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THE EFFECT OF MOISTURE ON THE THERMAL PROPERTIES OF WHEAT[1]

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ABSTRACT

The thermal properties of wheat containing various amounts of moisture, from 1.4% to 15.9% of the dry weight, were determined by placing the wheat in a cylindrical apparatus with the heating element stretched along the central axis and by measuring the radial temperatures. Three general conclusions can be drawn from the results of the experiments. The properties of dry wheat are: thermal conductivity 0.00030 cal. per sq. cm. per sec. per °C./cm.; thermal diffusivity 0.0012 sq. cm. per sec., specific heat 0.31 cal. per gm. per °C.; all three properties vary slightly depending on the kind of wheat. An increase in the moisture content of the wheat causes a linear increase in the thermal conductivity, a slight decrease in the thermal diffusivity and an increase in the specific heat. The migration of moisture through the wheat under the influence of a temperature gradient causes the thermal properties to vary at different locations in the wheat, depending on the moisture content.

INTRODUCTION

In a paper published recently Babbitt (2) measured the thermal properties of wheat by means of a cylindrical apparatus with an axial heating element. The wheat used in his experiment contained 9.2% by weight of moisture. To derive the specific heat of the wheat alone, it was necessary to allow for the heat capacity of the adsorbed water. In his paper Babbitt assumes the adsorbed water contributes to the specific heat as if it were liquid water. This may not be so, since the adsorbed molecules of water do not have the same freedom of movement as liquid molecules. To dispel this uncertainty it seemed worthwhile to make a series of measurements which would give some measure of the specific heat of the adsorbed water itself.

Thus it was decided to measure, following the procedure used by Babbitt, the thermal properties of a sample of wheat at a number of different moisture contents, beginning with dry wheat and increasing the moisture content for each consecutive measurement. However, owing to the temperature gradient, the moisture in the wheat migrated from points of high to points of low temperature and the latent heat exchanges involved upset the measurement of the thermal properties. It was known that there is a tendency for moisture to migrate when there is a temperature gradient in wheat, but previous measurements (Anderson, Babbitt, and Meredith (1) and Babbitt (3)) had indicated that this migration took place very slowly and it seemed unlikely that it should nullify our measurements. It is evident from the results following that this migration is sufficient, even at low moisture contents, to affect the measurements and that it is impossible to obtain from them an estimate of the contribution to the heat capacity made by the adsorbed water.

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However these measurements do give valuable information on the migration of water vapor through granular beds under a temperature gradient and show how this migration affects the thermal properties of the material. The effect of migration of moisture under temperature gradients is important in thermal insulating materials, and in soils. Therefore it seemed worthwhile to report our results and conclusions on the behavior of water vapor in wheat under the influence of a temperature gradient.

APPARATUS AND METHODS

The apparatus for measuring the thermal properties of wheat was the one used and described by Babbitt (2). Figs. 1, A and B are photographs of a second apparatus built and used for some of the experiments. The wheat container was a galvanized-iron cylinder 1 ft. in diameter and 2 ft. in length, closed with bakelite ends. The heating element was a single strand of 26 gauge Chromel A wire stretched along the axis of the cylinder. The 12 thermocouples were placed along a diameter halfway down the cylinder at radii of 0.5, 1.5, 2.5, 3.5, 4.5, and 5.5 in. The cylinder was placed in an insulated box fitted with a fan for circulating the air and with a heater and thermostat for controlling the temperature of the air surrounding the cylinder. Fig. 1, A and B, also show the thermocouple switch, ice-bath reference junction, and the control panel for the heating circuit.

Two lots of wheat were used in the tests. Both lots were No. 1 Northern Manitoba grade, but one lot was obtained in 1949 and the other in 1950. The first lot was dried in a vacuum oven at 105° C. to a moisture content of 1.4% dry weight before test. Before each succeeding test, water was added to the wheat and the whole was mixed well and allowed to stand for a couple of days until adsorption of the water was complete. By this method the moisture content of the wheat was increased by steps to 7.9%. The second lot of wheat contained 15.9% by weight of moisture when first used. It was tested in this state and then before each succeeding test it was partially dried in an oven, its moisture content being decreased by steps to 5.6%.

