U. S. Department of Agriculture, Forest Service

FOREST PRODUCTS LABORATORY

In cooperation with the University of Wisconsin

MADISON, WISCONSIN

TEMPERATURES NECESSARY TO KILL FUNGI IN WOOD

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Published in
Proceedings of the
AMERICAN WOOD PRESERVERS' ASSOCIATION
1937

TEMPERATURES NECESSARY TO KILL FUNGI IN WOOD[1]

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INTRODUCTION

Because incipient decay in wood is frequently difficult to detect, poles, piling, cross ties, and heavy structural timbers which contain decay organisms are often considered sound. Operators of wood-preserving plants as well as the people who use treated materials frequently inquire whether the temperatures employed during treating processes are sufficient to kill any fungi that might be in the wood. Similar questions arise in connection with kiln drying. Hoxie[4], Hubert[5], Long[6], and Snell[7] reported the temperatures to which wood was subjected in order to kill fungi in it, but their data are of limited application, since no record was made of the internal temperatures obtained. MacLean[8], [9], [10], [11] recently showed that the internal temperature attained by wood under heat treatment

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[1]Presented before the 33rd annual meeting of the American Wood-Preservers' Association, New Orleans, La., January 26-28, 1937.

[2]The author wishes to express her appreciation to C. A. Richards and J. D. MacLean for their helpful suggestions and criticisms during the investigation reported in this paper, and to M. E. Dunlap and R. C. Rietz for their assistance in the construction of some of the apparatus used in the experiments.

[3]Maintained at Madison, Wis., in cooperation with the Forest Products Laboratory.

[4]Hoxie, F. J. Dry rot in factory timbers. Inspection Dept., Associated Factory Mutual Fire Insurance Companies, Boston, pp. 23-38. 1930.

[5]Hubert, E. E. The heat treatment of infected wood. Hardwood Record 57 (12): 15, 18, 20, Oct. 10, 1924; 58(1): 18, 20, Oct. 25, 1924.

[6]Long, W. H. When is rot not rot? Amer. Wood-Preservers' Assn. Proc. 1925, pp. 202-219; and 1927, pp. 70-77.

[7]Snell, W. H. The effect of heat upon the mycelium of certain structural timber-destroying fungi within wood. Amer. Jour. Bot. 10:399-411. Oct. 1923.

(Footnotes 8, 9, 10, 11 on page 2.)

depends upon the species of wood used, the dimensions and moisture content of the materials, as well as the temperature and time to which the wood is exposed.

The purpose of the investigations reported here was to determine the internal temperatures and their durations necessary to kill certain fungi in wood.

METHODS

Sapwood sticks cut from green loblolly pine (Pinus taeda Linn.) 1 by 1 by 10 inches, were placed in 500 by 50 mm test tubes containing 50 cc of distilled water. Each stick was supported on glass so that its lower end came within 1/2 inch of the surface of the water. The tubes were then plugged with cotton and sterilized by steaming for 30 minutes at 212° F. After the wood cooled it was inoculated with either Poria incrassata (B. & C.) Burt., Lenzites sepiaria Fr., or Lentinus lepideus Fr. The first named is the most common building rot fungus in the South, and the others are common decay fungi in pine products. These sticks were incubated at room temperature (72° to 90° F.) until they were thoroughly infected with the fungus. This usually required a period of 4 to 6 weeks. In order to determine whether the sticks were thoroughly infected, 1 out of each 10 (selected at random) was split and 12 bits of wood (about 1/8-inch cubes) were cut from the interior and planted on malt agar. Any fungi living in the sticks grew out on the agar.

When the sticks were thoroughly infected, they were removed from the tubes and the surface fungous growth was removed by scraping. One inch was sawed from each end of the sticks for moisture determinations. These moisture samples were weighed immediately and dried in a drying oven (212° F.) for 24 hours or more and weighed. The moisture content was determined by the following formula:

$$\text{Moisture percentage} = \left(\frac{\text{original weight - oven-dry weight}}{\text{oven-dry weight}}\right) 100$$

The sticks were heated either in steam, between hot plates, or in hot air. A record was kept of the internal temperatures in the wood and

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[8] MacLean, J. D. Studies of heat conduction in wood. Results of steaming green round southern pine timbers. American Wood-Preservers' Assn. Proc. 1930, pp. 197-219.

