HEAT FOR CONTROL OF CEREAL INSECTS

OHIO Agricultural Experiment Station

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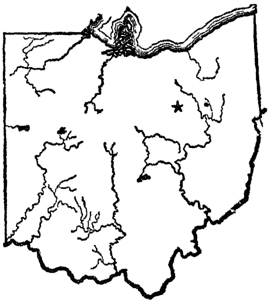

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[1] In cooperation with the College of Agriculture, Ohio State University, Columbus.
[2] In cooperation with the U. S. Department of Agriculture.

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HEAT FOR CONTROL OF CEREAL INSECTS

W. H. GOODWIN

For several years while at the Ohio Experiment Station and during a year with the Pennsylvania Department of Agriculture, the writer pursued investigations relating to heat as a method for controlling insects affecting cereal products in storage and especially as a treatment for mills which had become infested with one or more of the score or thereabouts of common grain insects spoken of under the general term of "weevil". Tests were made of the effect of varying degrees of heat and humidity on several of these insects, also how the viability of the principal grains were affected. Complete heating plants, assembled according to definite specifications, were installed in several mills under his direction. He has had access to more than 30 mills in the two states mentioned which now have successful heating systems and upon the data gathered from these various sources, the records and recommendations of this bulletin are based.

Insects Cause Insanitary Food.—Clean, sanitary products are important. Foods prepared from insect-contaminated grains or flours may cause serious derangement or illness. The writer has fed dogs with such contaminated products, checking against them dogs fed on products not injured by insects. The dogs fed on the contaminated food became very sick, while the check animals remained in perfect health.

Insects Responsible for Financial Failures.—The Mediterranean flour moth (*Ephestia kuehniella*) has been introduced in various ways into most of the flour mills throughout the northern United States. The smaller mills, which run only 8 to 12 hours per day, are most troubled, because the larvae crawl about freely, leaving a sticky, silken thread everywhere they go. The flour clings to this thread which soon forms masses between the buckets, on the elevator belts and in the spouts. These masses will ultimately clog the mill at some point, whenever one of them becomes dislodged and is precipitated into the machinery, this often occurring as the machinery is started for a day's run. This frequently recurring accident results in a loss of time, and oftentimes in a big waste of partly-milled wheat. Hindrances of this kind directly cause financial failure, since time, labor and cost of power become absolute losses.

An account of the life history of this insect has been given in Bulletin 234 of this Station. All stages of the insect are readily killed by maintaining a temperature of 120 degrees F. for several hours or in a shorter period with higher temperatures. In company with this mill pest are nearly always found several others, equally or more susceptible to death through a suitable degree of heat.

Applicability of Heat Treatment.—Heat can doubtless be used for other purposes of insect destruction than treating mills and stored grains. Many, probably most, of our common insect pests succumb readily to a temperature of 120 degrees to 130 degrees F. with practically no injury to the substances on which the insects feed. Some growing plants can be exposed to 120 degrees F. for 10 to 15 minutes with little or no injury. Insects affecting various nuts and dried fruits are amenable to heat treatment.

In practical experiments in flour mills, seed storage rooms, and when treating weevil-infested beans in a small drying room that had been constructed for drying fruit, corn and vegetables, the heat or high temperature method was found to be safe, simple, readily provided, permanently effective and not expensive, when first cost is distributed through the many years the equipment can be used.

Weevil in chestnuts and acorns, and the seeds of ash were killed when the seeds were raised to a temperature of 122 to 125 degrees, holding that temperature for 2 to 3 hours after it was reached, but in this case the seeds were not tested to see if they would germinate successfully after treatment. It appears that this method must be of considerable value in treating newly-threshed chestnuts, and that much of the injury by the nut weevils can be prevented without rendering the nuts unfit for food.

Other kinds of nuts, slightly-infested dried fruits, peas and beans can be treated in an especially-equipped room and all the insects destroyed. In such cases, a temperature of 130 to 150 degrees F. should be maintained continuously for 2 to 4 days, in order that the heat may penetrate to the center of the cartons or containers.

