PRESERVATIVE TREATMENT OF WOOD BY PRESSURE METHODS

Agriculture Handbook No. 40

UNITED STATES DEPARTMENT OF AGRICULTURE
Forest Service

ERRATA SHEET

for

Preservative Treatment of Wood by Pressure Methods

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Page

9 Line 2, "older and heartwood" should read "older the heartwood".

17 Group 4, second col. "(read heartwood)" should read "(red heartwood)".

38 Line 21, reference italic "(50)" should be italic "(51)".

47 Table 6, col. 4, change 200-200 to 200-210.

48 Table 7, col. 4, first line, change 01.0 to 11.0.

72 Table 9, col. 5, beginning with second line, change 235 to 135, 255 to 155, 276 to 176.

80 Table 13, col. 9, last line, change 37.7 to 3.7.

105 Table 17, col. 2, last line, change 2.067 to 2.167.

105 Table 17, col. 7 heading, change "per" to "both".

106 Table 17, col. 3, 7th line, change 1.090 to 1.091.

106 Table 17, col. 7, 8th line, change 6.808 to 6.818.

108 Equation bottom of page should read "0.531W" not ".0531W".

110 Example, last term in denominator should read "0.55" not ".055".

121 Table 20, col. 1, 4th line under "Steamed Green Lumber and Timbers", insert figure "1".

135 W_d definition should read "oven-dry wood per unit" etc.

139 Table 22, Footnote 1, *a*l should read a_1, f^1 should read f_1

150 First equation, delete "=(A)." insert "(A)" flush right.

150 Line 17, "pp. 149-150" should read "pp. 150-151".

150 Line 7 from bottom, "p. 150" should read "p.149".

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PRESERVATIVE TREATMENT OF WOOD BY PRESSURE METHODS[1]

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[1] This handbook supersedes the MANUAL ON PRESERVATIVE TREATMENT OF WOOD BY PRESSURE, U. S. Dept. Agr. Misc. Pub. 224.

[2] Acknowledgment is made to various members of the Forest Products Laboratory who have been consulted on subjects relating to their fields of investigation and from whom much helpful data and information have been obtained.

[3] Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

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INTRODUCTION

The principal wood-destroying agencies are the decay fungi, insects, marine borers, and fire. Preservative treatment, which is used to retard or prevent the operation of these agencies, has made wood an economical material to use in many fields, whereas without such treatment its short life and consequent high cost make its use prohibitive.

Pressure treatment with preservatives suitable for the particular service requirements is now widely employed for material such as ties, poles, piling, posts, bridge timbers, mine timbers, cross arms, conduits, and lumber and timbers used in buildings where conditions are favorable for attack by decay or insects. It is also employed in the impregnation of wood with fire-retarding chemicals.

Pressure treatment when intelligently applied results in lower annual cost, more satisfactory service, and a decreased drain upon the forest resources. The effectiveness and economy of preservative treatment depend on the qualities of the preservative and the thoroughness of the treatment. Good treatment is economical, but poor treatment, whether resulting from improper choice of preservative, improper specifications, low preservative retentions, or insufficient penetration, is expensive and may prove disastrous.

The problem of adequate treatment is complicated by many factors, including the species, size, form, condition, and proposed use of the timber; kind and amount of preservative to be injected; details of the treating process employed; and the skill of the treating-plant operator. The methods now in use for the injection of preservatives by pressure [4] are the result partly of technical research and partly of the accumulation of more than a century of world experience in wood preservation. By the proper use of these methods it is practicable for purchasers to obtain adequately treated timber that can be depended on for long life under the most severe conditions of exposure.

The Forest Products Laboratory has done much work on the many technical problems involved in the pressure treatment of wood, including numerous experiments and observations at commercial treating plants. The purpose of this publication is to discuss the application of the results of these experiments and observations, and to present general information that will be of value to engineers, treating-plant operators, inspectors, and others interested in pressure-treating processes and in the preparation of specifications.

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[4] The Treatment of timber by open-tank and other nonpressure methods is discussed in U. S. Department of Agriculture Farmers' Bulletin 2049, (*5a*).

Italic numbers in parentheses refer to Literature Cited, p. 152.

PRESSURE PROCESSES

The most effective method of treating wood with preservatives is by means of pressure.[5] There are a number of pressure processes, all of which employ the same general principle but differ in the details of application. The timber to be treated is loaded on tramcars, which are run into a large steel cylinder. After the cylinder door is closed and bolted, preservative is admitted and pressure applied until the required absorption has been obtained. Two principal types of pressure treatment, the full-cell (Bethell) and empty-cell (Lowry and Rueping), are in common use. The essential characteristics of these processes are described below; their fields of usefulness are discussed on pages 95, 125, and 126.

FULL-CELL PROCESSES

In making treatments with the so-called "full-cell" or Bethell process, a preliminary vacuum is first applied to remove as much air as practicable from the wood cells. The preservative is then admitted into the treating cylinder without admitting air. After the cylinder is filled with preservative, pressure is applied until the required absorption is obtained. A final vacuum is commonly applied immediately after the cylinder has been emptied of preservative to free the charge of dripping preservative.

When the timber is given a preliminary steaming-and-vacuum treatment (p. 39), the preservative is admitted at the end of the vacuum period following steaming. In case the charge has received a preliminary conditioning treatment by the Boulton or boiling-under-vacuum process (p. 44), the unfilled space at the top of the cylinder is filled with preservative and pressure is applied as soon as this conditioning process has been completed.

It is impossible to remove all of the air from the wood cells regardless of the method of treatment employed. For this reason, even under the most favorable conditions, there is some unfilled air space in the cell cavities of the treated wood after impregnation by the full-cell process.

When the full-cell process is used for treatment with zinc-chloride solution, it is commonly called the Burnett process.

EMPTY-CELL PROCESSES

Two empty-cell treatments, the Lowry and the Rueping, are commonly used, both of which depend upon compressed air in the wood to force part of the absorbed preservative out of the cell cavities after preservative pressure has been released.

Lowry Process

In the Lowry process, which is also designated as the "empty-cell process without initial air," the preservative is admitted to the treating cylinder at atmospheric pressure. When the cylinder is filled, pressure is applied and the preservative is forced into the wood against the air

[5] A discussion of pressure-treating-plant equipment and of various methods of treating wood by both pressure and nonpressure methods is given in WOOD PRESERVATION (*21, p. 329*).

originally in the cell cavities. After the required absorption has been obtained, pressure is released, a vacuum is drawn, and the air under pressure in the wood forces out part of the preservative absorbed during the pressure period. This makes it possible, with a limited net retention, to inject a greater amount of preservative into the wood and to obtain deeper penetration than when the same net retention is obtained with the full-cell process. The Lowry process is convenient to use in any pressure-treating plant, since no additional equipment is required.

Rueping Process

This process is also called "empty-cell process with initial air." The principal difference between the Lowry empty-cell process and the Rueping process is that, in the latter, air is forced into the treating cylinder before the preservative is admitted. The air pressure is then maintained while the cylinder is filled with preservative; thus, the wood cells are left more or less impregnated with air under pressure. In resistant woods this air pressure may penetrate only a short distance from the surface, while in wood that is fairly pervious to the penetration of air and liquids, such as the sapwood of many species, an air pressure is built up in all of the penetrable portion.

In the application of this process the preservative is often admitted from an equalizing tank (Rueping tank) and the air in the treating cylinder interchanges with the preservative in this tank. In some plants not equipped with a Rueping tank, the preservative is pumped into the treating cylinder against the preliminary air pressure and sufficient air is released during the filling period to keep the pressure constant. Impregnation of the wood is obtained by applying a pressure sufficiently high to force preservative into the timber against the air pressure in the wood cells. Then, upon release of preservative pressure and application of a vacuum, part of the preservative is forced out of the wood by the expanding air. The amount of such recovery will usually be greater with the Rueping than with the Lowry process, under comparable conditions.

WOOD PRESERVATIVES

Wood preservatives may be grouped into two broad classes: preservative oils and water-borne preservatives. Each of these classes may be further subdivided in various ways. For example, preservative oils include byproduct oils such as coal-tar creosote and other creosotes, mixtures of coal-tar creosote with coal-tar, petroleum, or other oils, solutions of toxic chemicals such as pentachlorophenol or copper naphthenate in selected petroleum oils or other solvents, and various mixtures of these solutions with the byproduct oils and mixtures. The water-borne preservatives include solutions of single chemicals such as zinc chloride or sodium fluoride, which are not resistant to leaching, and various formulations of two or more chemicals that react after impregnation and drying to form compounds with limited solubility and sometimes with high resistance to leaching, (*1*, *2*, *5*).

Preservatives vary greatly in effectiveness and in suitability for different purposes and use conditions. The effectiveness of any preservative depends not only upon the materials of which it is composed, but also upon the quantity injected into the wood, the depth of penetration, and the conditions to which the treated material is exposed in service.

COAL-TAR CREOSOTE

Coal-tar creosote is defined by the American Wood-Preservers' Association as a preservative oil obtained by the distillation "of coal tar produced by high-temperature carbonization of bituminous coal; it consists principally of liquid and solid aromatic hydrocarbons and contains appreciable quantities of tar acids and tar bases; it is heavier than water; and has a continuous boiling range of at least 125° C. beginning at about 200° C."

Coal-tar creosote is highly effective and is the most important and most extensively used wood preservative for general purposes.

WATER-GAS TAR AND WATER-GAS-TAR CREOSOTE

Water-gas tar is obtained from petroleum oil as a byproduct in the manufacture of water gas.

Water-gas-tar creosote is produced by distillation from water-gas tar. This creosote is defined as any and all distillate oils from such tars boiling between 200° and 400° C. While water-gas tar and the creosote produced from it are not considered so generally effective as coal-tar creosote, service-test records indicate that they have good preservative properties.

WOOD-TAR CREOSOTE

Wood-tar creosote is obtained from wood tar and distills mostly above 170° C. Since wood-tar creosotes have been produced in comparatively small quantities and have usually sold at higher prices than coal-tar creosote, they have not been extensively used as a wood preservative. Good wood-tar creosotes have demonstrated high effectiveness, but they seem to be somewhat less effective than coal-tar creosote.

COAL TARS

The various coal tars are, in general, unsuitable as wood preservatives when used alone because their relatively high viscosity makes it difficult to obtain satisfactory penetrations. They may not be quite so effective as coal-tar creosote, but they possess good preservative properties. Some of them have been used for the purpose and have given excellent results when satisfactory retentions and penetrations were obtained.

PETROLEUM OILS

Petroleum oils, such as crude petroleum, topped petroleum, fuel oil, and used crankcase oil, as a rule, do not possess toxic properties to make them suitable as wood preservatives when used alone. Although in a few cases good results have apparently been obtained with petroleum oils used alone, in other cases complete failure has resulted. They are used in preservatives merely as solvents of toxic chemicals or diluents of preservative oils.

CREOSOTE, COAL-TAR SOLUTIONS

Coal tar is extensively employed in solution with coal-tar creosote for the treatment of ties and to some extent other classes of timber. The coal-tar solutions are used principally in the Eastern and Southern States. Mixtures of coal tar and creosote commonly contain about 20 to 50 percent of tar by volume.

COAL-TAR CREOSOTE AND PETROLEUM SOLUTIONS

Mixtures of coal-tar creosote and petroleum are widely used in the Western States, principally for the treatment of ties, but also for the treatment of lumber, timber, and land and fresh-water piling. In general, their petroleum content ranges from 30 to 70 percent by volume, but the content is usually about 50 percent.

Since the toxicity of the petroleum mixtures is furnished by the creosote, it is important that the creosote be of high toxicity.

CHEMICALS DISSOLVED IN SOLVENTS OTHER THAN WATER

Preservatives composed of toxic chemicals carried in nonaqueous solvents, such as petroleum-oil distillates, are now being used to an increasing extent. These were originally devised for the purpose of providing a clean treatment without causing swelling of the wood and were originally applied by nonpressure methods.

A shortage of creosote that developed during World War II created an active interest in the use of these preservatives as a possible substitute for creosote, especially in the pressure treatment of poles. Particular attention was directed to the chlorinated phenols, which are known to have a high degree of toxicity. Pentachlorophenol is the best known and most widely used in this group.

Other preservatives of this type, which in the past have been largely limited to use in surface treatments, are the metallic naphthenates, such as copper naphthenate. The latter has also been used to a limited extent for pressure-treated poles.

Although some of these toxic chemicals, particularly pentachlorophenol, have been giving excellent results over a considerable period of time, service records are still inadequate to evaluate them completely in comparison with coal-tar creosotes.

WATER-BORNE PRESERVATIVES

A variety of chemicals in water solution are used as wood preservatives. These include zinc chloride, sodium fluoride, arsenic in various forms, copper sulfate, and similar toxic chemicals. Most of these salts are used in combination with one or more other chemicals, frequently including a chromium compound. Chromated zinc chloride, which is composed of a mixture of zinc chloride and sodium dichromate, has come into wide use in recent years. This preservative is now much more extensively used than straight zinc chloride, which was formerly the most widely used water-borne salt.

Sodium fluoride has moderate preservative properties, but it is seldom used alone. It is an important ingredient in several proprietary preservatives, some of which are finding considerable use in the treatment of building lumber and structural timber.

Arsenic compounds have been used as preservatives for many years. They are important ingredients of a number of proprietary preservatives, some of which have demonstrated high effectiveness and are extensively used.

Copper sulfate, although extensively used in Europe for many years and demonstrated to be moderately effective in retarding decay, has found little use for wood preservation in the United States except in certain proprietary preservatives, in which it is combined with other chemicals. Several of these preservatives are of high effectiveness and extensively used. Copper sulfate is corrosive to iron and steel and, therefore, cannot be used alone in ordinary treating equipment.

PROPRIETARY PRESERVATIVES

Various patented or proprietary preservatives are sold under trade names for pressure treatment. For the most part they are composed of various water-borne salts and are injected in water solutions. Others employ a volatile solvent to carry the toxic substance into the wood. Some of the water-borne preservatives contain chemicals that are intended to react after injection into the wood and to form substances that are of low solubility and resistant to leaching.

EFFECT OF WOOD STRUCTURE ON TREATMENT

Wood varies greatly in its structure. Hardwoods differ from softwoods, and in each of these groups there are differences among individual species. In fact, there are differences even in the same tree, since the heartwood, although its gross structure is the same, commonly contains certain substances not abundant in the sapwood. All these differences have their influence upon the penetrability of the wood by preservatives. An acquaintance with the following features of the structure of wood is needed for a full understanding and appreciation of this publication.

DIFFERENCES IN STRUCTURE OF HARDWOODS AND SOFTWOODS

Hardwood or broadleaf trees contain specialized cells that serve as sap conductors. These cells, set end to end, are known as pores or vessels, and form more or less continuous passages. Mechanical support is furnished by wood fibers that surround the vessels.

The softwoods, generally known as conifers,[6] do not have the specialized sap-conducting cells found in the hardwoods, but instead have elongated cells, called tracheids or fibers, that have closed ends. These tracheids serve both for sap conduction and for mechanical support in the living tree. Liquids pass from one tracheid to another through bordered pits, which are most numerous near the tracheid ends and may contain minute perforations.

The terms hardwood and softwood are somewhat misleading, as there are some softwoods that are even harder, from the mechanical standpoint, than some hardwoods. Although in general most of the hard-

[6] Native conifers include the pines, Douglas-fir, the true firs, the spruces, hemlocks, junipers, larches, and cedars, and cypress, redwood, and yew.

woods are actually very hard, some woods of this group are soft, such as basswood, willow, and cottonwood. Similarly, though most of the softwoods are relatively soft, some of them, such as yew, Douglas-fir, and longleaf pine, are very hard.

Figures 1 and 2 show the general structure of a hardwood and of a softwood, respectively.

Hardwoods, such as gum, beech, birch, and basswood, in which the pores or vessels are of fairly uniform size and distribution, are called

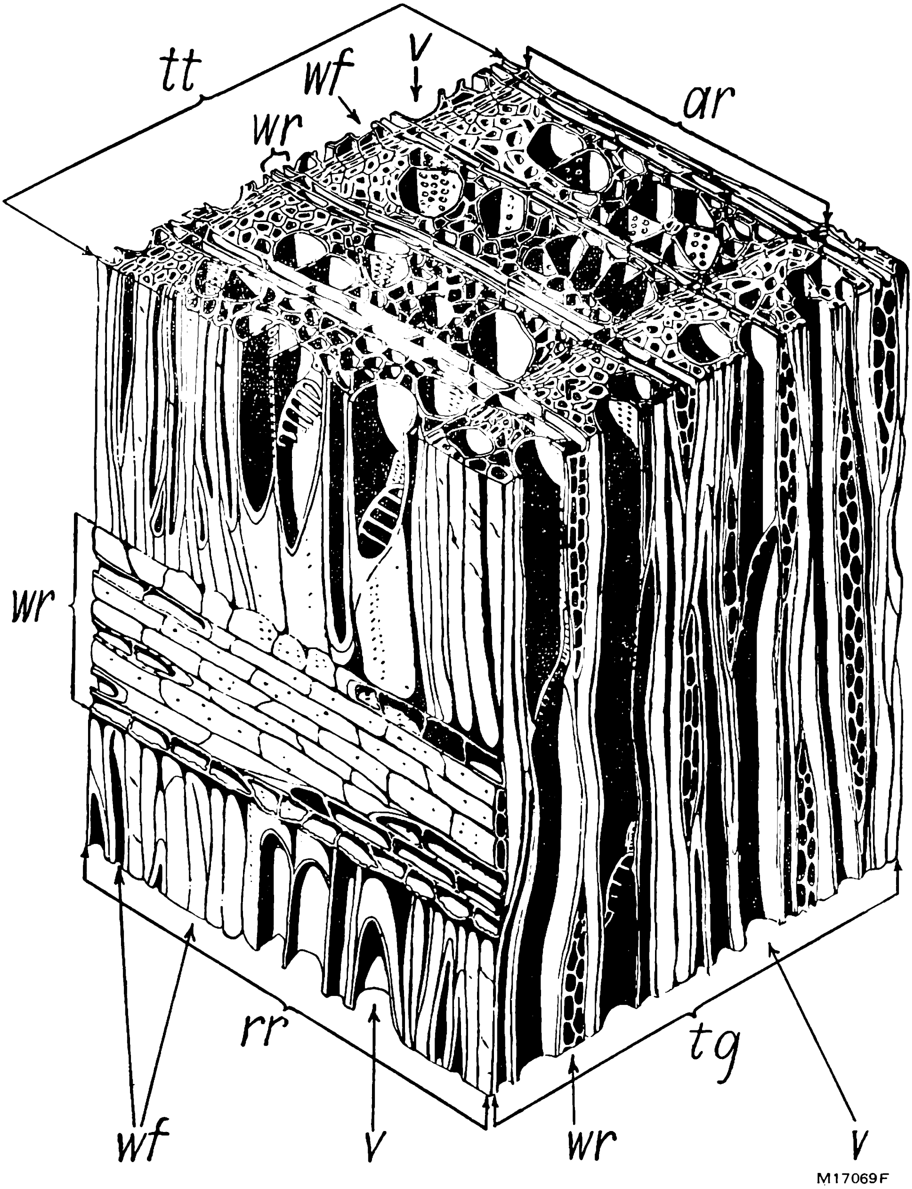

FIGURE 1.—Drawing of a highly magnified block of hardwood measuring about one-fortieth of an inch vertically: *tt*, End surface; *rr*, radial surface; *tg*, tangential surface; *v*, vessel or pore; *wf*, wood fibers; *wr*, wood rays; *ar*, annual ring.

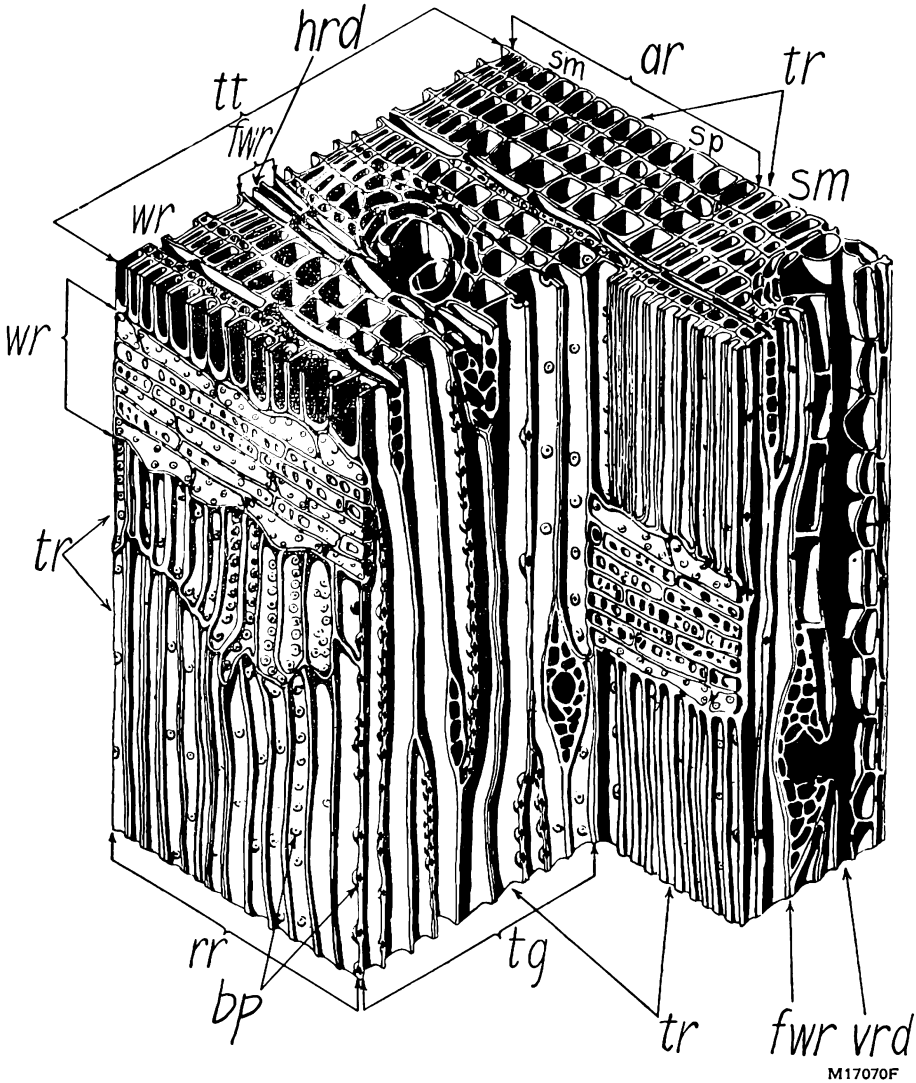

FIGURE 2.—Drawing of a highly magnified block of softwood measuring about one-fortieth of an inch vertically: *tt*, End surface; *rr*, radial surface; *tg*, tangential surface; *ar*, annual ring; *sm*, summerwood; *sp*, springwood; *tr*, tracheids, or fibers; *hrd*, horizontal resin duct; *vrd*, vertical resin duct; *fwr*, fusiform wood ray or ray having horizontal resin ducts; *wr*, wood rays; *bp*, bordered pits.

diffuse-porous woods; whereas those that have alternate layers of small and large pores, such as oak, elm, hickory, and chestnut, are called ring-porous woods. The penetrability of the hardwoods depends to a large extent on the open or closed condition of these pores or vessels. On the other hand, penetration in the softwoods is largely dependent on the permeability of the cell walls.