[9] _____ Studies of heat conduction in wood. Pt. II. Results of steaming green sawed southern pine timbers. Amer. Wood-Preservers' Assn. Proc. 1932, pp. 303-330.

[10] _____ Temperatures in green southern pine timbers after various steaming periods. Amer. Wood-Preservers' Assn. Proc. 1934, pp. 355-373.

[11] _____ Temperature and moisture changes in Coast Douglas fir. Amer. Wood-Preservers' Assn. Proc. 1935, pp. 77-103.

the temperatures applied at the surfaces of these sticks. MacLean's method of measuring internal temperatures was followed. A thermocouple was inserted in a 1/16-inch hole that extended approximately to the center of the stick (Fig. 1). A white pine peg was used to plug the hole and hold the thermocouple in place during heating. Care was taken not to bind the thermocouple with the peg.

The methods of heating the sticks were as follows: In an autoclave at 212° F.; between two heated plates at 212°, 194°, 185°, 167°, and 149° F.; and in an electric drying oven at 194°, 185°, 167°, and 149° F. with relative humidities ranging from 35 to 40 percent and 90 to 97 percent.

Preliminary tests were run with each heat treatment to narrow the range of temperature and heating periods that would kill the fungi. More extensive tests were then run using these critical ranges.

Sticks to be heated with steam (212° F.) were placed on a wire rack in a preheated autoclave (26 by 36 inches). Two records of the temperature within the autoclave were taken: one with a thermocouple leading from near the stick (about 1 inch away) through a rubber stopper in an opening at the top of the autoclave to a potentiometer indicator; and one taken with a thermometer built into the autoclave so that it measured the temperature 3 inches from the top. The internal temperature of the stick was measured with a thermocouple placed inside the stick, as already explained (Fig. 1).

Sticks heated by the plate method were placed between hollow cast iron baffle plates (3 by 18 by 18 inches), which were heated by hot circulating motor oil (Fig. 2). The oil, heated in a tank by an electric heater, was circulated through the plates as indicated in the diagram. The temperature of the oil, and, consequently, the temperature of the plates, was held constant while the specimens were heated. The temperature of the plates was measured on the top and bottom by thermocouples. A specimen heated between the plates was flanked on the sides with two pieces of wood the same size as the specimen to prevent evaporation of moisture.

The use of heated plates for temperature studies on wood was initiated by MacLean of the Forest Products Laboratory. The hot-plate method was adopted in order to heat wood specimens below the temperature of steam (212° F.) and yet employ a method of heating similar to steam in its effect on green wood.

The apparatus used to heat the wood specimens in moist air was a constant temperature drying oven with an automatic humidifier. In brief, the humidifying system consisted of a wood-element hygrostat[12] set on the

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[12] Loughborough, W. K., and Rietz, R. C. A sensitive wood element hygrostat. Instruments 5(6):143-144, A15, June 1932.

inside of the oven, which, through an electrically controlled circuit, operated a water evaporator. The relative humidity was determined by the dew point method[13] and the wet and dry bulb method. An electric fan was used to circulate the air in order to maintain a uniform temperature and humidity within the oven. The internal temperature of the sticks and the temperature of the oven were recorded as described for the steaming experiments.

As soon as the heated sticks were cooled they were split. From 6 to 8 small pieces were taken from the radial face of one of the sections of the stick, as shown in Figure 1, and planted on sterile malt agar. These transplants were kept at room temperature for at least 3 weeks before records were taken on the presence or absence of fungous growth. If no growth occurred it was concluded that the fungus had been killed by the heat to which the piece had been exposed.

RESULTS AND RECOMMENDATIONS

The results obtained from heating sticks infected with Lentinus lepideus, Lenzites sepiaria, or Poria incrassata at different temperatures applied at the surface for different lengths of time are recorded in Table 1. Table 2 shows, for the external temperatures applied, the minimum duration of heating required to kell the fungi, and the average internal temperatures of the sticks at intervals during the heating, for each of the heating methods. Each temperature shown in Table 2 is an average of 8 or more determinations. Table 2 also shows, for sticks heated in air with a relative humidity of 35 to 40 percent, the internal temperatures at intervals during a 12-hour period for an external temperature that failed to kell the fungus during the period. Lentinus lepideus and L. sepiaria were consistently more resistant to heat than P. incrassata.