Auxiliary Uses of Mill Heating Plant.—The mill heating plant is useful for other purposes than the destruction of insects. Expert millers state that the maintenance of an even temperature of 50 to 60 degrees F. in winter is necessary to produce a well-milled, even-in-quality grade of flour. This consideration alone might justify the installation of an adequate heating system.

Effect on Germination of Seeds.—Wheat, after being subjected to 150 degrees F. for 2 hours, germinated as well as untreated wheat from the same lots. Peas and beans were raised to a temperature of 140 degrees F. for 20 minutes and were apparently uninjured as they germinated well. Corn heated to a temperature of 140 degrees for almost 2 days germinated almost as well as an untreated sample from the same lot. Of course there is the possibility that damp seed might be injured by being raised too rapidly to such temperatures as here recorded.

RELATIVE SUSCEPTIBILITY OF DIFFERENT DEVELOPMENTAL STAGES OF INSECTS TO HEAT

The stage of development of the insect has much to do with the temperature required to cause its death. Larvae, pupae and adults vary in the degrees of heat required to kill them. In repeated tests with the different stages of some twenty different species of insects affecting stored grain and cereal products, it was found that a difference as great as 8 to 10 degrees F. was required to effect the destruction of the different species. In the case of newly-deposited insect eggs, none was found that would hatch when heated to a temperature of 108 to 109 degrees F. for a period of 20 to 30 minutes. Eggs which had been deposited several days, and which were approaching the point of hatching, were not sufficiently affected by this temperature to prevent the hatching of all of them. Sometimes a considerable proportion of them hatched, although the hatchings were never so large as of untreated eggs. In several instances, where the eggs of some of the smaller grain beetles were used, larvae appeared in the treated material from 4 to 5 weeks after it had been heated to a temperature of 110 degrees. However, the much higher temperature required for destroying the larvae, pupae and adults will always insure the destruction of the eggs.

Small larvae of *Trogoderma ornatum* lived through temperatures of 48, 49 and in one case 50 degrees C. or 118⅖ to 120⅕ and 122 degrees F. These tests were duplicated a number of times in order to make the determinations as exact as possible. These larvae, when transferred to food material containing sufficient moisture for their development, continued to grow for 9 to 11 days. At this point, it was decided that the heat treatment had not killed them, and that they would ultimately reach maturity if allowed to do so. Full-grown larvae of the same species were readily killed by these temperatures. The duration of the exposure periods at these temperatures ranged from 20 to 50 minutes.

Influence of Humidity on Results.—It was found that the amount of moisture contained in the air at the time of treatment had much to do with the destruction of the insects and their eggs. The development and hatching of the eggs were found dependent on certain moisture conditions. The eggs of the Cadelle (*Tenebroides mauritanicus*) placed in dry material, did not hatch until the moisture of the corn was increased to approximately 12 percent. This corn had been stored in glass-stoppered jars 8 months before the moisture content was raised to a point at which the eggs hatched. In two other cases the larvae of the Cadelle have appeared in corn which was stored in glass museum jars for more than 20 months. Metabolic moisture seems to increase in grain when it is placed in tight containers for many months with no aeration. The moisture necessary for the development of the eggs of the Cadelle must have increased through some changes in the cell content of the grain. Since the degree of temperature required varies with the amount of moisture present, these factors have not been separated in the records here given of tests in killing the various species. The drier the air, the higher is the temperature required to reach the killing point. Full-grown larvae of the Cadelle (*T. mauritanicus*) were readily killed by a temperature as low as 45 degrees C., or 114 degrees F., with the humidity extremely high,—approaching the saturation point. Normally, with a low moisture content of the atmosphere in which the insects are treated, not less than 47 to 48 degrees C., or 116 or 118 degrees F., is fatal to the full-grown larvae of this species. In most cases these temperatures, with an extremely dry atmosphere, killed most of the species of stored grain pests much quicker than with a moist atmosphere. The rice weevil (*Calandra oryzae*) when exposed to high temperature with an extremely moist atmosphere, would die at temperatures of 2 to 5 degrees F. lower than if the atmosphere were extremely dry.