HEARTWOOD AND SAPWOOD

In general, the most universal cause of the difference in the penetration of preservatives in both hardwoods and softwoods is the difference between heartwood and sapwood. Young trees are nearly all sapwood, but as they grow older and heartwood volume at the center gradually increases while new sapwood forms on the outside. The sapwood is living and takes an active part in the growth of the tree, whereas the heartwood is dead or inactive. During this transition from sapwood to heartwood, changes generally occur in the pores of hardwoods, which may become partially or completely closed with pithlike growths, called tyloses, or with gum; while in the conifers the openings in the tracheid walls may undergo changes that make them highly resistant to the passage of liquids.

The exact nature and the quantity of the various substances that accumulate in the heartwood are not well understood, but it is known that their character differs materially in different species and that their quantity differs among different trees of the same species and even in different parts of the same tree. They are sometimes referred to under the all-inclusive term, "gums, resins, and infiltrated substances." Those that can be dissolved out of the wood by water or other solvents are collectively called "extractives." An infinite amount of painstaking chemical work would be required to identify all of the compounds included in these substances.

Although the nature of the change from sapwood to heartwood is not fully understood, some of the major effects of the change are clearly evident. In most species there is a pronounced change to a darker color and the line of demarcation between heartwood and sapwood is distinct. However, in some species, such as the hemlocks and the spruces, there is little or no change in color. In some of the pines also it is not always easy to distinguish between heartwood and sapwood. A method for showing the demarcation in the pines is given on page 134.

In a large number of species there is a marked superiority in the decay resistance of the heartwood in comparison with that of the sapwood. The sapwood of all species has low decay resistance, whereas the heartwood of many is highly durable. The degree of durability in the heartwood depends mainly upon the amount and character of the substances that accumulate in it.

In most species the change from sapwood to heartwood greatly increases the resistance to penetration by preservatives, but this, again, is not universally true. In some species, eastern hemlock for example, both the sapwood and heartwood are resistant and the sapwood offers nearly the same resistance to penetration as the heartwood. In ponderosa pine and bristlecone pine the heartwood is more resistant to decay than the sapwood but still not difficult to penetrate. In white oak, sweetgum, and beech with red heartwood, the heartwood is almost impenetrable by ordinary methods, although the sapwood is easy to treat. These variations in penetrability affect the operation of treating plants, the selection of wood, and the preparation of specifications by purchasers.

A common fallacy is that heartwood is materially stronger than sapwood. The results of thousands of tests at the Forest Products Laboratory fail to show that this is true in any degree that is significant to the engineer interested in the preservative treatment of wood. The greater penetrability of the sapwood makes it superior from the standpoint of preservative treatment, and it should usually be preferred rather than discriminated against in wood that is to be treated.

x see errata, in front

EFFECT OF TYLOSES ON PENETRATION

In some of the hardwoods, white oak, chestnut, and black locust for example, the pores of the heartwood are filled with tyloses. Such species are usually resistant or almost impervious to treatment in the heartwood. In the sapwood, tyloses usually occur in the inner region near the heartwood where the vessels are beginning to lose their ability to conduct sap.

The influence of tyloses on penetration in the heartwood is illustrated by a comparison of the penetration obtained in the white oak group and in the red oak group. In most cases the heartwood of the white oaks is only slightly penetrable; that of the red oaks is, in general, readily penetrable. These two groups of species have practically the same wood structure, with the exception that the vessels in white oak heartwood are plugged with tyloses, whereas those of woods in the red oak group are usually free from tyloses. The other wood elements or fibers of these two groups of species are resistant to the penetration of liquids. The treatment of such species as red oak naturally depends to a large extent on penetration from the end surfaces. A discussion of penetration in the side surfaces is given on page 14. There are exceptional species, however, in both groups. For example, chestnut oak (*Quercus montana*) is a white oak that has relatively few tyloses. On the other hand, the red oak commonly called blackjack or jack oak (*Q. marilandica*) has pores that are closed by tyloses, and the species in this respect is similar to a white oak. Under certain growth conditions the other red oak species sometimes have a sporadic development of tyloses that may be sufficient to impede penetration.

Experiments on various hardwoods show that when the wood fibers are resistant to penetration the presence or absence of tyloses or other obstructions, such as gums, in the vessels largely determines whether the wood can be impregnated with preservatives (*8*, *59*). Tyloses may merely impede penetration in species in which they do not completely fill the pores. This is true in some of the ashes.

In some of the diffuse-porous woods, such as aspen and willow, tyloses occur more or less irregularly. Their influence in such species is, in general, proportional to their distribution. Diffuse-porous woods that are resistant to treatment appear to exhibit more erratic penetrations than do the ring-porous woods, possibly on account of the irregular distribution of tyloses or gums. Among such species are the maples, sycamore, and bigtooth aspen.

When the vessels or pores of a hardwood are filled with tyloses or gums so that the movement of liquids through them is completely obstructed, penetration must be obtained through the other vertical elements surrounding the vessels. The cells of these tissues have closed ends, so that liquids in passing from one cell wall to another must be absorbed through the wall or some portion of it. Very likely the penetration takes place through the pits or through checks in the fiber walls (*61*). Hickory is a good example of a wood in which these wood elements can be penetrated to a greater or less extent, and the oaks of wood in which these elements cannot be penetrated. Although the vessels of hickory are closed by tyloses as in the white oak, the other wood cells of hickory are much more permeable than those in oak.

BORDERED PITS AND SIMPLE PITS

A relatively unthickened portion of a cell wall, the thin membrane of which permits liquids to pass from one cell to another, is called a pit. A bordered pit (see *bp*, figure 2), has an overarching rim that is not present in a simple pit, is usually more or less circular, and is partitioned by the pit membrane. The central portion of this membrane, which is thickened, is known as the torus. Figure 3 shows an enlarged cross-sectional drawing of a bordered pit, and figure 4 shows both a face and a profile view of bordered pits as seen through a microscope. At *A* in figure 3 and *a* in figure 4 the pit membrane is shown centrally located. In many of the refractory woods, particularly in the heartwood, the membrane is often permanently displaced, as indicated at *B* in figure 3 and *b* in figure 4. In this position they may retard or prevent the penetration of liquids. When the tori are not displaced, or are not "well seated," it is possible that liquids pass from one tracheid to another through the pit membranes or minute openings in them.

In conifers the cells formed in the spring are relatively large with thin walls, while those formed later are smaller and have thicker walls. The wood in the annual ring composed of cells with thin walls is called springwood and the portion containing the more dense wood is called summerwood. In some hardwoods, for example the oaks, the springwood is differentiated primarily by the larger pores that it contains. In others, such as maple and sweetgum, there is no such marked distinction between springwood and summerwood.

The summerwood of most of the conifers is more easily penetrated than the springwood by both preservative oils and water solutions. In

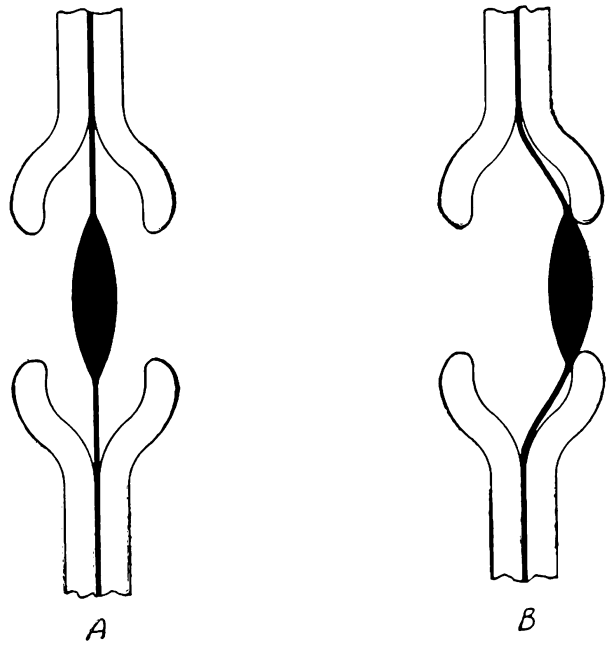

FIGURE 3.—Cross-sectional sketch of a bordered pit: *A*, Pit membrane centrally located; *B*, pit membrane permanently displaced.

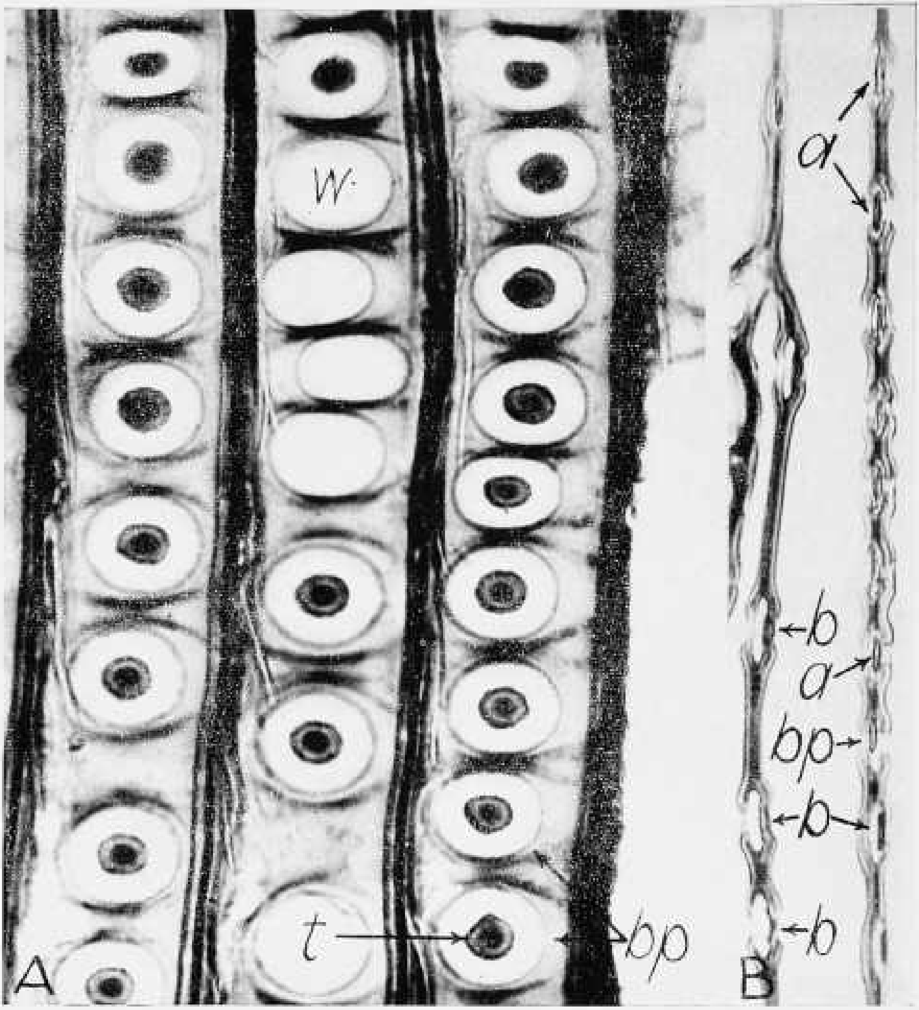

FIGURE 4.—Photograph taken through microscope showing greatly magnified bordered pits in longitudinal sections: *A*, Face view of bordered pits on cell wall; *t*, torus in bordered pit; *bp*, bordered pits; *w*, one of several white areas where section did not cut through torus. *B*, Profile view of bordered pits: *a*, tori centrally located; *b*, tori displaced; *bp*, bordered pits.

the summerwood more of the tori may be centrally located in the bordered pits than in the springwood, and it is possible that this is one of the reasons for the better penetrations obtained in the summerwood rings (*3*). Microscopical examinations of specimens that had proved very resistant to treatment in the summerwood showed that a large portion of the summerwood tori had been displaced (*11, 12, 53*). Some investigators, however, have indicated that penetration is not appreciably affected by the position of the tori in the bordered pits. Since these microscopical studies have been made on only a few species, much more work must be done to establish the relative importance of the position of the tori as a factor affecting penetration.

Simple pits are relatively unthickened portions in the cell walls that are limited by a thin membrane without such thickening as a torus and that do not have an overhanging border. These pits are found in the wood parenchyma and ray cells of softwoods and hardwoods and in some of the fibers of the hardwoods. Little is known about their influence on penetration. In some of the hardwoods the simple pits and the small bordered pits present may materially assist penetration when the vessels are closed by tyloses. They may also be of material assistance in distributing preservative through the wood from the open vessels.

RESIN PASSAGES

A number of the softwoods contain resin passages or ducts of indeterminate length. Resin passages are largest and most numerous in the pines. The longitudinal resin ducts are sometimes intersected by smaller radial resin passages within the wood rays, which, particularly in a number of the pine species, assist in the penetration of liquids.

Species that contain normal resin passages to a greater or less degree are the pines, spruces, tamaracks or larches, and Douglas-fir. The other softwoods, which include the true firs, hemlock, cypress, redwood, cedar, and yew, do not normally have resin passages. In some such woods as Engelmann spruce, white spruce, and the larches, the resin passages are very small, comparatively scarce, and open only for short distances. Species with resin ducts of this kind are usually resistant to treatment in the heartwood.

DENSITY

A comparison of the results obtained in the treatment of different species shows that there is no correlation between the density or specific gravity of the wood and the penetration of preservatives. Some of the woods having high specific gravities, such as the open-pored red oaks, are fairly easily penetrated; and some, like white oak, are very resistant. Similarly, some woods of low density, like ponderosa pine, are easy to penetrate; and some, like corkbark fir, are very resistant to treatment. Other factors, such as the presence and condition of pores and resin ducts and the difference between heartwood and sapwood, have so much greater influence that, if density has any effect at all, it is completely obscured.

Within the same species, however, density may under certain conditions appear to have some influence on penetration in the softwoods. Timbers of the conifers having a large proportion of springwood in comparison with the summerwood are of lower density and are usually more difficult to treat or take more erratic penetration than the denser timber of the same species. This is not really an effect of density, however, but of the difference in penetrability of springwood and summerwood, which is very marked in many of the conifers. The important factor here is the percentage and distribution of summerwood, which affect both the density and the penetrability. Differences in the relative penetrability of the summerwood and springwood are not particularly noteworthy in the hardwoods, except in species such as the red oaks, in which the springwood vessels are open and are larger than in the summerwood.

Softwood timbers of rapid growth often have both wide springwood and wide summerwood bands, and the density of material of this kind may be as high as that of slower-growth wood, although the springwood grows much more rapidly. Frequently the softwood timbers of rapid growth will show good penetration in the wide summerwood and little or no penetration in the wide springwood rings. The preservative in such timbers may follow the summerwood from the outside surface of sawed timbers or may enter through checks or resin ducts and then penetrate the summerwood in a tangential direction. In most cases the less heavily treated springwood is sufficiently protected against decay and insect attack by the adjacent covering of well-treated summerwood and by the preservative that may later diffuse into it from the summerwood. This, however, is not equally true for treated wood exposed to marine-borer attack. Complete penetration of both springwood and summerwood is desirable for the severe conditions of marine service.

Although density does not determine the penetrability of wood, it does influence the maximum amount of preservative that may be absorbed in seasoned material. The preservative enters the air spaces in the wood, and when a large part of the air space is occupied no more preservative can enter. Although water and water solutions are absorbed by the cell walls as well as in the cell cavities, preservative oils such as coal-tar creosote are absorbed chiefly in the cavities and only to a slight extent in the cell walls. Pure hydrocarbon oils such as petroleum are not absorbed by wood substance and therefore enter only the air spaces. The denser the wood the less air space it contains, and consequently the less preservative it can hold. Wood is seldom filled with preservative to complete saturation, however, since the various obstacles to penetration usually prevent complete penetration in timber of structural size. Some of the significant aspects of air space and density are discussed on page 28.

INFLUENCE OF STRUCTURE ON DIRECTION OF PENETRATION

Penetration may take place in wood in three directions, namely: Longitudinally, which is in the direction of the length of the tree trunk; radially, which is in the direction of the radius of the tree; and tangentially or circumferentially, which is in the direction of the annual rings.

Practically all species are most easily penetrated longitudinally, since liquids can follow in the direction of the vessels in the hardwoods and through the full length of the cellular space of the tracheids before passing through transverse cell walls in the softwoods. Liquids passing in a transverse direction, radial or tangential, must generally pass through many cell walls in moving a relatively short distance.

In some of the pines penetration is much better in the radial than in the tangential direction because it is assisted radially by the resin ducts of the wood rays (fig. 5). The heartwood of bristlecone, pinyon, and ponderosa pine is relatively easy to penetrate through the radial resin ducts, but the heartwood of species like red pine, longleaf, shortleaf, loblolly, and lodgepole pine are in general much more resistant to penetration. The penetration that is obtained in the latter woods, however, appears to be more or less dependent on the open or closed condition of the radial resin ducts.

Other conifers with radial resin ducts are Douglas-fir, the larches, and the spruces; but the radial resin ducts in these woods tend to be smaller than in the pines, are not so numerous, and are often closed, and they apparently have little if any influence on radial penetration.

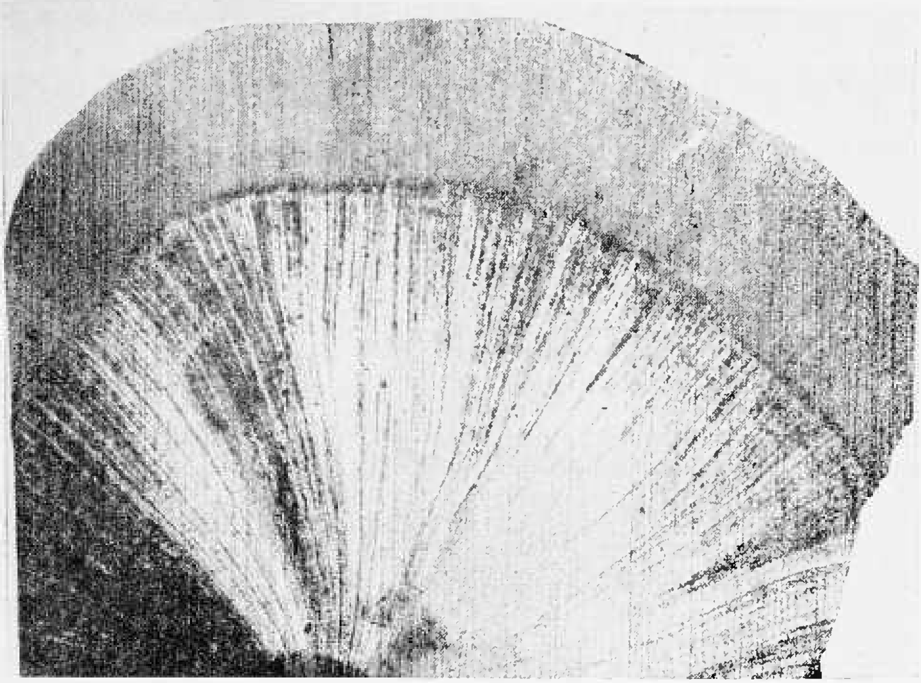

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FIGURE 5.—Cross section of treated bristlecone pine. The dark, radial streaks in the heartwood show that the penetration of the preservative was assisted by the wood rays.

In most of the conifers, except the pines, tangential penetration is usually better than the radial, although in some resistant species the difference is slight. Various hardwood species, such as birch, maple, and elm, also appear to take better penetration in the tangential than in the radial direction. In many of the conifers tangential penetration is assisted by the fact that summerwood bands are usually more permeable than either the wood rays or the alternate layers of springwood. Radial penetration is largely prevented when both the wood rays and the springwood bands are resistant.

It might seem that transverse or side penetration into the faces of a sawed or hewed timber must depend entirely on the penetrability in a direction across the fibers or cell walls, but this is not necessarily true. A certain amount of penetration in the direction of the fibers or vessels (longitudinal penetration) is obtained through practically all sawed or hewed surfaces, since many of the vessels of the hardwoods or tracheids of the softwoods lie at an angle with the cut faces and help conduct liquids to varying depths. When the angle made by the fibers is large, such as in timbers having a marked cross-grained structure, penetration is usually deeper than in timbers that are fairly straight-grained.