Of the three fungi tested, L. sepiaria was the most resistant to heat; however, there was not a great deal of difference between the resistances of this fungus and L. lepideus. The results obtained from heating sticks infected with L. sepiaria were used to plot the curves shown in Figure 3.

A given internal temperature required a longer period to kill fungi when the sticks were in an atmosphere of 35 to 40 percent relative humidity than when in one of 90 to 97 percent (Fig. 3). Since the atmosphere within the sticks heated between plates was almost saturated, one would expect the length of time required to kill at a given temperature in the case of sticks heated between plates would be little different from that required in air at 90 to 97 percent relative humidity. This is verified by results shown in Figure 3. In two out of three comparable temperatures in these two treatments the duration required to kill was the same. In one case, 149° F., the duration required to kill was somewhat longer in the moist air, 90 to 97 percent relative humidity.

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[13] Marvin C. F. Vapor pressure, relative humidity, and temperature of the dew point. U. S. Dept. Agr. Weather Bureau, No. 235, p. 11. 1915.

There seemed to be no difference in the effect of moisture content of sticks from 30 to 100 percent on the killing of the fungi.

On the basis of the results shown in Figure 3, recommendations on the length of time wood must be heated at certain temperatures in order to kill fungi may be made. The recommended heating periods given in Table 3 were based on the time of heating after the temperature reached approximately 150° F. For instance, the data showed that Lenzites sepiaria was killed after it was heated by the plate method 51 minutes at 149° F.; however, 60 minutes at 150° F. was considered a desirable time-temperature to be recommended in order to be on the safe side. Information regarding the length of time a given temperature must be applied to the surface of wood of different sizes in order for the wood to reach a certain internal temperature at a given point in the wood may be secured from MacLean's[8], [9], [10], [14] charts. The information in these charts applies to wood heated either in steam or hot oil. As yet no work has been published showing the conduction of heat in wood heated in air. The results of experiments reported here show that temperature rise in sticks heated in air with a relative humidity of 90 to 97 percent was just as rapid as the rise in sticks heated between plates, and much more rapid than the rise in temperature within sticks heated in air with a relative humidity of only 35 to 40 percent. All sticks treated had a moisture content above fiber saturation, which meant that unless the relative humidity of the air in which they were heated was near saturation, moisture would evaporate from the sticks. The temperature within a stick would not rise to the temperature applied at the surface of the wood until evaporation no longer took place, because of the cooling effect of the evaporation.

CONCLUSIONS

The results indicate that any of the three fungi tested will be killed if the temperature in the wood is maintained for 60 minutes at 150° F., 30 minutes at 170° F., 20 minutes at 180° F., 10 minutes at 200° F., or 5 minutes at 212° F., providing the moisture content of the wood remains above fiber saturation during treatment. This condition will exist as long as the medium through which heat is appliedat the surface of wood (for example, steam or oil) allows little water loss.

The results obtained from heating infected wood in air with 35 to 40 percent relative humidity indicate that higher temperatures or longer periods of exposure than those mentioned above are required to kill fungi within wood where conditions surrounding the wood allow it to dry out during treatment.

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[14] MacLean, J. D. Manual on preservative treatment of wood by pressure. U. S. Dept. Agr. Misc. Pub. No. 224. Aug. 1935.

Table 1.--The results obtained from heating 1 by 1 by 8 inch Pinus taeda sticks infected with fungi at various temperatures for different lengths of time

149° F. Applied at Surface of Sticks

Fungus	Length of time heated	Method of heating: Hot plate: Number of sticks treated	Hot plate: Percent of sticks with fungus dead	Moist air, Relative humidity -- 90 to 97 percent: Number of sticks treated	90 to 97 percent: Percent of sticks with fungus dead	Moist air, Relative humidity -- 35 to 40 percent: Number of sticks treated	35 to 40 percent: Percent of sticks with fungus dead
	Minutes						
Poria incrassata	6	3	67				
	20	3	100			9	100
	30	10	100	8	100	25	100
	60					4	100
	120					4	100
Lentinus lepideus	20	2	0				
	30	2	50				
	45	3	67				
	60	10	40			4	0
	75	10	100	10	40		
	90			7	86		
	120			8	100	4	0
	180					4	25
	300					6	0
	420					5	100
	720					17	88
Lenzites sepiaria	20	2	0				
	30	2	0				
	45	3	33				
	60	9	67			4	0
	75	10	100	9	67		
	90			7	71		
	120			8	100	4	0
	180					4	0
	300					6	17
	420					5	60
	720					17	82

