Heat sterilization as means of controlling cereal insects

by James Hubert Pepper

A THESIS Submitted to the Graduate Committee in partial fulfillment of the requirements for the Degree of Master of Science in Entomology
Montana State University

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Submitted to the Graduate Committee in partial fulfillment
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HEAT STERILIZATION AS A MEANS OF CONTROLLING CEREAL INSECTS

By James H. Pepper*

INTRODUCTION

In recent years heat sterilization, as a means of controlling mill and stored-grain insect pests, has been recommended by many workers and authors of text books in the field of economic entomology. Most of these recommendations are based on conclusions drawn when temperatures were recorded at some distance from the floor and no means of air circulation was provided.

Air, when heated, rises and tends to stratify, producing a marked difference between floor and ceiling temperatures. As the quantity of heat applied is increased the difference in these two temperatures becomes greater. In mill sterilization, the production of a killing temperature on all floors above the basement will be influenced to a marked degree by the rate at which heat will penetrate the concrete floors. The rate of heat penetration into various mill products is also of vital importance since, when present, they provide a place of escape for insects from the high surrounding temperatures.

This paper embodies the results of experiments with controlled floor and ceiling temperatures under varying conditions of heat and air circulation. In addition the results are given on the rate of heat penetration into concrete, wheat, flour and bran.

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The writer gratefully acknowledges his indebtedness to Doctor

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REVIEW OF PREVIOUS WORK

Dean (1)* was one of the earliest workers to publish the temperatures obtained when using heat sterilization for controlling mill insect pests. He records the temperatures noted at various selected places throughout the mill for a period of 24 hours. The following is a brief summary of the more important temperatures which he records. The average temperature in the mill at the time the heat was applied was about 90°F. The highest temperature recorded on the first floor was 105°F. This was taken in the center of the room and 6 feet above the floor. The lowest temperature on this floor was 96°F. which was recorded at a depth of 3 inches in flour in an elevator boot on the floor, in the center of the room. On the second floor the highest temperature, 133.5°F., was registered by a thermometer hanging in the open in the center of the room and 6 feet from the floor. The lowest temperature registered by a thermometer on this floor was 117.6°F., which was recorded at a depth of 3 inches in a sack of flour which was 3 feet above the floor. On the third floor the thermometer in the center of the room and 6 feet above the floor registered 141°F., while the lowest temperature, 129°F., was registered in a flour conveyor spout 4 feet above the floor. On the

*- Reference is made by number (italic) to Literature Cited.

fourth floor the thermometer 6 feet above the floor registered 128.6°F. The lowest temperature which was registered on this floor, 118°F., was recorded by a thermometer in flour in a conveyor 6 feet above the floor. Dean states that on a careful examination of the three upper floors, all parts of the mill, even the deepest accumulations in the most inaccessible parts, failed to show live insects, save one corner on the upper floor.

It will be noted that no actual temperatures were recorded on the floor surface. The closest point to the floor at which temperatures were recorded was in an elevator boot resting on the floor. The significance of this will be brought out in a later discussion on the subject of surface temperatures.

Goodwin (2) determined the relative susceptibility of different developmental stages of insects to heat and found that even though a difference as great as 8 to 10°F. was required to effect the destruction of different species, most of the common insect pests succumb readily to a temperature of 120 to 130°F. with practically no injury to the substances on which the insects feed. In determining the influence of air circulation he found that circulation of air in the testing oven by means of a small electrically-operated fan caused the death of the Confused flour beetle, Tribolium confusum, the minute grain beetle, Laemophlaeus minutus, and the larvae of the Mediterranean Flour and Indian Meal moths, at a temperature of two to three degrees below that required in the oven in an undisturbed atmosphere. This writer states that the required high temperatures in a flour mill may be secured by any safe method which will give dry heat at 122 to 140°F. and he outlined several methods for calculating radiation surface required to bring about these temperatures.

Grossman (3), in determining temperatures attained at different depths in corn, used the thermocouple method for taking temperatures. He found with a surface temperature of approximately 245°F. a lethal temperature was obtained to a depth of about one foot after heating for a period of 48 hours. In shucked corn with a surface temperature of approximately 235°F. a lethal temperature was obtained to a depth of $2\frac{1}{2}$ ft. In this case the heat was applied for 18 hours.

Many papers and text books on entomology outlined methods for heat sterilization, but since they do not state any temperatures except those desired to be obtained, no mention need be made of them here.

EXPERIMENTAL METHOD AND APPARATUS

The thermocouple method as described by Robinson (4) for determining temperatures was used. In studying heat penetration in a concrete block it was desired to obtain temperatures at the surface of the concrete,, every quarter inch for the first inch, every half inch for the next two inches and every inch for the remaining six inches.