In practical work in flour mills, it was found that if a high temperature was reached rapidly and without difficulty while only a normal amount of radiation surface was in the room or building, the air was always very dry. If through some accident, as the leakage of radiators, the air was very moist, approaching the saturation point, it became impossible to get a temperature which was fatal to the insects without increasing the amount of radiation. When the leaks in the heating system of one of our experimental mills were repaired, we readily obtained a temperature of 130 degrees F. which we could not attain until repairs were made. The amount of heat absorbed in vaporizing the water in the first test was so great that the radiation present could not heat the mill to a fatal temperature. This means that buildings which are very moist in some part, as may be the case in basements, must have a considerable excess of radiation installed.

Influence of Air Circulation.—Circulation of the 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 larvae of the Mediterranean flour and Indian meal moths, at a temperature of 2 to 3 degrees below that required in the oven with an undisturbed atmosphere. This series of experiments indicated the importance of circulating the air regardless of very low humidity. This operation hastened making the high temperature effective, probably through producing a more even temperature throughout the whole of the ovens and buildings, and thus more rapidly drying and fixing the insect tissues.

It is impossible to heat grain in ordinary bins without modifying the method and combining aeration with heat or high temperature. Most insect pests of stored grain will endeavor to leave it, if the grain is disturbed or thoroughly aerated. Rice weevil (*Calandra oryzae*) confined in grain in breeding jars, attempted to leave very soon after cold air was pumped through the grain for 20 minutes. Perforated tubes were thrust to the bottom of the jars, and air forced through the tubes, thoroughly aerating the grain. These tests were repeated with a number of other species (*Calandra granaria, Silvanus surinamensis and Tribolium confusum*) in later experiments with similar results.

Heated air can undoubtedly be used with even better results in practical tests in elevators, flour mills and farmers' grain bins, if forced through the grain by air pumps or pressure blowers. Such an operation would aid materially in reducing the moisture content of the grain, besides aerating it, and create conditions under which the insect pests commonly called "weevil" could not thrive.

REQUIREMENTS TO OBTAIN EFFECTIVE TEMPERATURES IN MILLS

The required high temperatures in a flour mill may be secured by any safe method which will give dry heat at 122 to 140 degrees F. or 50 to 60 degrees C. A plant capable of giving the higher temperature is preferable since it allows for some slight reserve capacity above the average requirement. Gas stoves or furnaces may be used, but steam radiation is more satisfactory in every respect. Pressures of 40 to 60 pounds of steam can be used, giving temperatures at the radiators much above those normally obtained at 8 to 12 pounds pressure. Eight to 10 pounds steam pressure gives a temperature of approximately 220 degrees F., while steam at 40 to 60 pounds gives about 260 to 300 degrees F. at the radiators. Steam radiation also has the advantage of being safe from the standpoint of fire hazards, and the radiators can be installed where most needed to give an even distribution of heat. The system can be forced to its highest capacity, if necessary, without injuring it.

CALCULATION OF RADIATION SURFACE

Successful Installations.—Flour mills, so open that a fumigation with hydrocyanic acid gas would be valueless, can be heated successfully to a killing temperature. Eight of this kind of flour mills under the writer's observation have been heated successfully. Three had radiation installed and tried until sufficient heating surface had been added to obtain results. Five others were successfully equipped from estimates made by the writer. More than thirty mills in Ohio and Pennsylvania have been equipped with successful heating systems for the destruction of the insect pests which caused trouble.

The amount of radiation needed in any particular building can be determined by experiment or trial, but most plumbers have engineer's heating tables or formulae from which the radiation required can be approximately calculated. These results should be corrected by taking into consideration variations in building construction.

Method No. 1: Plumber's Method.—This, the 2-20-200 formula is often used, but is an empirical method.

> One square foot of radiation is allowed for each 2 square feet of exposed window surface; 1 square foot for each 20 square feet of exposed wall surface*; and 1 square foot for each 200 cubic feet of content.

