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EFFECT OF KILN DRYING, STEAMING, AND AIR SEASONING ON CERTAIN FUNGI IN WOOD.[1]

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[In Cooperation with the Forest Products Laboratory of the Forest Service.]

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INTRODUCTION.

Among lumbermen and kiln-drying experts the belief is general that the temperatures and humidities used in the various commercial kiln runs and steaming processes, with the exception of stock that requires low temperatures and high humidities, are efficient in killing the various stain and decay producing fungi found in lumber and other wood products. Accurate tests to support this belief have never been made. It was the object of this study to determine whether the fungi in lumber are killed under ordinary commercial kiln conditions and steaming processes and to gain some idea of the minimum time and temperature limits necessary to kill these organisms. Such information has a wide application in the steaming processes commonly applied to gum, poplar, and other hardwoods previous to air seasoning and to the steaming of billets in the cooperage and other industries. It also has a very important bearing upon the sterilization of ties, posts, and poles and of mine, bridge, and building timbers when treated by a preservative process where

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Acknowledgments are due to Miss A. M. Waterman for aid in culturing some of the test blocks; to members of the section of timber physics, Forest Products Laboratory, for aid and advice in handling the dry kilns; and to Dr. C. J. Humphrey for advice in outlining the project and furnishing samples of infected wood.

heat is introduced as a preliminary steaming or during impregnation, or both.

The application of heat as a method of sterilization has a wide field. In most of the kiln-drying and steaming processes now in use where sufficiently high temperatures are used it serves the double purpose of seasoning and sterilizing the wood. However, in many of the steaming processes used primarily for the purpose of softening the wood little or no attention is paid to the sterilization of the stock. Adjustments in temperatures and periods of heating may not only result in the killing of such fungi present in the wood before treatment but may prove beneficial in rapidly drying the surface of the wood during subsequent air seasoning and thus aid in the prevention of sap stains, molds, and decay. The slack cooperage industry presents among others one notable case for experimentation along these lines.

In the preservative treatment of wood where heat is used during the process the sterilization of the inner portions of the wood not penetrated by the preservative is often desirable. Very often ties, posts, poles, and timbers of various kinds contain before treatment certain active decay organisms which are fully capable of reviving under favorable conditions, continuing the decay process, and eventually weakening the wood. Sterilization would not only greatly reduce the chances of loss from such a source, but would make it possible to utilize for less exacting purposes material containing to a limited extent certain types of incipient decay.

In this connection it is necessary to take into account several factors, among which the efficiency of the preservative, the relative absorptivity, and the strength qualities of the infected wood are paramount.

In the control of blue stain in lumber the use of chemical dips can at best protect only the surfaces of the wood against the stain organisms. In case the fungus is already present in the log before it is sawed into boards the dip solution has no effect upon the fungus within the board. Heat treatment in conjunction with the chemical action therefore would greatly increase the protection against blue stain.

Steaming is the common method of applying heat in most of the commercial operations connected with the production and manufacture of wood, although electricity may be used effectively in some cases. Directing an electric current through wood has been tested in this country, in France, and in Australia as a rapid method of seasoning,[2] and it is conceivable that the electric current may be used to advantage in the sterilization of wood, particularly as a means of checking incipient decay of structural timbers in buildings, ships, bridges, or other structural units where it may be found impracticable to apply other means of heating.

PREVIOUS WORK.

Both Hoxie (*2*)[3] and Snell (*8*, *9*) have contributed to the subject of the effect of heat on fungi in wood. Hoxie tried the experi-

[2] Menzel, C. A. Preliminary experiment in the drying of wood by passing an electric current through it. U. S. Dept. Agr., Forest Serv., Forest Products Lab. Unpublished manuscript. 1921.

[3] The serial numbers (italic) in parentheses refer to "Literature cited," at the end of this bulletin.

ment of heating a mill, the timbers of which were infected with dry rot, to about 115° F. The heat was applied from Saturday noon until Monday morning on four different occasions. Hoxie states that specimens were cultivated from 40 of the badly rotted beams and only 4 showed living fungi. The fungus in this case was given as *Merulius lachrymans*, which is particularly sensitive to heat. Snell, using ¾-inch blocks of spruce artificially inoculated with *Lenzites sepiaria*, *Lenzites trabea*, *Trametes serialis*, *Lentinus lepideus*, and *Trametes carnea*, respectively, subjected these blocks to both moist and dry heat at varying temperatures and periods of time. The results of his tests indicate that moist heat is much more effective in killing the fungi than dry heat. None of the fungi within these blocks were able to withstand 131° F. for 12 hours at moist heat, while it took a heat of 221° F. for 12 hours to kill all the fungi with dry heat. The experimental data are limited to tests on ¾-inch blocks, but statements are made that the temperatures employed in the kiln drying of lumber and in the various wood-preservation processes are sufficient to kill any fungi within the wood.

MATERIAL USED IN THIS STUDY.

The first lot of material consisted of 18 pulp logs of northern white spruce (*Picea canadensis*)[4] shipped in from northern Wisconsin. Six wood-destroying fungi were found infecting this material. In some cases the rots of two fungi were present in the same log; as, for example, *Polyporus anceps* in the sapwood and *Trametes carnea* in the heartwood, a faint colored zone showing at the junction of the two kinds of rot.

The second lot consisted of a carload of mixed hardwood and conifer logs 16 feet long shipped in from the Menominee Indian Mills, Neopit, Wis. These logs were selected by the writer from standing green trees on the logging area. An attempt was made to find trees with fruiting bodies of the attacking fungus attached, but this was not possible in all cases. A total of 23 logs representing 9 hosts and several wood-destroying fungi comprised the shipment, a detailed list of which is given on a succeeding page. The blue-stain fungus (*Ceratostomella* sp.) was found in three of the hosts and *Torula ligniperda* in two hosts. Dark brownish and black discolorations extending the full length of the log were found bordering the incipient decay of the brown cubical rot of tree No. 3 (eastern white pine) and trees Nos. 8 and 9 (eastern hemlock). Upon examining sections of the dark-colored wood under the microscope, typical spore chains of *T. ligniperda* were observed within the wood cells. The association of this stain-producing fungus with typical wood-destroying fungi in decaying wood is apparently quite general (*6*).

At the laboratory sawmill, disks 3 inches thick were cut from the middle point of each log. These disks were numbered and the decay area sketched upon record cards. Photographs taken of some of these disks show the types of infection. (Pl. I.)

There was some doubt as to the identity of the fungus causing the rot in tree No. 18, basswood (*Tilia americana*). The butt log showed a slight hollowing at the base, and within this hollow there

[4] Authorities for the scientific names are given in the list on page 4.

developed during storage several large yellow-colored mushrooms, tentatively determined as a species of Pholiota. Later, a block of the rotted wood was placed in the humidity room and kept moist. In about a month several typical sporophores of *Pholiota adiposa* were produced (Pl. II). Typical sporophores have also been produced on malt-agar cultures.

The third lot of infected logs consisted of a carload shipment of Douglas fir (*Pseudotsuga taxifolia*) and incense cedar (*Libocedrus decurrens*) shipped by Dr. J. S. Boyce from Oakridge, Oreg. The Douglas fir logs contained rots caused by *Trametes pini*, *Polyporus schweinitzii*, and *Fomes laricis*. The incense-cedar logs contained the rot caused by *Polyporus amarus*. The shipment consisted of 32 logs each 16 feet long, the total scaling 7,790 feet, board measure.

A few logs of *Alnus oregona*, intended for pulping experiments but rejected when found infected with *Polystictus hirsutus* and *Polystictus versicolor*, were also used in the study, as well as some miscellaneous material listed on the following pages.

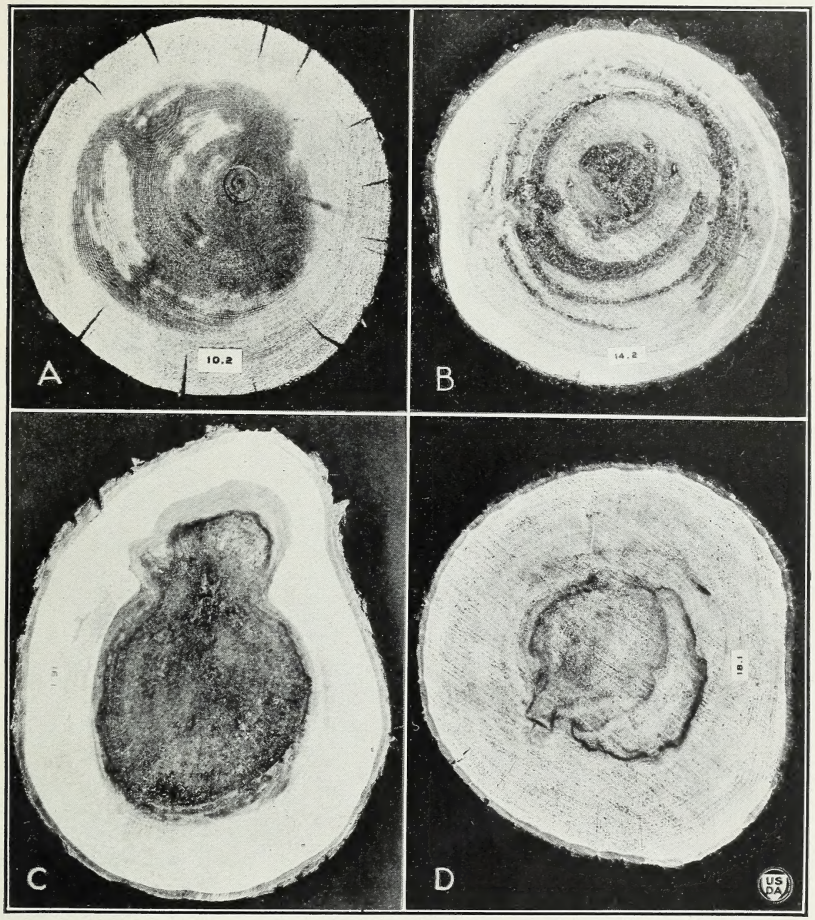
List of fungi and hosts.