Figure 1 shows the diagram of the apparatus used. In order to study heat stratification near the surface and heat penetration in mill products, a series of thermocouples (not shown in diagram) were extended to a distance of 8 inches above the floor surface. The distances between these couples were as follows; starting from the floor surface, every quarter inch for the first 2 inches, every half inch for the next 2 inches, and every inch for the remaining 4 inches. The part of the apparatus buried in the cement consisted of a piece of 1 by 1 in. board to which all the

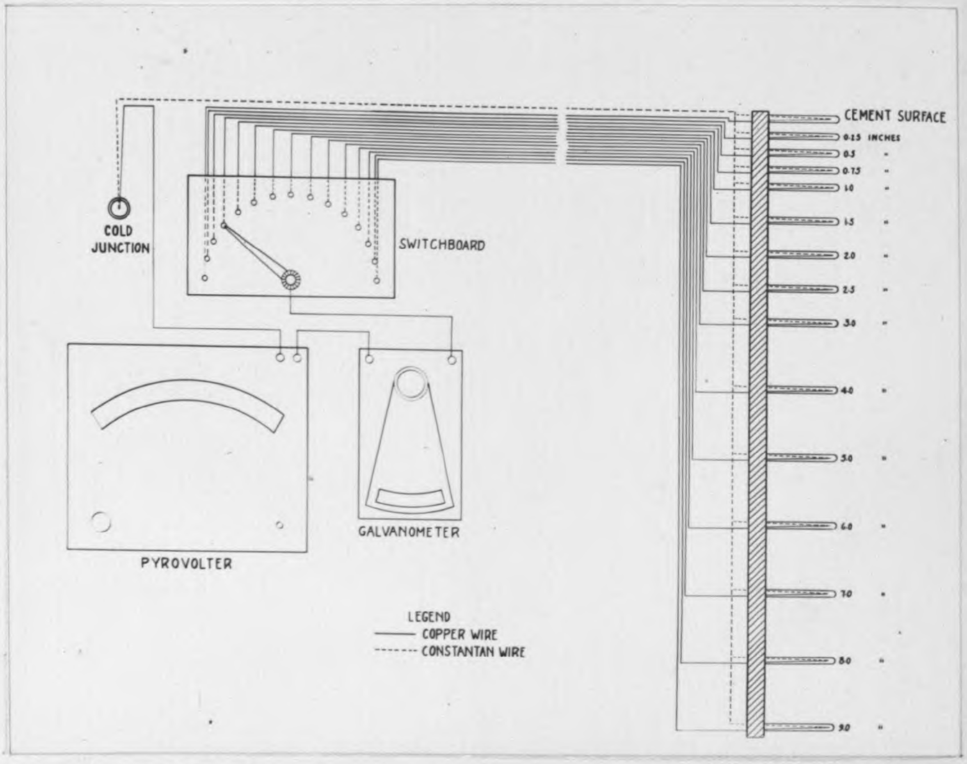

Fig.1. Diagram showing the system of wiring used in the apparatus for taking the temperatures in the concrete block.

couples were attached. This eliminated any chance of them not holding their correct position when the cement was being poured around them. Holes 1/8 inch in diameter were bored through the board at the required distances. Glass tubes which were 6 inches long and had one end sealed were inserted in these holes until the ends were flush with the back of the board, leaving 5 inches of tube projecting. A 28-gauge constantan wire was led down to the 9 inch hole where a junction was made with a 28-gauge copper wire. The constantan wire was tapped by short leads to the remaining holes and a junction made at each one with a copper wire. The insulated copper wires were twisted together and were wrapped with insulating tape, after which they were led through the side of the cabinet to the recording instrument. Each junction was then pushed through the hole and up to the end of the glass tube. The single constantan wire was led to the cold junction, which was in a Dewar flask containing cracked ice and water. The copper wire from this junction was connected to a Pyrovolter and galvanometer to the common terminal on the switch board. The copper wires were then in turn connected to the terminals on the switch board. The board containing the thermocouples was fastened in the center of a wooden frame which was 4 feet square and 10 inches deep. The frame was then filled with a 1 to 3 mixture of concrete to the point where the top couple, shown in Figure 1, was just resting on the surface of the cement. The cement block was covered by a cabinet 4 feet square and 4 feet high. This was built of a lumber frame and covered with cellotex. To prevent too great a loss of heat a double layer with an air space between was put on the ceiling. A small double glass window in the front served as a place through which observations on insects could be taken. In order to determine ceiling temperatures a thermometer was inserted in a horizontal position through a small hole in the wall 1 inch from the ceiling.

The heating element consisted of two independent units of 14 B & S gauge nichrome resistance wire. One unit was capable of delivering 3036 B.T.U. per hour and the other one 2337 B.T.U. per hour. The highest temperatures which will be discussed were obtained by using both of the units which delivered 5373 B.T.U. per hour.