This gives an approximation to the amount of radiating surface needed under normal conditions, and serves fairly well as a method for estimating the amount required in many flour mills. It does not allow for an increase in case of open wood-frame construction, nor for a reduction in well constructed buildings.

This method of calculation also fails to distribute the radiation properly. As a result the upper floors of the mill are heated much above the required killing temperature, and the lower floors will not become hot enough to destroy the insect pests. Openings, belt holes, spouts and elevators all allow the heated air to rise to the upper floors, raising the temperature there to a high point and leaving the lower floors below the killing temperature.

How to calculate with the 2-20-200 formula for a mill 50 by 40 feet, 4 stories and basement.

Basement concrete walls	50′ x 40′ x 12′ approximately	
Cubic content	$\frac{24000}{200}$	equals 120 sq. ft. of radiation
Square feet of window surface	$\frac{75}{2}$	equals 37 sq. ft. of radiation
¼ of wall exposed*	$\frac{1680}{80}$	equals 21 sq. ft. of radiation
Total		178 sq. ft. of radiation
First floor	50′ x 40′ x 12′ approximately	
Square feet of window surface	$\frac{198}{2}$	equals 99 sq. ft. of radiation
Square feet of exposed wall surface*	$\frac{1160}{20}$	equals 58 sq. ft. of radiation
Cubic content	$\frac{24000}{200}$	equals 120 sq. ft. of radiation
Total		277 sq. ft. of radiation

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*By exposed wall surface is meant those portions exposed to the wind especially if not abutting against banks of earth, other buildings, etc. The rapidly changing air on the exposed side carries away the heat much more rapidly than if the air were still.

Second floor 50′ x 40′ x 12′ approximately

Square feet of window surface $\frac{198}{2}$ equals 99 sq. ft. of radiation

Square feet of exposed wall surface* $\frac{1160}{20}$ equals 58 sq. ft. of radiation

Cubic content $\frac{24000}{200}$ equals 120 sq. ft. of radiation

Total ....277 sq. ft. of radiation

Third floor 50′ x 40′ x 10′

Square feet of window surface $\frac{330}{2}$ equals 165 sq. ft. of radiation

Square feet of exposed wall surface* $\frac{1400}{20}$ equals 70 sq. ft. of radiation

Cubic content $\frac{20000}{200}$ equals 100 sq. ft. of radiation

Total ....335 sq. ft. of radiation

Fourth floor 50′ x 40′ x 20′

Square feet of window surface $\frac{330}{2}$ equals 165 sq. ft. of radiation

Square feet of wall surface $\frac{1600}{20}$ equals 80 sq. ft. of radiation

Cubic content $\frac{40000}{200}$ equals 200 sq. ft. of radiation

Total ....445 sq. ft. of radiation

Basement	178
First floor	277
Second floor	277
Third floor	335
Fourth floor	445

Total radiation required in sq. ft. of heating surface 1512

Method No. 2: Factor Method.—The arbitrary factor method of estimating the amount of radiation needed is based on extensive actual trials or experiments of installing radiation and testing until the required temperature was obtained. From the results obtained

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*By exposed wall surface is meant those portions exposed to the wind especially if not abutting against banks of earth other buildings, etc. The rapidly changing air on the exposed side carries away the heat much more rapidly than if the air were still.

the following relations between radiation needed and dimensions of the buildings were found to hold:

> To the cubic content of each floor is added the number of square feet of exposed wall surface, the number of square feet of window surface, and also the area in square feet of all other openings, as doors.

Most flour mills are not equipped with excessive amounts of window or glass surface, hence these factors are fairly accurate, and give what the approximate distribution of the radiation should be much better than the other methods. The arbitrary factors and classifications are as follows:—

Factor	60	Damp basements Open first floors
Factor	70 to 80	Good first floors Fair second floors
Factor	100	Well built mills Second and third floors Fair fourth floors
Factor	140 to 180	Well built mills Third and fourth floors

The estimates are to obtain a difference of 40 to 45 degrees F. above the outdoor temperatures. If greater differences of temperature are desired, a corresponding increase in the amount of radiation needed can be obtained by using the smaller factors.