(continued on next page)

Table 1 (continued)

167° F. Applied at Surface of Sticks

Fungus	Length of time heated	Method of heating: Hot plate		Moist air: Relative humidity -- 90 to 97 percent		Moist air: Relative humidity -- 35 to 40 percent	
	Minutes	Number of sticks treated	Percent of sticks with fungus dead	Number of sticks treated	Percent of sticks with fungus dead	Number of sticks treated	Percent of sticks with fungus dead
P. incrassata	20	10	100	10	100	16	100
	60					4	100
L. lepideus	20	3	67				
	30	10	100	10	100		
	45	1	100				
	60	1	100			4	50
	75					4	50
	90					4	75
	120					6	17
	180					11	100
	240					10	100
L. sepiaria	20	3	100				
	30	10	100	10	100		
	45	1	100				
	60	1	100			4	50
	75					4	25
	90					4	25
	120					6	0
	180					11	91
	240					10	100
185° F. Applied at Surface of Sticks							
P. incrassata	5	10	20				
	10	10	100	10	100	22	100
	20					21	100
	30					7	100
	45					4	100
L. lepideus	20	10	80			2	0
	25	10	100	10	100		
	30	1	100			10	70
	45	1	100			10	90
	60					13	92
	75					10	100
	90					6	100

(continued on next page)

Table 1 (continued)

185° F. Applied at Surface of Sticks (continued)

Fungus	Length of time heated	Method of heating: Hot plate: Number of sticks treated	Hot plate: Percent of sticks with fungus dead	Moist air, Relative humidity -- 90 to 97 percent: Number of sticks treated	90 to 97 percent: Percent of sticks with fungus dead	Moist air, Relative humidity -- 35 to 40 percent: Number of sticks treated	35 to 40 percent: Percent of sticks with fungus dead
	Minutes						
L. sepiaria	20	10	50			2	0
	25	10	100	10	100		
	30	1	100			10	20
	45	1	100			10	50
	60					13	100
	75					10	100
	90					6	100
		194° F. Applied at Surface of Sticks					
P. incrassata	5	10	90				
	10	10	100			28	100
	20					4	100
	30					3	100
L. lepideus	10	3	33			2	0
	20	10	100			10	40
	30	1	0			9	89
	45					12	100
	60					11	100
L. sepiaria	10	3	100			2	0
	20	10	100			10	10
	30	1	100			9	33
	45					13	69
	60					11	100

(continued on next page)

Table 1 (continued)

212° F. Applied at Surface of Sticks

Fungus	Length of time heated	Method of heating: Hot plate		Moist air: Relative humidity -- 90 to 97 percent		Moist air: Relative humidity -- 35 to 40 percent	
	Minutes	Number of sticks treated	Percent of sticks with fungus dead	Number of sticks treated	Percent of sticks with fungus dead	Number of sticks treated	Percent of sticks with fungus dead
P. incrassata	3			*20	*100		
	5	10	100	*20	*100		
	15			* 3	*100		
L. lepideus	5	2	100	* 6	* 50		
	6	1	100	* 7	* 57		
	10	10	100	*20	*100		
	15	10	100	* 3	*100		
	30			* 1	*100		
L. sepiaria	5	2	50	* 6	* 67		
	6	1	100	* 7	* 71		
	10	10	50	*20	*100		
	15	10	100	* 3	*100		
	30			* 1	*100		

*Heated in steam.