Shipment from Port Edwards, Wis.:
- *Polystictus hirsutus* Fr. in northern white spruce (*Picea canadensis* (Mill.) B. S. P.).
- *Polyporus anceps* Pk. in northern white spruce.
- *Lenzites sepiaria* Fr. in northern white spruce.
- *Trametes carnea* Nees. in northern white spruce.
- *Polystictus abietinus* Dicks. in northern white spruce.
- *Trametes pini* (Thor.) Fr. in northern white spruce.
- *Fomes pinicola* Swartz in northern white spruce.

Miscellaneous material:
- *Polyporus anceps* Pk. Murr. in western yellow pine (*Pinus ponderosa* Laws.).
- *Polystictus hirsutus* Fr. and *P. versicolor* Fr. in red alder (*Alnus oregona* Nutt.).
- Blue stain in *Liquidambar styraciflua* L.
- *Alternaria* sp. in *Pinus rigida* Mill.
- *Trametes pini* in *Pinus banksiana* Lamb.

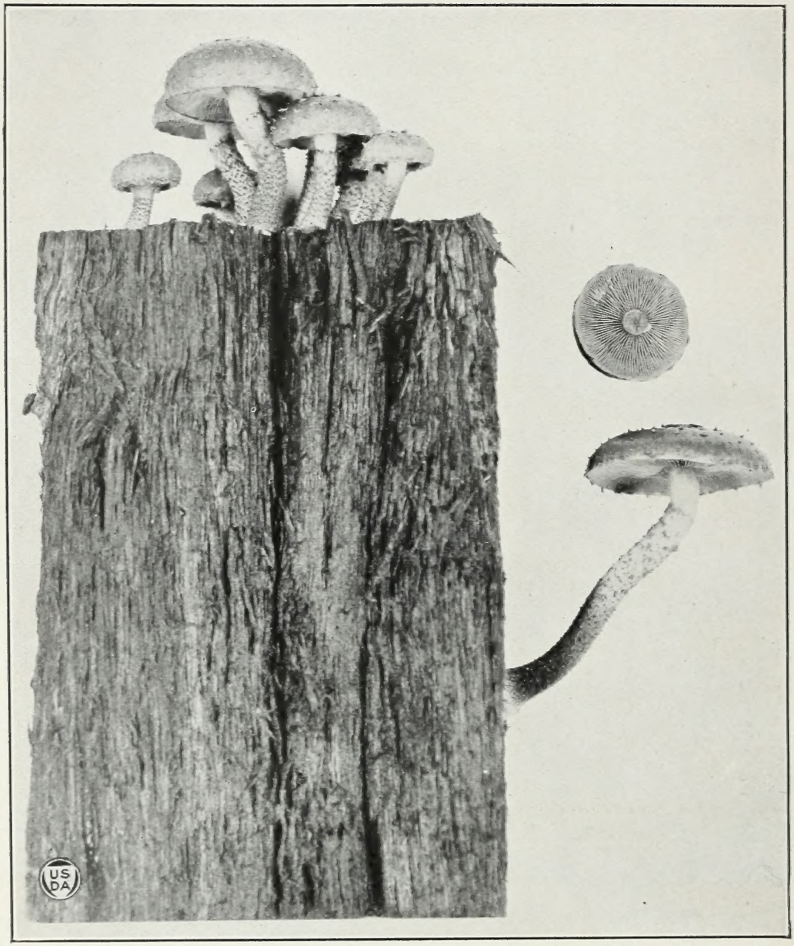
Shipment from Neopit, Wis.:
- *Trametes pini* in larch or tamarack (*Larix laricina* (Du Roi) Koch).
- Brown cubical rot in white pine (*Pinus strobus* L.).
- *Ceratostomella pilifera* Fr. and *Torula ligniperda* (Willk.) Sacc. in white pine.
- Brown cubical rot in northern white cedar (*Thuja occidentalis* L.).
- Blue stain in northern white cedar.
- Brown ring-rot in northern white cedar.
- *Fomes pinicola* in hemlock (*Tsuga canadensis* (L.) Carr.).
- *Torula ligniperda* (Willk.) Sacc. in hemlock.
- Brown cubical rot in hemlock.
- *Ganoderma tsugae* Murrill in hemlock.
- *Fomes fomentarius* Fr. in paper birch (*Betula papyrifera* Marsh.).
- *Fomes igniarius* (L.) Gillet in white elm (*Ulmus americana* L.).
- *Trametes pini* in white pine.
- Brown cubical rot in northern white cedar.
- *Fomes igniarius* in red maple (*Acer rubrum* L.).
- *Trametes pini* in larch (*Larix laricina*).
- *Pholiota adiposa* Fr. in basswood (*Tilia americana* L.).
- *Polyporus borealis* in sugar maple (*Acer saccharum* Marsh.).

Shipment from Oakridge, Oreg.:
- *Trametes pini* in Douglas fir (*Pseudotsuga taxifolia* (Lam.) Britt.).
- *Polyporus amarus* Hedg. in incense cedar (*Libocedrus decurrens* Torr.).
- *Polyporus schweinitzii* Fr. in Douglas fir.
- *Fomes laricis* (Jacq.) Murr. in Douglas fir.



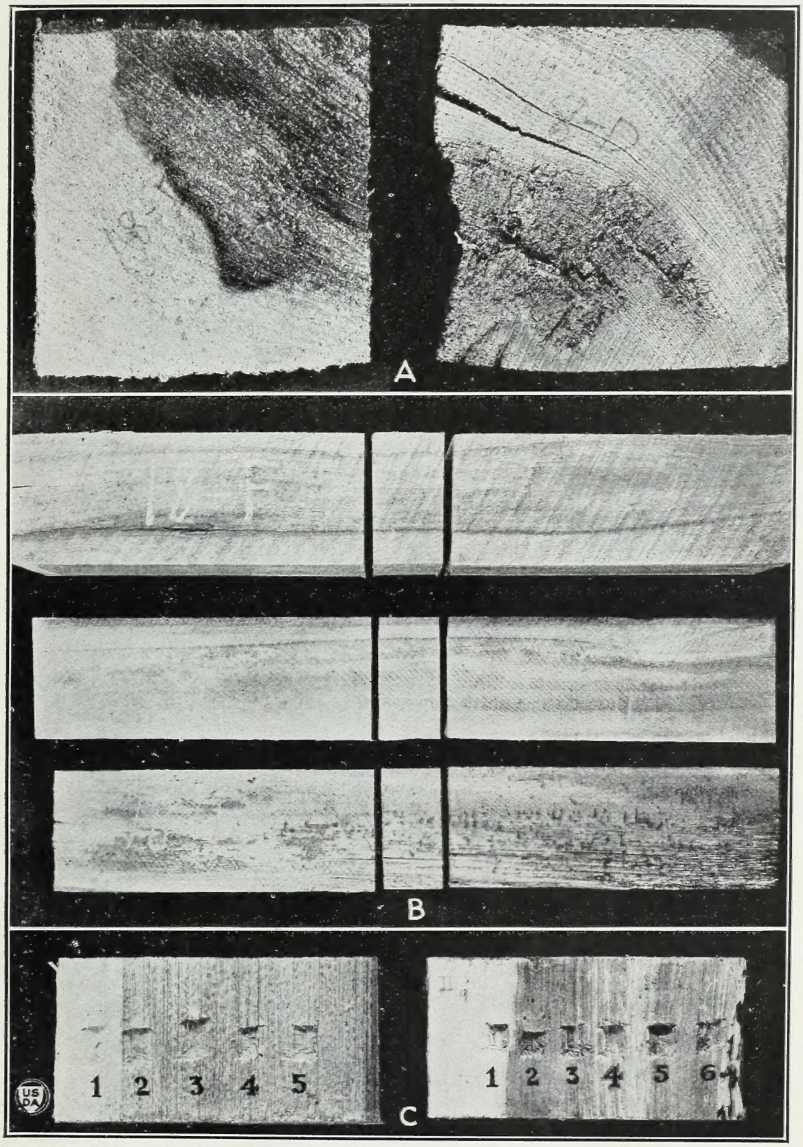
TRANSVERSE SECTIONS OF HEMLOCK, WHITE PINE, SOFT MAPLE, AND BASSWOOD, SHOWING ROTTED AREAS.

A, Transverse section of a hemlock (*Tsuga canadensis*) log from tree No. 10, showing the incipient stage of rot produced by *Ganoderma tsugae*. *B*, Transverse section of a white pine (*Pinus strobus*) log of tree No. 14, showing the ring-rot of *Trametes pini*. *C*, Transverse section of a soft maple (*Acer rubrum*) log of tree No. 16, showing the incipient and typical stages of *Fomes igniarius*. The dark area surrounding the central rotted area is the incipient region. *D*, The transverse section of a basswood (*Tilia americana*) log of tree No. 18, showing the incipient rot produced by *Pholiota adiposa*. Note the darker outer zone of discoloration.



BASSWOOD INFECTED WITH PHOLIOTA ADIPOSA.

Sporophores of *Pholiota adiposa* produced on a piece of infected basswood (tree No. 18) which was placed in a moist chamber for one month.



TIMBER TEST PIECES ILLUSTRATING THE METHODS OF STUDY.

A, Culture blocks cut from test pieces Nos. 8D and 18D, showing the distribution of the rots in the central portions of two 4 by 4 inch test pieces. The incipient stage of each rot is seen to extend into the center of each. *B*, Culture blocks cut from the center of 1-inch (lower), 2-inch, and 4-inch (center and upper) test pieces from tree No. 18. *C*, Culture blocks showing the hollows where fragments have been removed with the chisel forceps.