How to calculate by the factor method the amount of radiation needed in the same flour mill estimated on by Method No. 1.

Factors 60-70-80-100-130-180

Basement very dry, concrete walls	50′ x 40′ x 12′
Cubic content	24000 cu. ft.
Window surface	75 sq. ft.
¼ of wall surface exposed $\frac{1680}{4}$ equals	420 sq. ft.
	24495

$$\frac{24495}{70} = 350 \text{ sq. ft.}$$

Here the factor 70 is chosen for the basement because conditions approximate those expected on a good first floor.

First floor, frame, extra good construction—50′ x 40′ x 12′

Cubic content	24000
Window surface	198
Wall surface	1160
Factor 70	) 25358
	362 sq. ft.

Second floor, 50 by 40 by 12 feet

Cubic content	24000
Window surface	198
Wall surface	1160
Factor 100	) 25358
	253 sq. ft.

Third floor, 50 by 40 by 10 feet

Cubic content	20000
Window surface	330
Wall surface	1400
Factor 100	) 21730
	217 sq. ft.

Fourth floor, 50 by 40 by 20 feet

Cubic content	40000
Window surface	330
Wall surface	1600
Factor 140	) 41930
	299 sq. ft.

Basement	350
First floor	362
Second floor	253
Third floor	217
Fourth floor	299
Total	1481 sq. ft. of radiation

Method No. 3: Formula of Carpenter.—This formula gives one of the simplest methods for estimating the amounts of radiation needed to heat buildings, and in practical work mills are not as difficult to heat as dwellings or offices. The formula is:

> Radiation equals ¼ square feet of glass surface plus ¼ of the exposed wall surface in square feet plus .02 times the number of changes of air per hour, times the cubic content.

Allowing for two changes of air per hour, the radiation given by this formula is much greater than needed, excepting in very poorly built mills. Normally 1-5, 1-6 or 1-7 may be substituted for the coefficient ¼ for well-built mills or for extra good construction, the latter referring to hollow tile and frame construction with air spaces, or a combination of good construction. An example of this method is here given, but in actual tests it was found that the amount of radiation on the lower floors must be increased and that on the upper floors decreased in order to procure the best results.

How to calculate radiation required by formula of Carpenter: The dimensions of a well-built frame mill, with double, diagonally boarded wall, and sided over the diagonal boarding, are assumed to be the same as in the example used with the preceding formulae. Two changes of air are assumed per hour.

Mill, four stories and basement.

Basement cemented, approximately 40′ x 50′ x 12′.

R equals ⅕ [(75) plus (¼ of 1680) plus (.04 x 23200)]
R equals 15 plus 84 plus 185 equals 284 sq. ft.

First floor:

R equals ⅕ [(198) plus (¼ of 1160) plus (.04 x 24000)]
R equals 40 plus 58 plus 192 equals 290 sq. ft.

Second floor:

R equals ⅕ [(198) plus (¼ of 1160) plus (.04 x 24000)]
R equals 40 plus 58 plus 192.
R equals 290 sq. ft. of radiation.

Third floor:

R equals ⅕ [(330) plus $\frac{1400}{4}$ plus (.04 x 20000)]
R equals 66 plus 70 plus 160 equals 296 sq. ft.

Fourth floor:

R equals ⅕ [(330) plus (¼ of 1600) plus (.04 x 40000)]
R equals 66 plus 80 plus 320.
R equals 466 sq. ft. of radiation.

Basement	284
First floor	290
Second floor	290
Third floor	296
Fourth floor	466
Total	1626 sq. ft. of radiation

Method No. 4: British Thermal Heat System.—This allows for all types of construction and conditions. It is very exact as regards the total, but in flour mills the many spouts, elevator legs and belt holes permit much of the heat on the lower floors to rise. This necessitates an adjustment of the estimates for the different floors. Some radiation, estimated as required on the upper floors, must be installed in the basement and on the first floor.