When air circulation was required an electrically driven fan was placed directly behind the heating units. This gave an effect comparable to that produced by unit heaters.

Before any series of temperatures were taken the temperature of the various couples was first recorded. The heat was then turned on and the temperature noted at hourly intervals for a 10 or 15 hour period.

As a check on the surface temperatures a movable thermocouple which could be operated from outside the cabinet was used. This consisted of a rubber stopper with a thermocouple securely fastened to one end of it. The other end was connected by a hinge to one end of a wooden rod, the other end of which passed through a small hole in the ceiling. In order to prevent loss of heat the space around the rod, where it passed through the ceiling, was packed with ground up asbestos. By using this movable couple, which could be operated from outside of the cabinet, temperatures could be taken at any point on the floor, at any time, without introducing a source of error by opening the cabinet and so upsetting the experimental conditions.

DATA AND RESULTS

The experiments were planned with the object of determining; first, the rate of heat penetration into concrete; second, the rate of heat penetration in wheat, bran, and flour; and third, floor surface and ceiling temperatures when no means of air circulation was provided and again when a fan was used to keep the air in constant motion.

Table 1 shows the hourly temperatures obtained in concrete when 5373 B.T.U. of heat per hour were supplied. In this experiment a fan was used to keep the air in circulation.

Figure 2 shows graphically that while the surface temperature increased from 65.0°F. to 150.5°F. in ten hours, a rise of 85.5°F., the temperature 9 inches below the surface only increased from 65.5 to 104°F, a rise of 38.5°F. The average drop in temperature in the first quarter inch is about 7°F., this amount decreasing at each successive couple. This experiment was allowed to run for an additional 5 hours making a total of 15 hours to see if any significant changes would take place. It was found that the changes were very small and to be significant the heat would have to be applied for perhaps 24 hours or more.

Table II shows the rate of increase in temperature at the surface and 4 and 9 inches below the surface when applying 3036 B.T.U. of heat per hour. Also a comparison of still air against that kept in circulation by means of a fan.

Figure 3 shows a comparison of surface temperatures, also at 4 and 9 inches below the concrete surface, with and without air circulation. The same amount of heat (3036 B.T.U. per hour) was used in both cases. When a fan was used the surface was 7 to 10°F. higher than when no means of air circulation was provided, but at lower depths this difference was not as significant.

TABLE I. Hourly Temperatures Attained to a Depth of 9 inches in Concrete with 5373 B.T.U. per hour and air circulation.

Hours	0	1	2	3	4	5	6	7	8	9	10
Surface Temp.	65.0	103.0	116.5	126.5	134.0	141.5	145.0	147.5	148.5	149.5	150.5
T. at 1/4 in.	65.0	100.0	102.0	113.0	128.0	132.0	139.0	140.0	143.5	145.5	146.0
T. at 1/2 in.	65.0	95.0	97.0	110.5	125.0	128.0	133.0	138.0	139.0	142.0	143.0
T. at 3/4 in.	65.0	93.0	95.5	108.5	121.0	124.0	131.0	136.0	136.5	140.0	142.0
T. at 1 in.	64.5	90.5	93.5	106.5	120.0	122.0	129.0	134.0	135.0	138.0	140.0
T. at 1½ in.	64.5	88.5	93.0	104.5	119.0	120.0	126.5	129.0	132.0	136.0	137.0
T. at 2 in.	64.5	86.5	89.5	100.0	111.0	116.0	122.5	124.0	127.5	132.5	135.0
T. at 2½ in.	64.0	84.5	87.0	97.0	109.5	114.0	120.0	121.0	124.5	129.0	131.0
T. at 3 in.	64.0	82.5	85.0	95.0	106.0	112.0	116.5	119.0	121.5	125,5	128.0
T. at 4 in.	64.0	82.0	84.5	92.5	102.0	106.0	111.0	115.5	117.0	121.5	126.0
T. at 5 in.	64.0	81.5	84.0	90.5	97.0	102.0	105.0	109.5	111.0	115.0	122.0
T. at 6 in.	64.5	81.0	83.75	88.0	93.0	97.0	102.0	105.0	107.5	109.5	119.0
T. at 7 in.	64.5	80.0	83.5	86.0	92.0	95.0	99.5	101.0	105.5	106.5	113.0
T. at 8 in.	65.0	80.0	83.25	84.5	91.0	92.0	98.0	100.0	104.0	105.0	107.5
T. at 9 in.	65.5	79.5	83.0	84.0	87.5	90.0	96.5	99.0	102.0	103.0	104.0

TABLE II. Hourly Temperatures Attained in Concrete when 3036 B.T.U. per hour were applied, with an undisturbed atmosphere and with air circulation