The moisture content of the wheat was determined by an oven method. Five samples of wheat were taken from the cylinder while it was being filled. These were weighed, then dried in a vacuum oven at 105° C. to constant weight (i.e. for a week or 10 days). The moisture content was calculated for each sample from its weight before and after drying. The average of these five values was used as the moisture content of the wheat being tested.

After the temperatures of the wheat had come to equilibrium with the air in the box surrounding the cylinder, the heating element was switched on. The temperatures of the wheat at the 12 thermocouples were taken at intervals until a state of temperature equilibrium was reached. The average temperatures at the six radii were calculated and then reduced by subtracting from them the initial temperature of the wheat. This temperature, also called the zero temperature, was the same as that of the air surrounding the cylinder, and was approximately 90° F. for some of the tests and approximately 97° F.

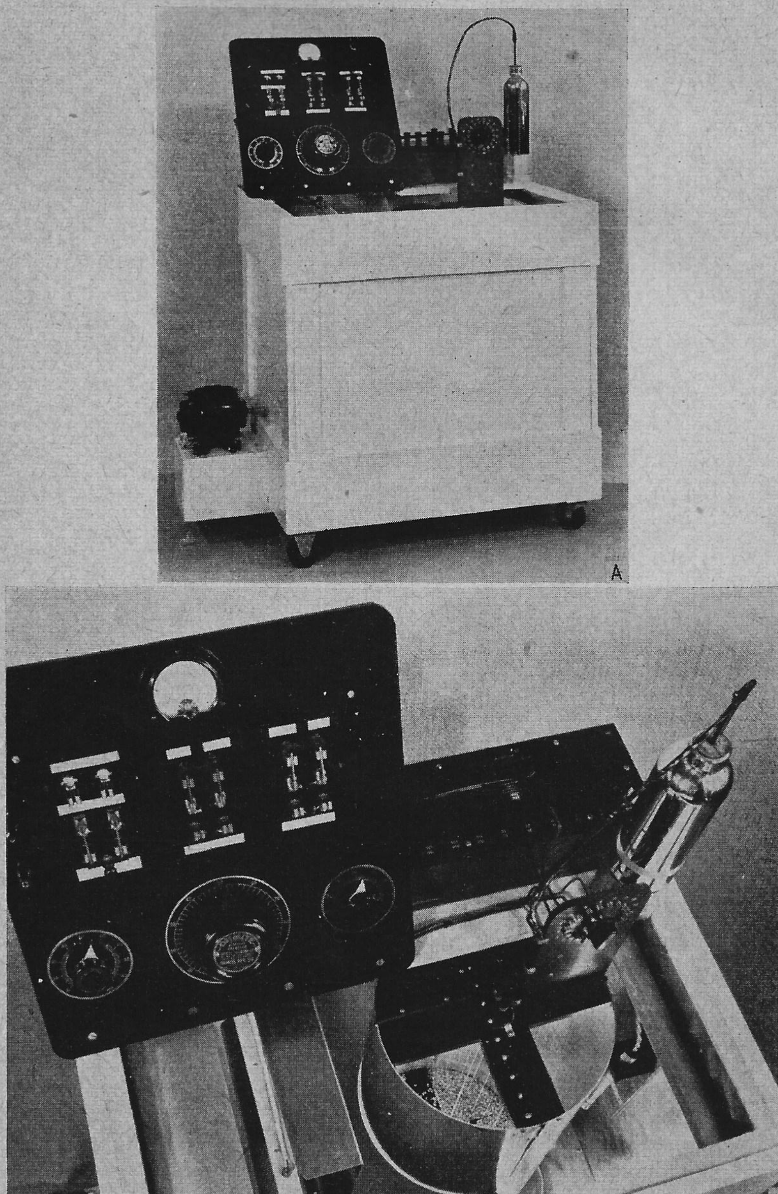

FIG. 1*A*. A side view of the apparatus showing the insulated box, the motor for the fan, the thermocouple switch on top of the cylinder, the control panel for the heating circuit, and the thermos flask containing the ice bath and reference junction.

B. A top view of the apparatus showing the heater at one end of the insulated box, the thermostat at the other end, and the baffles for controlling the air flow, as well as the cylinder containing the heating element, thermocouples, and a small amount of wheat. The control panel, thermocouple switch, and thermos flask are also shown.

for the others. The reduced temperatures at each radius were plotted against the time of heating, and these curves, which give the rate of change in temperature, were used in calculating the thermal diffusivity of the wheat. The final reduced temperature distribution at the six radii was used in calculating the thermal conductivity of the wheat.