The rearrangement necessitates the changing of about one-half of the fourth floor radiation in four-story mills to the basement and first floors and also one-third of the third-floor radiation should be transferred lower down.

In practice, the British Thermal Heat method allows for the wide variation in construction of different buildings and since the data needed for estimating the requirements for high temperature heating of flour mills are not extensive, a table (adapted from the American District Steam Company's Bull. 142) is given, page 12.

Differences of temperature between outdoors and indoors rarely exceed 50 degrees F., and two changes of air per hour are allowed for mills doubling that given in the tables for British Thermal Heat Units required to heat the air or cubic content of ordinary buildings.

Divide the total British Thermal Heat Units obtained for each floor by 240 for high pressure steam heating of 25 to 60 pounds steam pressure per square inch.

Heat losses result from three sources and must be calculated or estimated as follows:

a. The amount needed to heat the air in the room, which is constantly changing, due to leakage around windows, and the opening and closing of doors, etc.

b. The amount needed to overcome the cooling effect of windows and doors.

c. The amount needed to overcome the cooling effect of exposed walls, floors or ceilings.

The amount of heat required to heat the air in the room can be easily computed from the fact that 1 British Thermal Heat Unit will heat approximately 50 cubic feet of air 1 degree F. From this, the following factors would obtain for each cubic foot of air with various degrees of difference in temperature.

For 40 degrees difference in temperature between indoors and outdoors multiply each cubic foot of air by .8.

For 50 degrees difference in temperature between indoors and outdoors multiply each cubic foot of air by .1.

Figuring that air is changed twice per hour doubles these factors.

The amount of radiation required to overcome the cooling effect of windows, doors and exposed walls, can be closely estimated by the table shown below.

Table Showing British Thermal Heat Unit Loss Per Square Foot Of Surface Per Hour, Through Various Building Materials

Type of Construction	Difference in temperature between outside air and air in room, in degrees Fahrenheit		
	30	40	50
Single window (good)	34	46	59
Single window (average)	36	48	61
8-inch brick wall	14	18	23
Door (⅓ glass)	17	22	28
Plain door	12	16	20
12-inch brick wall	9	13	16
16-inch brick wall	8	10	13
12-inch sandstone wall	16	20	25
16-inch sandstone wall	15	18	21
12-inch limestone wall	18	22	26
16-inch limestone wall	14	18	22
1½-inch pine plank	8	12	15
2-inch pine plank	8	10	13
Sheathing and clapboards	12	14	16
Sheathing paper and clapboards	8	10	12
Lath and plaster partition (1 side)	13	20	23
Lath and plaster partition (both sides)	10	13	16
¾-inch floor, lath and plaster below	8	10	13
1½-inch double floor, no plaster	9	11	14
Average frame	15	18	21
Average frame, back plastered	14	17	20
Average red brick, back plastered	14	17	20
Poor frame	20	24	28

For the concrete wall basement and the sheathing and clapboard wall the factor 14 is used with a difference of temperature of 40 degrees F.

Two changes of air per hour with a difference of .8 for a difference of 40 degrees F. equals 1.6 times the cubic content.

Window surface is reckoned as good and as single window factor 46. The following example is based on these ratings:

No allowances are made for floor or ceiling in this estimate, and in most flour mills need not be considered.

Example of the B. T. U. method of estimating radiation required in a flour mill.

Basement, 50 by 40 by 12 feet.

12 windows 75 sq. ft., good, (40° F. difference in temperature) factor 46 B. T. U. per square foot.

75 sq. ft. window surface, 46 x 75 equals 3450
Exposed wall surface, 1680 x 14 B. T. U. per sq. ft. = 23520
Cubic content 24000 cu. ft. x 2 changes of air x .8 = 38400

Div. by 240 B. T. U. per sq. ft. of ste'm rad'on 240) 65370
272 sq. ft. of radiation

First floor, 50 by 40 by 12 feet.