Variability in penetration at different points along the surface of a sawed timber is apparently influenced to a considerable extent by the number of cells that assist in longitudinal penetration from the side surfaces. It is natural that at some points most of the vessels or tracheids may lie nearly parallel with the surface, while at other points a variable number will lie at an angle with it. Even longitudinal penetration is slight in the heartwood of some of the more resistant species, such as corkbark fir and sweetgum, and it is practically impossible to obtain appreciable penetrations in the radial and tangential directions in the heartwood of such species.

CLASSIFICATION OF SPECIES WITH RESPECT TO PENETRABILITY

It is impossible to arrange the different species in exact order of their relative resistance to penetration by wood preservatives, because of the many variables that must be considered. The following rough classification, however, should be helpful: (1) Heartwood easily treated, (2) heartwood moderately difficult to treat, (3) heartwood difficult to treat, and (4) heartwood very difficult to treat. This grouping is based both on the results of laboratory experiments and on observations made under commercial treating conditions. Although it is recognized that there may be considerable variation in the penetrability of the heartwood of species within the same group, nevertheless, if the classification is taken as a whole, there is a definite difference in the relative resistance to treatment of the woods in one group as compared with those in another.

With a few exceptions, the sapwood of most of the softwood species in the different groups is not particularly difficult to impregnate under pressure. The more important exceptions are the hemlocks, the true firs, and the spruces. These woods have sapwood that is nearly as resistant as the heartwood. The sapwood of these species is also very difficult to distinguish from the heartwood. Although the sapwood of the other softwood species will in most cases take satisfactory treatment under pressure, there is, nevertheless, a marked difference in the relative ease with which the sapwood of some species takes treatment in comparison with that of other species. For example, the sapwood of the cedars is much more resistant than that of the pines and Douglas-fir. The sapwood of Douglas-fir, in turn, is considerably more resistant than the sapwood of most pine species. Even species within the same genus may vary over a considerable range in the relative penetrability of the sapwood. This is notable in the treatment of round timbers of different pine species.

The sapwood near the circumferential surface is generally less resistant than that near the heartwood. Apparently during the gradual transition of the sapwood into heartwood, the process of change affects the sapwood permeability to an increasing extent as the heartwood is approached. This variability, however, is more conspicuous in some species than in others.

In treating-plant operation, easily treated woods and resistant woods should not be included in the same charge. The easily treated material under such conditions would absorb more than the average and the resistant material less than the average amount of preservative per unit volume calculated for the charge. Differences in average absorption between the two groups might be several hundred percent.

In round material, such as poles, posts, and piles, only the treatability of the sapwood ordinarily needs to be considered because the heartwood is so deeply covered with sapwood that it cannot be penetrated except at end surfaces. In ties, or other sawed material, much sapwood and also considerable heartwood area is sometimes exposed. In such material the treating-plant operator cannot avoid having easily treated and

Group 1.—*Heartwood easily penetrated*

SOFTWOODS

Bristlecone pine (*Pinus aristata*).
Pinyon (*P. edulis*).
Ponderosa pine (*P. ponderosa*).
Redwood (*Sequoia sempervirens*).

HARDWOODS

American basswood (*Tilia americana*).
Beech (white heartwood) (*Fagus grandifolia*).
Black tupelo (blackgum) (*Nyssa sylvatica*).
Green ash (*Fraxinus pennsylvanica* var. *lanceolata*).
Pin cherry (*Prunus pensylvanica*).
River birch (*Betula nigra*).
Red oaks (*Quercus* spp.).
Slippery elm (*Ulmus fulva*).
Sweet birch (*Betula lenta*).
Water tupelo (*Nyssa aquatica*).
White ash (*Fraxinus americana*).

Group 2.—*Heartwood moderately difficult to penetrate*

SOFTWOODS

Baldcypress (*Taxodium distichum*).
California red fir (*Abies magnifica*).
Douglas-fir (coast) (*Pseudotsuga taxifolia*).
Eastern white pine (*Pinus strobus*).
Jack pine (*P. banksiana*).
Loblolly pine (*P. taeda*).
Longleaf pine (*P. palustris*).
Red pine (*P. resinosa*).
Shortleaf pine (*P. echinata*).
Sugar pine (*P. lambertiana*).
Western hemlock (*Tsuga heterophylla*).

HARDWOODS

Black willow (*Salix nigra*).
Chestnut oak (*Quercus montana*).
Cottonwood (*Populus* sp.).
Bigtooth aspen (*P. grandidentata*).
Mockernut hickory (*Carya tomentosa*).
Silver maple (*Acer saccharinum*).
Sugar maple (*A. saccharum*).
Yellow birch (*Betula lutea*).

Group 3.—*Heartwood difficult to penetrate*

SOFTWOODS

Eastern hemlock (*Tsuga canadensis*).
Engelmann spruce (*Picea engelmanni*).
Grand fir (*Abies grandis*).
Lodgepole pine (*Pinus contorta* var. *latifolia*).
Noble fir (*Abies procera*).
Sitka spruce (*Picea sitchensis*).
Western larch (*Larix occidentalis*).
White fir (*Abies concolor*).
White spruce (*Picea glauca*).

HARDWOODS

American sycamore (*Platanus occidentalis*).
Hackberry (*Celtis occidentalis*).
Rock elm (*Ulmus thomasi*).
Yellow-poplar (*Liriodendron tulipifera*).

Group 4.—*Heartwood very difficult to penetrate*

SOFTWOODS

Alpine fir (*Abies lasiocarpa*).
Corkbark fir (*A. lasiocarpa*, var. *arizonica*).
Douglas-fir (Rocky Mountain) (*Pseudotsuga taxifolia*).
Northern white-cedar (*Thuja occidentalis*).
Tamarack (*Larix laricina*).
Western redcedar (*Thuja plicata*).

HARDWOODS

American beech (read heartwood)* (*Fagus grandifolia*).
American chestnut (*Castanea dentata*).
Black locust (*Robinia pseudoacacia*).
Blackjack oak (*Quercus marilandica*).
Sweetgum (redgum) (*Liquidambar styraciflua*).
White oaks (*Quercus* spp.).

*(Red heartwood) see ERRATA, in front.

resistant wood in the same charge. It is not enough in treating such material merely to get some specified retention, because the preservative may be absorbed almost entirely by the sapwood and the heartwood be left with little protection. The operator should assure himself that as much penetration as possible is obtained in the heartwood faces, and all his technical skill may be called into play to bring this about. The empty-cell processes are particularly useful in the treatment of such material, because they permit a larger gross absorption for a given net retention than is possible when the full-cell method is employed.

MOISTURE CONTENT, FIBER SATURATION POINT, SHRINKAGE AND SWELLING, SPECIFIC GRAVITY, WEIGHT OF WOOD, AND AIR SPACE IN WOOD

Wood contains wood substance, moisture, and air or gas. Wood substance includes both the cellular structure and extractives and usually has a variable quantity of water in the cell walls. When wood is green or wet, the water also occupies a part or, in some cases, nearly all of the cell cavities. In addition, there is usually more or less air or gas in the wood cells, depending on the density of the wood and the moisture content. In the present discussion the volume occupied by air or gas is designated as air space.

MOISTURE CONTENT

The amount of water contained in a piece of wood is commonly called the moisture content. In the case of green timbers this is sometimes called the sap. Since, however, sap often contains various organic or mineral substances in solution, it is more satisfactory to designate the evaporable liquid as the water or the moisture content in the wood.

It is almost universal practice in this country to base the moisture content on the weight of the wood when oven-dry. This procedure has several advantages. Among the more important are the following:

(1) The oven-dry weight can be determined at any time and therefore affords a constant base.

(2) On the oven-dry-weight basis the moisture percentage shows directly the number of parts of water by weight to the number of parts of oven-dry wood. For example, if a piece of wood has a moisture content of 15 percent, there are 15 parts of water by weight to 100 parts of wood substance.

(3) The moisture content in equilibrium with a given temperature and relative humidity is a fairly definite figure regardless of the density or specific gravity of the wood. There would be no concordant relation in this respect if the moisture content were based on the total weight of wood and water.

The amount of moisture content on the oven-dry-weight basis, may be computed by using the formula $M=\frac{(W_o-W_d)}{W_d}100$, in which M represents the percentage of moisture in the wood, W_o the original weight, and W_d the oven-dry weight.

Pulp-and-paper chemists and others sometimes prefer to use the total or original weight as the base. If m represents the percentage of moisture determined on this basis, then $m=\frac{(W_o-W_d)}{W_o}100$, where W_o and W_d are the original weight and oven-dry weight, respectively. If it is desired to change from one base to the other, this is easily done, since

$$M=\frac{100\ m}{100-m} \text{ and } m=\frac{100\ M}{100+M}.$$

Moisture Content in Green Timbers

The sapwood of freshly cut timbers often contains a much higher moisture content than the heartwood, and this is especially true for most of the softwoods. Table 1 shows data on the average moisture content of green sapwood and heartwood determined for various species. These data are average values of moisture determinations from specimens taken from a varying number of trees of each species and also from different parts of the trees.

TABLE 1.—*Average moisture content of green heartwood and sapwood for various species of softwoods and hardwoods*

Species	Average moisture content		Species	Average moisture content	
	Sapwood	Heartwood		Sapwood	Heartwood
Softwoods:	*Percent*	*Percent*	Hardwoods:	*Percent*	*Percent*
Baldcypress	171	121	Ash, green	58	----------
Douglas-fir (coast)	115	37	Ash, white	44	46
Fir, grand	136	91	Beech, American	72	55
Hemlock, eastern	119	97	Birch, sweet	70	75
Hemlock, western	170	85	Birch, yellow	72	74
Redcedar, western	249	58	Chestnut, American	----------	120
Fir, white	160	98	Elm, American	92	95
Larch, western	119	54	Elm, cedar	61	66
Pine, loblolly	110	33	Hickory, water	62	97
Pine, lodgepole	120	41	Maple, silver	88	60
Pine, longleaf	106	31	Maple, sugar	72	65
Pine, ponderosa	148	40	Oak, black	75	76
Pine, western white	148	62	Oak, northern red	69	80
Pine, red	134	32	Oak, southern red	75	83
Pine, shortleaf	122	32	Oak, swamp red	66	79
Pine, sugar	219	98	Oak, water	81	81
Redwood (virgin growth)	210	86	Oak, white	78	64
Spruce, Engelmann	173	51	Oak, willow	74	82
Spruce, Sitka	142	41	Tupelo, black	115	87
			Tupelo, water	----------	158
			Sycamore, American	130	114
			Sweetgum	137	79
			Yellow-poplar	106	83

FIBER SATURATION POINT

When seasoned wood absorbs water, the water will first be taken up by the fibers or cell walls until they become saturated. The moisture

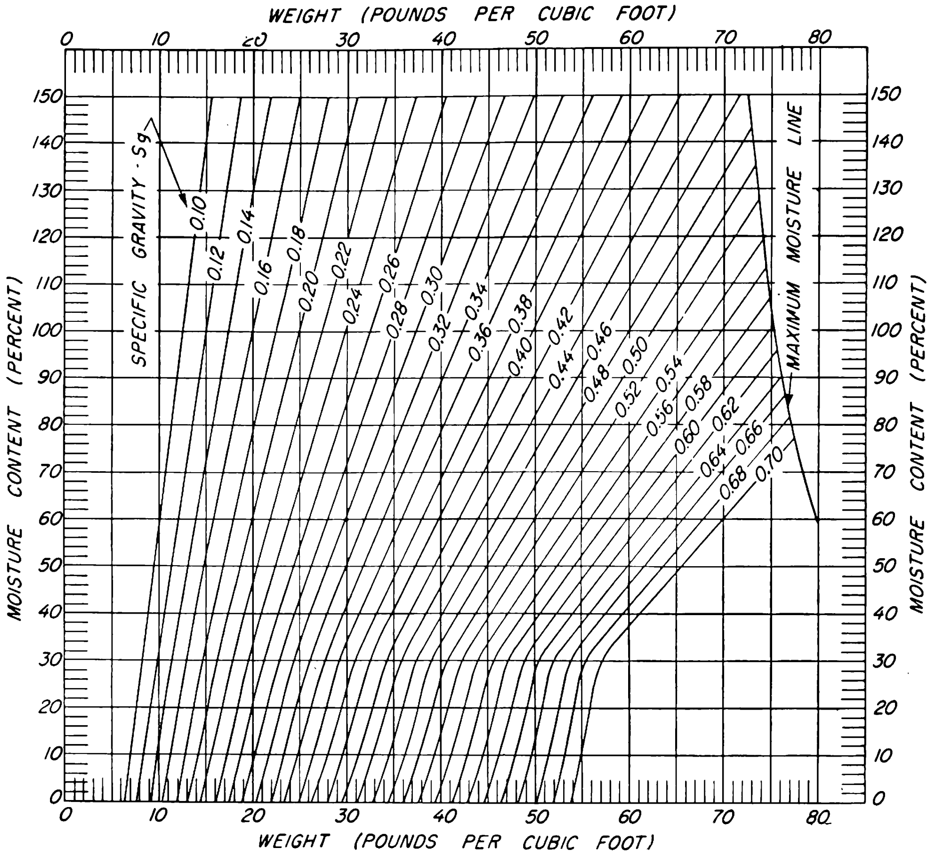

FIGURE 6.—Relation of moisture content, specific gravity, and weight of wood in pounds per cubic foot. (Specific gravity based on weight when oven-dry and volume when green = S_g.)

content of the wood at the point when the fibers are saturated but there is no free water in the cells is called the "fiber saturation point." The water contained in the cell walls is known as hygroscopic or adsorbed water. Up to the fiber saturation point, swelling of the wood accompanies the adsorption of water. After the walls have become saturated, water may be absorbed in the lumina or cell cavities. Water contained in these spaces is called free water. Swelling is not affected by the free water contained in the cell cavities, and swelling therefore does not continue with increasing moisture content after the fiber saturation point is reached.

The fiber saturation point is not determined with exactness and varies for the different species. Various methods have been employed at the Forest Products Laboratory to determine the moisture content at which the fiber walls are saturated (*54*, *55*, *56*).

These studies show that among the more important factors affecting the moisture content at the fiber saturation point are temperature of the wood, chemical substances in the cell walls, and chemical composition of the wood. The moisture content at the fiber saturation point usually ranges from about 25 to 35 percent. Data obtained from experiments indicate that for normal wood temperatures a satisfactory average value for the moisture content at the fiber saturation point is about 30 percent, based on the oven-dry weight. The effect of increasing temperature is to reduce the moisture content at the fiber saturation point, roughly about 1 percent per 10° C. (18° F.) rise in temperature.

The weighing of green timbers should be done when the moisture content of the wood near the surface is above, or at least not much below, the fiber saturation point (about 30 percent moisture), so that the effect of shrinkage will not be an important factor affecting the volume. The data given in figure 6 are based on a fiber saturation point of 30 percent. With this as a base, weights shown for moisture-content values below the fiber saturation point were computed by assuming that the volumetric shrinkage is proportional to the change in moisture content that occurs in seasoning. Equations 14 to 17, page 137, can be used for computing the weight of wood at any given moisture content.

To illustrate the use of figure 6, assume that sample poles of green Douglas-fir weigh about 43 pounds per cubic foot. Table 2 shows that the average specific gravity (S_g) (based on weight when oven-dry and volume when green) for this species is about 0.45. Directly above the weight of 43 pounds on the horizontal scale, a point midway between $S_g=0.44$ and 0.46 (which corresponds to the value $S_g=0.45$) is opposite a moisture-content value of about 53 percent. This figure represents the average moisture content of the timber including sapwood and heartwood.

Equation 18, page 137, or figure 7 can be used in finding the percentage of sapwood in the total volume, when the average diameter and the average sapwood thickness are known. In estimating the average moisture content from the weight of the timbers, it should be understood that knots, variations in the specific gravity of different timbers, and similar factors, influence the results; hence the moisture content determined by this method will necessarily be a rough approximation.

Methods of Determining Moisture Content in Timbers

Several methods are in use for determining the moisture content of wood (*52*). They vary considerably in detail and in their suitability for use under different circumstances.

The most common method is oven-drying, which consists in weighing a representative small sample of the wood, heating it in an oven at 100° to 105° C. (212° to 221° F.) until the weight remains constant, then weighing again to determine the loss in weight and the dry weight. The method is reasonably accurate for most woods, but in highly resinous wood the readings may be high if the resins are melted and drip out during the drying process. The amount of volatile resin products that evaporate at temperatures employed in oven-drying is small, and even in very resinous woods whatever volatile oils might be driven off would normally have little effect on the moisture content determined by the oven-drying method. If, however, the heavier constituents are melted

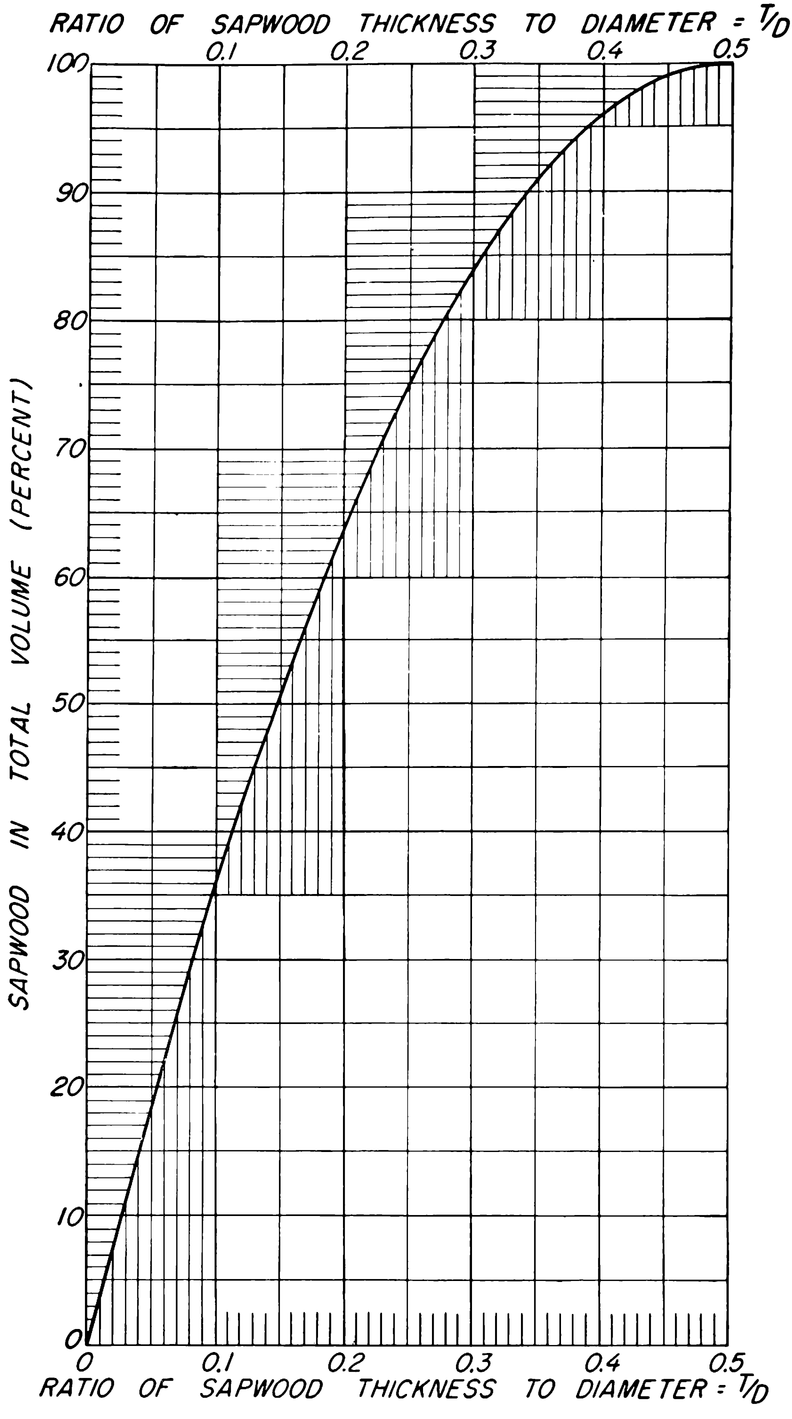

FIGURE 7.—Chart showing percentage of sapwood in the total volume for any ratio of sapwood thickness to diameter.