THEORETICAL CONSIDERATIONS

The Fourier heat equation for the temperature at any point in a right circular cylinder whose initial temperature is a function of the radius only is

[1] $$\frac{dv}{dt} = \frac{k}{c\rho}\left(\frac{d^2v}{dr^2} + \frac{1}{r}\frac{dv}{dr}\right)$$

where v is the temperature, t is the time, r is the radius, k is the thermal conductivity, c is the specific heat, and ρ is the density. According to Carslaw (4), in a circular cylinder where the initial temperature is constant, taken as zero, and heat is supplied at a constant rate along the axis of the cylinder, for steady state conditions the equation for heat flow is

[2] $$V_r = \frac{I^2R}{2\pi k}\log_e a - \frac{I^2R}{2\pi k}\log_e r$$

where V_r is the temperature at radius r, I is the current, and R is the resistance per unit length of the heating element, a is the radius corresponding to boundary temperature conditions, and k is the thermal conductivity. To determine the thermal conductivity k, equation [2] is compared with

[3] $$V = B + C\log_e r$$

obtained from the final temperature distribution of the experiment.

$$\text{Thus}\quad B = \frac{I^2R}{2\pi k}\log_e a$$

$$\text{and}\quad C = -\frac{I^2R}{2\pi k}$$

and since B, C, and a can be obtained from the slope and intercepts of the equilibrium curve, k is calculated from

[4] $$\frac{I^2R}{2\pi B}\log_e a$$

or

[5] $$-\frac{I^2R}{2\pi C}$$

The thermal diffusivity is defined as the constant in the Fourier equation [1] i.e.

[6] $$\kappa = \frac{k}{c\rho}$$

Carslaw (4) gives the following solution of the Fourier equation when the initial temperature is a function of the radius only and when the surface of the cylinder is kept at zero temperature

$$[7] \qquad v = \sum_{n=1}^{\infty} A_n \, J_0(\alpha_n r) \, e^{-\kappa \alpha_n^2 t}$$

where v is the temperature at time t, A_n is a constant determined from the initial temperature distribution, $J_0(\alpha_n r)$ is Bessel function of order zero of the first kind, and α_n are the roots of $J_0(\alpha_a) = 0$, κ is the thermal diffusivity. From this Babbitt (2) has derived the equation for an experiment in which the surface of the cylinder is maintained at the initial or zero temperature of the whole mass and the final temperature is a function of the radius given by

$$V = B + C \log_e r$$

as

$$[8] \qquad v = V_r - \sum_{n=1}^{\infty} A_n \, J_0(\alpha_n r) \, e^{-\kappa \alpha_n^2 t}$$

where

$$[9] \qquad A_n = \frac{B \dfrac{a}{\alpha_n} J_1(\alpha_n a) + C \left[\dfrac{a}{\alpha_n} J_1(\alpha_n a) \log_e a - \dfrac{1}{\alpha_n^2} \right]}{a^2/2 \; J_1(\alpha_n a)^2}$$

and V_r is the final temperature. To calculate κ one experimental point, chosen so that only one term of equation [8] is significant, is substituted into equation [8] after B, C, a, α_n and A_n have been calculated.

After the values of thermal conductivity k and thermal diffusivity κ have been calculated, the specific heat is calculated using equation [6].

This theory deals with the conduction of heat in a cylinder when the initial, final, and boundary conditions are given, but does not indicate the effects of temperature changes from other sources. It has been noted that during the time of an experiment moisture migrates through the wheat and this affects the thermal properties. This movement of moisture under the influence of temperature gradients has been described by Oxley (5) and by Anderson, Babbitt, and Meredith (1). If there were no movement of moisture or change in the thermal properties during an experiment equilibrium should be reached in 80 to 100 hr. For this reason it was decided to calculate the thermal properties from the temperatures of the wheat after 100 hr. of heating and to compare these values with those determined from the final temperatures. While the former do not represent the true thermal properties at the initial moisture content because of the moisture migration, they should be a better approximation to them than those obtained from the final temperatures.