198 sq. ft. of window surface x 46 equals		9108
1160 sq. ft. of wall surface x 14 equals		16240
24000 cubic content x 1.6 equals		38400
240 B. T. U. per sq. ft. of heating surface	240	) 63748
		265 sq. ft. of radiation

Second floor, 50 by 40 by 10 feet.

198 sq. ft. of window surface x 46 equals		9108
1160 sq. ft. of wall surface by 14 equals		16240
24000 cu. ft. of space x 1.6 equals		38400
	Divide by 240	) 63748
		265 sq. ft. of radiation

Third floor, 50 by 40 by 10 feet.

330 sq. ft. of window surface x 46 equals		15180
1400 sq. ft. of wall surface x 14 equals		19600
20000 cubic content x 1.6 equals		32000
240 B. T. U. per sq. ft. of heating surface	240	) 66780
		278 sq. ft. of radiation

Fourth floor, 50 by 40 by 20 feet average

330 sq. ft. of window surface x 46 equals		15180
1600 exposed wall surface, exclusive of roof x 14		22400
Cubic content 40000 x 1.6		64000
240 B. T. U. per sq. ft. of radiation	240	) 101580
		423 sq. ft. of radiation

Total radiation B. T. U. Method

Basement	272
First floor	265
Second floor	265
Third floor	278
Fourth floor	423
	1503 sq. ft. of radiation

Comparison Of Radiation Estimates Obtained By The Different Methods For The Same Mill

	Installed at present	2-20-200	Carpenter's (Modified)	Factor	B. T. U.
Basement	300	178	284	350	272
First floor	392	277	290	362	265
Second floor	270	277	290	253	265
Third floor	252	335	296	217	278
Fourth floor	196	445	466	299	423
Square feet radiation	1,410	1,512	1.626	1,481	1,503

This mill was heated in the summer to destroy the insect pests. After 24 hours of heating the temperature was above the killing point excepting in the basement. Heating there was difficult, due to its being much lower than the heating plant. At the center it was 14 feet deep. The average depth was rated at 12 feet. The fourth floor was averaged at 20 feet in height, but was higher at the ridge and lower at the plate, the pitch of the roof making the average height 20 feet. The estimates given are for the minimum amount of radiation needed to get a killing temperature.

An excess of radiating surface increases the cost of the installation, but is a valuable asset since with it there is no need of forcing the system should there be a sudden drop in the temperature out of doors at the time of treatment in June or September. In old frame mills, where the siding has become warped and the openings are abundant, still days must be chosen in order to get a killing temperature, as a strong wind will force the heat to one side or out of the building.

Sizes, Heights And Amounts Of Radiation Per Section Are Given For A Few Types Of Radiators

Cast radiators	Three column		Four column	
	45 inches	38 inches	45 inches	38 inches
Square feet of heating surface per section	6 square feet	5 square feet	10 square feet	8 square feet

Wall radiators usually have 5, 7 or 9 square feet of heating surface per section.

Type and Location of Radiators.—The steam radiation installed may be of any type giving the necessary heating surface, but several things must be taken into consideration. Location of the radiating surface is important because the central part of the mill needs most of the heat. This will give to the elevator legs, spouts and machines the highest temperature, if the radiators are located somewhat centrally. This is sometimes inconvenient as the piping blockades needed space. The best compromise possible should be effected between convenience and essential location requirements for the pipes. The radiation should be easily cleaned, neat in appearance, and effective in use. It should not cost so much more than wrought pipe, that it becomes uneconomical to install it. The "more compact units of radiation", three-and-four-column tall radiators or wall radiators, require a minimum of labor to install, and are much easier to keep clean, if enameled or painted. The enameled, coated radiation surface is also about 20 percent more efficient than a bronzed surface, and is a little more efficient than the uncoated surface of the case radiator, besides requiring less labor to keep it clean.

The heating surface per foot in length of iron pipe for several of the commonly used sizes are appended, for the convenience of the miller in making an estimate of the number of feet of pipe needed in a mill. When the amount of radiating surface in square feet has been determined, 1 inch, 1¼ inch and 1½ inch pipe are the best sizes to use, and can be readily handled by any good pipe fitter.

