factors associated with moisture which may influence the respiratory activity of grains (2) are the density of the wheat kernel, the period of dampness of the grain, frost damage and climatic conditions.

It is this recognition of the role of fungi in the deterioration of damp grain that has stimulated the possible use of chemicals as a preservative treatment. However, Geddes (4) states that a large number of compounds have been investigated which were claimed to prevent deterioration of grain. Although several chemicals such as carbon tetrachloride inhibited mold growth and heating in grain, no chemical has appeared that can be applied in actual practice.

Previously it was believed that grain could be safely stored for extended periods if the moisture content did not exceed 14 percent. However, Olson, et al.(11) state that recent studies have shown that a damage known as "sick" wheat may result whenever the moisture content is in excess of 12 percent. This condition generally appears following the normal "dormant" period (30 to 45 days after harvest) and whenever atmospheric conditions are favorable for development.

Storage of high-moisture grain in the colder climates is subject to a condition known as "moisture migration" (3). Grain stored in bulk cools slowly, and early in the winter the grain in the center is warm, while that on the sides and surface is cold. A gradual upward movement of moist air occurs within the bulk as a result of the temperature differential. The circulation of air is downward in the cold grain near the wall. Consequently, as the warm moist air moves upward and strikes the colder grain a part of the moisture is condensed out and is absorbed by the colder grain. The air movement is slow and the amount of moisture condensed out is small in any one day, but as this process continues over an extended winter period, the accumulation of moisture in the surface and walls may be sufficient to cause damage to the grain.

Where grain of high-moisture content is harvested and stored during adverse weather conditions some means of preventing heating are necessary. Since chemical treatments (4) are ruled out as a satisfactory prevention at the present time, ventilation must be considered. Three individual types of systems are used with their success dependent upon the local conditions under which each is employed.

Natural ventilation (8) (14) is limited in its area of adaptation. Efficiency of this method being dependent upon relative humidity of the atmosphere, volume of grain to be dried, number and types of ventilators employed and the general cleanliness of the grain.

Ventilation, with forced unheated air, has been described by agricultural engineers and others (3, 5, 6, 8, 13, 14). Shedd and Cotton (14) state that a grain depth of from 3 to 6 feet is the most economical range for drying by this method. Kirk, et al. (8) state that the most efficient use of power is obtained if the grain depth is not in excess of 4 feet. The shallower the depth, the quicker and more effective will be the drying operation.

No specific requirements can be stated as to the rate of air flow through a given volume of grain. Authors differ in their recommended rates of air flow at the present time. Fenton, et al. (3) state that the air volume should be from 2 to 4 c.f.m. (cubic feet per minute) per bushel of grain when drying with unheated air, while Holman (5) recommends an air volume of 3 to 15 c.f.m.; best drying results being obtained when the atmospheric temperature is above 50° F and the relative humidity well below 50 percent. Olson, et al. (11) figure the minimum required volume by allowing an air flow of 1 c.f.m. for each square foot of bin area and for each foot of depth of clean grain, when using either heated or unheated air.

The latter recommendation appears to be a satisfactory method of estimating the minimum air volume. With this information at hand, it is possible to more accurately determine the type and capacity of a fan that will be required for forced air drying operations under any particular situation. To produce the required air flow, a fan will have to operate against a certain static pressure (back pressure). In forcing a specific volume of air through grain, the static pressure increases as the grain depth is increased.

According to Shedd and Cotton (14) it is uneconomical to force large volumes of air through deep layers of grain because of the excessive power requirement to operate against a static pressure above 2 to 3 inches of water.

The static pressure is expressed in terms of the height of the column of water which it can support. It is usually measured by inserting a manometer tube connection in a small hole in the wall of the duct through which the air is flowing.

Table I (Appendix) shows static pressures, which might be expected for different clean grains at varying depths (5). Pressures will vary under bin conditions as the percentage of foreign material--cracked grain, green weeds and seeds, chaff, etc.--increases. Such materials may increase minimum static pressure requirements to as much as twice that shown.

The efficiency of forced ventilation with unheated air, like drying by natural ventilation, is dependent upon the conditions of relative humidity and atmospheric temperature. According to Shedd and Cotton (14) "Heating grain can be cooled to within a few degrees of atmospheric temperature by about 6 hours of power ventilation at any time, summer or winter, using air flow of 3 c.f.m. per bushel. Drying will be very slow in winter or during periods of high humidity in the summer. In warm, dry summer weather, grain moisture content sometimes may be reduced 2 percent in 24 to 48 hours of operation, but usually a longer period will be necessary."

"Drying is more rapid during the day than at night. The fan may well be started at 9 or 10 o'clock in the forenoon on clear days and operated until 7 to 9 o'clock in the evening."

Forced ventilation with heated air has the advantage that rapid drying can be accomplished at any season of the year, regardless of weather conditions (3) (14).