TABLE 2.—*Average shrinkage and specific gravity of various commercial species grown in the United States*

Species	Average shrinkage from green to oven-dry condition (percent of dimensions when green)			Average specific gravity based on oven-dry weight and green volume $=S_g$	Average specific gravity based on oven-dry weight and oven-dry volume $=S_d$
	Radial	Tangential	Volumetric		
Ash, commercial white	4.6	7.5	12.8	0.55	0.64
Aspen, quaking	3.5	6.7	11.5	.35	.41
Basswood, American	6.6	9.3	15.8	.32	.40
Baldcypress	3.8	6.2	10.5	.42	.48
Beech, American	5.1	11.0	16.3	.56	.67
Birch, yellow	7.2	9.2	16.7	.55	.66
Cherry, black	3.7	7.1	11.5	.47	.53
Chestnut, American	3.4	6.7	11.6	.40	.45
Cottonwood:					
Eastern	3.9	9.2	14.1	.37	.43
Northern black	3.6	8.6	12.4	.32	.37
Douglas-fir:					
Coast type	5.0	7.8	11.8	.45	.51
Intermediate type	4.1	7.6	10.9	.41	.47
Rocky Mountain type	3.6	6.2	10.6	.40	.45
Elm:					
American	4.2	9.5	14.6	.46	.55
Rock	4.8	8.1	14.1	.57	.66
Slippery	4.9	8.9	13.8	.48	.57
Fir:					
Balsam	2.8	6.6	10.8	.34	.41
Commercial white [1]	3.2	7.1	9.8	.36	.41
Hackberry	4.8	8.9	13.8	.49	.56
Hemlock:					
Eastern	3.0	6.8	9.7	.38	.43
Western	4.3	7.9	11.9	.38	.44
Hickory:					
Pecan [2]	4.9	8.9	13.6	.59	.64
True [3]	7.3	11.4	17.9	.64	----------
Honeylocust	4.2	6.6	10.8	.60	.67
Larch, western	4.2	8.1	13.2	.50	.59
Locust, black	4.4	6.9	9.8	.66	.71
Maple:					
Bigleaf	3.7	7.1	11.6	.44	.51
Black	4.8	9.3	14.0	.52	.62
Red	4.0	8.2	13.1	.49	.55
Silver	3.0	7.2	12.0	.44	.51
Sugar	4.9	9.5	14.9	.56	.68
Oak:					
Red [4]	4.3	9.0	14.8	.57	.68
White [5]	5.4	9.3	16.0	.60	.72
Pine:					
Loblolly	4.8	7.4	12.3	.47	.54
Lodgepole	4.5	6.7	11.5	.38	.43
Longleaf	5.1	7.5	12.2	.54	.62
Eastern white	2.3	6.0	8.2	.34	.37
Red	4.6	7.2	11.5	.41	.51
Ponderosa	3.9	6.3	9.6	.38	.42
Shortleaf	4.4	7.7	12.3	.46	.54

See footnotes at end of table.

TABLE 2.—*Average shrinkage and specific gravity of various commercial species grown in the United States*—Continued

Species	Average shrinkage from green to oven-dry condition (percent of dimensions when green)			Average specific gravity based on oven-dry weight and green volume $=S_g$	Average specific gravity based on oven-dry weight and oven-dry volume $=S_d$
	Radial	Tangential	Volumetric		
Slash	5.5	7.8	12.2	.56	.66
Sugar	2.9	5.6	7.9	.35	.38
Western white	2.6	5.3	11.8	.36	.42
Redcedar:					
Eastern	3.1	4.7	7.8	.44	.49
Western	2.4	5.0	7.7	.31	.34
Redwood	2.6	4.4	6.8	.38	.42
Spruce:					
Eastern [6]	4.3	7.7	12.6	.38	.43
Engelmann	3.4	6.6	10.4	.32	.35
Sitka	4.3	7.5	11.5	.37	.42
Sugarberry	5.0	7.3	12.7	.47	.54
Sweetgum	5.2	9.9	15.0	.44	.53
Sycamore, American	5.1	7.6	14.2	.46	.54
Tamarack	3.7	7.4	13.6	.49	.56
Tupelo:					
Black	4.4	7.7	13.9	.46	.55
Water	4.2	7.6	12.5	.46	.52
Walnut, black	5.2	7.1	11.3	.51	.56
White-cedar, northern	2.1	4.7	7.0	.29	.32
Yellow-poplar	4.0	7.1	12.3	.38	.43

NOTE: To compute the shrinkage due to seasoning from green to any moisture content below fiber saturation point, multiply figure from table 1 by $\left(1-\frac{M}{30}\right)$, where M is the moisture content (percent) to which wood is seasoned.

[1] Average of grand fir and white fir.
[2] Average of bitternut hickory, nutmeg hickory, water hickory, and pecan.
[3] Average of shellbark hickory, mockernut hickory, pignut hickory, and shagbark hickory.
[4] Average of black oak, laurel oak, pin oak, northern red oak, scarlet oak, southern red oak, swamp red oak, water oak, and willow oak.
[5] Average of bur oak, chestnut oak, post oak, swamp chestnut oak, swamp white oak, and white oak.
[6] Average of black spruce, red spruce, and white spruce.

out, the effect on the oven-dry weight would be more important, depending on the size of the moisture specimens and the amount of nonvolatile material melted out. The samples used must be thoroughly representative of the timber being tested, and the weighing must be done promptly after sampling; otherwise a false indication will be obtained. A serious disadvantage of the method is the necessity of cutting a sample from the timber, and thus the probable destruction of its usefulness.

Another method, which causes less damage to the timber, is to take borings with a bit or increment borer. The wood removed from the bored holes should be placed immediately in a container, such as a test tube or small bottle, and the container should be tightly corked to prevent loss of moisture until the sample can be weighed. After weighing, the wood can be oven-dried and the moisture content can be computed from the weights taken before and after oven-drying. If it is desired to find the moisture content of the sapwood and heartwood separately, the borings can be separated where the heartwood starts and the two portions can be weighed and dried separately.

Electric moisture meters are now used extensively in connection with dry-kiln operations and in the manufacture of wood products. They are also used to a limited extent at some wood-preserving plants. These meters were introduced in commercial work about 1930. Several companies now manufacture instruments that measure the moisture content by one of the following methods: (1) By determining the electrical resistance of the wood by what is known as the resistance-type meter, or (2) by determining the radio-frequency power loss by what is known as the radio-frequency power-loss type of meter.

These instruments are generally used for moisture determinations in wood that has a moisture content between 7 percent and about 25 percent, or close to the fiber saturation point (p. 21). Because of the high resistance of the wood at low moisture values, the meters are not usually calibrated for readings below 6 to 7 percent.

Some manufacturers also make instruments to determine the moisture content below 6 percent, and some make instruments that read as high as 120 percent moisture. Greater accuracy, however, is obtained in the moisture content range below the fiber saturation point (p. 20).

When it is inconvenient to make direct moisture determinations from timbers that are seasoning, a rough estimate of the average moisture content can be made by weighing representative timbers and then consulting figure 6. The average specific gravity (S_o) for the species in question can be found in table 2.

SHRINKAGE AND SWELLING

The amount of shrinkage or swelling that occurs in wood will depend mainly on its density and the change in moisture content (*24*, *39*, *46*). When wood is drying, shrinkage does not start until the water in the cell cavities or lumina has evaporated and the fiber saturation point is reached. The wood near the surface of a timber may, however, season considerably below the fiber saturation point while the average moisture content of the piece is well above the fiber saturation point. This is especially true for timbers of fairly large cross-sectional dimensions.

Pure hydrocarbon oils are not absorbed by wood substance and therefore cause no swelling when timbers are impregnated with them. Preservative oils, like the creosotes, are absorbed only to a small extent, and the amount of swelling as a result of treatment is so slight that for practical purposes it can be overlooked. Water solutions will, of course, cause swelling if the wood has been partially seasoned before treatment.

No change in moisture content can take place unless a moisture gradient or a combined relative-humidity, moisture-content gradient exists. Sometimes those not familiar with this fact claim they are able to maintain a uniform moisture content throughout the timber when seasoning by the use of heat and changing humidity. Under such conditions a moisture gradient is just as essential for seasoning as a difference in pressure is necessary to force a liquid or gas through a pipe, or a difference in voltage is necessary to make an electric current flow through a conductor. Both the rate of seasoning and the rate of water absorption are functions of the moisture gradient, for the rate decreases as the difference in moisture content between the surface and interior is reduced.

Wood shrinks chiefly in the radial and tangential directions, that is, at right angles and parallel to the annual rings. In normal wood, longitudinal shrinkage is very slight (between 0.1 and 0.2 percent) and for such material may be considered negligible. The ratio of radial to tangential shrinkage is roughly about 1 to 2, but this may vary to quite an extent, depending on the species. The volumetric shrinkage of hardwoods ranges from about 12 to 18 percent in seasoning from the green to the oven-dry condition, and the corresponding shrinkage of the conifers or softwoods ranges from about 8 to 14 percent. Wood when air-dry usually has a moisture content of 12 to 15 percent, and shrinkage from the green to the air-dry condition is therefore about half as much as that to the oven-dry or moisture-free value. Table 2 shows the average radial, tangential, and volumetric shrinkage from the green to the oven-dry condition for various commercial woods.

SPECIFIC GRAVITY OF WOOD

The specific gravity of wood is usually defined as the ratio of the weight of a given volume of wood when oven-dry at the current moisture content, to the weight of an equal volume of water at its maximum density (4° C.). If the specific gravity is represented by S, the oven-dry weight per unit volume by W_d, and the weight of an equal volume of water by W_w then $S=\frac{W_d}{W_w}$. In this expression $W_w=1$ in the Centimeter-gram-second (C.G.S.) system and equals 0.0361 pound per cubic inch, or 62.4 pounds per cubic foot.

For example, assuming that a cubic inch of wood at 15 percent moisture content weighs 0.023 pound, the oven-dry weight would be $0.023 \div 1.15 = 0.020$ pound. The specific gravity would then be computed as $\frac{0.020}{0.0361}=0.55.$

Since density equals the mass per unit volume, the numerical values for specific gravity and density would be the same in the C.G.S. system. In other systems of measurement the density is necessarily expressed in the units employed. For example, in the English system, the density of water is 62.4 pounds per cubic foot, although the specific gravity of water is unity, as it is in the C.G.S. system.

For practical purposes the specific gravity, based on the weight of the oven-dry wood and the volume at current moisture content, may be assumed to increase in about direct proportion to the loss of moisture content below the fiber saturation point. The specific-gravity range will then be between the specific gravity based on the weight of the oven-dry wood and the volume when green and that based on the weight of the oven-dry wood and the volume when oven-dry. From this relation the specific gravity at any moisture content M can be determined from the following equation:

$$S_a = \left[S_d - (S_d - S_g) \frac{M}{30} \right]$$

where S_a is the specific gravity at the moisture content M, S_d is the specific gravity based on the weight and volume when oven-dry, S_g is the specific gravity based on the weight when oven-dry and the volume when green, and M is the moisture content under consideration below the fiber saturation point. In this equation the fiber saturation point is taken as 30 percent. Average values of S_d and S_g for various species

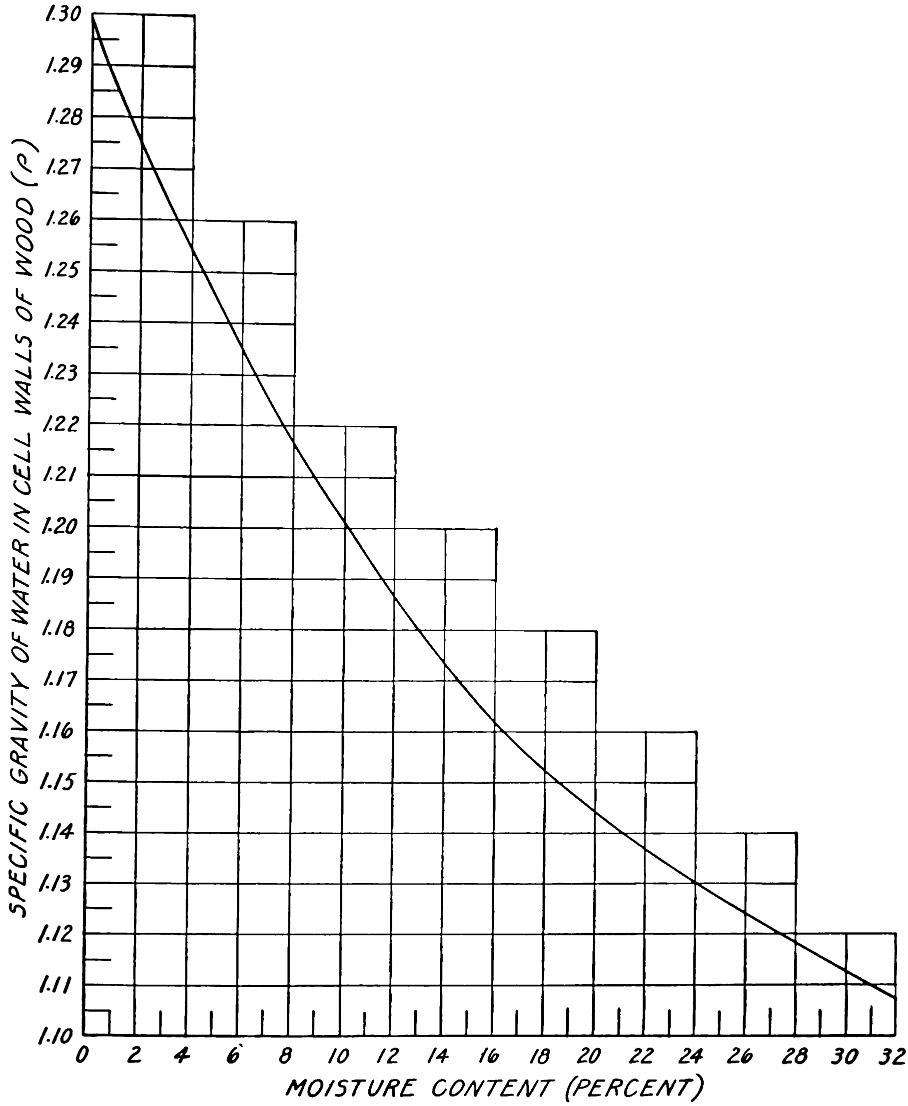

FIGURE 8.—Specific gravity of water in cell walls of wood at different percentages of moisture.

are given in table 2. Since the maximum volume is obtained at the fiber saturation point, the specific gravity S_g remains constant for all moisture-content values above the fiber saturation point.

While changes in specific gravity normally occur because of shrinkages as the moisture is reduced below the fiber saturation point, there is a condition known as "collapse" that sometimes occurs during seasoning or when the wood is subjected to treating pressures that are too high. As the term collapse suggests, the cell walls are more or less broken down, and this causes a decrease in the amount of air space in the lumena or cell cavities. This condition tends to increase the amount of wood substance per unit volume and, consequently, increases the specific gravity.

SPECIFIC GRAVITY OF WOOD SUBSTANCE

Oven-dry wood normally contains a large amount of air space or voids because of the cellular structure, and the volume occupied by wood substance alone in a block of wood is considerably less than the total volume of the block. A certain amount of compression occurs in the water contained in the cell walls, and the density or specific gravity of wood substance determined in water is therefore somewhat higher than when measured in a substance like helium gas that is not compressed by the force of adsorption. Studies made at the Forest Products Laboratory (*55*, *56*) showed that the density of wood substance measured in helium gas was about 1.46, while an average value of the density determined in water was about 1.53. From these results the true specific volume of wood substance is $\frac{1}{1.46}$, or about 0.685, while the apparent specific volume in water is $\frac{1}{1.53}$, or about 0.654, a difference of 0.031. Figure 8 shows the relation of the density of water in the wood cell walls to the moisture content up to the fiber saturation point.

Figure 9 shows the weight of water in wood of any specific gravity and having various percentages of moisture up to the maximum content when all the air space is filled, and figure 10 shows the percentage of volume filled with water when the wood has various percentages of moisture. It should be borne in mind that a given volume of seasoned wood will swell when water is absorbed; hence a unit volume of seasoned wood when wet will have a capacity to absorb more water than if the volume remained constant. In general, the volumetric shrinkage or swelling is about proportional to the change in moisture content.

RELATION OF SPECIFIC GRAVITY, MOISTURE CONTENT, AND AIR SPACE IN WOOD

A knowledge of the amount of air space in wood is useful in estimating the maximum amount of unoccupied space that is available under the moisture conditions at which the wood is treated. This information is needed if one is interested in computing the maximum absorptions that can be expected. Laboratory experiments show that even in small specimens of easily penetrated wood given a full-cell treatment, about 5

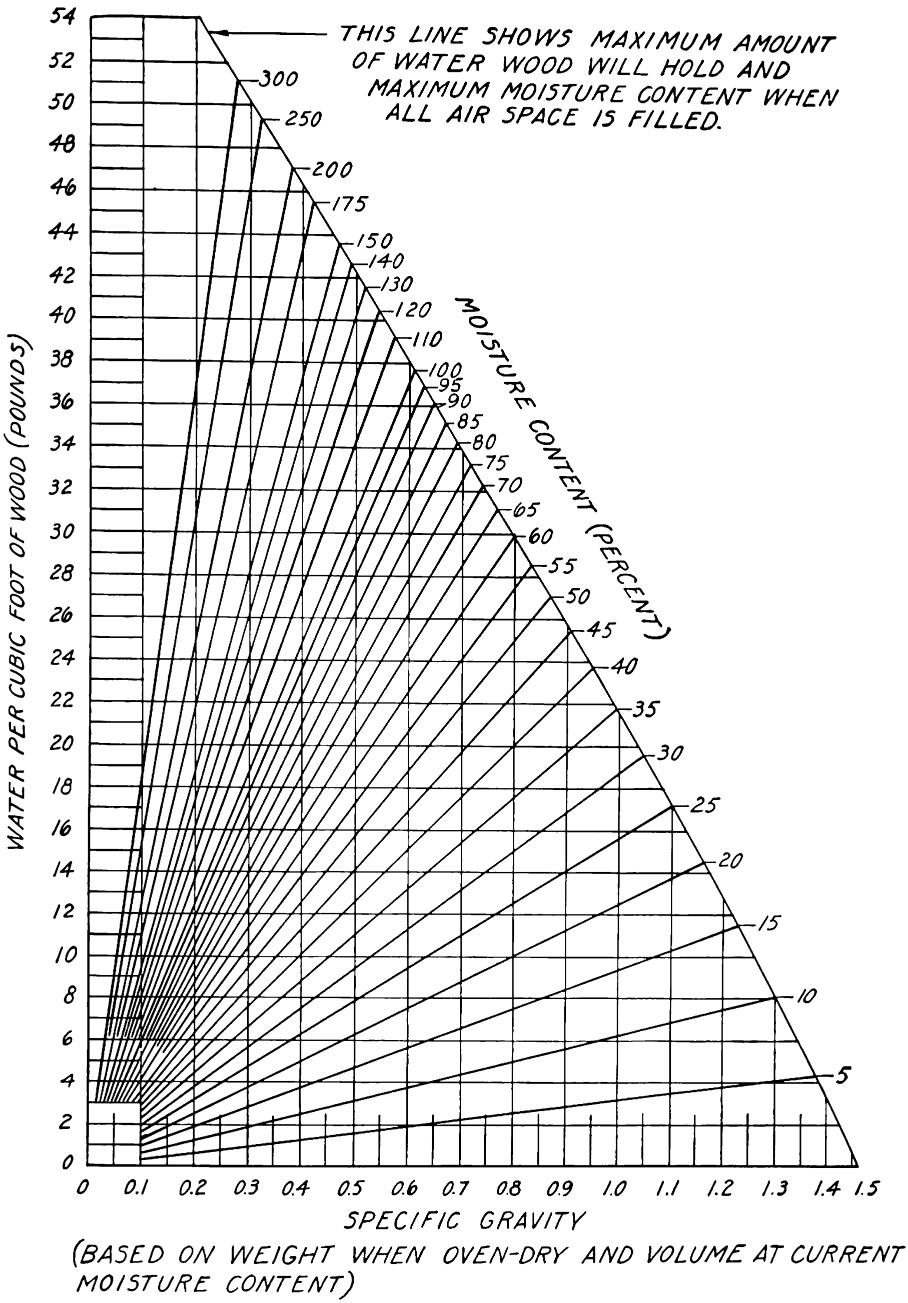

FIGURE 9.—Relation of weight of water in wood, specific gravity, and percentage of moisture.

to 10 percent of the air space will be unfilled. It is usually not practical to obtain net retentions (using the full-cell treatment) that will fill more than about 80 to 85 percent of the available air space in the penetrated portion of commercial-size timbers. Figure 11 shows the relation of air space, moisture content, and specific gravity.

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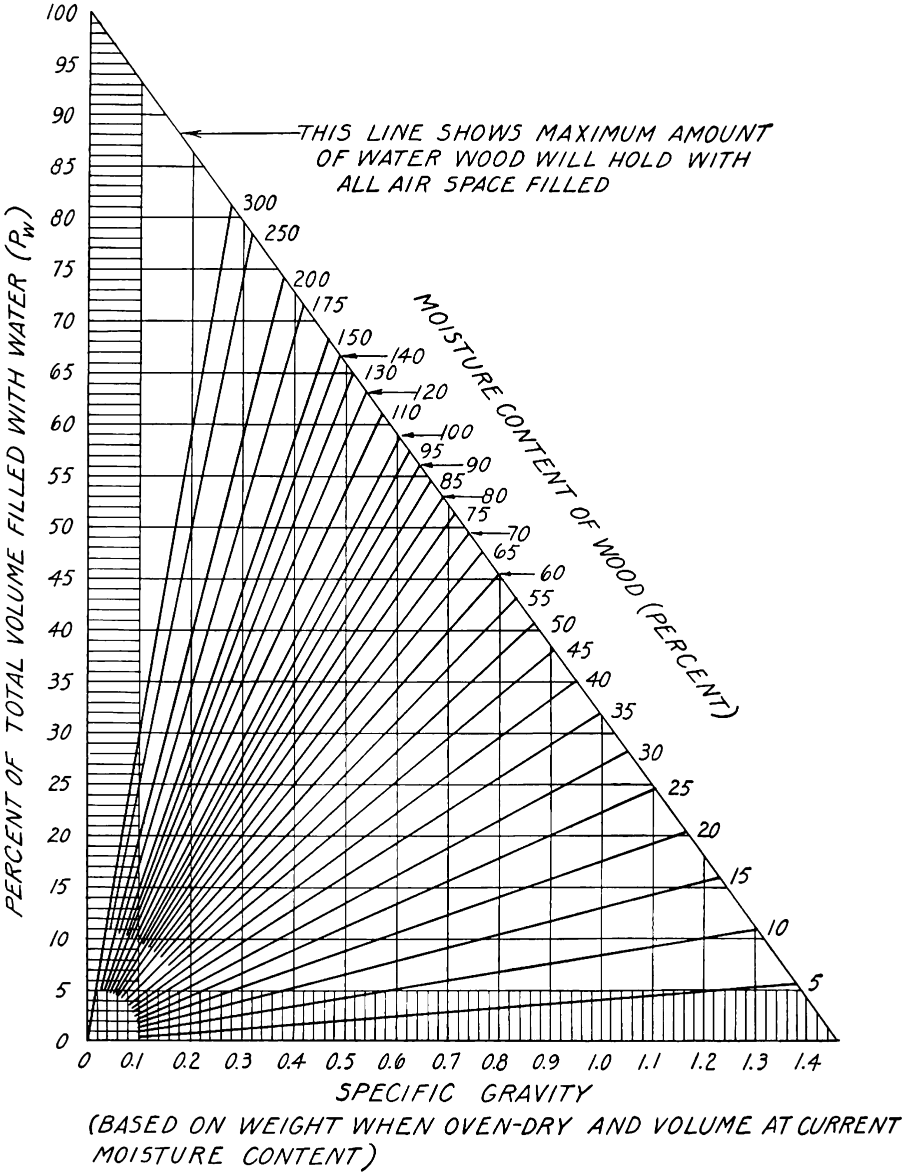

FIGURE 10.—Percentage of volume filled with water when wood has various amounts of moisture and any given specific gravity.