Table 2.--Temperature changes within 1 x 1 x 8 inch sticks infected with fungi

HEATED IN MOIST AIR - 35 TO 40 PERCENT RELATIVE HUMIDITY

Fungus	Temperature applied at surface	Length of time heated	Internal temperatures at various intervals (Minutes)																		Results
			0	3	6	9	12	15	18	21	24	27	30	45	60	75	90	105	120	180	240	480	720	
	° F.	Minutes	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.	
L. lentinus lepideus	149	720	77	95	111	118	124	126	129	132	132	133	133	137	138	139	140	141	142	144	145	147	147	Growth
L. sepiaria	149	720	77	98	111	120	123	127	129	130	131	133	134	136	138	139	141	141	142	143	144	146	148	Do.
Poria incrassata	149	30	79	87	98	110	117	122	125	127	131	133	135											No growth
L. lepideus	167	240	73	88	104	118	126	133	136	138	144	144	144	147	149	149	149	------	151	152	154			Do.
L. sepiaria	167	240	81	100	118	129	136	138	142	142	144	145	147	149	151	152	153	153	154	156	158			Do.
P. incrassata	167	20	73	95	115	126	131	135	136	[1]138														Do.
L. lepideus	185	75	81	104	120	136	144	151	------	154	156	158	158	162	163	165								Do.
L. sepiaria	185	75	75	102	------	133	[2]142	145	151	154	154	154	156	158	158	162								Do.
P. incrassata	185	10	82	102	120	136	[2]144																	Do.
L. lepideus	194	60	73	118	140	147	154	158	162	163	163	165	165	169	171									Do.
L. sepiaria	194	60	81	108	127	142	147	154	154	158	158	160	162	166	169									Do.
P. incrassata	194	10	81	102	122	136	[2]146																	Do.

HEATED IN MOIST AIR - 90 TO 97 PERCENT RELATIVE HUMIDITY

L. lepideus	[3]149	120	86	111	129	136	142	145	147	147	149	149	149	149	149	149	149	149	149					No growth
L. sepiaria	[3]149	120	82	104	120	133	140	144	145	145	147	147	149	149	149	149	149	149	149					Do.
P. incrassata	[3]149	30	86	106	122	133	142	145	147	149	149	149	149											Do.
L. lepideus	[3]167	30	82	111	135	154	163	165	167	167	167	167	167											Do.
L. sepiaria	[3]167	30	82	108	140	158	165	167	167	167	167	167	167											Do.
P. incrassata	[3]167	20	84	106	133	147	156	160	163	[1]165														Do.
L. lepideus	[3]185	25	90	120	149	163	171	176	178	180	[4]180													Do.
L. sepiaria	[3]185	25	88	104	138	156	[2]169	174	178	180	[4]181													Do.
P. incrassata	[3]185	10	86	117	151	165	[2]169																	Do.

HEATED BETWEEN PLATES

L. lepideus	149	75	72	93	109	124	129	135	138	142	145	147	149	149	149	149								No growth
L. sepiaria	149	75	73	93	113	126	136	142	145	147	149	149	149	149	149	149								Do.
P. incrassata	149	30	73	88	106	118	131	136	142	142	144	144	145											Do.
L. lepideus	167	30	68	88	109	124	136	144	145	154	160	160	162											Do.
L. sepiaria	167	30	70	90	109	126	138	149	153	[1]160	162	165	165											Do.
P. incrassata	167	20	72	91	111	126	138	145	151	[1]154														Do.
L. lepideus	185	25	70	88	122	138	154	163	171	174	178	[4]180												Do.
L. sepiaria	185	25	77	99	135	[2]151	163	171	176	180	181	[4]183												Do.
P. incrassata	185	10	71	91	128	[2]146																		Do.
L. lepideus	194	20	73	93	122	142	158	169	176	[1]180														Do.
L. sepiaria	194	20	72	95	124	145	[2]160	172	178	[1]181														Do.
P. incrassata	194	10	72	95	124	142	[2]147																	Do.
L. lepideus	212	15	73	106	136	160	178	189																Do.
L. sepiaria	212	15	73	111	[5]147	172	187	198																Do.
P. incrassata	212	5	72	95	[5]104																			Do.

HEATED WITH STEAM (212° F.)

L. lepideus	212	10	73	131	181	205	[2]208																	No growth
L. sepiaria	212	10	73	131	[5]185	205	[2]208																	Do.
P. incrassata	212	5	75	115	[5]154																			Do.

[1] Surface temperature applied 20 minutes.
[2] Surface temperature applied 10 minutes.
[3] Wet-bulb reading.
[4] Surface temperature applied 25 minutes.
[5] Surface temperature applied 5 minutes.

Table 3.--Time-temperatures recommended to kill fungi in wood[1]

Heated in steam or equivalent		Heated in air			
		90 to 97 percent relative humidity		35 to 40 percent relative humidity	
Temperature	Time	Temperature	Time	Temperature	Time
° F.	Minutes	° F.	Minutes	° F.	Minutes
150	60	150	100		
				160	190
				165	60
170	30	170	30	170	50
180	20	180	20		
200	10				
212	5				

[1] The temperature is the temperature of the wood and not the temperature applied at the surface of the wood.