There are two types of heaters designed for farm type driers(5); the direct and the indirect. With the direct type drier, the burnt gases pass directly into the circulating air stream and through the drying grain. Approximately 90 to 95 percent of the heat released by the burning fuel may pass into the air stream and through the drying grain. Although this system is of highest efficiency, design of the system presents somewhat of a fire hazard and the gases may affect some crops if the burner is out of adjustment.

The indirect type of heater is designed so that the burnt gases pass out through the stack (5). Thermal efficiency of this type is reduced but there is a greater margin of safety, both from a fire hazard and crop injury standpoint.

The heaters are usually of the oil burning type or bottled or natural gas.

Temperatures for drying seed grain should be limited to 110° F, according to Shedd and Cotton (14) and Holman (5). For market wheat, Holman (5) and Kirk, et al. (8) recommend a maximum temperature of 180° F.

According to Shedd and Cotton (14), economy in the drying operation is not considered to be any more efficient at high than at low temperatures. Kirk, et al. (8) point out that rapid drying by high temperatures may result in overdrying and high grain temperatures in the heating section with a consequent damage to baking quality. They also say that the cooling effect of evaporation is reduced, as the grain becomes drier with a resulting increase in grain temperature. The relation of final grain temperature to moisture and baking quality is best illustrated in Table II, (Appendix).

MATERIALS AND METHODS

Wasatch Winter Wheat, with a germination of 95 percent, containing 10 percent moisture and having a test weight of 62.5 pounds per bushel, was used for this experiment. The grain was cleaned prior to use and contained only a very small amount of inert material, mainly chaff.

The moisture content of the grain was increased by adding water and thoroughly mixing with a barrel-type churn. Amount of water added varied from approximately one-half to one gallon per bushel, depending upon the desired moisture content to be obtained within a range of 13 to 19 percent. After setting 24 hours in a closed metal container, the grain was remixed and allowed to remain 24 to 48 hours before beginning of drying operation. This time seemed sufficient to provide uniform absorption of moisture by the grain.

The drying chamber was constructed so as to provide three individual vertical drying columns. This made it possible to run triplicate samples at one time with grain depths ranging from one to six feet. The maximum depth at which grain was dried in this study was four feet.

The chamber was constructed of two sections of 1/4-inch plywood 21 x 84 inches for the sides. Two, 1 x 6-inch boards, 84 inches long were used for the ends and two, 1 x 6, 74 inches long, were used for the two inner partitions. Wire screen, 14 mesh per inch, was used as a perforated floor, which was set in 10 inches above the bottom of the vertical chamber. The air chamber in the bottom was 5 3/4 inches wide, 9 inches deep and 19 inches in length.

To eliminate absorption of moisture by the wood two coats of shellac were applied to the inner walls. With a high ratio of wall surface in accordance with the grain volume it was necessary to glue wheat to the walls to increase resistance and prevent excess air loss. Shellacking and gluing of grain was done prior to assembly of materials.

Insulating board was used to cover the outside of the drying chamber to eliminate excess heat loss.

A drying oven containing a thermostatically controlled electrical heating element and an 8-inch squirrel-cage fan was used to supply heat and forced draft. Heater temperatures maintained for the individual operations were 110° F for the 1-and 2-foot depths and 140° F for 1-, 2-, and 4-foot depths. In two cases at the 2-foot level no heat was used, except that of room temperature which ranged between 68° and 80° F.

Two to five 110° C thermometers were installed in one side of the chamber in each of the 3 vertical sections and used to measure grain temperatures at the 3-, 9-, 21-, 33- and 45-inch grain depths. The number of thermometers being used was dependent upon the depth of grain being dried with each individual operation. One thermometer was installed in the air duct to check the uniformity of heater temperature.

Periodic temperature readings were made during each operation. The frequency of readings being dependent upon the heater temperature and the grain depth--the higher the temperature or the shallower the depth of grain the more frequent were the readings. An average of the three readings at each level was taken for each analysis.

A manometer was installed in the air duct to record static pressure. With no rheostat control on the fan its speed could not be regulated and a variability in pressures resulted. Air volumes ranged from an average of 3 c.f.m. per bushel at the 4-foot depth to a high of 10 c.f.m. at the 1-foot depth.

An anemometer was used to measure air velocity at the exit, in order that the volume or rate of air flow determination could be made. Anemometer readings were made approximately 30 minutes after the beginning of each drying operation.

A Tag-Heppenstall electrical conductivity moisture meter was used to obtain moisture percentages at periodic intervals during each drying operation. Samples of grain were obtained in each vertical section at the 3-, 9-, 21-, 33- and 45-inch depths, depending on the grain depth with each operation. To obtain samples corks were removed from 11/16-inch holes drilled in the side of the chamber opposite the thermometers at the respective levels and a probe inserted to draw the grain. The probe had a uniform diameter of approximately 5/8 of an inch and a length of six inches. Samples were kept in a closed container until moisture determinations were made.