EXPERIMENTAL RESULTS

The thermal conductivity was calculated from the slope of the curve obtained when the final temperatures, given in Table I, were plotted against the logarithm of the radius. These equilibrium curves were drawn for each test and two of them, namely those for wheat containing 2.2% and 15.9%

TABLE I

FINAL EQUILIBRIUM TEMPERATURE DISTRIBUTION OF WHEAT

Moisture content, % dry weight	Radius in inches					
	0.5	1.5	2.5	3.5	4.5	5.5
	Final temperatures in °F.					
1.4	48.0	27.6	17.9	11.5	6.6	2.8
2.2	47.8	27.3	17.6	11.2	6.5	2.7
2.6	46.1	26.3	16.8	10.8	6.4	2.8
3.0	47.4	26.8	17.3	11.0	6.4	2.7
3.6	46.5	26.4	16.8	10.6	6.1	2.6
4.8	46.1	26.1	16.9	10.8	6.3	2.7
5.6	42.9	24.4	15.7	10.2	5.9	2.6
6.9	45.2	25.4	16.4	10.5	6.2	2.7
7.4	43.5	24.7	15.9	10.3	6.1	2.6
7.4	43.2	24.1	15.4	9.9	5.6	2.3
7.9	44.7	25.2	16.3	10.5	6.2	2.7
8.3	41.8	23.3	14.9	9.5	5.5	2.4
10.8	41.8	23.2	14.9	9.6	5.5	2.3
12.2	41.8	23.5	15.2	9.8	5.7	2.4
15.9	42.0	23.5	15.2	9.7	5.7	2.6

moisture, are shown in Fig. 2. The equilibrium curve for wheat containing 2.2% moisture is a straight line of the form $V = B + C \log_e r$ where V is the final temperature at radius r and B and C are constants, whereas the equilibrium curve for wheat containing 15.9% moisture is not a straight line; its slope gradually increases at the smaller radii. This deviation from a straight line was noted in the equilibrium curves for wheat containing more than 3.5% moisture, and is illustrated in Fig. 3 where the slopes of the equilibrium curves have been plotted against the radius for five of the tests. Fig. 3 shows that,

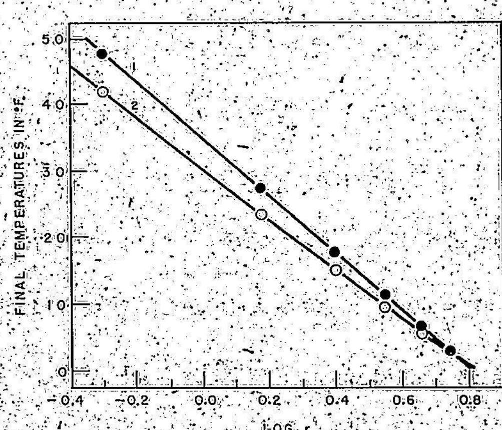

FIG. 2. Final temperature distribution of wheat containing (1) 2.2% and (2) 15.9% by weight of moisture.

Carslaw (4) gives the following solution of the Fourier equation when the initial temperature is a function of the radius only and when the surface of the cylinder is kept at zero temperature

$$[7] \qquad v = \sum_{n=1}^{\infty} A_n J_0(\alpha_n r) e^{-\kappa \alpha_n^2 t}$$

where v is the temperature at time t, A_n is a constant determined from the initial temperature distribution, $J_0(\alpha_n r)$ is Bessel function of order zero of the first kind, and α_n are the roots of $J_0(\alpha_a) = 0$, κ is the thermal diffusivity. From this Babbitt (2) has derived the equation for an experiment in which the surface of the cylinder is maintained at the initial or zero temperature of the whole mass and the final temperature is a function of the radius given by

$$V = B + C \log_e r$$

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$$[8] \qquad v = V_r - \sum_{n=1}^{\infty} A_n J_0(\alpha_n r) e^{-\kappa \alpha_n^2 t}$$

where

$$[9] \qquad A_n = \frac{B\frac{a}{\alpha_n} J_1(\alpha_n a) + C\left[\frac{a}{\alpha_n} J_1(\alpha_n a) \log_e a - \frac{1}{\alpha_n^2}\right]}{a^2/2 \; J_1(\alpha_n a)^2}$$

and V_r is the final temperature. To calculate κ one experimental point, chosen so that only one term of equation [8] is significant, is substituted into equation [8] after B, C, a, α_n and A_n have been calculated.