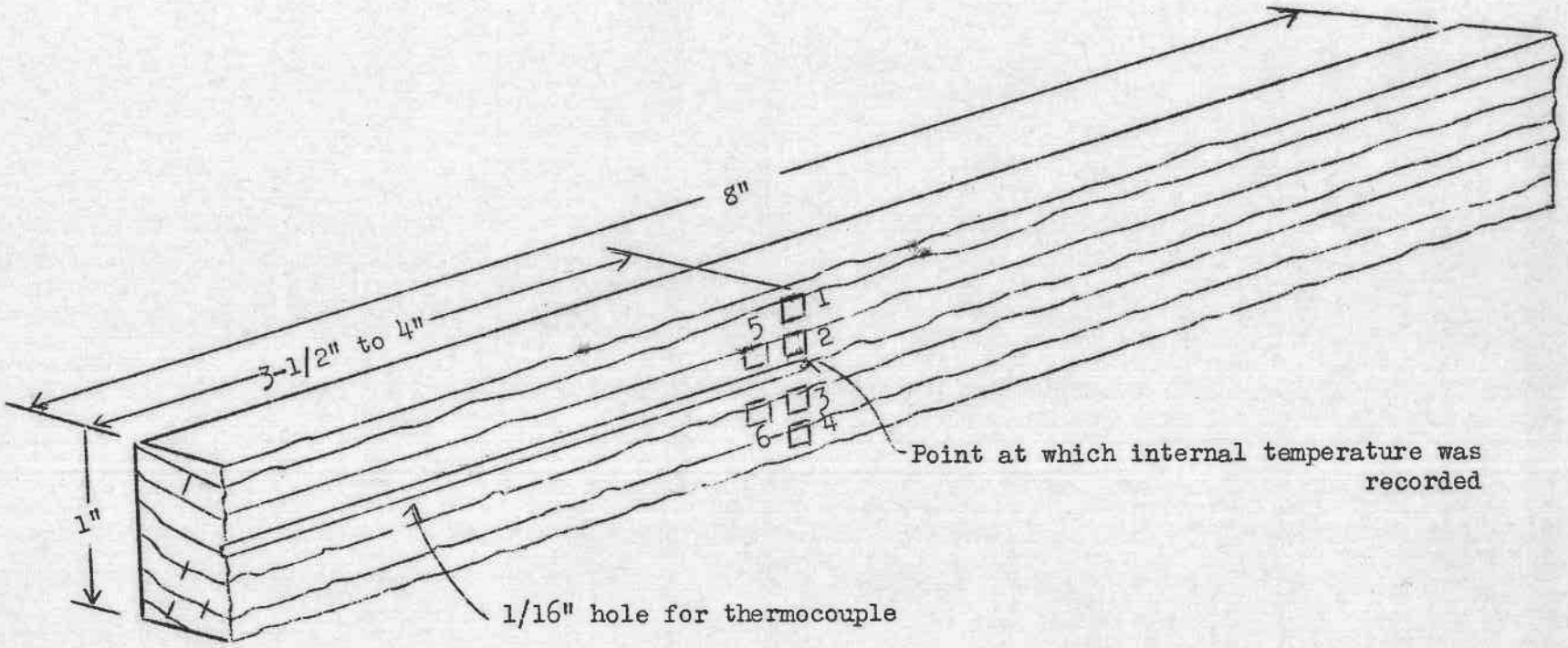


Figure 1.—Split section of specimen showing where transplants 1 to 6 were taken.