Hours	0	1	2	3	4	5	6	7	8	9	10
Without fan	0										
Surface Temp.	68.0	77.8	95.3	96.8	98.6	102.5	105.3	109.5	111.2	112.2	113.2
T. at 4 in.	70.3	75.1	84.0	85.8	87.0	89.5	92.2	92.8	97.0	100.8	103.5
T. at 9 in.	71.3	74.0	76.0	78.0	80.0	83.0	85.0	86.8	87.5	93.5	96.8
With fan											
Surface Temp.	63.6	96.0	102.5	107.6	113.0	113.8	114.8	116.8	119.8	123.0	125.6
T. at 4 in.	64.6	77.2	86.2	86.8	87.9	90.5	93.5	94.8	98.0	102.0	107.0
T. at 9 in.	66.0	76.0	78.2	80.5	82.0	84.0	86.2	87.5	90.3	95.3	98.0

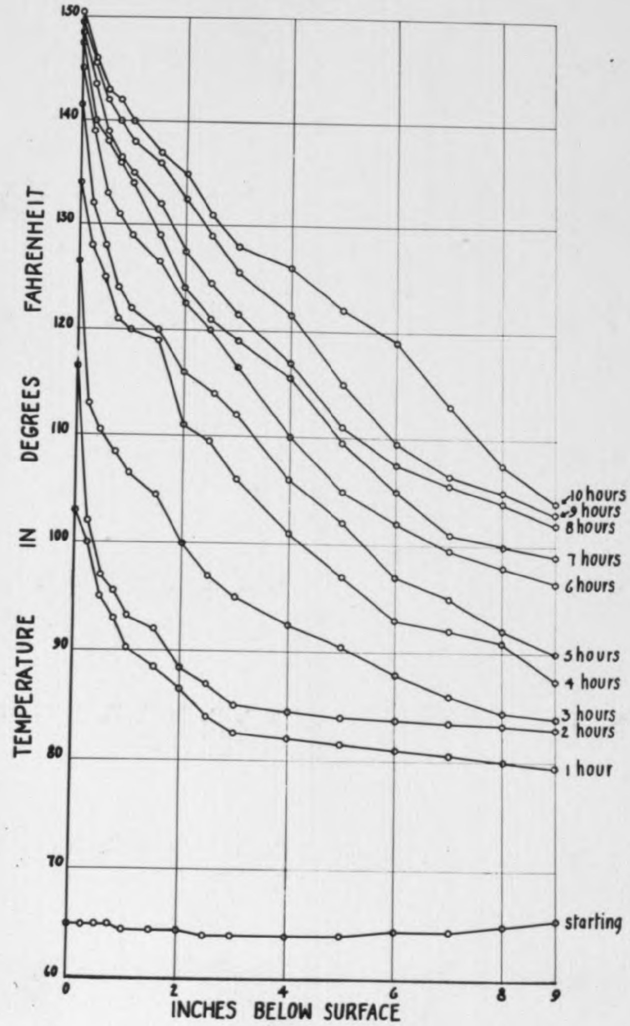

Fig.2. Hourly temperatures obtained to depth of from 1 to 9 inches in concrete with the application of 5373 B.T.U. per hour and with air circulation.

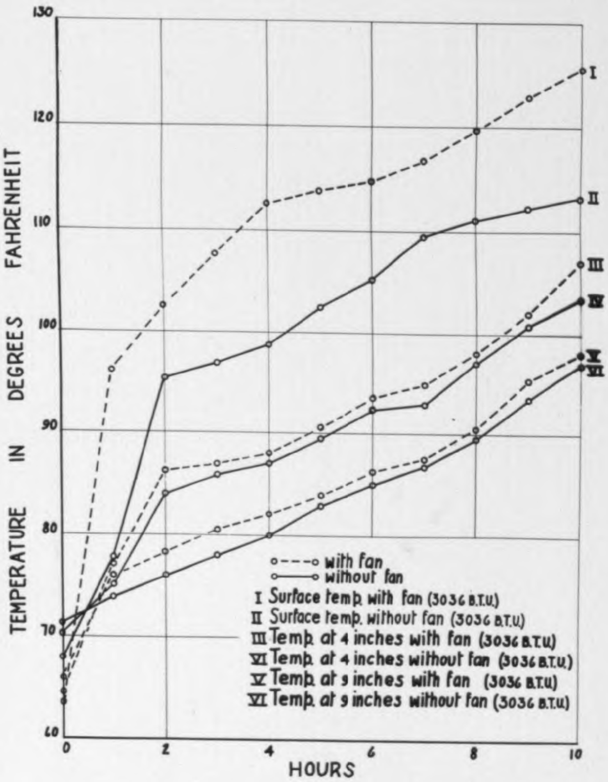

Fig.3. Hourly temperatures obtained in concrete when 3036 B.T.U. per hour were applied and under conditions of an undisturbed atmosphere and with air circulation.