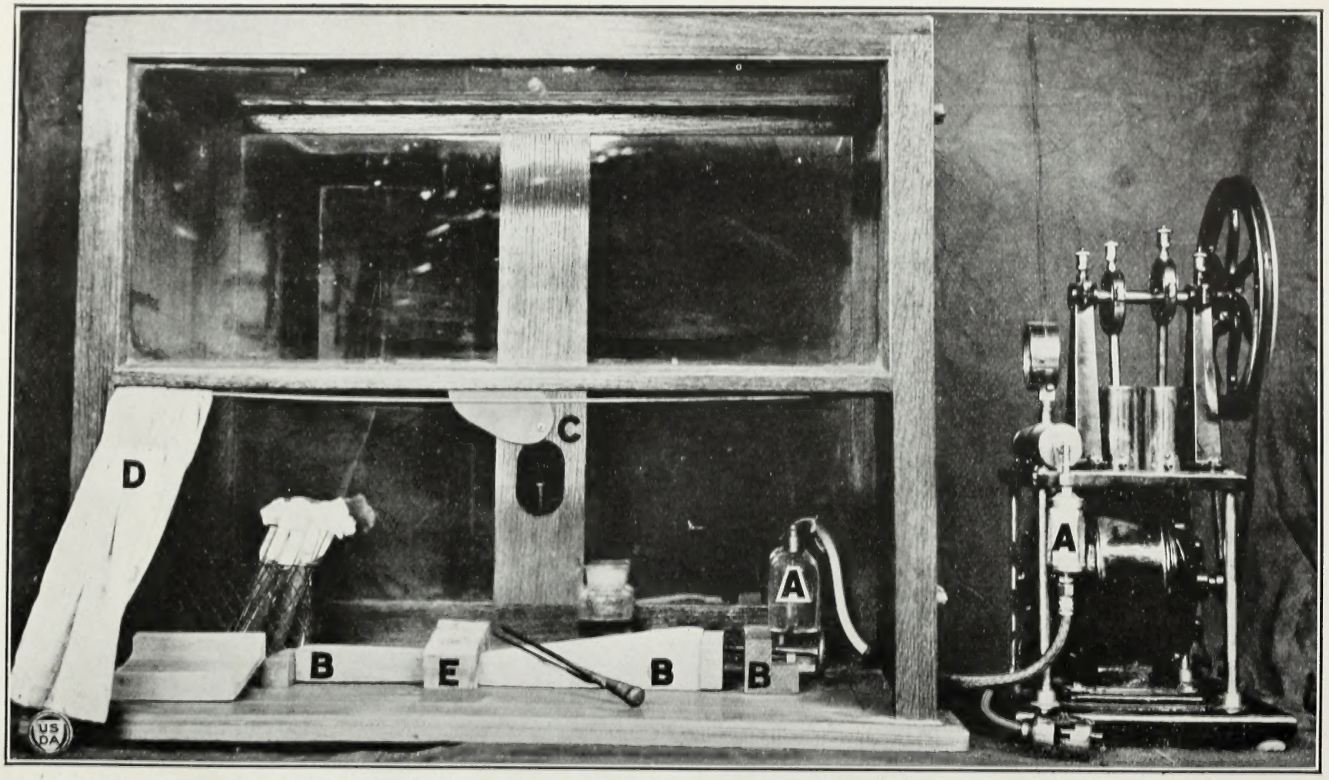
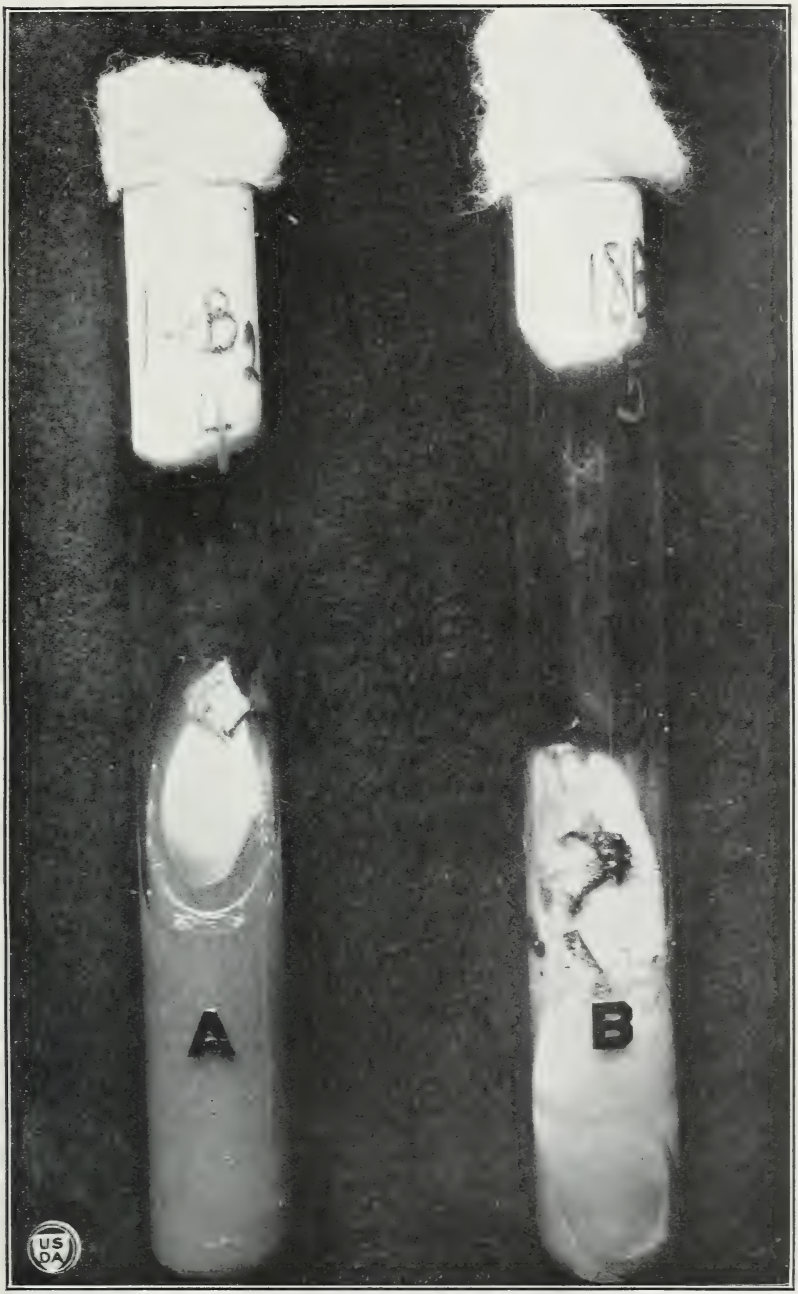


PLATE IV.

SPECIAL CULTURE CASE AND EQUIPMENT USED IN MAKING CULTURES FOR THE TESTS.

A, Atomizer filled with either distilled water or an antiseptic solution attached to an electrically driven air pump and used to spray the interior of the culture case. *B*, Parts of the clamp used to hold the culture block *E*. *C*, Opening in the rear of the case which permits the sterilization of instruments and the flaming of test tubes with the gas flame outside of the case. *D*, Cloth curtain with armholes and sliding on a rod. *E*, Culture block from which fragments of infected wood are removed with the chisel forceps shown at the right. *F*, Electric switch used in starting and stopping the pump.



CULTURE TUBES SHOWING NEGATIVE AND POSITIVE RESULTS.

A, Culture tube showing a negative result: no fungous growth has developed from the fragment of wood. The white area on the surface of the agar is due to reflections of light. *B*, Culture tube showing a positive result: the fungus has grown from the fragment of infected wood, and a small sporophore (*Pholiota adiposa*) has developed.

METHODS OF STUDY.

The logs and other pieces assembled for this study were cut into test pieces at the sawmill of the Forest Products Laboratory under the direct supervision of the writer. The 16-foot logs were first cut into 8-foot logs. A 3-inch disk was then cut from one of the 8-foot logs. (Pl. I.) The 8-foot logs were divided into imaginary 4-foot bolts and lettered A, B, C, D, etc., beginning at the first bolt at the base of the first log taken from a tree. The tree number was used in conjunction with these letters in labeling the bolts, the planks, and the test pieces cut from each. For example, the first 4-foot bolt in tree No. 14 was labeled 14A, the second 14B, and so on, including the second and third 16-foot log. The 8-foot logs were cut into 2-inch and 4-inch planks, and an attempt was made to include the maximum quantity of incipient decay in each plank. The planks from each log were numbered consecutively, and records were thus made, showing the position of each plank in the log. Diagrams of the longitudinal extent of the rot in each plank were also made. The planks were next cut into the required sizes for test pieces, 1 by 4 by 24 inches, 2 by 4 by 24 inches, 4 by 4 by 24 inches. These are referred to in this bulletin as 1-inch, 2-inch, and 4-inch stock. These test pieces were numbered and sorted. In cutting the test pieces care was taken to include in each piece a maximum of the incipient stage of decay. Incipient or typical decay extending from the edge to the center of the piece constituted the minimum requirements. (Pl. III, *A*.)

A series of preliminary cultures was next made, using fragments of infected wood taken from test pieces cut from each of the logs. This was done to test the vitality of the fungous mycelium within the infected wood.

The sets were open piled, using half-inch to 1-inch crossing sticks between layers, thus providing free circulation of air about the pieces and about the piles.

CULTURAL METHODS.

Upon the removal of the test pieces from the kiln, culture blocks 2 inches thick were cut from the center of each piece. (Pl. III, *B*.) These were given the piece number and placed in boxes to await culturing. The culture work called for special equipment in order to handle more efficiently and speedily the large number of cultures. A special culture or transfer case (Pl. IV) was constructed with motor-driven spray apparatus (Pl. IV, *A*, *F*), special clamp for holding the culture blocks (Pl. IV, *B*), an opening in the rear of the case allowing the instruments used to be sterilized over a gas flame placed on the outside of the case near the opening (Pl. IV, *C*), and a sliding cloth curtain (Pl. IV, *D*), which allowed the free use of the hands during the operations.