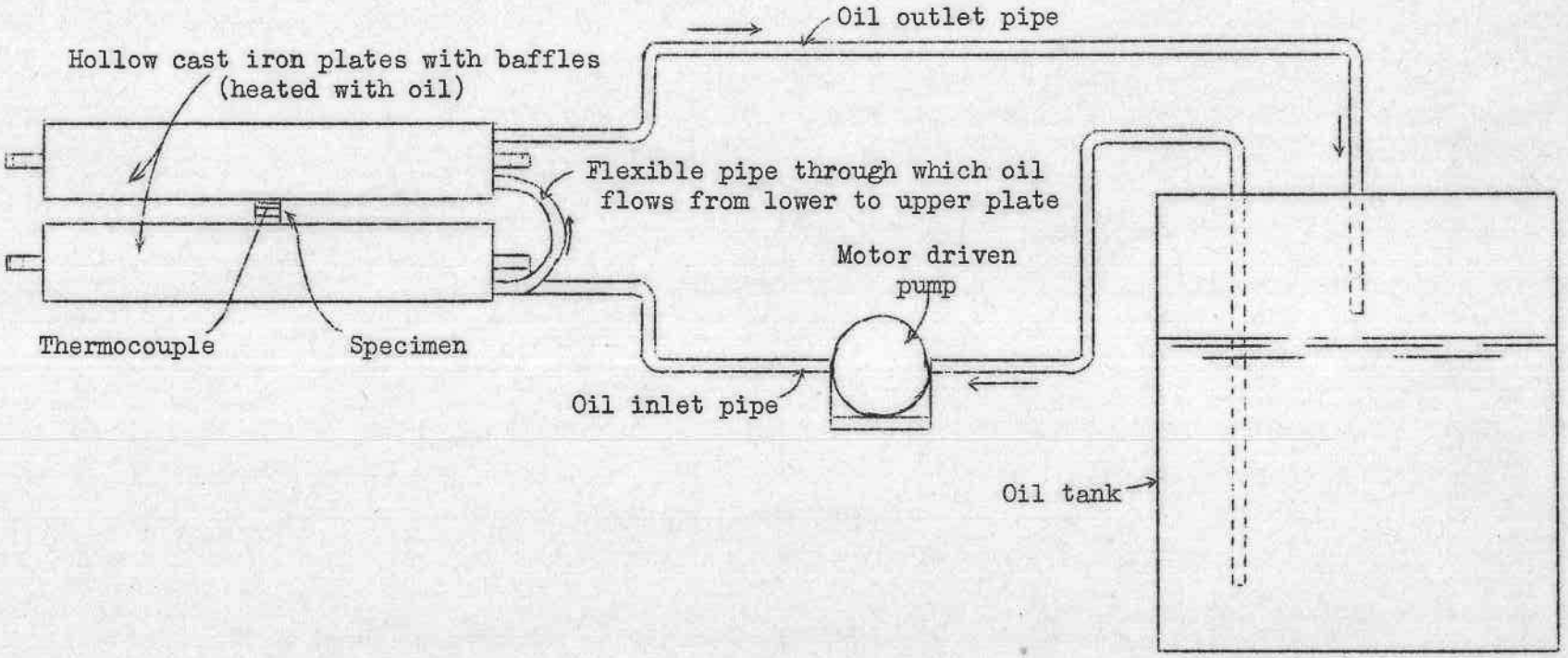
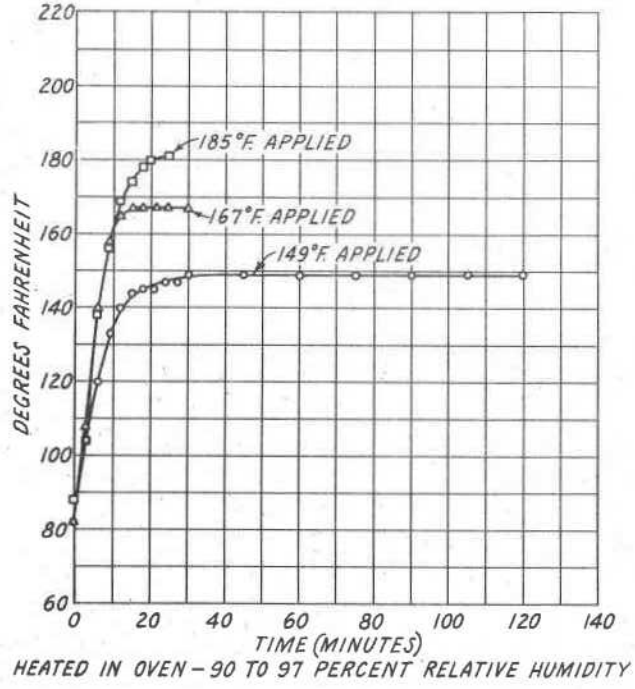
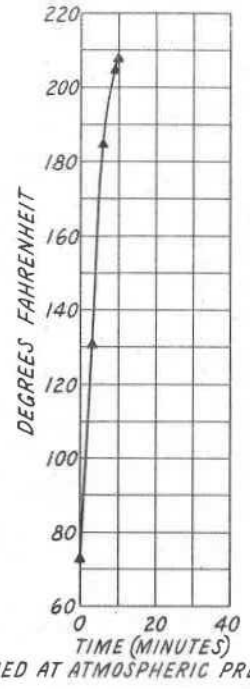