It was necessary to alter the procedure of sampling as the study progressed as the total volume of grain in the drier during any one operation was low--slightly less than 1/3 of a bushel in each vertical section at the 2-foot level. A one-half pound grain sample was necessary to obtain an accurate moisture determination at each level. With a rapid reduction of grain volume in each section as a result of drying and sampling, the frequency of sampling for moisture was reduced and fewer samples were taken from the lower levels when the moisture was below 12 percent. In the later operations it was deemed advisable to draw samples from one vertical section at each interval.

To obtain the effect of temperature on germination at the various levels after drying, samples were taken and a germination test was made by the Montana Grain Inspection Laboratory. Where no heat was used in drying a germination test was not made.

A 1-3/4 x 4-inch slot was cut in each vertical section, immediately above the wire screen floor, to draw out the dried grain. A block was fitted to each hole and cotton batten used to seal up the edges to prevent excessive air loss.

The actual experimental grain drying study was conducted in the agricultural engineering shop as outdoor temperatures were below freezing when the project was started. Drying operations were conducted during March and April of 1952.

Initial moisture percentage of grain, grain depth in drying chamber, static pressure and heater temperature used in each drying experiment were as follows:

Number	Initial Moisture Percent	Grain Depth	Static Pressure*	Heater Temperature (°F)	Relative humidity (% range)
1	15	2 ft	.75	110	18 - 30
2	16.8	2 ft	.75	110	18 - 30
3	19.06	2 ft	.75	140	18 - 30
4	15.90	2 ft	.90	140	18 - 30
5	16.80	4 ft	.90	140	18 - 30
6	15.45	4 ft	.90	140	18 - 30
7	12.90	2 ft	1.00	68 - 75 **	18 - 30
8	16.10	2 ft	1.00	68 - 75 **	18 - 30
9	16.90	1 ft	.90	110	18 - 30
10	17.0	1 ft	.90	140	18 - 30

* Expressed in inches of water.

** Room temperature range.

EXPERIMENTAL RESULTS

Table III contains a summary of data secured from the individual experiments which were selected on which to base the conclusions of this study.

Figure 1 shows the relationship of the average rate of air flow to depth of grain in each of the 3 vertical sections of the drying chamber in 6 individual operations.

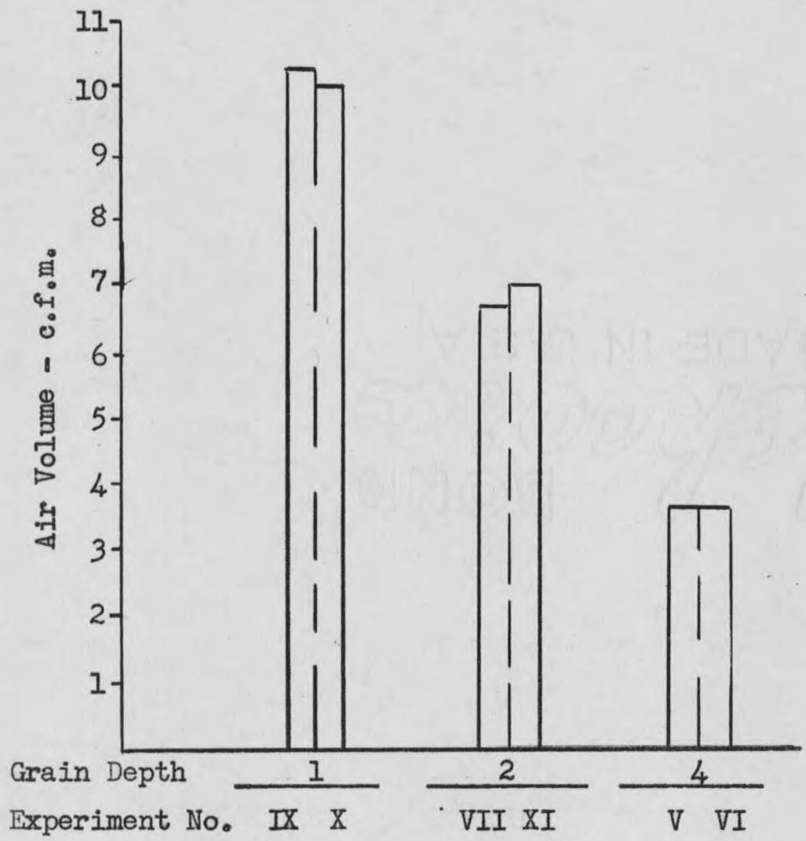

Figure 1. Relationship of the average rate of air flow to grain depth.

In experiments V, VI, IX and X the static pressure was 0.90 inches of water at the 1 and 4-foot depths. In experiments number VII and XI the static pressure was 1.0 inch of water with the grain depth at 2