After the values of thermal conductivity k and thermal diffusivity κ have been calculated, the specific heat is calculated using equation [6].

This theory deals with the conduction of heat in a cylinder when the initial, final, and boundary conditions are given, but does not indicate the effects of temperature changes from other sources. It has been noted that during the time of an experiment moisture migrates through the wheat and this affects the thermal properties. This movement of moisture under the influence of temperature gradients has been described by Oxley (5) and by Anderson, Babbitt, and Meredith (1). If there were no movement of moisture or change in the thermal properties during an experiment equilibrium should be reached in 80 to 100 hr. For this reason it was decided to calculate the thermal properties from the temperatures of the wheat after 100 hr. of heating and to compare these values with those determined from the final temperatures. While the former do not represent the true thermal properties at the initial moisture content because of the moisture migration, they should be a better approximation to them than those obtained from the final temperatures.

EXPERIMENTAL RESULTS

The thermal conductivity was calculated from the slope of the curve obtained when the final temperatures, given in Table I, were plotted against the logarithm of the radius. These equilibrium curves were drawn for each test and two of them, namely those for wheat containing 2.2% and 15.9%

as the moisture content of the wheat is increased, the amount of deviation from the straight line becomes greater and the deviation begins at larger radii i.e. farther from the central heating axis. There is a tendency for the slopes at all moisture contents to approach that at moisture content of 2.2% as radius becomes smaller. Since the thermal conductivity is inversely proportional to the slope of the equilibrium curve, the graphs of Fig. 3 indicate

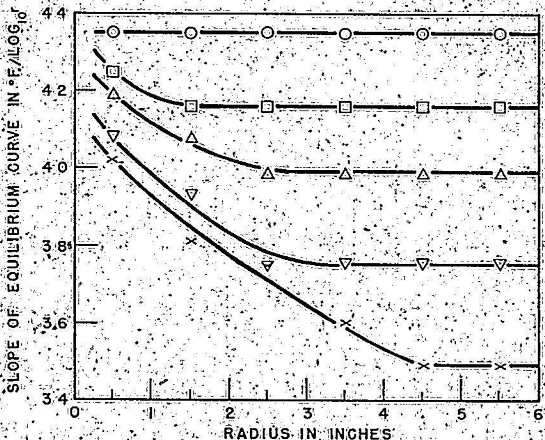

FIG. 3. The slope of the equilibrium curve plotted against the radius for wheat containing 2.2%, 4.8%, 6.9%, 7.4%, and 15.9% of moisture respectively.

that the thermal conductivity of wheat containing more than 3.5% moisture must be less near the central heating axis than it is near the outside of the cylinder. The difference between the values of conductivity at these two positions is greater at higher moisture contents of the wheat. As there may have been a transfer of moisture through the wheat during the experiments owing to the temperature gradient, it was decided to measure the moisture content of the wheat near the center and also near the edge of the cylinder at the end of those experiments in which the initial moisture content was more than 4%. Table II contains the results of these measurements and shows very clearly that a considerable amount of moisture has been transferred during the experiments.

TABLE II

CHANGE IN MOISTURE CONTENT OF WHEAT DURING TEST, % DRY WEIGHT

Moisture content before test	Moisture content after test	
	Near axis	Near the outside of the cylinder
4.8	2.9	4.9
5.6	3.7	5.9
7.4	4.2	7.9
7.9	5.1	8.6
8.3	5.0	8.7
10.8	5.8	11.8
12.2	5.7	13.2
15.9	8.1	17.2

CALCULATION OF CONDUCTIVITY, DIFFUSIVITY, AND SPECIFIC HEAT

The final temperature distribution curves similar to those in Fig. 2 were drawn for each test on the wheat and from them the values of B, C, and a were calculated. In the tests on wheat containing appreciable amounts of moisture, where the equilibrium curves are not straight lines, the straight portions drawn through the points corresponding to the larger radii were used. The thermal conductivity for each test was then calculated from equation [4] or [5].