PREPARATION OF TIMBER FOR TREATMENT

Much of the success of treating operations depends upon the preparation of the timber to receive the preservative. Timbers of practically all species require more or less seasoning or conditioning before they can be satisfactorily impregnated. Air-seasoning is the method most generally employed, but for various reasons, such as unfavorable climatic conditions, rush orders, or restricted storage space, it is often necessary to use one of the artificial methods such as steaming and vacuum or boiling in oil under vacuum in order to condition the wood for treatment.

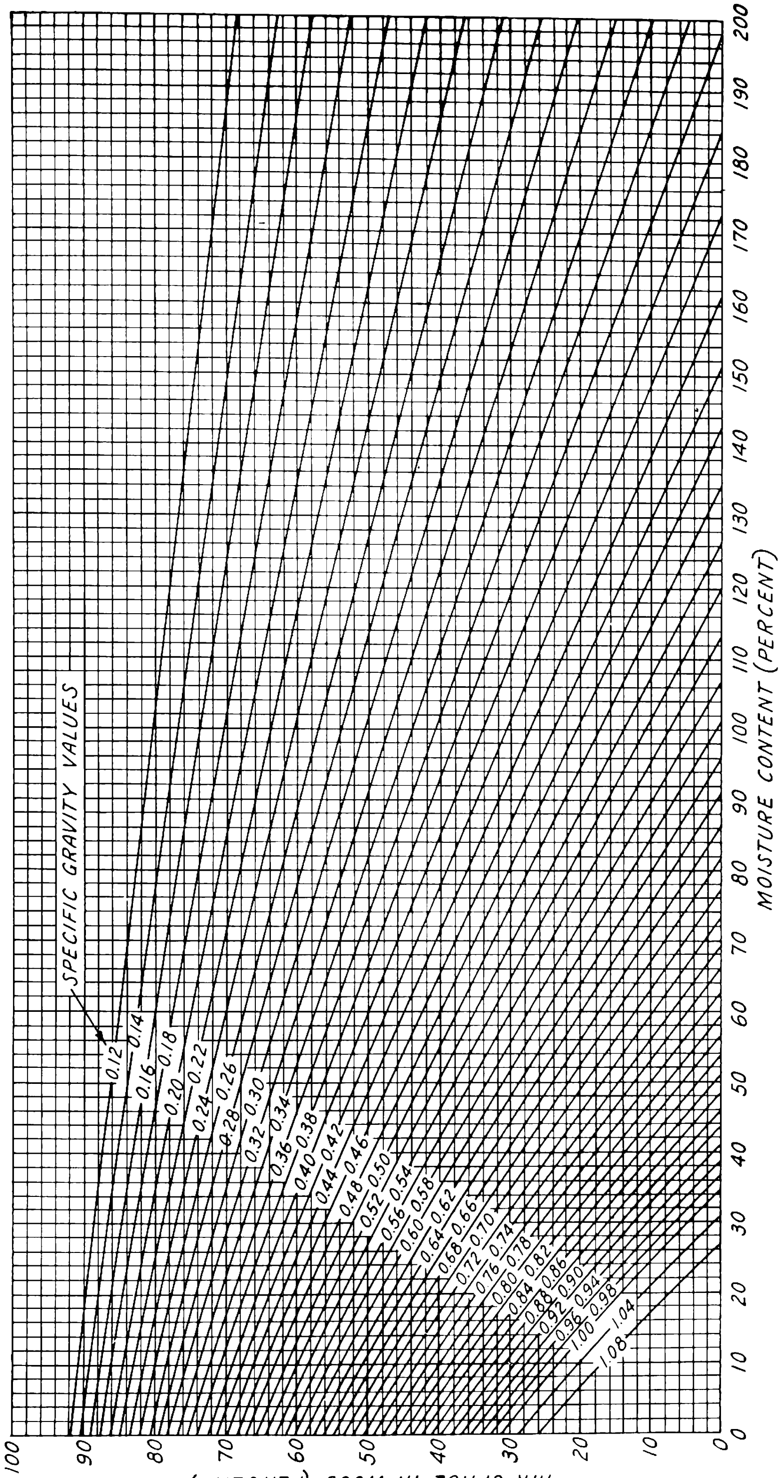

FIGURE 11.—Relation of specific gravity, moisture content, and air space in wood (specific gravity based on weight when oven-dry and volume at current moisture content).

AIR-SEASONING

Some of the more important considerations in air-seasoning include species and size of timber, proportion of sapwood, time of cutting, peeling, climatic conditions, locality in which the timber is seasoned, and method of piling.

Species and Size of Timber

Even under the same conditions, timbers of similar size but of different species often vary considerably in the time required for air-seasoning. This is partly on account of wide variations in the original moisture content of the wood and partly because various woods differ greatly in the rate at which they give off moisture. Table 1, p. 19, shows average moisture-content values for green heartwood and sapwood of many of the species commonly treated. It may be noted from this table that the softwoods usually show a much higher moisture content in the sapwood than in the heartwood and that this difference is less marked in the hardwoods. The values given in the table are averages for a varying number of trees of each species. Individual timbers of a given species, or material obtained from a given locality, may differ to a greater or less extent from the averages given.

Large timbers season more slowly than those of small dimensions because of the greater volume of wood in proportion to the surface area and because the moisture at the interior must travel a greater distance through the wood to reach the surface. It is advisable to season large timbers slowly in order to avoid excessive damage from checking. Large timbers have a higher average moisture content after a given period of air-seasoning than timbers of smaller sizes, although the outer inch or two of the larger timbers may be practically as dry as the smaller material.

Seasoning of Heartwood and Sapwood

The sapwood of most species seasons at a much faster rate than the heartwood. On the other hand, the sapwood often contains a higher percentage of moisture than the heartwood, and this tends to offset its greater seasoning rate. In round timbers or sawed material in which the heartwood is surrounded by sapwood, the faster seasoning rate of the sapwood may encourage checking. Furthermore, the sapwood is on the outside of the piece and, except at end surfaces, begins to season sooner than the heartwood. As a result, the sapwood dries and begins to shrink, while the heartwood still retains its original size. Checking of the sapwood is inevitable in such cases, and the checks later may extend into the heartwood as it dries. The size and severity of the checks can be limited to a considerable extent, however, by controlling the drying rate through piling methods and by the use of end coatings. In material that is all sapwood there is less danger of checking than in all-heartwood material.

Since sapwood has low resistance to decay, it should be seasoned with as little delay as possible and under the most favorable drying conditions. Rapid seasoning requires conditions contrary to those that favor reduced checking. The danger of infection and the danger of checking vary considerably with locality and species, however, so that each operator must work out as best he can the seasoning methods most suitable for his species and locality.

Coatings Used to Reduce End Checking

Since wood dries more rapidly from the end than from the side grain, end checking is a problem in the seasoning of some material, particularly hardwoods. Two types of coatings are commonly used with hardwood lumber to prevent end checking. In one type the coating is applied cold, and in the other it is heated first (*57*).

Although end coatings have been used considerably in kiln-drying operations, they have not been widely used for reducing end checking in ties, poles, and other timbers being air-seasoned for treatment. The added cost, difficulty of early application, possibility that the end coatings may contaminate the preservative and retard penetration or may clog the pumps, valves, or piping of the treating equipment, would need consideration. These are doubtless among the factors responsible for the limited interest in the use of end coatings for ties and similar material.

Moisture-retardant coatings such as tar, rosin, or other compounds that are soluble in preservative oils might be helpful, but careful study would be required to determine their merits or whether the extra cost would be justified.

Use of Antichecking Irons to Reduce End Checking

Because hardwood ties may give considerable trouble from end checking, especially when they contain boxed heart (enclosing the pith portion of the tree), antichecking irons are often driven in the ends of the ties when they are stacked for air-seasoning. These irons should be driven before important checking can develop. The antichecking irons most commonly used are the so-called S-iron and C-iron. These names indicate the shape of the irons used. The use of antichecking irons does not always prevent serious end checking, and there is some disagreement regarding their value. Their continued use by various railroads, however, indicates that some still consider them an important help in reducing the danger of injury from end checking.

Spiral Dowels

Another method of preventing end checking in ties and sawed timbers is to drill holes near the ends at approximately right angles to the direction of the expected checking and to drive in spiral-shaped metal dowels. A tight fit is obtained by making the holes slightly smaller than the dowels. A machine has been developed to bore and dowel hardwood ties automatically. The same general method may be used with timbers that have checked seriously in seasoning, by first clamping the end of the timber to close the check and then boring and doweling.

Peeling

All material should be peeled before seasoning because bark retards the drying of the wood, harbors insects, and favors decay infection in the sapwood. The peeling should be thoroughly done, even to the removal of the inner bark. The inner bark of many species, particularly the conifers, is highly impervious to liquids, and if strips of appreciable size are left on the wood they may not only interfere with seasoning but also subsequently prevent the penetration of preservatives.

As a rule, timber cut during the active growing months from May to July peels more easily than that cut at other seasons of the year. The peeling of timbers cut in fall and winter can be facilitated by boiling or steaming them for 1 to 3 hours.

Peeling or shaving machines are now being widely used in the wood-preserving industry for peeling poles and posts. They vary widely in character and are used both for removing bark and for removing knots and other irregularities on the surface (*7*).

Time of Cutting

Although round timbers peel most easily when cut in spring or early summer, the most favorable time for cutting timber from the stand-point of preventing damage while awaiting treatment is in the late fall or winter. With proper care, however, most kinds of wood can be seasoned satisfactorily for treatment if cut at any time during the year. In cold weather wood seasons more slowly, and there is less danger of severe checking than in warm, dry weather. Insects and decay fungi are inactive during cold weather; hence there is less danger of winter-cut wood becoming infected. By the time warm weather causes the revival of insect and fungus activity, the timber is usually out of the woods and partly seasoned so that its resistance to infection is increased.

The advantage from winter cutting depends partly upon the climatic conditions and partly upon the susceptibility of the wood to damage. Greatest care is required in the Southern States where the winter is short and not very cold and where many of the species of wood cut for ties and poles have a large percentage of sapwood and are very susceptible to insect and fungus damage. Winter cutting is best in the Southern States, as in colder climates, and the necessity of removing the wood promptly from the woods to proper seasoning yards is greater there than where long, cold winters prevail. This holds for ties, piling, and poles that are manufactured in the woods and for logs that are later to be sawed into lumber, ties, or timbers.

It is commonly believed that there is less sap in the trees in winter than in summer, but experiments do not substantiate this belief. Experiments made both in North America (*10, 22*) and in Europe show that trees cut in winter have fully as much if not more sap in them as trees cut in the spring or summer. Possibly the fact that sap is moving through the sapwood in the warmer period of the year has led to the belief that there is more sap in the wood during the spring and summer months.

Climatic Conditions and Locality

Climatic conditions influence air-seasoning. In parts of the South where the rainfall is considerable and the temperature and humidity are relatively high throughout a large part of the year, it is difficult and sometimes practically impossible to thoroughly air-season ties and round timbers of certain species before serious injury occurs from decay. This difficulty is experienced particularly with material that is largely sapwood or is low in decay resistance. When timber must be air-seasoned under such unfavorable conditions, it is essential that every precaution be taken to regulate the controllable factors so that the most desirable seasoning conditions will be provided. Some plant operators pretreat with chemicals that temporarily prevent decay and safely allow a longer seasoning period. For example, some plants pretreat poles and piling by the Rueping method with light retentions of creosote, such as 4 pounds per cubic foot, or with a water-borne preservative by the full-cell method, to protect the timber against decay while seasoning or while stored in the yard awaiting orders for treatment. Good pretreatment should provide effective protection against decay for many months of seasoning.

In dry or arid regions decay infection is seldom encountered during seasoning except under the most careless handling. In such regions the prevention of severe checking caused by too rapid drying may be the most important consideration, and the methods of handling and piling must be selected accordingly.

Drainage and Method of Piling

Much of the annual loss of ties, poles, and timbers ruined or damaged by decay while seasoning or in storage could be prevented through improvement in piling methods. The seasoning yard should be located on dry, well-drained ground where there is good air circulation. Low or filled ground favors the retention of water in the soil, and if surrounded by higher ground it may act as a pocket for the collection of damp air and fog. The location of wood-preserving plants, however, is determined most often by shipping facilities, cost of land, and the like, rather than by the advantages of the site for seasoning. Under such conditions the plant operator must make the best of what is available.

Good pile foundations are essential for efficient air-seasoning. They should be of treated wood or of some other material that does not decay. It is bad practice to place the bottom course of timber directly on the ground because it does not season well and, in most localities, is almost sure to become infected with decay. Well-treated reject ties and timbers make excellent foundation material. The foundations should be high enough to keep the bottom course of timbers 1½ to 2 feet above the ground, because air circulates downward through a seasoning pile and the moisture-laden air must have freedom to flow out at the bottom. The seasoning piles should be built openly and far enough from each other to allow free circulation (*21*).

The foregoing precautions are especially necessary where there is severe danger of decay infection. In extremely dry or arid regions, however, the precautions should be modified by making the piles tighter and the spacing closer in order to prevent too rapid drying and excessive checking. Every treating-plant operator should study his own conditions thoroughly, select the methods best adapted to these conditions, and keep constantly on the alert for improvements.

Sanitation

The seasoning yard should be kept clean and free from holes where water, waste wood, or debris of any kind may accumulate. Weeds and brush should be kept down not only within the yard but around it. Neglect in these respects retards seasoning, favors decay, and increases the fire hazard.

Length of Seasoning Period

Table 3 gives the air-seasoning periods employed by wood-preserving plants in various parts of the United States for timbers of different species. The periods are for ties, piles, and poles, since such timbers comprise most of the material air-seasoned for treatment. The seasoning periods used for lumber, bridge timbers, and similar material are more variable than those for ties, poles, and piles on account of the greater differences in cross-sectional dimensions. The lack of uniformity in practices indicates the variety of opinions among plant operators as to the amount of seasoning desirable, differences in details of yard location and piling methods, and differences in treating methods and purchasers' requirements.

Most of the seasoning that occurs in larger-size timbers, such as ties, will be obtained within the first year (*51*). The rate of seasoning becomes extremely slow afterward, and it is doubtful whether there is enough additional moisture loss to justify longer seasoning periods. Severe decay infection may occur when timbers are air-seasoned for more than 12 months, and in some parts of the country sapwood timbers cannot be yard-seasoned longer than 2 to 3 months without danger of serious loss from decay. In the Northern States only a limited amount of seasoning occurs in the 6-month period from about the middle of September to the middle of March.

TABLE 3.—*Air-seasoning periods employed by individual wood-preserving plants in different parts of the United States for ties, piling, and poles, of various species, 1949–50*

Species	Form of timber	Number of plants	Region in which plants are located [1]	Seasoning period (months)
Beech	Ties	1	Interior eastern	6
Do	do	1	do	6–12
Douglas-fir (Rocky Mountain)	do	1	Interior western	4–12
Do	do	1	do	9–12
Do	do	1	do	6
Do	do	1	do	1½
Douglas-fir (coast)	do	1	do	10–12
Do	do	1	do	4– 5
Do	do	3	Pacific	10–12
Do	do	2	do	6– 7
Do	do	3	do	6–12
Gum	do	2	Southern	3– 5
Do	do	1	do	5– 6
Do	do	1	do	6– 8
Do	do	1	do	2– 3
Do	do	2	do	4– 6
Do	do	1	Interior western	5– 6
Lodgepole pine	do	2	do	3– 6
Do	do	1	do	8–10
Do	do	1	do	9–10
Maple	do	1	Interior eastern	6–12
Ponderosa pine	do	1	Interior western	6
Do	do	2	do	4– 6
Red oak	do	2	Interior eastern	12–14
Do	do	1	do	10–12
Do	do	3	Southern	11–12

TABLE 3.—*Air-seasoning periods employed by individual wood-preserving plants in different parts of the United States for ties, piling, and poles, of various species 1949-50.*—Continued

Species	Form of timber	Number of plants	Region in which plants are located [1]	Seasoning period (months)
Red Oak (Continued)	Ties		Southern	
Do	do	1	do	2- 3
Do	do	2	do	12-18
Do	do	1	do	10-12
Southern yellow pine	do	2	do	3
Do	do	5	do	2- 3
Do	do	1	do	3- 4
Do	do	1	Interior eastern	4- 6
Western larch	do	1	do	6-12
Do	do	1	Interior western	4-10
White oak	do	1	Interior eastern	12-15
Do	do	1	Atlantic	10-12
Yellow birch	do	1	Interior eastern	6-12
Douglas-fir (coast)	Piling	1	Pacific	12-24
Do	do	1	do	12-15
Southern yellow pine	do	3	Southern	2- 3
Do	do	3	do	3
Do	do	1	do	2
Lodgepole pine	Poles	2	Interior western	4- 6
Southern yellow pine	do	8	Southern	2- 3
Do	do	3	do	2
Do	do	2	do	3- 4
Do	do	2	do	1- 2
Do	do	1	do	3

[1] The Atlantic region comprises Maine, New Hampshire, Vermont, Massachusetts, Rhode Island, Connecticut, New York, New Jersey, Pennsylvania, Maryland, Delaware, West Virginia, and Virginia. The southern region comprises Kentucky, Tennessee, North Carolina, South Carolina, Georgia, Alabama, Mississippi, Florida, Arkansas, Louisiana, Oklahoma, and Texas. The interior eastern region comprises Michigan, Ohio, Indiana, Illinois, Wisconsin, Minnesota, Iowa, Missouri, and the eastern parts of North Dakota, South Dakota, Nebraska, and Kansas. The interior western region comprises Idaho, Montana, Wyoming, Nevada, Utah, Colorado, Arizona, New Mexico, and the western parts of North Dakota, South Dakota, Nebraska, and Kansas. The Pacific region comprises Washington, Oregon, and California.

There is a limit to the amount of water that should be removed from resistant wood if the best results are to be obtained in treatment. Timbers that have been seasoned too long, or perhaps too rapidly, sometimes develop an increased resistance to penetration at the surface that is commonly called "case-hardening." [7] The degree of seasoning for optimum penetration is not definitely known, but results obtained in the treatment of both round and sawed timbers of various kinds, having different amounts of moisture, indicate that the moisture content of the treatable portion of the timber should not be much below the fiber saturation point. This applies particularly to the treatment of resistant material.

[7] A better term might be "surface-hardening," since case-hardening is the name applied in kiln-drying or air-drying when internal stresses are set up in which the inner layers of the wood are in tension and the outer layers are in compression.

On the other hand, more thorough seasoning is beneficial from the standpoint of limiting checking after treatment. Fairly permeable wood, such as the sapwood of the southern pines and various hardwoods, can usually be penetrated without difficulty when well air-seasoned and also when the moisture content is considerably above the fiber saturation point, but this is not usually true of other species when they have resistant sapwood. The surfaces of easily peeled, rapidly seasoned round material are sometimes made resistant to penetration by the accumulation of resins or other exudates on the surface during the early part of the seasoning period. This is not a matter of degree of seasoning, but of surface coating, and it is mainly confined to softwoods.

Most species have a resistant heartwood, and this may be particularly difficult to penetrate when the moisture content is too low. It must be borne in mind that it is not the average moisture content of the timber but the moisture content of the portion to be penetrated that is of particular importance. For example, studies of the moisture content of red oak cross ties seasoned for 14½ and 18 months in Illinois and Ohio showed an average moisture content of 26 to 28 percent in the first outer inch, an average around 46 percent in the next inch, and from 57 to 61 percent at the core, while the average for the whole section was from 39 to 41 percent (*50*).* Much more study is needed to develop the relations between the character and degree of seasoning and the treatability of the wood with different preservatives and processes.

If the treated timbers are to be used in dry climates where objectionable seasoning checks are likely to develop and untreated wood might be exposed, it is important to make sure that the wood is well seasoned before treatment.

MECHANICAL PREPARATION[8]

Incising

It is common practice to incise sawed timbers of resistant woods prior to treatment, particularly Rocky Mountain and western species, by passing the timbers through a machine equipped with cutting teeth projecting from rollers.[9] As the timber passes through the machine, the teeth are pressed into the wood to form a predetermined pattern of incisions that penetrate to a specified depth, usually one-half, five-eighths, or three-fourths of an inch. A machine of different design is required for incising round timbers.

The benefit of incising is attributable to the fact that longitudinal penetration is much greater in most species than either radial or tangential penetration. The incising teeth cut, tear, or break the wood fibers so that some end-grain wood is exposed to the preservative and penetration takes place longitudinally in both directions from each incision. There is also some side penetration, but this is usually slight. In order to get fairly complete penetration of all the wood to the depth of the incisions, these must be spaced properly along and across the surface so that the preservative will meet as it spreads from them. The necessary spacing

[8] For a more extended discussion of this subject see reference (*21*).