Comparing Figure 4 with Figure 3 it will be seen that at higher temperatures the fan has a more pronounced effect in raising the floor surface temperature. The degree of penetration to lower depths is directly proportional to the difference in surface temperatures. It will be noted that this was also the case when lower temperatures were used, this being shown in figure 3.

In figure 5 the surface temperature was taken in contact with the material but with the top of the couple exposed. It will be seen that this temperature is the same as that of the air which is directly in contact with the wheat. It is probable in this case that temperatures at the lower depths, that is 6 and 8 inches, were influenced to some extent by the temperature of the floor so that some of the 9° rise in temperature could be attributed to this fact.

In figure 7 it is quite possible that, as in the case of wheat, the temperatures at the lower depths were influenced to some extent by that of the floor.

Table VII shows floor surface and ceiling temperatures obtained when 3036 B.T.U. per hour of heat were applied. A comparison is shown when no means of air circulation was supplied and when a fan was used. Also the temperatures obtained when 5373 B.T.U. per hour of heat were applied. In the latter case a fan was used for air circulation.

In this experiment (figure 8) floor and ceiling temperatures were taken for a short interval when no fan was used but the ceiling temperature became so high after the first hour that it was decided to discontinue the experiment.

TABLE III. Hourly Temperatures Attained in Concrete when 5373 B.T.U. per hour of heat were applied with an Undisturbed Atmosphere and with Air Circulation.

Hours	0	1	2	3	4	5	6	7	8	9	10
Without fan											
Surface Temp.	62.6	89.8	96.0	102.0	105.8	109.5	116.0	118.0	119.0	122.0	125.0
T. at 4 in.	66.0	74.5	78.5	80.5	84.0	87.5	89.5	92.1	94.0	97.5	98.2
T. at 9 in.	60.2	73.5	75.2	77.8	80.0	82.0	84.0	85,0	86.0	87.5	88.5
With fan											
Surface Temp.	64.4	103.0	116.5	126.5	134.2	141.5	145.0	147.5	148.5	149.5	150.6
T. at 4 in.	64.4	82.5	85.0	90.5	97.2	101.8	105.0	109.5	112.0	114.8	117.0
T. at 9 in.	60.2	79.5	83.5	85.8	87.5	90.0	96.5	98.8	102.0	103.5	105.5

TABLE IV. Temperatures Obtained in Wheat at the Depths Noted for a Period of 15 Hours.

Hours	0	1	2	3	4	5	6	7	8	9	10	15
Surf.Temp.	68.0	141.0	159.5	173.0	179.0	183.0	187.0	191.0	194.0	196.0	198.0	200.0
T. at 2 in.	64.0	71.0	76.0	81.0	85.0	90.0	95.0	99.0	104.0	107.0	111.0	122.0
T. at 4 in.	62.0	66.0	68.0	71.0	74.0	76.5	79.0	81.5	84.5	87.0	90.0	101.0
T. at 6 in.	61.0	64.0	67.0	69.0	72.1	74.2	76.0	78.5	81.2	82.5	85.0	91.0
T. at 8 in.	61.0	62.0	63.5	65.0	66.5	68.0	69.0	70.0	71.5	73.0	74.0	79.0