The cultural process in detail is as follows:

A culture block is selected and quickly dipped in a solution of 1 to 1,000 mercuric chlorid; it is then split open along a central line with a sterilized hatchet blade. After the interior of the case has been thoroughly sprayed with distilled water or an antiseptic solution, half of the block is clamped as shown in Plate IV, *E*. The chisel forceps is next sterilized by dipping it in 95 per cent alcohol and flaming over the gas jet. The fragments of

infected wood are then cut and pried out of the block with this instrument and placed in sterile test tubes containing plain malt agar. The area from which each fragment is removed is numbered and the test tube containing it is similarly marked. The block when removed from the clamp shows the numbered hollows (Pl. III, *C*) and their distribution over the face of the block. A sketch was made of the split block, showing the areas from which fragments were removed, indicating the stages of decay and the limits of the discolored areas.

A large percentage of the cultures are contamination free, and an average of 96 to 100 tube cultures can be made in two hours. When three out of six tubes showed contamination, or when results seemed doubtful, the cultures were repeated.

Plain malt agar[5] was used in the tubes and the surface of the agar slanted. All cultures were grown at room temperatures and were kept for a minimum period of six weeks, in order to observe the negative cultures and watch for delayed revival of the fungi in the inoculum. A negative culture is shown in Plate V, *A*, and a positive culture in Plate V, *B*.

KILN-DRYING AND STEAMING EXPERIMENTS.

RUN 1.

A set of test pieces of the Neopit and Oakridge material was placed in a small experimental dry kiln for a period of 16 days.

The temperature range during the run was from 120° to 135° F. The relative humidity averaged 85 per cent during the test, with a range between 100 and 70 per cent.

Cultures made from the blocks removed from the test pieces at the end of the run showed all the fungi to be dead within the centers of all the 1-inch, 2-inch, and 4-inch pieces.

RUN 2.

Eighteen spruce (*Picea canadensis*) pulp logs received from northern Wisconsin were sawed into test planks 2 by 10 by 48 inches. These logs were infected in the storage pile by various wood-destroying fungi, and in most cases both the typical stage and the incipient stage of decay were included in the test planks. In many cases the rots of more than one fungus were present in the same test plank.

A set of 20 planks was placed in a Tiemann dry kiln along with a commercial run of 2½-inch bald cypress lumber for a period of 40 days. Three planks of western yellow pine (*Pinus ponderosa*) infected with *Polyporus anceps* and 15 pieces from the Neopit material were also added. The initial temperature was 95° and the end temperature 160° F. During the kiln drying the relative humidity ranged between 50 and 84 per cent. At the end of the run, culture blocks were cut from the center of each plank. Cultures were made in the usual manner, and it was found that all the fungi had been killed.

RUN 3.

A set of test pieces of the Neopit and Oakridge material combined was placed in a Tiemann dry kiln for a period of 12 days. The set was placed on top of a charge of oak lumber.

The temperature range during the run was from 143° to 168° F. The relative humidity averaged 57 per cent during the run, with a range between 28 and 95 per cent.

[5] Distilled water, 1,000 cubic centimeters; Trommer malt extract, 25 grams; agar (powdered), 15 grams.

The fungi were found to be dead within the centers of all the 1-inch, 2-inch, and 4-inch pieces.

RUN 4.

A set of test pieces of the Neopit material was placed in a Tiemann dry kiln for a period of 18 days. The set was placed on top of a charge of 1-inch commercial birch lumber. The temperature range during the run was from 135°, the initial temperature, to 180° F. The range in relative humidity was from 50 to 85 per cent. On the seventeenth day of the run the charge was conditioned for 20 hours at 180° F. and 85 per cent relative humidity.

At the end of the run, cultures made from these blocks showed all the fungi to be dead within the center of each test piece.

RUN 5.

(*a*) Six green 1-inch sap gum (*Liquidambar styraciflua*) boards showing blue stain were subjected to 30 pounds of steam, gauge pressure at approximately 274° F., for a period of 40 minutes in a Kraetzer preparator. Samples containing blue stain were cut from these boards after the treatment and forwarded from Memphis, Tenn.

Cultures made by using fragments of the blued wood taken from the center of each board showed the fungus to be dead in each case.

(*b*) Six blocks of pitch pine (*Pinus rigida*), each measuring 1 by 2 by 2 inches and infected with the brown-stain fungus (*Alternaria* sp.) were subjected to a so-called dry heat of 221° F. for a period of 24 hours. Cultures showed the fungus to be dead in all of the blocks at the end of the test.

(*c*) Disks cut transversely from the central part of two jack-pine (*Pinus banksiana*) railroad ties which had been treated with creosote and subjected during the treatment to a temperature of 178° to 188° F. for a period of 47 to 50 minutes were sent to the writer for examination. The ties were infected before treatment and showed the typical stage of rot characteristic of *Trametes pini*. Disks cut from several untreated ties and showing various stages of the same rot were also received. Cultures made from the central areas in the various disks showed the fungus to be alive in the central part of the treated disks as well as in the untreated ones. The treated ties were 7 by 8½ inches and 8 by 9¼ inches in cross section, respectively.

(*d*) Two sets of test pieces from the Oakridge material were subjected to 20 pounds of steam (gauge pressure, 259° F.) followed by a vacuum of 1 hour. The first set was steamed for 1½ hours and the second set for 2 hours. The results show that the 1½-hour treatment killed the organisms in the 6-inch but not in the 8-inch pieces. The 2-hour treatment killed the organisms in both sizes.

RUN 6.

A set of test pieces from the Neopit and Oakridge material was placed on stickers in an open pile in a Tiemann dry kiln. The pieces were subjected to a temperature of 110° to 116° F. at saturated atmosphere for a period of 48 hours. This set contained three 6-inch and three 8-inch test pieces of Douglas fir, the pieces of each

size being infected with *Polyporus schweinitzii*, *Tramctes pini*, and *Fomes laricis*, respectively.

Upon removal from the kiln most of the pieces showed a considerable area covered with mold, which had developed during the test. The test pieces of Douglas fir of the 6 by 6 by 24 and the 8 by 8 by 24 inch sizes, freshly cut, showed green-mold growth covering the sapwood. It is apparent that the conditions were favorable to mold growth.

At the end of the test the cultural methods showed the fungi in most of the test pieces to be dead. Positive cultures developed as follows:

For the 4-inch pieces—blue stain in *Pinus strobus* and *Thuja occidentalis*, *Ganoderma tsugae* in *Tsuga canadensis*, *Trametes pini* in *Larix laricina*, *Pholiota adiposa* in *Tilia americana*, *Polyporus borealis* in *Acer saccharum*, *Polyporus amarus* in *Libocedrus decurrens*, *Polystictus hirsutus* and *P. versicolor* in *Alnus oregona*.

For the 6-inch and 8-inch pieces—*Fomes laricis* and *Polyporus schweinitzii* in *Pseudotsuga taxifolia*.

RUN 7.

Five sets of test pieces of the Neopit material were stacked in a Tiemann dry kiln. Steam was turned on gradually into the kiln until the recording instruments showed a temperature of 120° F. and a relative humidity of 100 per cent. The test was begun at this point, and this temperature and humidity were maintained.

A set of the test pieces was removed at the end of 3, 6, 9, 12, and 24 hours. Culture blocks were cut from the centers of each of the test pieces, and fragments from each block were cultured to determine the viability of the fungi.

The set of test pieces subjected to 120° F. at 100 per cent humidity for three hours upon culturing showed most of the cultures positive. In the 1-inch pieces the following were positive: Blue stain in *Pinus strobus*, brown ring-rot in *Thuja occidentalis*, *Torula ligniperda* in *Tsuga canadensis*, *Fomes pinicola* in *Tsuga canadensis*, *Fomes fomentarius* in *Betula papyrifera*, brown cubical rot in *Tsuga canadensis*, *Trametes pini* in *Pinus strobus*, and *Polyporus borealis* in *Acer saccharum*. The following were negative: Blue stain in *Thuja occidentalis*, *Trametes pini* in *Larix laricina*, brown cubical rot in *Thuja occidentalis*, *Ganoderma tsugae* in *Tsuga canadensis*, *Fomes igniarius* in *Ulmus americana*, brown cubical rot in *Pinus strobus*, *Fomes igniarius* in *Acer rubrum*, and *Pholiota adiposa* in *Tilia americana*.

The blue-stain organisms remained alive in all three sizes of test pieces, 1-inch, 2-inch, and 4-inch, during the 3-hour test in the wood of *Pinus strobus*. The blue-stain organism in the 1-inch and 2-inch test piece of *Thuja occidentalis* when cultured did not revive. The heartwood of this particular test piece was infected with a wood destroyer producing a brown crumbly or cubical rot.

In general, all the 4-inch test pieces gave positive cultures. Of the 2-inch pieces 13 gave positive and 3 negative results. The results indicate that the time and temperature factors used with this set are not practicable in killing wood-inhabiting fungi in 1-inch, 2-inch, and 4-inch stock.

The set removed from the kiln at the end of six hours upon culturing showed, in general, that the fungi were killed in all of the 1-inch

test pieces with the exception of three cases, namely, the blue-stain organism in *Pinus strobus*, the brown ring-rot in *Thuja occidentalis*, and the brown cubical rot in *Tsuga canadensis*. In this set, again, the blue-stain organism in *Pinus strobus* resisted the heat in all three sizes of test pieces, 1-inch, 2-inch, and 4-inch, and in general it stood out as a particularly heat-resistant type of infection in comparison with the rot-producing type. For the other fungi the 2-inch test pieces showed positive results in 6 cases and negative results in 10 cases, and of the 4-inch pieces 13 gave positive and 3 negative results.