For reasons discussed above, these calculations were repeated using the temperatures of the wheat after 100 hr. of heating instead of the final temperatures in drawing the equilibrium curves. These latter values of conductivity are called the k' values and are given in Table III as well as the k values. In Fig. 4 the k' values of thermal conductivity are plotted against the moisture content of the wheat. Table III and Fig. 4 indicate that the thermal conductivity of dry wheat is approximately 0.00030 cal. per sq. cm. per sec. per °C./cm. and varies slightly for the two wheats measured and that it increases with moisture content at a rate of approximately 0.000007 cal. per sq. cm. per sec. per °C./cm. for every 1% dry weight increase in moisture content. There is a considerable difference between the k values and k' values of the thermal conductivity of wheat when it contains more than 4.8% of the dry weight of moisture.

TABLE III

THERMAL CONDUCTIVITY RESULTS FOR WHEAT AT VARIOUS MOISTURE CONTENTS

Wheat lot No.	Moisture content, % dry weight	Thermal conductivity k, cal./sq. cm./sec./$\frac{°C.}{cm.}$	Thermal conductivity k', cal./sq. cm./sec./$\frac{°C.}{cm.}$
1	1.4	.000313	.000312
1	2.2	.000316	.000324
1	2.6	.000332	.000329
1	3.0	.000324	.000329
1	3.6	.000335	.000332
1	4.8	.000328	.000336
2	5.6	.000325	.000328
1	6.9	.000341	.000355
1	7.4	.000352	.000361
2	7.4	.000331	.000345
1	7.9	.000342	.000364
2	8.3	.000347	.000358
2	10.8	.000351	.000364
2	12.2	.000343	.000379
2	15.9	.000367	.000400

For the calculation of thermal diffusivity κ, the values of A_1, A_2, and A_3 were first calculated using equation [9]. Then one point was chosen from the experimental time–temperature curves where t was sufficiently large that only one term of equation [8] was significant, and these values for v and t were substituted into equation [8]

$$v = V_r - \sum_{n=1}^{\infty} A_n \, J_0(\alpha_n r) \, e^{-\alpha_n^2 \kappa t}$$

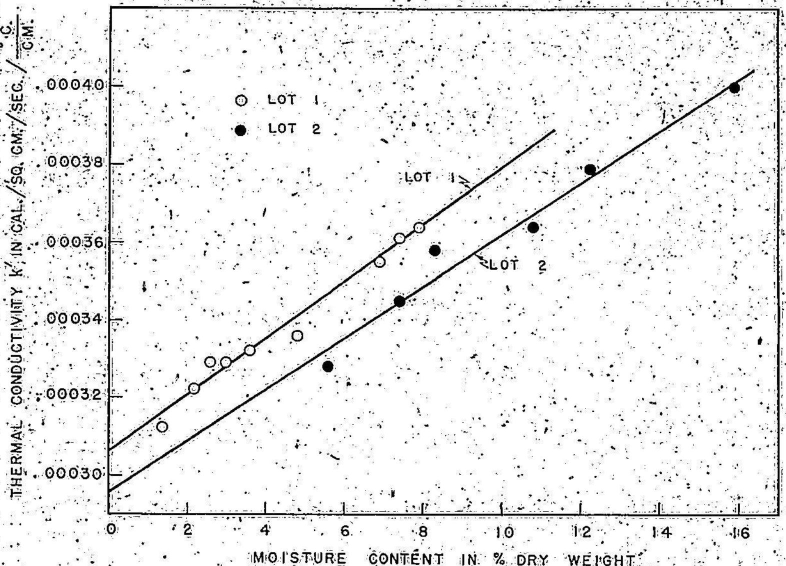

FIG. 4. Variation of the thermal conductivity k' with the moisture content of the wheat.

The results of these calculations of the thermal diffusivity κ for the experiments are given in Table IV. The thermal diffusivity was also calculated using the temperatures after 100 hr. of heating in place of the final temperatures V_r,

TABLE IV

THERMAL DIFFUSIVITY RESULTS OF WHEAT AT VARIOUS MOISTURE CONTENTS

Wheat lot No.	Moisture content, % dry weight	Thermal diffusivity κ, sq. cm. per sec.	Thermal diffusivity κ', sq. cm. per sec.
1	1.4	.00113	.00115
1	2.2	.00105	.00113
1	2.6	.00114	.00116
1	3.0	.00113	.00114
1	3.6	.00107	.00110
1	4.8	.00094	.00105
2	5.6	.00109	.00111
1	6.9	.00101	.00111
1	7.4	.00094	.00107
2	7.4	.00096	.00106
1	7.9	.00089	.00105
2	8.3	.00095	.00105
2	10.8	.00089	.00102
2	12.2	.00080	.00105
2	15.9	.00072	.00106

and these results called κ' are also given in Table IV. The following conclusions were drawn:

1. The thermal diffusivity of dry wheat is approximately 0.00117 sq. cm. per sec. and it decreases as the moisture content is increased.