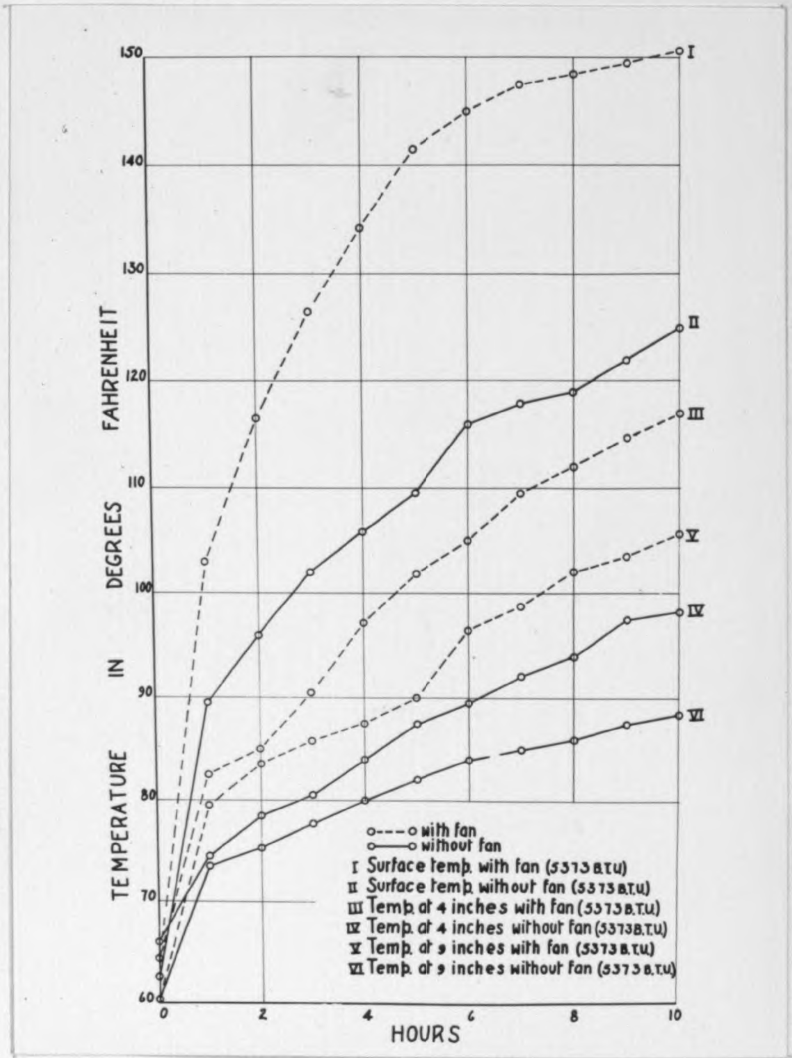

Fig. 4. Hourly temperatures obtained in concrete when 5373 B.T.U. per hour were applied and under conditions of an undisturbed atmosphere and with air circulation.

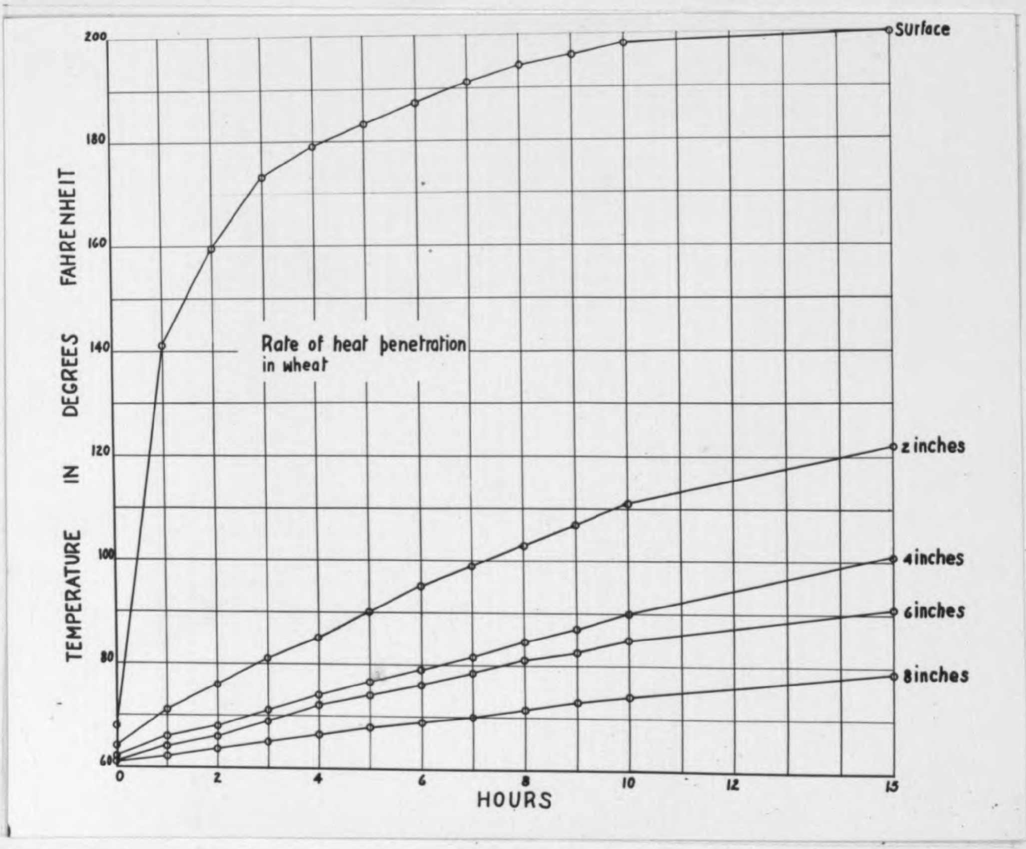

Fig. 5. Temperatures obtained at different depths in wheat for a period of 15 hours.

TABLE V. Temperatures Obtained in Bran at the Depths Noted for a Period of 15 Hours.