The test pieces of the set subjected to the trial conditions for nine hours upon culturing showed negative results in most cases. The blue-stain organism in *Pinus strobus* was killed in the 1-inch stock. In the 2-inch stock the same organism was dead in the outer portions of the block but alive in the fragment taken from the center of the block. In the 4-inch block the organism was alive in all the fragments except those taken within a general area extending from the edge of the block to approximately 1 inch inward from the edge.

All of the 1-inch test pieces gave negative results. Of the 2-inch stock, all but two pieces gave negative results. These were *Trametes pini* in *Larix laricina* (of which only one of the five fragments gave positive results) and blue stain in *Pinus strobus*. Cultures of the 4-inch stock showed only 5 positive and 8 negative. The negative results in the 4-inch stock showed a steady increase through the 3, 6, and 9 hour tests. The conditions in this trial test were effective in sterilizing all the 1-inch stock, nearly all the 2-inch stock, and only about 61 per cent of the 4-inch stock.

The set subjected for 12 hours gave negative cultures in all but two cases. In the 2-inch and 4-inch *Pinus strobus* pieces the blue stain resisted the heat successfully.

The 24-hour test was effective in killing all the organisms in all the test pieces.

RUN 8.

Two sets of test pieces, consisting of test material from both the Neopit and Oakridge shipments, were placed in a Tiemann dry kiln for periods of six and nine hours, respectively. The temperature was maintained at 130° F. and the relative humidity at 100 per cent. Test pieces of the Oakridge shipment, 6 by 6 inches and 8 by 8 inches square, were used in this test.

At the end of the test the cultural method showed that after six hours the fungi in the centers of the 6 by 6 and 8 by 8 inch test pieces were still alive. At the end of the 9-hour test, however, all of the test pieces, including the 6-inch and 8-inch pieces, showed negative cultures.

RUN 9.

Five sets of test pieces of the Neopit material were stacked in a Tiemann dry kiln. Steam was introduced gradually into the kiln until the recording instruments showed a temperature of 140° F. and a relative humidity of 100 per cent. The test started at this point, and this temperature and humidity were maintained.

A set of test pieces was removed from the kiln at the end of 3 hours, the second set at 6 hours, the third at 9 hours, the fourth at

12 hours, and the fifth at 24 hours. As soon as the test sets were removed, 2-inch blocks were cut from the center of each piece and cultures made from these.

In the set exposed for three hours at 140° F. at saturation all the fungi were killed in the 4-inch test pieces except the blue-stain fungus (*Ceratostomella* sp.) in *Pinus strobus* and *Thuja occidentalis*, *Trametes pini* in *Pinus strobus*, *Torula ligniperda* in *Tsuga canadensis*, and the brown ring-rot of *Thuja occidentalis*. *Torula ligniperda* was alive in the 1-inch and 2-inch pieces. These results indicate that in a few cases the penetration of heat into the centers of the 4-inch test pieces was not complete at the end of three hours, at least not sufficient to kill these particular fungi. The test pieces subjected to 140° F. for 6, 9, 12, and 24 hours all gave negative results when cultured. In the three-hour trial one 2-inch test piece infected with blue stain, when cultured, gave positive results with the fragment taken from the center of the block. Fragments taken nearer the edge of the block, however, showed no revival of the fungus in the cultures.

RUN 10.

One set of test material from both the Neopit and Oakridge shipments was placed in a Tiemann dry kiln for a period of three hours at 145° F. and at saturated atmosphere.

Cultures made from the culture blocks at the end of the run showed all of the fungi to have been killed within the test pieces.

RUN 11.

Two sets of test pieces from both the Neopit and Oakridge shipments were placed in the usual manner in a Tiemann dry kiln. The pieces were subjected to a temperature of 150° F. at saturated atmosphere for a period of one hour for the first set and two hours for the second set.

Of the set subjected to the above condition for one hour the following 4-inch pieces showed positive cultures: *Polystictus hirsutus* and *Polystictus versicolor* in *Alnus oregona*, blue stain in *Thuja occidentalis* and in *Pinus strobus*, *Polyporus borealis* in *Acer saccharum*, *Trametes pini* in *Larix laricina*, *Fomes igniarius* in *Acer rubrum*, *Fomes fomentarius* in *Betula papyrifera*, and *Polyporus schweinitzii* in *Pseudotsuga taxifolia*. The remainder were negative.

Of the set subjected for two hours all of the test pieces showed upon culturing no evidence that the fungi were alive.

RUN 12.

A set of test pieces, consisting of material from both the Neopit and Oakridge shipments, was placed on stickers in an open pile in a Tiemann dry kiln. The pieces were subjected to a temperature of 170° F. at saturated atmosphere for 40 minutes. It took 20 minutes for the temperature to rise from 80° to 170° F. within the kiln after the charge was in and the doors closed. At the end of the run all the fungi were found to be dead.

BRIEF SUMMARY OF THE TEST RUNS.

Table 1, a summary of the results obtained in the 12 runs, is based upon the examination of over 1,000 test pieces and the positive or

negative results of over 8,000 culture tests. The graphs in Figure 1 are smoothed curves based upon the same data and represent graphically the time and temperature conditions required to kill the fungi under discussion.

Test runs 1 to 4, in which the ordinary commercial kiln-drying conditions were used, show conclusively that the temperatures, humidities, and periods of time were effective in killing the various fungi within the 1-inch, 2-inch, and 4-inch test pieces. These data furnish evidence which leaves little doubt concerning a phenomenon which has previously been accepted at its face value without positive proof. The additional fact that all of the samples of kiln-dried or steamed stock infected before drying and sent in by various lumber firms for examination gave negative results when cultured fur-

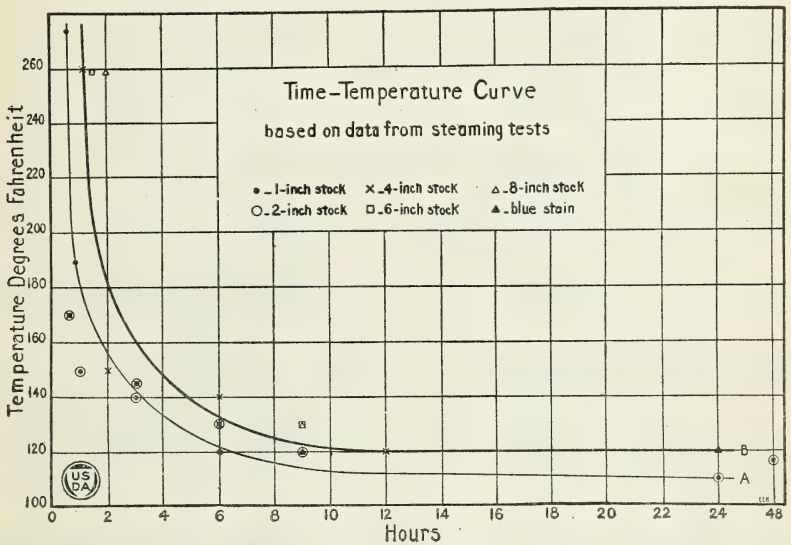


FIG. 1.—Curves showing the time-temperature relation of the data on 1-inch, 2-inch, and 4-inch test pieces from the steaming tests. Data on the 6-inch and 8-inch test pieces are included for completeness and comparison. Curve A represents roughly the time-temperature relation as expressed by the data on the 1-inch pieces. Curve B represents roughly the time and temperature limits necessary to kill certain fungi in wood up to and including 4 inches in thickness.

nishes further evidence of the sterilizing efficiency of this method of seasoning lumber.

The experimental tests, runs 5 to 12, inclusive, give somewhat more accurate data in regard to the effect of temperature on fungi in wood when acting under a constant humidity of 100 per cent. The effect of increasing the length of time during which the infected wood is subjected to a constant temperature and humidity and the relatively greater resistance of the larger sized test pieces to the penetration of heat are both clearly shown in runs numbered 6, 7, and 11 in Table 1 and in Figure 1. In run No. 7 the temperature used, 120° F., was sufficiently low to require a period of 24 hours before all the fungi were killed in the test pieces. This gave a fairly good comparison of the relative resistance to heat of the various fungi within the wood.

TABLE 1.—*Effect of various heat treatments on certain fungi in various species of wood of different sizes.*

[For tests listed under run No. 5, see text, p. 13. Under run 6, *Fomes pinicola* was dead in *Picea canadensis*. Symbols used: D=dead, L=live.]