Figure 2.--Diagram of hot plates and heating units designed by MacLean

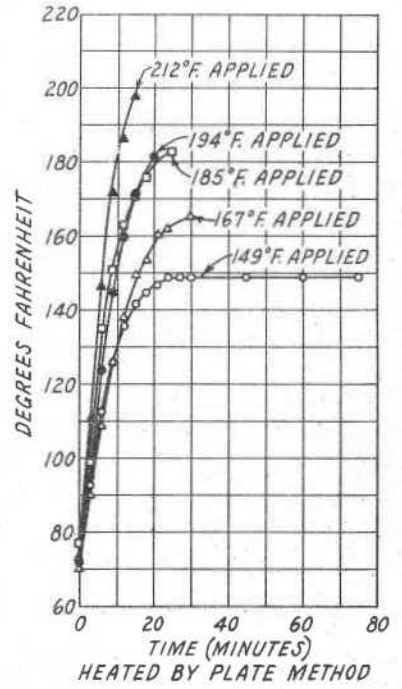
Figure 3.--Temperature changes within 1 x 1 x 8 inch *Pinus taeda* sticks infected with *Lenzites sepiaria*. Points on curves represent the time intervals at which internal temperatures were recorded. The last point on curves (except curve representing 12 hours at 149° F. in moist air -- see Table 1) represents the time required to kill fungi within the sticks. The numbers inserted on the curves represent the temperatures applied at surface of sticks.



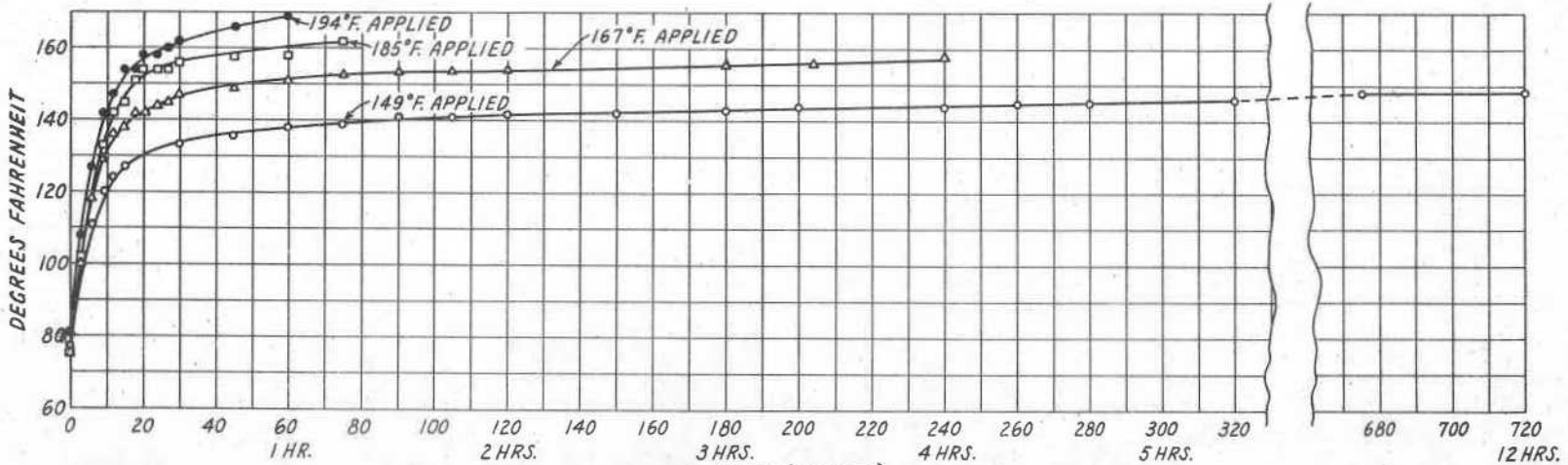
HEATED IN OVEN – 90 TO 97 PERCENT RELATIVE HUMIDITY



STEAMED AT ATMOSPHERIC PRESSURE (212°F.)



HEATED BY PLATE METHOD



HEATED IN OVEN – 35 TO 40 PERCENT RELATIVE HUMIDITY

TEMPERATURE CHANGES WITHIN 1x1x8 INCH PINUS TAEDA STICKS INFECTED WITH LENZITES SEPIARIA