Hours	0	1	2	3	4	5	6	7	8	9	10	15
Surf. Temp.	68.0	151.0	169.0	179.5	186.0	190.0	195.0	196.0	197.5	199.0	201.0	203.0
T. at 1 in.	68.0	102.0	121.0	131.0	138.0	144.0	149.0	153.0	156.0	159.0	161.0	168.0
T. at 2 in.	68.0	84.0	102.0	113.0	118.0	123.0	126.0	129.0	131.0	133.0	134.0	138.0
T. at 3 in.	68.0	80.0	92.0	100.0	106.0	111.0	113.0	115.0	117.0	118.0	120.0	121.0
T. at 4 in.	68.0	77.0	83.0	88.0	89.0	91.0	93.0	95.0	96.0	97.0	98.0	104.0

TABLE VI. Temperatures Obtained in Flour at the Depths Noted for a Period of 15 Hours.

Hours	0	1	2	3	4	5	6	7	8	9	10	15
Surf. Temp.	68.0	123.0	142.0	156.0	163.0	173.0	179.5	183.0	187.0	190.0	192.0	196.0
T. at 2 in.	64.0	68.0	75.0	81.0	87.0	91.0	97.0	102.0	107.0	109.0	112.0	120.0
T. at 4 in.	62.5	66.5	71.0	75.0	79.0	82.5	86.0	90.0	93.0	96.0	98.0	101.0
T. at 6 in.	60.0	64.0	66.0	68.0	70.0	71.0	72.0	74.0	75.0	76.0	76.5	80.0

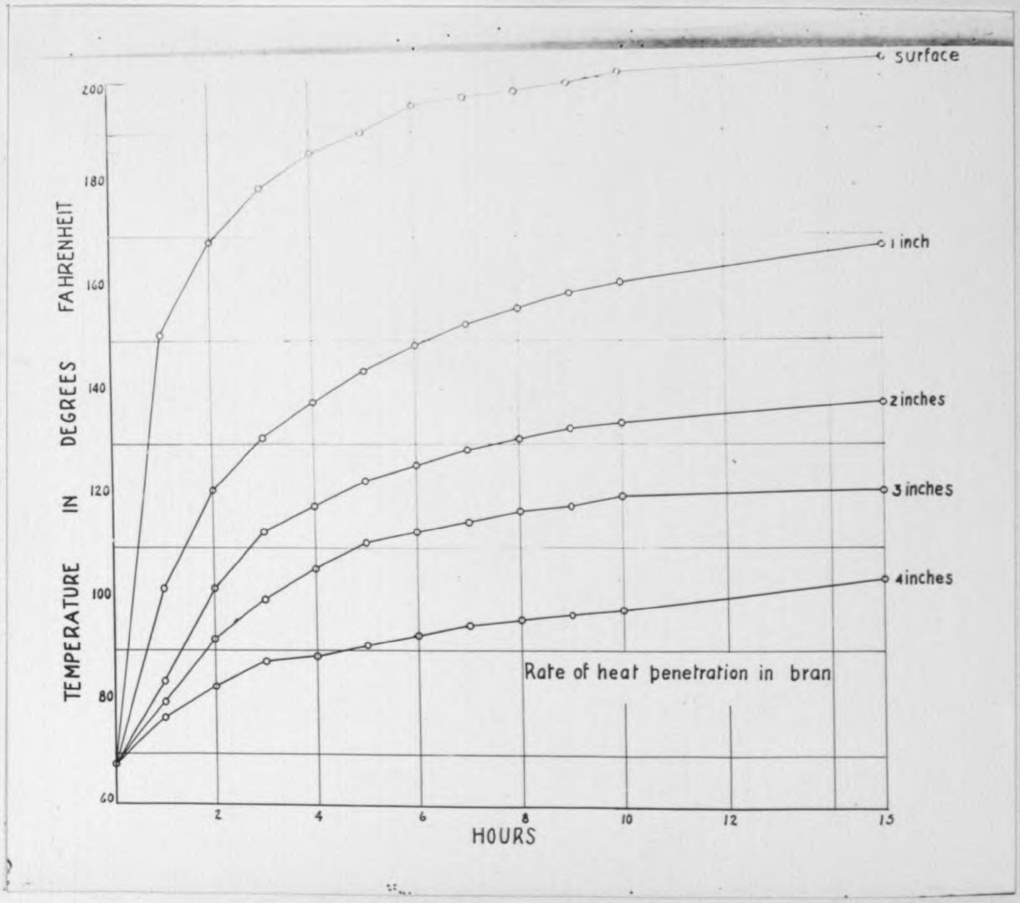

Fig. 6. Temperatures obtained at different depths in bran for a period of 15 hours.