Fungus or rot and host	Size of test piece (inches)	Run No. 1: 120° to 135° F., 16 days.	Run No. 2: 95° to 160° F., 40 days.	Run No. 3: 143° to 168° F., 12 days.	Run No. 4: 135° to 180° F., 18 days.	Run No. 6: 110° to 116° F., 48 hours.	Run No. 7: 120° F. 3 hours.	Run No. 7: 120° F. 6 hours.	Run No. 7: 120° F. 9 hours.	Run No. 7: 120° F. 12 hours.	Run No. 7: 120° F. 24 hours.	Run No. 8: 130° F. 6 hours.	Run No. 8: 130° F. 9 hours.	Run No. 9: 140° F. 3 hours.	Run No. 9: 140° F. 6 hours.	Run No. 9: 140° F. 9 hours.	Run No. 9: 140° F. 12 hours.	Run No. 9: 140° F. 24 hours.	Run No. 10: 145° F. 3 hours.	Run No. 11: 150° F. 1 hour.	Run No. 11: 150° F. 2 hours.	Run No. 12: 170° F. 40 minutes.
Ceratostomella pilifera in Pinus strobus	1 by 4 by 24	D	D	D	D	D	L	L	D	D	D	--	D	D	D	D	D	D	D	D	D	D
	2 by 4 by 24	D	D	D	D	D	L	L	L	L	D	--	D	D	D	D	D	D	D	D	D	D
	4 by 4 by 24	D	D	D	D	L	L	L	L	L	D	--	D	L	D	D	D	D	D	L	D	D
Ceratostomella sp. in Thuja occidentalis	1 by 4 by 24	D	----	D	D	D	D	D	--	D	D	----	----	D	D	D	D	D	D	D	D	D
	2 by 4 by 24	----	----	D	D	D	D	D	--	D	D	----	----	D	D	D	D	D	D	D	D	D
	4 by 4 by 24	----	----	D	D	L	L	L	--	D	D	----	----	L	D	D	D	D	D	L	D	D
Fomes fomentarius in Betula papyrifera	1 by 4 by 24	----	D	D	D	D	L	D	D	D	D	--	D	D	D	D	D	D	D	D	D	D
	2 by 4 by 24	----	D	D	D	D	L	D	D	D	D	--	D	D	D	D	D	D	D	D	D	D
	4 by 4 by 24	----	D	D	D	D	L	L	D	D	D	--	D	D	D	D	D	D	D	L	D	D
Fomes igniarius in Ulmus americana	1 by 4 by 24	D	D	D	D	D	D	D	D	D	D	----	----	D	D	D	D	D	D	D	D	D
	2 by 4 by 24	D	D	D	D	D	D	D	D	D	D	----	----	D	D	D	D	D	D	D	D	D
	4 by 4 by 24	D	D	D	D	D	L	L	D	D	D	----	----	D	D	D	D	D	D	D	D	D
Fomes igniarius in Acer rubrum	1 by 4 by 24	D	----	D	D	D	D	D	D	D	D	--	D	D	D	D	D	D	D	D	D	D
	2 by 4 by 24	D	----	D	D	D	D	D	D	D	D	--	D	D	D	D	D	D	D	D	D	D
	4 by 4 by 24	D	----	D	D	D	L	L	D	D	D	--	D	D	D	D	D	D	D	L	D	D
Fomes laricis in Pseudotsuga taxifolia	1 by 4 by 24	----	----	----	----	D	----	----	----	----	----	D	D	----	----	----	----	----	----	----	----	----
	2 by 4 by 24	----	----	----	----	D	----	----	----	----	----	D	D	----	----	----	----	----	----	----	----	----
	4 by 4 by 24	----	----	----	----	D	----	----	----	----	----	D	D	----	----	----	----	----	----	----	----	----
	6 by 6 by 24	----	----	----	----	L	----	----	----	----	----	L	D	----	----	----	----	----	----	----	----	----
	8 by 8 by 24	----	----	----	----	L	----	----	----	----	----	L	D	----	----	----	----	----	----	----	----	----
Fomes pinicola in Tsuga canadensis	1 by 4 by 24	----	D	D	D	D	L	D	D	D	D	--	D	D	D	D	D	D	D	D	D	D
	2 by 4 by 24	----	D	D	D	D	L	D	D	D	D	--	D	D	D	D	D	D	D	D	D	D
	4 by 4 by 24	----	----	D	D	D	L	L	L	D	D	--	D	D	D	D	D	D	D	D	D	D
Trametes carnea in Picea canadensis	2 by 10 by 48	----	D	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
Ganoderma tsugae in Tsuga canadensis	1 by 4 by 24	----	----	D	D	D	D	D	D	D	D	--	D	D	D	D	D	D	D	D	D	D
	2 by 4 by 24	----	----	D	D	D	L	D	D	D	D	--	D	D	D	D	D	D	D	D	D	D
	4 by 4 by 24	----	----	D	D	L	L	D	D	D	D	--	D	D	D	D	D	D	D	D	D	D
Lenzites sepiaria in Picea canadensis	2 by 10 by 48	----	D	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
Pholiota adiposa in Tilia americana	1 by 4 by 24	D	----	D	D	D	D	D	D	D	D	--	D	D	D	D	D	D	D	D	D	D
	2 by 4 by 24	D	----	D	D	D	L	D	D	D	D	--	D	D	D	D	D	D	D	D	D	D
	4 by 4 by 24	D	----	D	D	L	L	L	L	D	D	--	D	D	D	D	D	D	D	D	D	D
Polyporus amarus in Libocedrus decurrens	1 by 4 by 24	D	----	D	----	D	----	----	----	----	----	----	D	----	----	----	----	----	D	--	D	D
	2 by 4 by 24	D	----	D	----	D	----	----	----	----	----	D	D	----	----	----	----	----	D	--	D	D
	4 by 4 by 24	D	----	D	----	L	----	----	----	----	----	D	D	----	----	----	----	----	D	--	D	D
Polyporus anceps in Picea canadensis	2 by 10 by 48	----	D	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
Polyporus anceps in Pinus ponderosa	2 by 10 by 48	----	D	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
Polyporus schweinitzii in Pseudotsuga taxifolia	1 by 4 by 24	D	----	D	----	D	----	----	----	----	----	----	D	----	----	----	----	----	D	D	D	D
	2 by 4 by 24	D	----	D	----	D	----	----	----	----	----	----	D	----	----	----	----	----	D	D	D	D
	4 by 4 by 24	D	----	D	----	D	----	----	----	----	----	----	D	----	----	----	----	----	D	L	D	D
	6 by 6 by 24	----	----	----	----	L	----	----	----	----	----	L	D	----	----	----	----	----	----	----	----	----
	8 by 8 by 24	----	----	----	----	L	----	----	----	----	----	L	D	----	----	----	----	----	----	----	----	----
Polyporus borealis in Acer saccharum	1 by 4 by 24	----	----	D	D	D	L	D	D	D	D	--	D	D	D	D	D	D	D	D	D	D
	2 by 4 by 24	----	----	D	D	D	L	L	D	D	D	--	D	D	D	D	D	D	D	D	D	D
	4 by 4 by 24	----	----	D	D	L	L	L	D	D	D	--	D	D	D	D	D	D	D	L	D	D
Polystictus abietinus in Picea canadensis	2 by 10 by 48	----	D	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----

TABLE 1.—*Effect of various heat treatments, etc.*—Continued.

Fungus or rot and host.	Size of test piece (inches).	Run No. 1: 120° to 135° F., 16 days.	Run No. 2: 95° to 160° F., 40 days.	Run No. 3: 143° to 168° F., 12 days.	Run No. 4: 135° to 180° F., 18 days.	Run No. 6: 110° to 116° F., 48 hours.	Run No. 7: 120 F. 3 hours.	Run No. 7: 120 F. 6 hours.	Run No. 7: 120 F. 9 hours.	Run No. 7: 120 F. 12 hours.	Run No. 7: 120 F. 24 hours.	Run No. 8: 130° F. 6 hours.	Run No. 8: 130° F. 9 hours.	Run No. 9: 140° F. 3 hours.	Run No. 9: 140° F. 6 hours.	Run No. 9: 140° F. 9 hours.	Run No. 9: 140° F. 12 hours.	Run No. 9: 140° F. 24 hours.	Run No. 10: 145° F. 3 hours.	Run No. 11: 150° F. 1 hour.	Run No. 11: 150° F. 2 hours.	Run No. 12: 170° F. 40 minutes.
Polystictus hirsutus in Picea canadensis	2 by 10 by 48	----	D	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
Polystictus hirsutus and P. versicolor in Alnus oregona	1 by 4 by 24	D	D	D	D	D	----	----	----	----	----	----	----	----	----	----	----	----	D	D	D	D
	2 by 4 by 24	D	D	D	D	D	----	----	----	----	----	----	----	----	----	----	----	----	D	D	D	D
	4 by 4 by 24	D	D	D	D	L	----	----	----	----	----	----	----	----	----	----	----	----	D	L	D	D
Torula ligniperda in Tsuga canadensis	1 by 4 by 24	----	----	D	D	D	L	D	D	D	D	D	D	L	D	D	D	D	D	D	D	D
	2 by 4 by 24	----	----	D	D	D	L	D	D	D	D	D	D	L	D	D	D	D	D	D	D	D
	4 by 4 by 24	----	----	D	D	D	L	L	D	D	D	D	D	L	D	D	D	D	D	D	D	D
Trametes pini in Picea canadensis	2 by 10 by 48	----	D	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
Trametes pini in Larix laricina	1 by 4 by 24	----	----	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D
	2 by 4 by 24	----	----	D	D	D	L	L	L	D	D	D	D	D	D	D	D	D	D	D	D	D
	4 by 4 by 24	----	----	D	D	L	L	L	L	D	D	D	D	D	D	D	D	D	D	L	D	D
Trametes pini in Pinus strobus	1 by 4 by 24	D	----	D	D	D	L	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D
	2 by 4 by 24	D	----	D	D	D	L	L	D	D	D	D	D	D	D	D	D	D	D	D	D	D
	4 by 4 by 24	D	----	D	D	D	L	L	D	D	D	D	D	L	D	D	D	D	D	D	D	D
Trametes pini in Pseudotsuga taxifolia	6 by 6 by 24	----	----	----	----	D	----	----	----	----	----	L	D	----	----	----	----	----	----	----	----	----
	8 by 8 by 24	----	----	----	----	D	----	----	----	----	----	L	D	----	----	----	----	----	----	----	----	----
Brown cubical rot in Pinus strobus	1 by 4 by 24	----	----	D	D	D	D	D	----	D	D	----	D	D	D	D	D	D	D	D	D	D
	2 by 4 by 24	----	----	D	D	D	L	D	----	D	D	----	D	D	D	D	D	D	D	D	D	D
	4 by 4 by 24	----	----	D	D	D	L	D	----	D	D	----	D	D	D	D	D	D	D	D	D	D
Brown cubical rot in Thuja occidentalis	1 by 4 by 24	----	----	D	D	D	D	D	----	D	D	----	D	D	D	D	D	D	D	D	D	D
	2 by 4 by 24	----	----	D	D	D	L	D	----	D	D	----	D	D	D	D	D	D	D	D	D	D
	4 by 4 by 24	----	----	D	D	D	L	D	----	D	D	----	D	D	D	D	D	D	D	D	D	D
Brown cubical rot in Tsuga canadensis	1 by 4 by 24	----	----	D	D	----	L	L	D	D	D	----	----	D	D	D	D	D	D	D	D	----
	2 by 4 by 24	----	----	D	D	----	L	L	D	D	D	----	----	D	D	D	D	D	D	D	D	----
	4 by 4 by 24	----	----	D	D	----	L	L	L	D	D	----	----	D	D	D	D	D	D	D	D	----
Brown ring-rot in Thuja occidentalis	1 by 4 by 24	----	----	D	D	----	L	L	D	D	D	----	----	D	D	D	D	D	----	D	D	----
	2 by 4 by 24	----	----	D	D	----	L	L	D	D	D	----	----	D	D	D	D	D	----	D	D	----
	4 by 4 by 24	----	----	D	D	----	L	L	D	D	D	----	----	L	D	D	D	D	----	D	D	----