[9] The incising of ties and timbers was patented in the United States in 1918 by O. P. M. Goss. This patent, No. 1,252,428, was purchased by the Pacific coast wood-preserving companies and was dedicated by them to the free use of the public.

* (51) See ERRATA, in front.

is worked out empirically. On the other hand, the incisions should not be more numerous than necessary, so that the strength of the wood will not be greatly impaired.

Incising is least effective in resistant woods that cannot be penetrated well longitudinally. In suitable woods, however, it is an effective means of getting uniform depth of penetration in heartwood or in resistant sapwood.

Framing, Adzing, and Boring

Whenever practicable, all framing, adzing, and boring of ties, poles, or structural timbers should be done before treatment. Cutting into timber after treatment exposes untreated wood that is difficult to protect properly by any surface treatment applied afterwards. The life of the structure may be seriously affected or maintenance costs increased when such cutting is permitted. When preframing is done at a properly equipped plant, there is the additional advantage that it often costs less than framing on the job. Preframing is widely practiced at the present time (*9*, *62*).

Machine adzing and boring ties before treatment is common practice and is highly effective in prolonging their useful life. The adzing provides suitable seats for the tie plates, and boring the spike holes makes it possible for the preservative to penetrate the wood around the spike holes where decay often starts.

CONDITIONING PROCESSES

Purpose and Processes Used

Frequently timbers must be treated without waiting for them to air-season. This is necessary in some cases because of unfavorable climatic conditions that make air-seasoning a decay hazard, or because in other cases rush orders make it necessary to treat the timbers soon after they are cut. When green material is to be treated, it is customary to condition the wood by a special heat treatment so that it can be penetrated with the preservative. The conditioning treatment generally removes a substantial amount of moisture from the timber and also heats the wood to a more favorable treating temperature.

Two methods for accomplishing this conditioning have been extensively used in this country for many years. One is the steaming-and-vacuum method, which is used mainly for southern yellow pine and to a less extent for other pines. The second is the boiling-under-vacuum or Boulton process, which is used mainly with Douglas-fir and, to a limited extent, for western hemlock, western larch, and some hardwoods. A third method, called "vapor-drying," has recently come into limited use, mainly for southern pine poles and hardwood ties.

Steaming-and-Vacuum Treatment

In applying the steaming-and-vacuum process the charge of timber is first steamed for several hours in the treating cylinder, the time depending on the size of the timber and the steam temperature. At the end of the steaming period, the steam pressure is released and a vacuum is applied as quickly as possible in order to utilize the maximum amount of heat available for moisture removal.

During the steaming period, a temperature gradient is set up from the surface to the interior of the timbers and the temperature at any given distance from the surface will depend upon a number of variables such as steam temperature, length of steaming period, cross-sectional dimensions, and density of the wood.

Experiments have shown (*20*) that practically no reduction in the moisture content of the wood occurs during the steaming. In fact, some water is actually added by condensation in the early part of the steaming period, when the wood is cold. The amount of water absorbed as a result of condensation will depend to a considerable extent on the species, initial moisture content of the wood, initial wood temperature, steam temperature, amount of sapwood present, resistance of the wood to water absorption, and cross-sectional dimensions of the timber.

When the steaming is discontinued and a vacuum is applied, the boiling point is lowered and part of the water in the wood, especially that near the surface, is forced out mechanically by the steam generated in the wood cells or is evaporated during the vacuum period. Since there is a limit to the amount of heat that can be stored in the wood, there is also a limit to the amount of water that can be removed by the subsequent vacuum.

The resistance of the wood to moisture movement, the heat losses from various causes, and the relatively slow rate at which heat is conducted through wood make it impossible to utilize all of the stored heat that would theoretically be available in the region from which moisture is removed. Calculations show that if the resistance of the wood to moisture movement and all heat losses were neglected, the heat stored in the wood and in the absorbed moisture could not evaporate even the limited amount of water commonly taken out by the steaming-and-vacuum treatment (*38*). It is therefore evident that a large part of the water removed from steam-conditioned timbers is forced out by the steam pressure developed in the wood when the outside pressure is released and the vacuum is applied.

Experiments made at the Forest Products Laboratory, in which green specimens of different species were weighed during the steaming-and-vacuum periods, showed that a large part of the total amount of water removed came out of the specimens during the first few minutes after steam pressure was released and the vacuum was applied (*20*). A considerable part of the water removed was actually found to come out of the wood when the steam pressure was released and before the vacuum was started. In subsequent experiments on both green and water-soaked specimens the pieces were steamed in a glass cylinder (about 5½ inches in diameter and 46½ inches long), and it was observed that water flowed from both the sides and ends of the specimens while the steam pressure was being released and during the early part of the vacuum period.

Most of the water removed by the vacuum after steaming is taken out during the early part of the vacuum period when the wood is hottest and evaporation is most rapid. Experiments on green, round southern yellow pine timbers indicate that when a vacuum period of 5 to 6 hours is employed, from 50 to 60 percent of the total water removed is taken out during the first hour of the vacuum period and from 70 to 80 percent in the first 2 hours. The effectiveness of the vacuum is greatly reduced when the temperature of the wood surface is lowered below the boiling point corresponding to the vacuum. From the standpoint of moisture removal there seems to be little need to continue the vacuum much longer than 2 hours.

The average amount of water removed by the steaming-and-vacuum process from green southern pine poles and piling, which naturally have a high moisture content in the sapwood, is usually not more than 5 to 6 pounds per cubic foot. This would reduce the average moisture content by about 15 to 20 percent. Practically all this water comes from the sapwood, which comprises from 85 to 95 percent of the total volume of the round timber. Much less water is removed from green sawed southern pine timbers with exposed heartwood faces because the moisture content of the heartwood is only about 30 to 35 percent as much as the moisture content of the green sapwood. In addition, the heartwood is very resistant to moisture movement, which is not a characteristic property of the sapwood of southern pine.

Seasoned or partially seasoned wood often shows some increase in moisture content after the steaming-and-vacuum treatment is completed (*20*). In such cases the benefit derived from the conditioning treatment arises from the preheating of the wood that makes it easier to penetrate. The effect of the wood temperature on treatment is discussed in more detail on page 79.

When green, round southern pine timbers with deep sapwood are steam-conditioned, the free water in the cell cavities is often forced into the inner part of the sapwood zone during the pressure treatment and this region may show little or no oil penetration. In such cases, when an increment boring is taken, the water may gush out through the bored hole because pressure on some of the confined water is released. Prolonged steaming, which is sometimes used in an effort to remove more of this water when the vacuum is applied, is not effective.

Undue attention is sometimes given to the amount of water left in the wood after the timber has been treated. The best criterion as to how well the wood is impregnated is the retention of preservative and the uniformity and depth of penetration—not the amount of water removed by the steaming-and-vacuum treatment. The free water found in the wood after treatment is not necessarily evidence of insufficient steaming, since experiments show that, except on the surface, even the most effective steam treatment rarely, if ever, brings the moisture content of green wood close to the fiber saturation point. Moreover, free water remaining in the wood after treatment, except when it prevents acceptable penetration, has no influence on the ultimate checking or durability, since checking does not start until the water in the cell walls is below the fiber saturation point.

Large timbers, which have a smaller ratio of surface area to volume, will normally lose less water per unit volume during steaming-and-vacuum treatment than timbers of smaller cross-sectional dimensions. In some cases an attempt is made to judge the amount of water left in the sapwood of steam-conditioned timbers by squeezing the wood in the core of an increment boring. This is a very unreliable method of estimating the moisture condition of the timber, because too many variables must be taken into consideration and the conclusions depend too much on guesswork. The objection that creosoted wood containing free water will not season after treatment is not valid, because the preservative will merely retard, not prevent, the loss of moisture. In one respect this is an advantage, since the slower rate of seasoning helps to reduce the amount of checking that normally occurs in more rapid seasoning.

The practice of keeping the steam coils heated during the vacuum period does not aid appreciably in reducing the moisture content of the wood because heat does not circulate freely in a vacuum. While some radiated heat may reach timber surfaces facing the hot metal surfaces, most of the timbers in a cylinder charge will be heated very little by radiation.

Experiments show that alternate steaming-and-vacuum treatments are considerably more effective in reducing the moisture content of wood than are a continuous steaming and a final vacuum period of the same total duration (*28*). In such treatments, however, the initial steaming period must be sufficient to allow a reasonable time to heat the wood, and this period will depend upon the size of the timber and the steam temperature. Since the rate of temperature change decreases rapidly as the distance from the surface increases, as may be noted from the time-temperature curves, the use of alternate steaming and vacuum treatments should be more effective than a long-continued steaming followed by vacuum.

It should be understood that the steaming-and-vacuum process will not reduce the moisture content of green material sufficiently if particularly heavy retentions of preservative are needed. This is an important consideration in the case of piles and other timbers that will be exposed to marine-borer attack, since timbers used in marine structures should be treated with maximum retentions. For example, even if the timbers were nearly all sapwood, calculations show that it is not possible to get retentions of 18 pounds or more of creosote per cubic foot in green southern pine piles conditioned by the steaming process. Such material should be well air-seasoned before treatment or should be seasoned by some other means that will remove enough water to allow retentions that meet the service requirements.

Steam pressure and steaming period.—The maximum steam temperature and steaming period that may be used with safety cannot be stated with technical accuracy because there is insufficient knowledge of the effect of steaming on the strength and other properties of wood. Undoubtedly the effects vary considerably with the size, moisture content, and species of the wood. In commercial specifications, however, certain limits have been set that are based on observation and experience in the treatment of different species and in the uses and serviceability of the wood.

Temperatures ordinarily used in steaming wood are, of course, much lower than those that would disintegrate or char wood in the heating periods employed, but they are high enough to injure the wood seriously unless care is exercised in selecting them and in determining the length of the steaming period. The common practice of steaming southern pine timbers at 20 pounds' gage pressure as a maximum (approximately 259° F.) may be considered satisfactory until further experiments show otherwise. The use of more severe steaming conditions, such as 30 pounds' gage pressure (about 274° F.) or more, or the application of particularly long steaming periods does not appear to be justified, and the danger of injury is considerably increased thereby. Steaming temperatures of 259° F. are common also with jack, red, and lodgepole pine, but with most other species 240° is usually the maximum permitted.

Although there is a definite steam temperature for each steam pressure, a thermometer as well as a pressure gage should be used in determining the temperature of the steam within the heating cylinder, because pockets of air are frequently left in the cylinder after the steam is admitted. Where air pockets exist, the required pressures may be indicated on the gage when the steam temperature is actually lower than that which should be obtained for the specified pressure. The use of both a thermometer and pressure gage also serve as a check in case one instrument is in error.

Table 4 summarizes the steaming and vacuum conditions employed at various plants treating green southern pine timbers in 1950. It may be noted that all but one plant steamed at 20 pounds per square inch.

TABLE 4.—*Steam-and-vacuum treatments used at various plants treating green southern pine timbers, 1950*

Plant No.	Material	Steam pressure	Steaming period	Vacuum period after steaming
		Pounds per square inch	*Hours*	*Hours*
1	Poles	20	10–12	2
2	Poles	20	8–16	2
	Lumber and timber	20	8	2
3	Poles	20	12–18	2
	Piling	20	20	2
	Lumber and timber	20	10	2
4	Poles	20	10–14	2
5	Lumber and timber	30	12–14	1
	Posts	30	8	1
	Piling	30	16	3
6	Poles	20	12–15	2½–3
	do	20	10–15	2½–3
	Piling	20	12–16	2½–3
	Posts	20	6– 7	2½–3
7	Poles	20	8–14	2 –2½
	Piling	20	12–15	2 –2½
	Lumber and timber	20	5– 6	2 –2½
	Posts	20	6	2
8	Poles	20	10–14	2
	Piling	20	12–14	2 –2½
9	Poles	20	8–12	2 –2½
10	do	20	12–13	2
11	Poles	20	9–10	3
	Posts	20	6	2
12	Poles	20	5–12	2
13	do	20	12–15	2¼
14	Piling	20	15–18	2½
	Poles	20	10–12	2½
	Lumber and timber	20	8–10	2½
15	Poles	20	10–12	2
	Cross arms	20	8–10	2
	Lumber and timber	20	8–10	2
16	Poles	20	8–10	2
	Lumber and timber	20	8– 9	2
17	Poles	20	10–14	2½

TABLE 4.—*Steam-and-vacuum treatments used at various plants treating grean southern pine timbers, 1950*—Continued

Plant No.	Material	Steam pressure	Steaming period	Vacuum period after steaming
		Pounds per square inch	*Hours*	*Hours*
18	Poles	20	8–10	2
	Lumber and timber	20	8–10	2
19	Poles	20	8–12	2
	Cross arms	20	10–12	2
	Lumber and timber	20	11–12	2
	Piling	20	14	3
20	Poles	20	10–12	1
	Piling	20	14	2½
	Cross arms	20	8	2½
21	Poles	20	8–12	2
	Sawed timber	20	8–10	2
22	Poles	20	8–12	3
23	do	20	10–12	2½
24	Poles	20	8–15	2½
	Sawed timber	20	7–10	2½
25	Piling	20	13	2½
	Poles	20	10–14	2½
	Posts	20	7	2½
	Sawed timber	20	10–12	2½
26	Poles	20	8–14	3
27	do	20	8–12	2

The plant in which there was an exception to this rule used a steam pressure of 30 pounds, which is contrary to standard specifications and is considered poor practice.

Advantages and disadvantages of steaming.—Among the principal advantages of steaming are: Steam heats faster than any of the other heating mediums; it is easily applied and requires no special equipment, either on or attached to the treating cylinder; the temperature can be easily controlled, both in the rate at which it is raised and after the desired temperature is reached; and the wood is left clean after steaming is completed.

The principal disadvantages are: No moisture is evaporated during the time steam pressure is applied, hence the wood surfaces are exposed to the actual steam temperature during the entire steaming period; only a limited amount of moisture can be removed during the subsequent vacuum, even when the wood is heated throughout to the temperature of the steam; and it is generally necessary to use considerably higher temperatures than would be needed, for example, in the use of the Boulton process.

The Boulton Process

The original process for seasoning or conditioning timber by boiling in creosote under vacuum was patented by S. B. Boulton in England in 1879 and in the United States in 1881 (*30*). The Boulton process as applied at the present time is essentially as follows: The treating cylinder is filled with hot preservative oil so that all timbers are covered, although some unfilled space may be left above the oil surface. The preservative is then kept heated while a vacuum is applied. In this case the oil serves to keep the wood hot while the vacuum lowers the boiling point of the water in the wood and causes part of the water to evaporate. The evaporated moisture and some of the accompanying vapors from the oil pass through a condenser, and the rate of accumulation of condensed moisture is a measure of the progress of the conditioning treatment.

In conditioning sawed timbers of Douglas-fir by the Boulton process, the temperature is customarily maintained at 180° to 200° F., although specifications permit 210°. For poles and piling, temperatures of about 200° to 220° are generally employed. A low vacuum is often used at the start and gradually increased as the moisture evaporation progresses. Some plants, however, apply the vacuum as rapidly as possible, while others first heat the wood in the preservative for a few hours at atmospheric pressure before starting the vacuum.

Since the Boulton process requires time at the start to heat the wood so that the water will evaporate from it, the condensate comes off somewhat slowly at first, gradually increases to a maximum, and then gradually decreases as the heating and vacuum are continued. Increasing the vacuum too rapidly may cause oil to surge over into the vacuum system in plants not specially designed to prevent it. In plants treating Douglas-fir, the maximum vacuum towards the end of the conditioning period commonly reaches 24 inches of mercury or more. The condensate can be weighed or measured to determine how much water has been removed from the charge, and the volatile oils evaporated from the creosote and condensed with the water may be separated from the water and returned to the preservative tank.

When an empty-cell treatment is specified, the cylinder is emptied of preservative after the conditioning period and air at atmospheric pressure or higher is admitted as desired. The preservative treatment is then applied as for air-seasoned material. In treating by the full-cell process, the cylinder is filled with preservative after the conditioning is completed and pressure is applied at once. Some preservative is absorbed during the boiling-under-vacuum period, depending on the kind of timber treated, amount of sapwood and heartwood, and other variables

Although the Boulton process or a modification of it has been widely and successfully employed on the Pacific coast for a long time, it is only within fairly recent years that the process has been used in other parts of the United States for species other than Douglas-fir. Unseasoned red oak, which is severely checked by the steam-and-vacuum treatment, has shown but little checking when conditioned by the Boulton method, and the in-service results reported for the treated wood appear to be satisfactory. Green beech, gum, and southern yellow pine have also been conditioned successfully by the Boulton process.

Conditions employed for the Boulton process.—Table 5 gives data on the temperature and conditioning periods employed in 1949–50 at various commercial plants using the Boulton process, mostly in the treatment of coast-type Douglas-fir. Considerable variation in the treating conditions is evident, due in part, perhaps, to variations in local conditions or in moisture content of timbers, and to differences of opinion as to the best conditions to use.

TABLE 5.—*Conditions employed at various plants using the Boulton process, chiefly for coast-type Douglas-fir timbers, 1949–50*

Plant No.	Kind of material conditioned[1]	Boiling-under-vacuum conditions	
		Boiling period	Temperature of preservative during boiling period
		Hours	*°F.*
1	Poles and land piling	30–36	215
2	Poles	30–40	220
	Piling	36–45	220
	Ties	14–15	190
	Lumber and timber	15–18	190
3	Poles	20–25	190–200
	Ties	8–12	190–200
4	Poles and piling	20–25	210–220
5	Poles	18–19	200
	Piling	40	210
	Ties	14–16	190
	Lumber and timber	12–14	190
6	Poles	18–36	200–220
	Ties	15	200
7	Piling	35–40	220
	Ties	12–14	195
	Lumber and timber	12–16	190–195
8	Poles	20–30	220
	Piling	20–40	220
9	Piling	20–40	190–200
	Ties and lumber	8–15	190–200
10	Ties	10–12	185–190
11	Gum ties	16–18	210
	Southern pine ties	8	190–200
	Ties	8	210
12	Lodgepole pine ties	9–10	200–205

[1] All coast-type Douglas-fir except as otherwise indicated.

Amount of moisture removed by the Boulton process.—Table 6 gives the average amount of moisture removed from timbers conditioned at some commercial plants using the Boulton process.

Treating-plant operators sometimes overlook the fact that the high moisture content of the sapwood that may be present on some parts of sawed Douglas-fir timbers, and evaporation of water from the end surfaces, may be responsible for most of the water removed in the Boulton treatment, and that the heartwood as a whole loses only a small amount of moisture. Since the moisture content of green Douglas-fir heartwood usually averages less than 40 percent, the green heartwood has about 55 percent of air space, so that no additional seasoning is necessary to obtain the preservative retentions usually specified. Even if the moisture content were reduced to 15 percent, the air space would not be greatly increased. At 15 percent moisture content the air space in heartwood would average about 60 percent in comparison with 55 percent air space in green wood with a moisture content of about 35 percent.

TABLE 6.—*Amounts of water collected from green timber of various species conditioned by the Boulton process in commercial treatments*

Species	Charges treated	Kind of material	Average temperature of preservative during conditioning	Average time in hot bath before starting vacuum	Average length of boiling period length of	Average amount water collected during boiling period
	Number		*°F.*	*Hours*	*Hours*	*Pounds per cubic foot*
Red oak	11	Ties and bridge timbers.	180	--------	24.5	8.7
Beech	7	Switch ties.	180	--------	13.5	5.0
Southern pine.	7	Ties and timbers.	180	--------	11.1	4.6
Douglas-fir (coast type).	25	Sawed timbers.	180–190	4	10.8	1.9
Do	52	Piling.	200–200 *	6	43.0	13.4

There is apparently a high resistance to the movement of moisture in the heartwood of Douglas-fir, and it is probable that much of the water removed during the Boulton treatment of this species is from the wood within the first inch or two from the surface. Some plants using the Boulton process for Douglas-fir timbers continue the boiling period until the average moisture content within 1 to 1½ inches from the surface has been reduced below the fiber saturation point. Where the timbers are short and therefore have a considerable amount of end-surface area exposed, more water will be removed than when the timbers are long and moisture movement is largely from the side surfaces.

More moisture can be removed in a given time from incised heartwood timbers of coast Douglas-fir than from unincised material. Some plant operators say that they boil sawed timbers under vacuum for sufficient time to reduce the average moisture content of the incised wood well below the fiber saturation point. Unless the timbers are of fairly small cross section, however, little, if any, seasoning can be expected below the depth of the incisions.

Round Douglas-fir piles and poles contain more moisture than sawed material because they have more sapwood and commonly are also kept in the water in log booms until just before treatment. Their average moisture content after treatment is also high. Table 6 shows that about 13 pounds of water per cubic foot were removed from the round timbers in comparison with about 2 pounds from the sawed material. This difference is to be expected, considering the appreciably higher moisture content of the sapwood, higher oil temperatures, the longer seasoning periods employed for the piles, and the smaller resistance of the sapwood to moisture movement.

* 200-210
See ERRATA,
in front.

TABLE 7.—*Amounts of water collected in Boulton treatment of green southern yellow pine pole specimens 10 feet long*

Specimens in group (number)	Average diameter of specimens [1]	Temperature of creosote during boiling period [2]	Length of boiling period	Average amount of water collected during boiling period [3]
	Inches	*°F.*	*Hours* *	*Pounds per cubic foot*
3	8.2	180	01.0	9.2
6	9.8	200	10.0	9.3
6	9.0	200	11.0	9.9
3	10.8	200	12.0	11.8
12	11.2	200	13.0	10.5
3	10.1	210	12.0	9.0
6	9.8	220	6.6	6.5
3	10.3	220	11.0	8.3
6	11.0	220	13.0	13.3
3	11.3	235	13.0	16.2

[1] Average depth of sapwood about 3.25 inches.
[2] Temperature of preservative maintained constant during entire boiling period, except that in some treatments from 15 to 20 minutes were required to reach the desired temperature.
[3] Average initial moisture content of sapwood varied from about 90 to 100 percent.