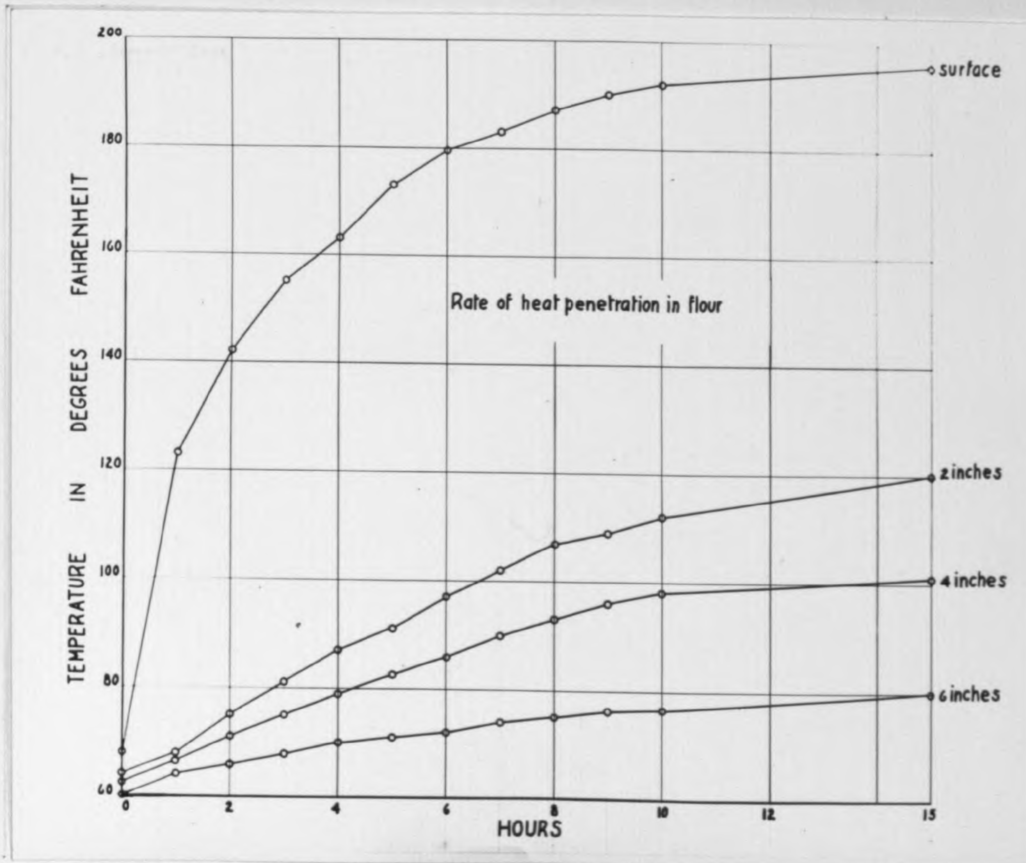

Fig.7. Temperatures obtained at different depths in flour for a period of 15 hours.

In Table VIII temperatures are given at the floor surface, quarter of an inch above the floor surface and half an inch above the floor surface, when 5373 B.T.U. per hour of heat were supplied, and a fan used to keep the air in circulation.

Figure 9 shows the air stratification in the first half inch above the floor surface. The air temperatures in this distance vary from 9 to 16°F. After ten hours the temperatures remain fairly constant. The fluctuations occurring after this time could be attributed to radiation brought about by the changes in the outside air temperature.

TABLE VII. Floor and Ceiling Temperatures.

Hours	0	1	2	3	4	5	6	7	8	9	10
Without fan 3036 B.T.U.											
Floor Surf.T.	68.0	77.8	95.3	96.8	98.6	102.5	105.3	109.5	111.2	112.2	113.2
Ceiling Temp.	68.0	184.5	194.0	204.0	210.0	214.5	219.0	220.5	221.8	222.0	222.0
With fan											
Floor Surf. T.	63.6	96.0	102.5	107.6	113.0	113.8	114.8	116.8	119.8	123.0	125.6
Ceiling Temp.	63.6	119.0	122.0	129.0	131.0	133.0	134.5	135.0	136.2	138.2	140.0
With fan 5373 B.T.U.											
Floor Surf. T.	64.4	103.0	116.5	126.5	134.2	141.5	145.0	147.5	148.5	149.5	150.6
Ceiling Temp.	64.4	149.0	156.0	165.0	174.0	176.0	177.0	178.0	178.5	179.0	180.0

TABLE VIII. Air Temperatures at Floor Surface and Quarter and Half an Inch above the Floor

Hours	0	1	2	3	4	5	6	7	8	9	10
Floor Surf.T.	63.6	96.0	102.5	107.6	113.0	113.8	114.8	116.8	119.8	123.0	125.6
T. at 1/4 in.	63.6	105.6	115.5	117.5	120.0	122.0	124.0	126.0	127.5	128.2	129.6
T. at 1/2 in.	63.6	113.0	120.5	124.0	127.5	130.0	131.5	132.5	133.5	134.0	134.5