Minor preliminary tests were included under run No. 5, a, b, c, and d. The test given in 5, a, indicates that the steaming process, where pressure is used for short periods of time, is effective in killing the blue-stain fungus, at least in 1-inch stock. The sterilizing effect of the ordinary method of oven drying blocks of wood is given under 5, b, and the data on the failure of a particular preservative treatment in sterilizing the center of 8-inch ties infected with a heart rot is given under 5, c. It was noted that in the areas where the creosote had penetrated the infected wood the fungus no longer revived when cultured, but revived in cultures made by using fragments taken from the untreated portions near the center of the ties. From the face of the tie to a point 2 inches in from the face no positive cultures were obtained from the infected area; beyond this point and toward the center, positive cultures were obtained. The heat apparently was effective in sterilizing to a depth of 2 inches. Under 5, d, it was found that a steaming treatment of two

hours followed by a vacuum of one hour was necessary in order to sterilize to the center the 8-inch test pieces.

AIR-SEASONING EXPERIMENTS.

In the first air-seasoning experiments infected planks 2 by 10 inches and 4 feet long cut from spruce (*Picea canadensis*) pulp logs were used. These planks contained typical and incipient stages of the decays produced by *Lenzites sepiaria*, *Trametes carnea*, *Polyporus anceps*, *Trametes pini*, *Polystictus abietinus*, and *Fomes pinicola*.

On July 28, 1920, 21 planks representative of the above material were stacked in the yard of the Forest Products Laboratory. The open method of stacking was used, and the layers of planks were separated by half-inch stickers. Adjacent to this pile another pile containing 33 planks was constructed. In this case the planks were closely piled one on top of the other. A third set of 39 planks of the same material was stacked open piled, while a fourth set of 28 planks was stacked close piled in a well-inclosed shed.

On June 11, 1921, records were taken concerning the number and species of fungous sporophores developed upon the planks since the piles were constructed. The open pile in the yard showed a total of 41 sporophores, of which 35 were *Lenzites sepiaria* and 6 were *Trametes carnea*. There were 23 sporophores on the planks in the close-piled set, and of these 13 were of *Lenzites sepiaria*, 2 were *Trametes carnea*, 6 *Polystictus abietinus*, and 2 *Polyporus anceps*. Most of these sporophores were of small size, but capable of producing spores. Many of the smaller of these dried out perceptibly during the warm, dry weather, but revived again during the prolonged rainy periods. Most of the sporophores appeared during the spring months. It is interesting that the largest number of sporophores were found upon the open pile and that of these over 85 per cent were of *Lenzites sepiaria*, a fungus which thrives under comparatively dry conditions. In the closed pile only 56 per cent of the total sporophores were of *Lenzites sepiaria*, and three other species were represented, in contrast to two species in the open pile.

Cultures made from test blocks cut from the planks stored in the two piles in the shed showed that the fungi within the wood were still alive, although there were no indications that the decays had progressed within the planks. No sporophores had developed on any of these planks.

On April 25, 1922, notes were again taken on the sporophore crop appearing upon the planks stacked in the yard. On the planks in the open pile a total of 61 sporophores were noted. Some of these were resupinate in character, and a few were buttons, or rudimentary fruit bodies. Of this total, 50 (or about 82 per cent) were *Lenzites sepiaria*, 7 *Trametes carnea*, 2 *Polyporus anceps*, and 2 *Stereum* sp. On the closed pile were found 69 sporophores with about 10 buttons. Of this total, 42 (or about 61 per cent) were *Lenzites sepiaria*, 13 were *Trametes carnea* with 10 buttons, 7 were *Polyporus anceps*, 5 *Polystictus abietinus*, and 2 *P. versicolor*.

A comparison of the closed pile with the open pile indicates that the closed pile is more favorable to sporophore production and pre-

sumably to decay activity. The records taken on April 25, 1922, show an additional genus and two additional species over those taken on June 11, 1921.

As an additional control, a closed pile was constructed in the yard on July 28, 1920. This was made of the infected planks removed from the kiln (run 2) which showed by culturing that the fungi in the wood had been killed. This pile was subject to the same environment as the other two piles in the yard. No sporophores developed upon these planks.

REVIVAL OF FUNGI IN WOOD AFTER AIR DRYING.

Green infected lumber piled for air seasoning or for storage contains the live organisms which cause rot and sap-stain. These organisms can remain inactive in wood during periods when the lumber is kept dry, but can revive and continue their development and therefore extend the decay or stain in the presence of favorable moisture and temperature conditions. The approximate length of time during which wood-destroying and sap-stain organisms can remain alive in wood under continued air-dry conditions has been determined for certain fungi by means of the method here outlined.

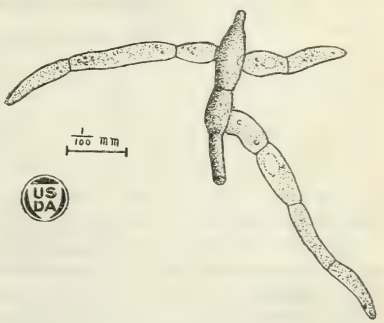


FIG. 2.—An old fungous thread (hypha) of the blue-stain fungus which has revived and produced three new growing branches. The hyphæ in the wood (*Pinus strobus*) were air dry and dormant for some time, but revived when sufficient moisture was supplied. Enlarged about 800 times.

Blocks of wood infected with known fungi were stored on shelves in the dry air of the laboratory, in which the temperature range was between 64° and 74° F. Cultures were made at intervals, usually six months apart, using fragments of the infected wood. Positive cultures indicated the revival of the fungus in each case. In order to determine whether the new growth developing from the infected fragment grew from the old hyphæ in the wood and not from spores, either secondary or primary, or from young hyphæ of a possible recent infection of the wood, cover-glass cultures were made. Thin sections of the infected wood were cut, washed in distilled water, and under sterile conditions placed under a cover glass on a thin layer of malt agar on a glass side. Here the growths of the hyphæ were observed under the microscope. In all cases the new growth was traced to the "sprouting" of the old hyphæ in the wood (fig. 2). This was observed for the following fungi: *Trametes carnea*, *T. pini*, *Polyporus anceps*, *Trametes serialis*, *Fomes pinicola*, and *Ceratostomella* sp.

The results given in Table 2 show the cultures completed up to January, 1923.

The blue-stain fungus in one case was estimated to have remained more or less dormant for a period of seven years. *Trametes serialis* (?) in a Douglas fir timber was found to revive after use of the

timber in a building for 4½ years and subsequent storage in the laboratory for over 7 years. Complete records on *Polyporus amarus* in *Libocedrus decurrens* showed that the fungus remained alive up to about eight months. Cultures made from the infected wood one month and eight months later showed no growth. Cultures of this fungus develop slowly when fragments are taken from material not freshly cut from the tree or log. In some cases 20 to 25 days elapsed before the growth appeared on the agar slants or the inoculum.

The fungi recorded in the "Live" column are still under observation, and in no way can these results be taken as the limits of vitality of the different fungi. The figures in the "Dead" column indicate only that the fungus did not revive when cultured. Just when the ability to revive was lost has not been determined.

TABLE 2.—*Length of time certain fungi remain alive but inactive in wood stored in the air-dry conditions of a room.*

[Date when last cultured, January, 1923.]

Fungus.	Host.	Length of time in storage, air-dry condition.			
		Live.		Dead.	
		Years.	Months.	Years.	Months.
Ceratostomella sp	Pinus ponderosa	3	0		
Do	Pinus strobus	3	0		
Do	Southern yellow pine	7	0		
Echinodontium tinctorium	Tsuga heterophylla	5	7		
Fomes annosus	do			5	0
Fomes applanatus	Populus trichocarpa	1	5	2	4
Fomes igniarius	Acer rubrum	1	5		
Do	Populus tremuloides			10	0
Fomes laricis	Pseudotsuga taxifolia	1	0		
Fomes pinicola	Tsuga heterophylla	1	4		
Trametes carnea	Picea canadensis	2	9		
Do	do	2	7		
Ganoderma tsugae	Tsuga canadensis		6	1	3
Lentinus lepideus	Southern yellow pine			2	4
Lenzites sepiaria	do	2	7		
Do	Picea canadensis	2	9		
Do	do	6	2		
Do	do	6	3		
Pholiota adiposa	Tilia americana	1	5		
Do	Abies grandis			6	3
Pholiota sp	do	6	0		
Polyporus adustus	Nyssa sylvatica	1	8		
Polyporus amarus	Libocedrus decurrens		7		8
Polyporus anceps	Picea canadensis	2	7		
Do	Pinus ponderosa	3	5		
Polyporus schweinitzii	Pseudotsuga taxifolia	1	0		
Polyporus stipticus	Pinus ponderosa	2	1		
Polyporus sulphureus	Quercus sp	1	4		
Do	Quercus rubra			10	0
Polystictus versicolor	Alnus oregona	2	6		
Polystictus hirsutus	do	2	6		
Trametes pini	Larix laricina	1	5		
Do	Picea canadensis	2	3		
Do	Pinus monticola			5	0
Do	Tsuga heterophylla			7	2
Trametes serialis (?)	Pseudotsuga taxifolia	7	5		
Fusarium negundi (red stain)	Acer negundo	1	6		
Brown cubical rot	Thuja plicata	1	6		
Do	Thuja occidentalis	1	6		
Brown pocket rot	Sequoia sempervirens	5	0		

In general, the results at this time show that certain fungi in wood can remain alive though dormant for long periods under the air-dry conditions of a room and are capable of reviving and producing new growth when sufficient moisture is added.