Table 7 is a summary of data obtained in Boulton treatments on specimens of green southern yellow pine poles. These experiments were made at the Forest Products Laboratory to study the feasibility of using the Boulton process instead of the steaming-and-vacuum method for conditioning green southern yellow pine poles preparatory to treatment (*36*).

Although appreciable quantities of water may be removed in the Boulton process, the wood, as in the steaming-and-vacuum process, may be but partially seasoned and may still have a high average moisture content at the end of the conditioning treatment. Both the heartwood and sapwood of red oak have a high moisture content when green, and in some individual charges treated after conditioning by the Boulton process as much as 9 or 10 pounds of water have been removed per cubic foot of wood. Even then, however, the wood was left very wet. To illustrate, by taking the average moisture content of green red oak heartwood as 85 percent and the average specific gravity (based on weight when oven-dry and volume when green) as 0.56, the original weight of water is found from figure 9, p. 29, to be nearly 30 pounds per cubic foot of wood. By assuming that 10 pounds of water per cubic foot are removed by the Boulton treatment, figure 9 shows that the moisture content of the wood still remains more than 56 percent, which is much above the fiber saturation point. Nevertheless, creosote can be made to penetrate it satisfactorily at this high average moisture content.

Green Douglas-fir heartwood has an average moisture content of

* 11.0
See ERRATA
in front.

only about 36 percent, which during the Boulton treatment may be reduced appreciably below the fiber saturation point in the outer inch or so. However, the interior of all but thin material will have little moisture change, and the average moisture content may still be considerably above the fiber saturation point. By using the specific gravity of 0.45 given in table 2, p. 23, it is found from the data given in figure 9 that with 36 percent moisture content the heartwood contains more than 10 pounds of water per cubic foot. If the water could be removed as readily and in such large quantities as from red oak or southern pine sapwood, the Douglas-fir heartwood could be made very dry by the Boulton process, but this is not the case.

Experiments made at the Forest Products Laboratory on green Douglas-fir heartwood specimens, which were boiled under vacuum at 200° F. for periods of 10 to 20 hours, showed average moisture reductions varying from 8 to 15 percent (*37*). The final average moisture content, however, was usually at or above the fiber saturation point even in specimens as small as 4 by 4 inches in cross section boiled under vacuum for more than 20 hours. The specimens used in these experiments ranged from about 4 by 4 inches to about 6 by 12 inches in cross section and were from 4 to 7 feet long. Evaporation from the ends was prevented by steel plates with gaskets, which were bolted over the end faces.

Similar experiments were made with green, round Douglas-fir specimens boiled under vacuum for 21 to 23 hours with the preservative held at 190° F. (*37*). Some of these specimens contained sapwood that averaged from ¾ to 1¾ inches in thickness for the different pieces. Other specimens were turned in a lathe to remove all the sapwood, so that moisture movement through the heartwood was in a radial direction. These various specimens averaged about 10 inches in diameter. The average moisture content of the sapwood before boiling under vacuum was about 100 percent, and that of the heartwood about 36 percent. When the boiling period was completed, a disk was cut from the midsection of each specimen and moisture samples were taken of the sapwood alone and of the heartwood at intervals of 1 to 1½ inches from near the surface to the center.

The specimens were removed as soon as the boiling period was completed, and only very slight absorption of the preservative occurred even in the sapwood. Moisture determinations were made of the unpenetrated wood only. The final average moisture content of the sapwood varied from about 18 to 42 percent, depending on the original depth. When the average moisture content of the sapwood was brought below the fiber saturation point, the average moisture content of the first inch of heartwood directly under the sapwood was usually 5 to 6 percent higher than that of the sapwood. Otherwise there was very little change in the moisture content of the heartwood covered with sapwood.

With the specimens that were turned on the lathe to remove the sapwood, the average moisture content after the Boulton treatment was about 26 percent for the first 1½ inches from the surface, with practically no change beyond that distance. These specimens were unincised. Incising would probably have increased the moisture evaporation appreciably.

In these experiments a vacuum of 25 to 26 inches was usually reached within 2 to 3 hours after the preservative was admitted to the cylinder.

Temperature Changes in Wood When Boiled Under Vacuum and When Heated in Creosote at Atmospheric Pressure

A study of the rate of temperature change in green Douglas-fir heartwood timbers boiled in creosote under vacuum at temperatures of 190° to 210° F. showed that the rate of temperature change was, in general, about the same as when the wood was heated without vacuum until within 5° or 10° of the creosote temperature. For example, with the creosote temperature at 200° and the maximum vacuum about 25 to 26 inches of mercury, the rate of temperature change in these specimens was about the same as without vacuum until a temperature of 190° to 195° was reached. The temperature would then remain fairly constant, as long as the vacuum was not broken, until the rate of evaporation became sufficiently slow to permit an increase in the wood temperature. In these tests the temperature of the creosote was constant during the boiling period, and the maximum vacuum of about 26 inches was reached within an hour.

Experiments on green, round coast-type Douglas-fir specimens boiled under vacuum showed that when the timber contained a considerable amount of sapwood and a high moisture content the rate of temperature change was about the same as when the wood was heated at atmospheric pressure, until a temperature about 20° to 25° F. lower than the creosote temperature was reached. Beyond this limit the rate of temperature change was usually much slower than when the wood was heated at atmospheric pressure, because further temperature increase was retarded by the evaporation of moisture. The diameter of these specimens varied from about 9 to 12 inches, and the sapwood depth varied from ¾ to 1½ inches. The moisture content of the sapwood averaged about 100 percent for the different specimens, and that of the heartwood about 36 percent. In these experiments on round specimens the preservative temperature was kept constant during the boiling period, and the maximum vacuum of 25 to 26 inches was usually reached within 2 or 3 hours after the test was started. The total boiling period was from 21 to 23 hours.

In green, round southern pine timbers boiled under vacuum the effect of vacuum on the rate of temperature change was more pronounced than that noted for round Douglas-fir timbers, because of the lower resistance and greater depth of sapwood in the pine and the consequently higher rate of evaporation. The rate of temperature change in the round pine specimens boiled under vacuum was about the same as when heated without vacuum until the wood reached a temperature about 35° or 40° F. below the creosote temperature. The wood temperature then changed but little until a considerable amount of water had been removed from the sapwood.

The increase in temperature above the boiling point corresponding to the vacuum conditions used in the Boulton process is largely because of the resistance of the wood to air and moisture movement. In other words, the vacuum within the timber is less than that surrounding it and may decrease rapidly from the surface to the interior. As a matter of fact, pressure measurements in heartwood timbers have shown that an appreciable pressure can be built up and remain for hours in the interior of the heated wood with a high vacuum surrounding it. As might be expected, the vacuum will affect the rate of temperature change within the timber to a greater extent in wood that has a large proportion of sapwood than it will in wood that is largely heartwood and therefore very resistant to the movement of liquids and vapors. No temperature measurements were made in red oak while boiled under vacuum, but the effect of the vacuum on temperature changes would undoubtedly be very pronounced in this species, on account of its open-porous structure.

The effect of the resistance of the wood on interior temperatures has been discussed. A certain increase in wood temperature above the boiling point corresponding to the vacuum is also necessary to overcome the pressure due to the weight of the preservative above the timber. When the wood begins to season below the fiber saturation point in the surface portion, the resistance to moisture movement increases and a correspondingly higher wood temperature is necessary to overcome this resistance. As the wood dries below the fiber saturation point, the rate of temperature rise also tends to decrease, since seasoned wood heats more slowly than green material. If the boiling period is continued a sufficient length of time, the temperature throughout the timber will eventually become about the same as that of the heating medium. Except in the case of timbers of small cross-sectional dimensions, however, the wood is rarely heated throughout to the temperature of the heating medium because of the extremely long time that would be required and because little advantage would be accomplished by heating the interior to the maximum temperature at the surface.

In the case of round timbers, however, such as poles and piling that have been heated under vacuum until the rate of water evaporation is fairly rapid, the rate of temperature change will be considerably slower that when the wood is heated at atmospheric pressure. Factors affecting the results to a greater or less extent will be diameter of timber, moisture content of sapwood, depth of sapwood, temperature of the preservative, rate of applying vacuum, and maximum vacuum applied. For general conditions, however, it may be assumed that in boiling under vacuum the rate of temperature change at any particular point in a round timber will be about the same, until a temperature about 25° F. lower than the preservative temperature is reached, as would be obtained if no vacuum were used. The temperature would then probably change very slowly or remain fairly constant until seasoning had progressed sufficiently to require a higher temperature for further seasoning.

If the timbers had a large amount of sapwood so that the preservative could penetrate a considerable distance from the surface, the temperature would, of course, be higher than when no penetration of preservative occurs, since more or less heat would be carried in by the preservative. In the case of heartwood timbers and those with resistant sapwood, penetration is usually very limited and the heating effect of the creosote that penetrates the timber does not have such an important influence, especially when the cross-sectional dimensions are fairly large.

The temperature changes in seasoned wood heated in oil would be little influenced by vacuum because heat consumption due to moisture evaporation would be slight.

Advantages and Disadvantages of the Boulton Process

The chief advantage of the Boulton process, in comparison with the steaming-and-vacuum method for preparing timber for treatment, lies in the milder temperatures that can be employed to make possible good treatment with minimum effect on the strength and on the physical condition of the wood. This effect is the determining factor in the choice of a conditioning process for woods that are sensitive to high temperatures.

Other advantages are: The Boulton treatment never increases the moisture content of the wood or of the oil, and a greater moisture reduction can be obtained than is possible with the steaming process. With the Boulton process it is possible to reduce the moisture content of green round timbers below the fiber saturation point in the sapwood. Because of the higher resistance of the heartwood of most species, even long boiling-under-vacuum periods will not often season the wood in heartwood material more than a short distance from the surface.

The Boulton process is sometimes employed for seasoned or partially seasoned wood; but, in general, there is little advantage to be gained by using it under such conditions, except when it is desired to remove air from the wood so that higher retentions can be obtained in material treated by the full-cell process. Such removal is an important consideration in treating timbers for structures that will be exposed to marine-borer attack.

Because of the important advantages of this conditioning process, it has found widespread use in the past, and at the present time it is considered the standard method for conditioning green Douglas-fir timbers at the western treating plants.

The chief disadvantages of the Boulton process are that it is suitable for oils only, it often costs more than air-seasoning, it heats the wood more slowly than steaming or boiling at high temperatures without vacuum, and it usually requires a considerably longer time than the steaming-and-vacuum process. Nevertheless, it is much more effective than the latter process in removing moisture from wood.

Vapor-Drying Process

Recently a conditioning treatment called the "vapor-drying process" has been developed and patented (patent No. 2,273,039, Feb. 17, 1942, and others), which utilizes the heat of vapors from boiling organic liquids at or below atmospheric pressure. The drying agents generally used are coal-tar or petroleum fractions with initial boiling points in the range of 212° to 400° F. This process has been employed largely for conditioning green cross ties and poles prior to pressure treatment (*16*, *17*). Evaporation of water from the green wood during the heating period is said to keep its temperature down sufficiently to prevent detrimental effects from the vapor temperatures employed. Up to the present time green red oak ties and green southern pine poles have made up a large part of the tie and pole material conditioned by this process.

The following advantages are claimed for the process: The time required to condition the timbers for treatment is relatively short because the vapors can be maintained at a fairly high temperature while the water is being removed; deep checking is said to be considerably less than in air-seasoned wood, especially in species like red oak that have a tendency to develop large checks; it is also said to give good results both in removing moisture and in heating the wood to a favorable treating temperature; and it is finding increasing commercial use.

RATE OF TEMPERATURE CHANGE IN WOOD AND VARIOUS FACTORS AFFECTING THE RESULTS

The temperature of the wood is one of the most important factors affecting treatment and is also an essential consideration when conditioning material for treatment. It is therefore desirable, when round or sawed timbers are being heated in any given heating medium, to know the approximate rate of temperature change [10] that will occur at different distances from the surface. Such information is useful in selecting heating periods for timbers of different dimensions when the wood is conditioned by the steaming-and-vacuum or by the Boulton process; in finding the temperature that can be expected at any point in the timber when the wood is heated in the preservative; for determining the time at which heating should be discontinued because of the slower rate at which temperature changes take place as the temperature of the heating medium is approached; for comparing the advantage of using different heating-medium temperatures; and in determining the time required to sterilize the timber.

A large amount of experimental work has been done at the Forest Products Laboratory to determine the rate of temperature change in both round and sawed timbers and also to study the factors that affect the rate of heat transfer under different heating conditions. These experiments were made by using steam, water, preservative oils, hot plates, and air at different humidities, as heating mediums. Formulas based on the results of these experiments were developed for computing the approximate temperatures at any particular point in a timber. The methods of conducting the tests, the development of formulas employed, and the data obtained are discussed in other publications (*18*, *34*, *35*, *37*, *38*, *40*, *42*, *43*, *44*, *45*, *47*, *48*, *64*, *65*).

The following were found to be the principal factors affecting the rate of temperature change, apart from the timber dimensions: (1) The heating medium; (2) the moisture content of the wood; (3) the direction in which heat movement takes place with respect to the grain of the wood, that is, whether radially (at right angles to the annual rings), tangentially (parallel to the annual rings), or longitudinally (along the fibers); and (4) the density or specific gravity.

HEATING MEDIUM

Results of these experiments showed that steam heats wood faster than liquids, liquids heat it faster than hot plates, and hot plates heat it faster than dry air, if the heating temperature and heating period are the same in each case. Water heated wood faster than preservative oils, but not so fast as steam. In general, the rate of heating in water was about 5 to 10 percent slower than in steam. Although the rate of heating was slowest in dry air, the rate of heating in air, of course, increased as the humidity was increased.

Variations in the rate at which wood heats at the same temperature

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[10] Although wood is not a homogeneous, isotropic substance, it has sufficient uniformity of structure to permit the application of the mathematical theory of heat conduction in solids to determine the approximate rate of temperature change in timbers of different sizes and shapes. The results are sufficiently accurate for practical purposes.

in different mediums are caused by variables such as type of surface contact, which affects the surface coefficient of heat transfer; the rate of circulation of the heating medium, and some limited surface penetration of the heating medium when liquids and gases are used; specific heat of the heating substance; and heat of vaporization, as in the case of steam. Timbers that have checks extending to various depths as a result of seasoning and sapwood that is well seasoned and easily penetrated, may absorb some of the heating medium during the early part of the heating period. This may help hasten the rate of temperature change to a limited extent. Reliance, however, should not be placed on such factors, especially if the wood is not particularly permeable, if it has a fairly high moisture content, or if it does not show a considerable amount of deep checking over a large part of the surface.

The use of a vacuum during the heating period will naturally affect the rate of heating when moisture is evaporated, as mentioned earlier in the discussion of the Boulton process.

MOISTURE CONTENT

Experiments showed that seasoned wood heated somewhat more slowly than green wood in steam and in liquids. The rate of heating increased to some extent with increasing moisture content up to the fiber saturation point of the wood, beyond which no significant change was found. Green material will therefore heat at about the same rate, regardless of differences in the moisture content, above the fiber saturation point. In making calculations of the rate of temperature change, it should be sufficient for practical purposes to assume that timbers with an average moisture content at or below 20 percent are seasoned and that those in which most of the wood has a moisture content above 20 percent are green. Seasoned material will usually heat about 10 to 20 percent slower than green wood under the same conditions, depending on the moisture content and on the moisture distribution from the surface to the interior of the seasoned timbers.

RATE OF TEMPERATURE CHANGE IN TRANSVERSE AND LONGITUDINAL DIRECTIONS

For normal wood there is apparently no significant difference in the rate of heating in the radial and tangential directions, but the rate is about 2¼ to 2¾ times faster in the longitudinal direction (along the fibers) than in the transverse direction. Longitudinal heating, however, does not need to be taken into consideration unless the timbers are exceptionally short and the cross section is large in proportion to the length. End heating will have no effect or will be a negligible factor, in heating the wood at the midportion of round timbers if the length is five to six times the diameter or more, even if the heating period is sufficiently long to heat all of the wood to the temperature of the heating medium. Since most round timbers are only partially heated to the temperature of the heating medium in ordinary treating operations, lengths considerably less than six times the diameter can be considered as heated in the radial direction only.[11]

[11] A discussion of temperature changes in short-length round timbers, and curves showing the temperature distribution from the end surfaces to the midlength, are given in a publication on this subject (*47*).

End heating will have no effect on sawed timbers the surfaces of which are at the same temperature, and may be disregarded as a factor affecting the temperature toward the midsection, if the length of the sawed timber is about 10 times the shortest cross-sectional dimension.

EFFECT OF SPECIFIC GRAVITY ON THE RATE OF TEMPERATURE CHANGE IN WOOD

The rate of temperature change in any solid depends upon the diffusivity, which, like conductivity, may be considered a constant over normal ranges of temperature. Diffusivity is a measure of the rate of temperature change, and it may be defined as the change in temperature produced in a unit volume of the substance by the quantity of heat that passes in unit time through unit area of a layer of unit thickness and having unit difference of temperature between the faces.

The equation showing the relation of diffusivity, conductivity, specific heat, and specific gravity is given in the appendix. (See list of symbols used in formulas, page 149).

In the case of wood, the product of specific heat and density that appears in the formula represents the heat capacity of both the wood substance and the water in the wood.

Although the heat conductivity of wood increases with increase in specific gravity, the diffusivity decreases with increase in specific gravity. That is, the lighter woods will reach a given temperature more rapidly than the heavier woods, although the latter are better heat conductors (*40*, *42*).

In determining the required heating period to be used in conditioning wood for treatment, the following items should be taken into consideration.

EFFECT OF SNOW OR ICE ON RATE OF HEATING

When wood is covered with ice or snow or when moisture is frozen in the timber, a somewhat longer heating period will be required to melt the ice and heat the wood than when the water is not frozen. In heating round or sawed timber in steam, of which there is an ample supply and good circulation, not more than about 20 to 30 minutes' increase in the normal heating period would probably be required to provide for the extra time needed to melt the ice or snow. The initial wood temperature would, of course, be taken as the temperature under the frozen conditions, which might be well below 32° F. in winter.

EFFECT OF VACUUM ON RATE OF HEATING

Since the evaporation of water during the heating period will tend to lower the wood temperature, timbers heated under vacuum will heat more slowly after the temperature has been raised somewhat above the boiling point corresponding to the vacuum applied. This is discussed under the subject heading Temperature Changes in Wood When Boiled under Vacuum and When Heated in Creosote at Atmospheric Pressure, p. 50.

DIFFERENCE IN TEMPERATURES OBTAINED AT TOPS AND BUTTS OF LONG POLES AND PILES

Long poles and piles are often much smaller at the top than at the butt because of the natural taper of the timber. For this reason the top portion will be heated to a higher temperature than the butt when the heating period is completed. This fact should be considered in selecting the heating temperature and heating period, especially when steaming, to avoid conditions that may subject the top region to temperatures that will unnecessarily impair the strength properties. On the other hand, it is particularly important that the heating period be sufficient to bring the butt part to a favorable treating temperature.

COMPENSATING FOR THE TIME NEEDED TO BRING THE HEATING MEDIUM UP TO THE REQUIRED TEMPERATURE

Usually it is not practicable to maintain a constant temperature from the time heat is first applied; in the early part of the heating period the temperature of the timber and that of the treating cylinder are generally close to the atmospheric temperature and a certain amount of time is needed for the heating medium to reach the desired maximum temperature. Some plant operators also feel that it is desirable to raise the temperature gradually, and very commonly from 1 to 2 hours is taken to reach the maximum.

It can generally be assumed that the rate of temperature rise of the heating medium is reasonably uniform. Therefore, it is sufficient to count the time required to reach the maximum temperature as the time equivalent to heating at the maximum temperature for half the time needed to reach the maximum. If, for example, 2 hours were taken to reach the maximum, this would count as heating for 1 hour at the maximum temperature in order to adjust for the lower temperature at the start.

If the temperature conditions are not reasonably uniform on all surfaces of the timbers, or if the heating-medium temperature is not fairly constant after the maximum temperature is obtained, the length of the heating period should be increased to compensate for the temperature difference. The plant operator must depend on his judgment in estimating the additional time needed to compensate for the variable conditions.

TEMPERATURE COMPUTATIONS

In addition to the effect of the variables mentioned, the diffusivity determined experimentally was found also to be influenced by the heating medium and other variables; hence the diffusivity factors thus determined may be considered as "apparent" rather than actual since the influence of these variables is included. In the following discussion, however, they will be called diffusivity factors for the sake of simplicity.

Figure 12 shows diffusivity factors obtained from green and from seasoned wood of different specific gravity when heated in steam and in creosote. Average diffusivity factors for green and for seasoned wood of different species heated in creosote or steam are shown in table 22, p. 139.

Even when the diffusivity factor is known, temperature computations require a large amount of work because of the involved equations that are unsuitable for convenient numerical computations.