2. The rate of decrease of the thermal diffusivity is greater for the κ values than for the κ' values.

The specific heat was calculated from the corresponding values of k and κ and the density ρ using equation [6].

$$c = \frac{k}{\kappa\rho}$$

The density ρ was the bulk density of the wheat and was measured for each experiment. In Table V the values of the density as well as the calculated

TABLE V

CALCULATED VALUES OF SPECIFIC HEAT OF WHEAT AT VARIOUS MOISTURE CONTENTS

Wheat lot No.	Moisture content, % dry weight	Moisture content, % wet weight	Density, gm. per cc.	Specific heat, $c^1 = \frac{k'}{\kappa'\rho}$
1	1.4	1.4	0.842	0.319
1	2.2	2.2	0.846	0.339
1	2.6	2.5	0.825	0.344
1	3.0	2.9	0.822	0.351
1	3.6	3.5	0.853	0.354
1	4.8	4.5	0.859	0.373
2	5.6	5.3	0.828	0.357
1	6.9	6.4	0.858	0.373
1	7.4	6.9	0.881	0.385
2	7.4	6.9	0.831	0.392
1	7.9	7.4	0.860	0.403
2	8.3	7.7	0.828	0.412
2	10.8	9.7	0.831	0.429
2	12.2	10.9	0.821	0.440
2	15.9	13.7	0.821	0.460

values of specific heat are given for the various moisture contents of the wheat. The values of specific heat were calculated from the k' and κ' values of conductivity and diffusivity as these values were not affected by the migration of moisture to the same extent as the k and κ values. At very low moisture contents, there was no significant movement of moisture so the values for specific heat of wheat containing 1.4% and 2.2% moisture are presumably correct. By extrapolation from these values, the specific heat of dry wheat is found to be 0.314 and 0.310 for the two lots of wheat.

Pfalzner (6) has determined the specific heat of wheat at various moisture contents by a method of mixtures. He obtained the following results for three lots of wheat: $c = .283 - .00724U$; $c = .301 - .00733U$; and $c = .288 - .00828U$ respectively, where c is the specific heat and U is the moisture content expressed in per cent of the wet weight of the wheat. His values of specific heat of dry wheat (.283 to .301) agree fairly well with our values (.310 and .314). In Fig. 5 are plotted the values of specific heat given in Table IV as well as the values obtained by using our values of the specific heat of dry wheat and the proportionality constants from Pfalzner.

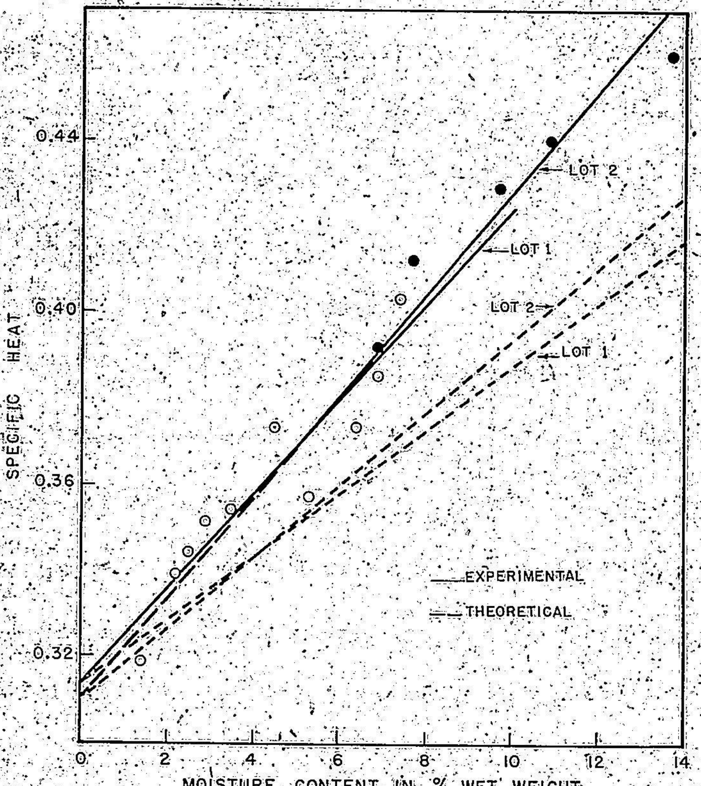

FIG. 5. Variation of the specific heat with the moisture content of the wheat. ——— Specific heat values obtained from the experimental results. – – – – – – – Specific heat values obtained from Pfalzner's equations.