REVIEW OF THE RESULTS.

Sterilization by heat is a well-known process and has its examples in many everyday activities. The canning of fruit is probably the best-known example, and it is but a short step from this to the sterilization of wood—a very similar process. The protection of wood against future infection is not accomplished by sterilization alone. Proper care following sterilization is absolutely essential, and in the case of lumber proper storage to insure dryness is the process by which reinfection is prevented. This fact has prompted the inclusion of the air-seasoning data for correlation with the results of the heat experiments. It will be of interest to note here that wood when properly kiln dried is equal in strength to air-dried wood when moisture contents are carefully considered (*10*).

A brief consideration of the factors affecting the penetration of heat into sound and infected wood may not be out of place here. Very little has been published on this subject. Hunt (*3*) in a series of experiments obtained data on the rate of heat penetration into sound wood of various sizes and species. Using sawed ties of maple, red oak, loblolly pine, and hemlock 6 by 8 inches by 8½ feet he found that under the conditions of the experiments no appreciable difference in rate of increase of temperature due to difference in species could be determined. He also observed that the interior of the ties never quite gained the temperature of the heating medium and that seasoned ties heated more rapidly than green ties. In the treatment with steam at 20 pounds pressure the time required for the interior to reach 212° F. varied from 2¾ to 5 hours, averaging 4 hours and 20 minutes. With steam treatment at atmospheric pressure the ultimate maximum temperatures within the ties varied from 2 to 17 degrees F. less than the temperatures of the surrounding medium. With steam at 20 pounds pressure the variation was from 2 to 21 degrees F.

In regard to the experimental data in this bulletin, the effect of heat upon the fungi in the wood was observed to vary with the size of test pieces and the relative porosity of the wood as expressed by the stage of decay. In many cases negative cultures were obtained from portions of the culture block, showing a typical stage of decay which was obviously more porous than the near-by areas of incipient decay. In other cases the blue-stain fungus present in the sapwood of the piece was killed in blocks showing a brown cubical or brown ring-rot in the adjoining heartwood, and it remained alive in blocks of similar size containing only incipient stages of decay in the adjoining heartwood. The data on the steaming experiments when plotted on coordinate paper show in general a definite relationship between time and temperature. This is clearly evident in the curves shown in Figure 1. Curve A is drawn through points representing data on the 1-inch test pieces. Curve B is more or less theoretical and represents roughly the time and temperature limits necessary to kill certain fungi in wood up to and including 4 inches in thickness. The point in Figure 2 showing death of the fungi in 4-inch stock subjected to 140° F. for six hours is considerably outside the curve and theoretically should coincide with the curve near the 4½-hour point. It is evident that the fungi in this case were killed

before the six-hour limit was reached, as another test (run 10) shows that the fungi were dead in the 4-inch stock subjected to 145° F. for three hours. For completeness, the points representing the data on 6-inch and 8-inch stock, as well as the high values obtained for the blue-stain organisms, are given.

In the steaming experiments a saturated atmosphere was used in order to avoid as much as possible variations in heat penetration which might be due to variations in moisture content of the test pieces, since the experiments of Hunt (*3*) have shown that seasoned wood heats more quickly than green wood. The data from the steaming experiments are thus directly applicable to the preliminary steaming now generally recommended for various commercial kiln runs. This preliminary steaming consists of subjecting the wood at the beginning of the run to live steam (160° to 185° F.) for half an hour to three hours. By glancing at the temperatures and periods of time given in Table 1 and comparing these with the temperatures and periods of time given for the hardwood and softwood drying schedules by the Forest Products Laboratory (*1*, *4*, *11*) it will be seen that with very few, if any, exceptions the heat and periods of duration of each schedule are sufficient to sterilize wood (for the fungi of these experiments) up to and including 4 by 4 inches in cross section. In the drying schedules for hardwoods the lowest temperature used is 115° F. for an average period of 56 days and the highest temperature 170° F. for 3 to 4 days. The lowest and highest temperatures used in the various schedules for drying softwoods are 135° and 200° F., respectively. The lowest temperature used in the steaming experiments was 110° F. for 48 hours; the highest was 170° for 40 minutes at atmospheric pressure and 274° at 30 pounds gauge pressure. The first is successful in sterilizing wood up to but not including all the test pieces of a thickness of 4 inches; the last has been tested for 1-inch stock only.

From the experimental data obtained in this study the following results are shown for the hosts and fungi studied:

(1) A long list of fungi consisting of both wood-destroying and sap-stain organisms in a variety of hosts can effectively be arrested in their development through sterilization by heat.

(2) The blue-stain fungus is apparently the most resistant of those tested.

(3) The stage of decay of certain fungi may affect the rate of heat penetration within infected wood.

(4) The temperature of commercial kiln runs, excepting temperatures below 120° F., are effective in sterilizing infected wood up to and including 4 by 4 inches square. Pieces 6 by 6 inches and 8 by 8 inches square were sterilized by treatment at 130° F. for nine hours at saturated atmosphere and by steam-pressure treatment.

(5) Infected wood piled in the yard at Madison, Wis., in both open and closed piles and unprotected against rain, will continue to develop decay and in many cases fungous fruiting bodies.

(6) Similar material piled in dry sheds protected from moisture showed no outward signs of fungous activity, but the fungi remained alive though inactive. Uninfected wood in the same shed remained sound.

(7) Certain fungi dormant or inactive within air-dry wood for long periods of time are capable of reviving and continuing their development upon the return of favorable moisture conditions.

One investigator (*12*) has shown that a fairly high moisture content of the wood, about 25 per cent, is needed before spores of *Lenzites sepiaria* will germinate readily upon the surface and subsequently cause infection.

Münch (*5*) has shown that for a blue-stain fungus (*Ceratostomella coerulea* Münch) in the sapwood of Scotch pine (*Pinus sylvestris* L.) the optimum moisture content of the wood lies between 33 and 74 per cent, based upon the oven-dry weight. Above and below these limits the activity of the fungus decreases, and at 143 per cent no growth was noted. At 28 per cent little growth was evident. The same writer also states that the moisture content favorable for the blue-stain fungus agrees in general with the moisture requirements of certain wood-destroying fungi.

Snell (*7*) has reported on one series of experiments in which he used *Lenzites sepiaria*, *L. trabea*, *Trametes serialis*, *Fomes roseus*, and *Lentinus lepideus* in loblolly-pine sapwood (*Pinus taeda* L.) and Sitka spruce (*Picea sitchensis*), presumably heartwood. He found that the results upon loblolly-pine sapwood agreed very closely with those of Münch on Scotch pine. Very little decay was recorded when the quantity of water in the wood was below the fiber saturation point, a moisture content of 25 per cent in terms of the oven-dry weight of the wood. With the increase in moisture content the decay increased, and the greatest development of decay occurred between 33 and 42 per cent (or 49 and 72 per cent based on the oven-dry weight). At 50 per cent there was little decay, and no decay was noted at 60 per cent (150 per cent, oven dry). With spruce the decay began a little below the fiber saturation point, and the greatest development was noted between 30 and 57 per cent (43 and 133 per cent, oven dry). At 67 per cent (203 per cent, oven dry) neither penetration by the hyphæ nor decay was noted.

These experiments indicate that a moisture content considerably above the fiber saturation point of wood is required for the optimum development of at least certain fungi within wood. How long this optimum condition must be maintained to produce decay in stored lumber is not known, nor are there any figures to show whether alternate wetting to the fiber-saturation point and above and drying to 17 per cent and lower is favorable or unfavorable to fungous development. In regions where the rainfall is heavy and continuous over long periods the unprotected and poorly protected lumber would unquestionably develop wood-inhabiting fungi. It is doubtful whether lumber properly dried and carefully stored under cover would absorb sufficient moisture from a humid atmosphere to sustain continuous fungous growth within the wood.

With these facts as a basis, it seems reasonable to suppose that wood properly kiln dried will be sterilized and that if it is then properly stored in dry well-ventilated piles protected from all moisture (except the moisture absorbed from the air) the stock will remain bright and sound.

SUMMARY.

The need is shown for some practical method or methods of sterilizing wood against the fungi inhabiting it, and the wide application of such methods to the wood producing and consuming industries is indicated.

The tests carried out show that a long list of wood-inhabiting fungi in a variety of woods can effectively be arrested in their development through sterilization by heat.

Of the various fungi tested the blue-stain fungi appear to be the most resistant to heat. No great differences in resistance were noted among the various rot-producing fungi tested.

Commercial kiln conditions and steaming processes coming within the effective limits of temperature and time as determined by the tests are effective in sterilizing infected wood up to and including pieces 4 by 4 inches square. Pieces 6 by 6 and 8 by 8 inches square were sterilized when subjected to 130° F. for a period of nine hours. Sterilization was also effected by steam-pressure treatments.

Methods of piling and storage are important factors in protecting wood against deterioration due to fungi.

Certain fungi continue to develop in wood as long as favorable conditions are present, and they will revive and continue development after long periods of drying.

From the data obtained it is assumed that wood that is properly kiln dried will be sterilized and that with proper storage it will remain bright and sound.

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