Heating Surface Of Radiator Pipe

Length of pipe	Diameter of pipe	Square feet of heating surface
Feet	*Inches*	
3	1	1
7	1¼	3
2	1½	1
8	2	5
8	2½	6
1	3	1

THE MILLER CAN ESTIMATE FOR HIS OWN MILL

The estimation of the amount of radiation needed is not impossible for the average owner or operator of a flour mill. He ought to familiarize himself with all four methods of estimating outlined in this bulletin so he can check them against each other. These methods have not been used extensively by the owners or operators of flour mills but the writer feels sure that they will meet a need, and assist materially in getting many more mills equipped with an effective system for insect control.

Procedure in Heating.—The mill should be carefully cleaned before the heating is begun. In every modern mill some type of vacuum cleaner system is of much value in keeping the flour mill clean. Modern flour mill equipment eliminates much of the dust and dirt, but the cleaner of the vacuum type removes all of the dirt without being disagreeable and leaves practically no material in cracks or corners where insects can breed. The best modern construction eliminates, so far as possible, places where quantities of flour or other cereals may collect, and with the vacuum cleaner as an item of the equipment approaches perfection. The prevention of flour dust in the air of the mill is also important because it may be the means of obviating an explosion and a fire loss to follow.

All reserve or extra stocks of flour and feed should be moved out of the mill proper, as such stock will act as a place of refuge for insects when the mill is heated. Flour in sacks will require 4 or more days continuous exposure to the high temperature—130 to 140 degrees F.—before it will be heated through. This means that the cooler flour left in the mill will act as a refuge trap for every insect that comes near it before a killing temperature is reached.

Loosen all belt tighteners, but there is no need of moving the belts. Open all machines, take off all removable sections of spouts and elevators, so that the heat can reach such places. See that all openings leading outside are closed or well-covered, so the heated air cannot escape. Building paper tacked to the wall over the many openings will serve to retain the heat. Avoid leaks in the heating system, repairing any such as soon as possible. Any excess of moisture in the air because of wet floors is almost sure to prevent the heating of the mill to a killing temperature, unless an excess of radiating surface is provided.

Watch the Weather Bureau reports, and choose if possible warm days in June and September for heating the flour mill. The hotter the day, the less coal will be required to heat the flour mill to the 130 degree F., or approximately 55 degrees C. Estimates for radiation in flour mills are seldom for greater differences than 50 degrees F. between the indoor and outdoor temperatures. This means we must have 80 degrees F. or above, out of doors in order to get 130 degrees F. indoors. Most flour mills, if equipped with a normally good steam heating system, will require only a small amount of additional radiation to equip them for summer use against all destructive mill insects.

SUMMARY

1. Several species of insects consume cereal grains and mill products in storage. Some of them cause stoppage of work in mills and all of them are likely to be carried away from the mill in flour, meal, and such products, where they breed and multiply and which they devour and pollute with poisonous substances, deleterious to the health of men or animals.

2. If mills are equipped with a heating plant which can produce and maintain a temperature of 130 to 140 degrees F. for four days or more, practically all life stages of such insects will be destroyed.

3. The recommendations in this bulletin are based on successful heating plants installed in more than 30 mills in the states of Ohio and Pennsylvania.

4. Heat can be used for the destruction of susceptible insects on hardy plants, to destroy weevils in nuts and pests working in dried fruits, beans, peas, etc.

5. The germination of most seeds will not be interfered with by heating them sufficiently to kill insects working in them.

6. There is a difference in the amount of heat which the different life stages of each species of insect can withstand.

7. The drier the air, the less will be the amount of heat required to reach the killing point for insects.

8. The amount of radiation surface required for a steam heating plant, designed for killing insects, can be calculated for any mill by use of one of the four formulas given in this bulletin. All four formulas may be used in calculating for the same mill and the results checked against each other to secure accuracy.

9. After being satisfied that his plant has adequate capacity, and that all leaks from both the radiation system and mill are closed, the owner should choose, if possible, a warm, dry day in summer or fall and proceed to heat according to directions.