GENERAL DISCUSSION

In these experiments the effect of moisture on the thermal properties was twofold; one effect was due to the presence of moisture in the wheat kernels and the other was due to the migration of moisture from the hot to the cooler wheat, and these two effects could not be separated. The migration of moisture through the wheat took place by diffusion of the water vapor through the intergranular air spaces and by the interchange of moisture between the wheat kernels and the air surrounding them. Of these two processes the adsorption and desorption of water vapor by the wheat would have the greater effect on the thermal properties. The heat of desorption required when the hot wheat gave up moisture and the heat of adsorption acquired when the cool wheat adsorbed this moisture resulted in a heat transfer from the central axis toward the outside of the cylinder. This transfer of heat increased the rate of heat flow causing an apparent increase in the thermal conductivity and thermal diffusivity. But when equilibrium had been reached, this transfer of heat no longer took place and the measured values of thermal conductivity and thermal diffusivity were less than they were while migration was taking place.

This is illustrated by the results in Tables III and IV; for the k' and κ' values of thermal conductivity and thermal diffusivity respectively obtained during the migration of moisture are greater than the corresponding k and κ values obtained after migration. After equilibrium had been reached, there was a gradient in moisture content across the wheat. Thus the thermal conductivity varied across a radius of the cylinder, being least near the axis and greatest near the outside as indicated by the graphs in Fig. 3.

The time required for the temperature of the wheat to reach equilibrium depended on the moisture content. At low moisture contents the equilibrium temperatures were reached in less than one week; at higher moisture contents the time required was much longer—in fact up to 400 hr. for the wheat containing 15.9% moisture. This may be explained by the movement of moisture through the wheat and its effect on the thermal conductivity. For as the moisture moved through the wheat under the influence of the temperature gradient, the thermal conductivity of the wheat near the central axis decreased and its temperature rose. The rise in temperature increased the temperature gradient across the wheat and more moisture began to diffuse through the wheat. This process continued until a state of moisture equilibrium as well as temperature equilibrium had been established. Whether this state of equilibrium had been reached in the time of an experiment is difficult to say. The experiments were considered completed when there was no longer an appreciable change in temperature over a period of a day—but this may have been only a gradual deceleration of the process, not its conclusion.

The graphs in Fig. 3 show how the migration of moisture affects the thermal conductivity measurements. The thermal conductivity varies within the wheat depending on its moisture content, but the measurements are based on a constant value of conductivity throughout the bulk. The difference between the k values and the k' values of thermal conductivity shown in Table III indicates that the movement of moisture in the wheat causes the measured values of thermal conductivity to be lower than the actual values if no movement had taken place.

The thermal diffusivity measurements are also affected by the migration of moisture. Table IV shows that the κ values decrease at a greater rate than the κ' values of diffusivity when the moisture content of the wheat is increased. Since the κ values are affected by the migration of moisture more than the κ' values, this indicates that the migration of moisture causes the measured values of thermal diffusivity to be lower than the actual values if no migration had taken place.

The specific heat results are also affected by the migration of moisture since they depend on k and κ. Using the k' values of conductivity and the κ' values of diffusivity in calculating the specific heat, this effect of migration will be less. However after comparison of these calculated values of specific heat with those using Pfalzner's relation between specific heat and moisture content in Fig. 5, it appears that our values of specific heat are still considerably affected by the migration of moisture.

As mentioned above, there is a slight difference in the thermal properties of the two lots of wheat used. This may be partly due to the difference in the procedure of changing the moisture content. The first lot of wheat was dried and moisture was gradually added to it, whereas the second lot was dried by steps and tests made between the drying periods. After the wheat had been completely dried, its ability to absorb moisture may have been changed.

ACKNOWLEDGMENT

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