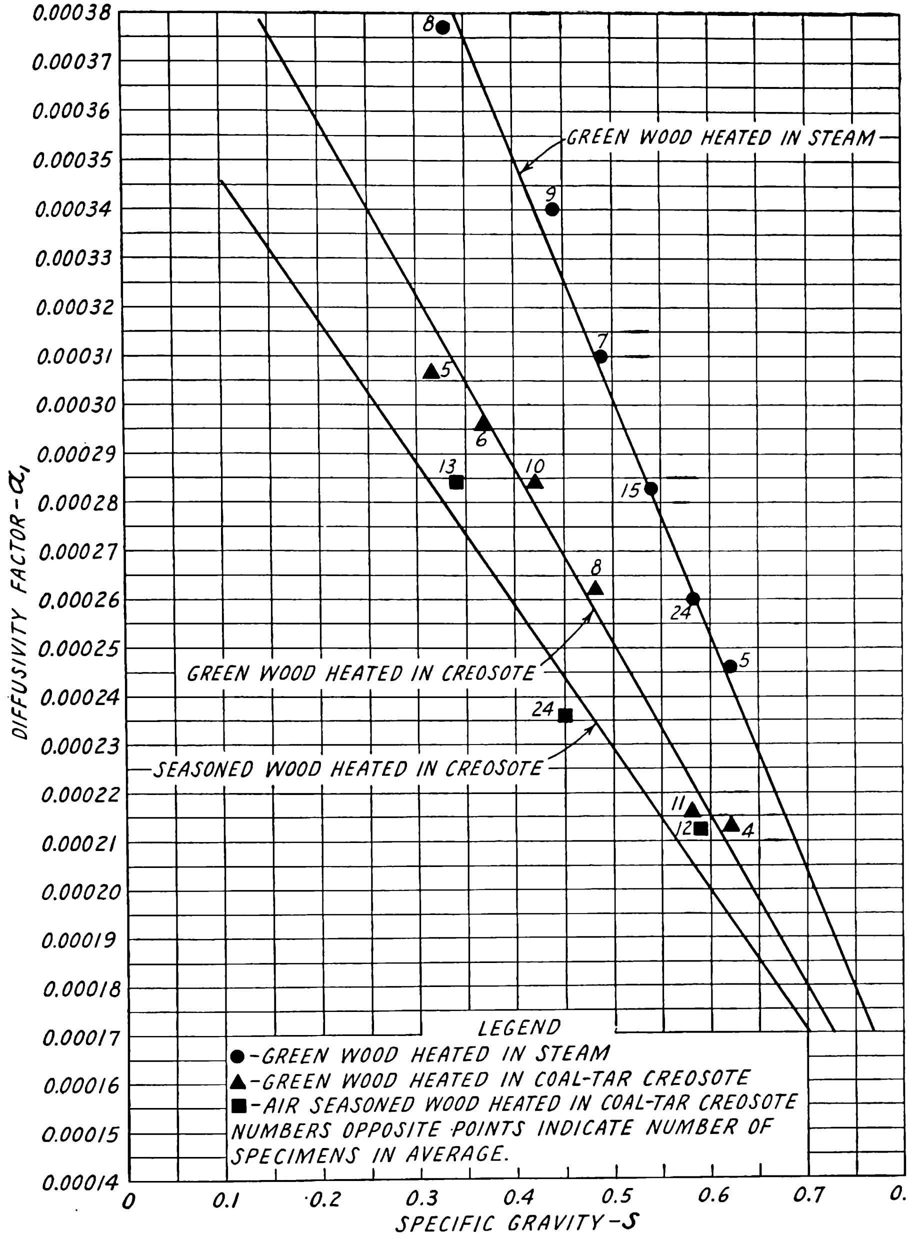

FIGURE 12.—Relation of diffusivity and specific gravity of wood.

If, however, computations are made for any assumed timber dimensions, diffusivity, initial wood temperature, and heating-medium temperature, there are simple time-temperature relations that make it possible to use computed data when these data are tabulated or plotted in the form of curves. Such computed data can be used for finding the temperature to be expected at a given point in a timber when any or all of the three variables, diffusivity, initial wood temperature, and heating-medium temperature, are different from those used in making the original calculations. Figures 13 to 22 show the computed rate of temperature change at different distances from the surface of timbers of various cross-sectional dimensions. The method of using the plotted data for any particular type of timber heated under any given temperature condition is explained in the appendix, pp. 138–151. Examples are also given in the appendix showing the procedure to be followed in finding the temperature in either round or sawed material.

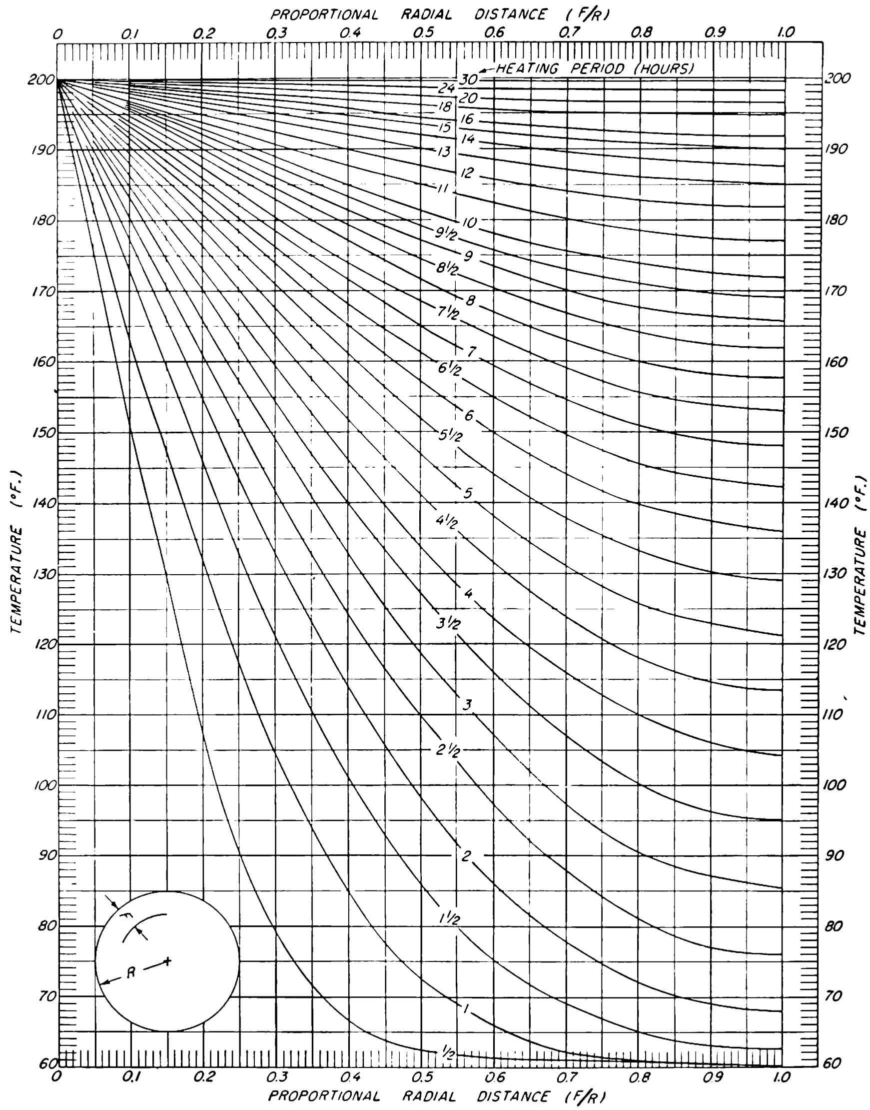

FIGURE 13.—Temperatures between surface and center of 10-inch-diameter timber after various heating periods. Distance from surface expressed as proportion of radius $\frac{F}{R}$. (Diffusivity = 0.00025; initial wood temperature = 60° F.; heating-medium temperature = 200° F.) (See appendix pp. 143–147 for discussion of method of using figure 13 and for illustrative examples.)

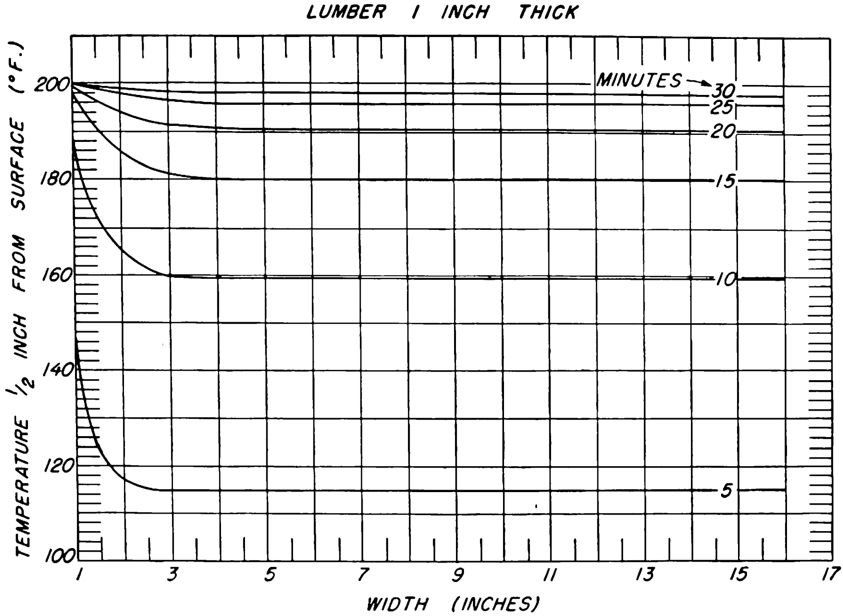

FIGURE 14.—Temperatures at a distance of 1/2 inch from surface of sawed lumber 1 inch thick after various heating periods. (Diffusivity = 0.00025; initial wood temperature = 60° F.; heating-medium temperature = 200° F.)

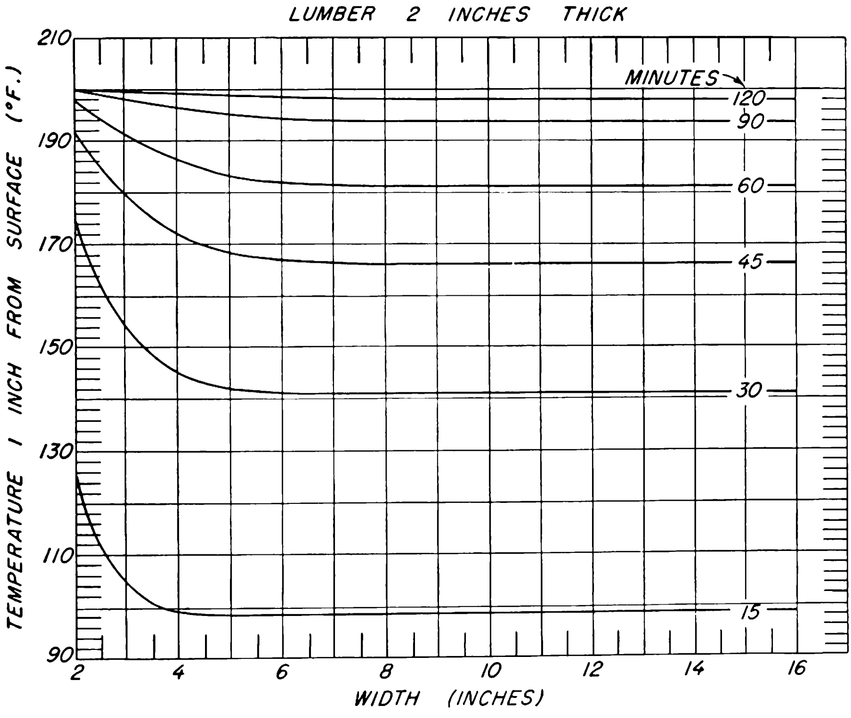

FIGURE 15.—Temperatures at a distance of 1 inch from surface of sawed lumber 2 inches thick after various heating periods. (Diffusivity = 0.00025; initial wood temperature = 60° F.; heating-medium temperature = 200° F.)

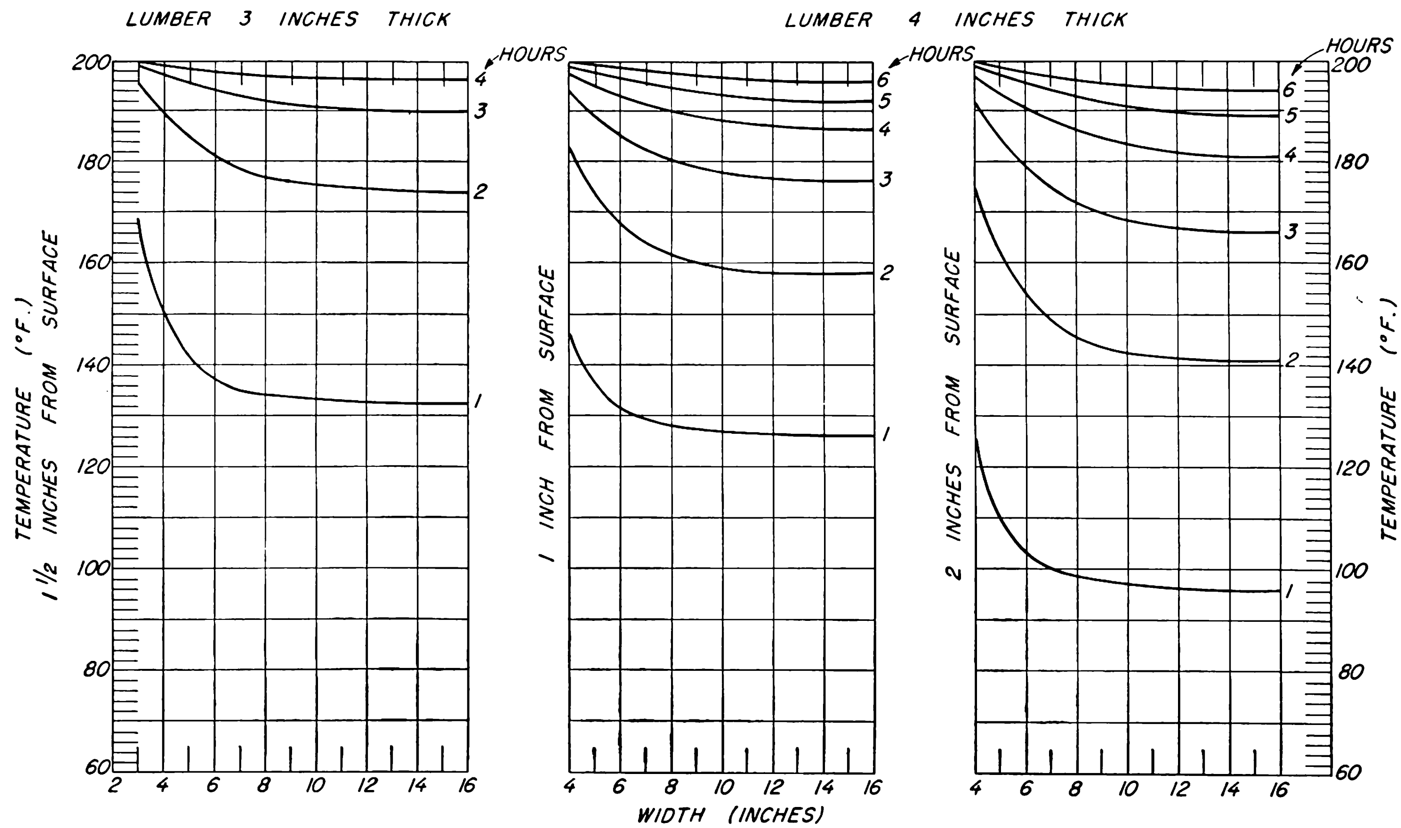

FIGURE 16.—Temperatures at a distance of 1½ inches from surface of sawed lumber 3 inches thick and at distances of 1 and 2 inches from surface of lumber 4 inches thick after various heating periods. (Diffusivity = 0.00025; initial wood temperature = 60° F.; heating-medium temperature = 200° F.)

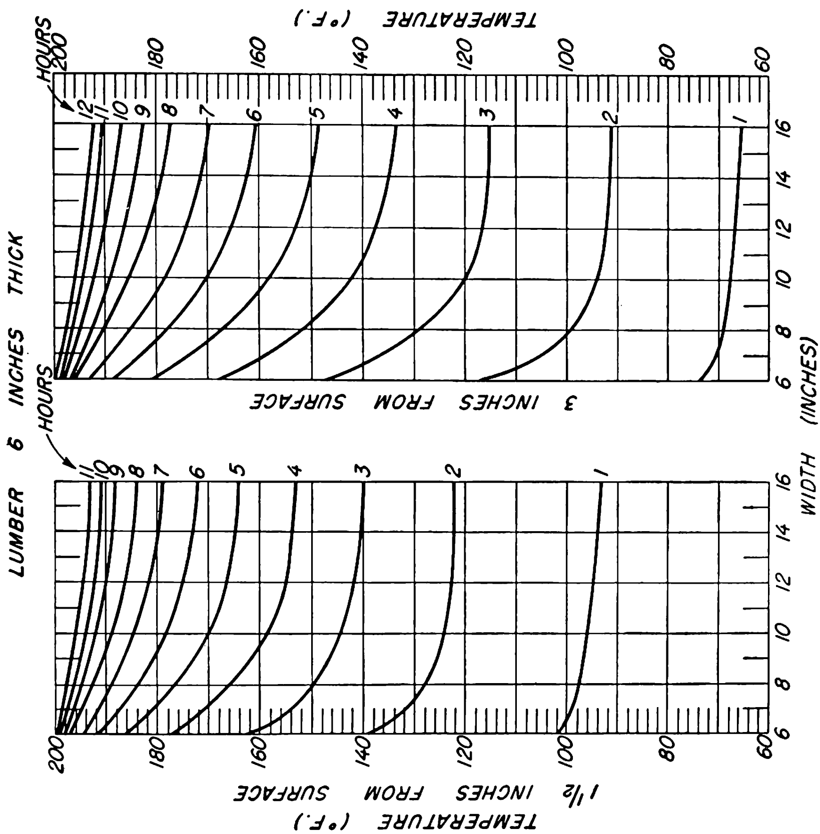

FIGURE 17.—Temperatures at distances of 1½ and 3 inches from the surface of timbers 6 inches thick after various heating periods. (Diffusivity = 0.00025; initial wood temperature = 60° F., heating-medium temperature = 200° F.)

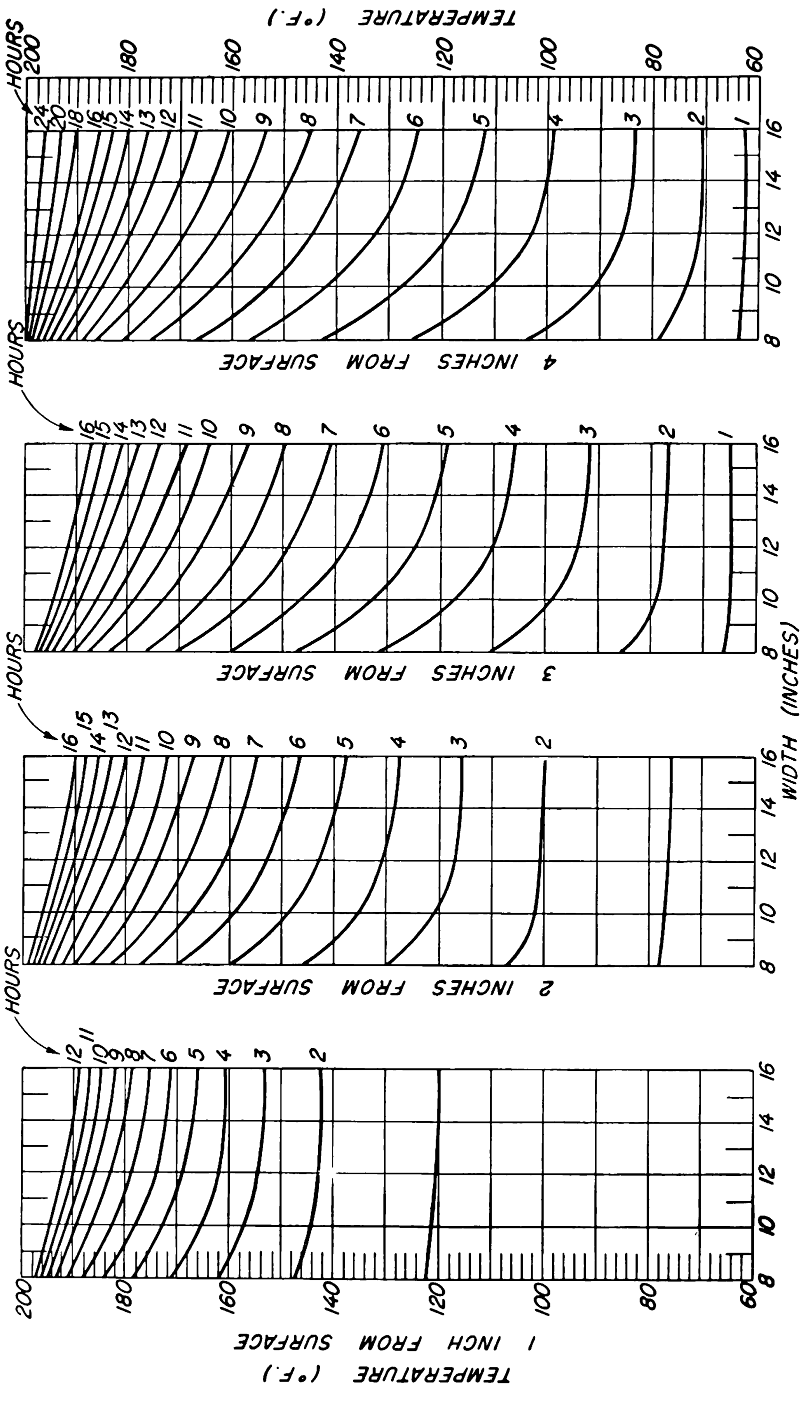

FIGURE 18.—Temperatures at distances of 1, 2, 3, and 4 inches from the surface of timbers 8 inches thick after various heating periods. (Diffusivity = 0.00025; initial wood temperature = 60° F.; heating-medium temperature = 200° F.)

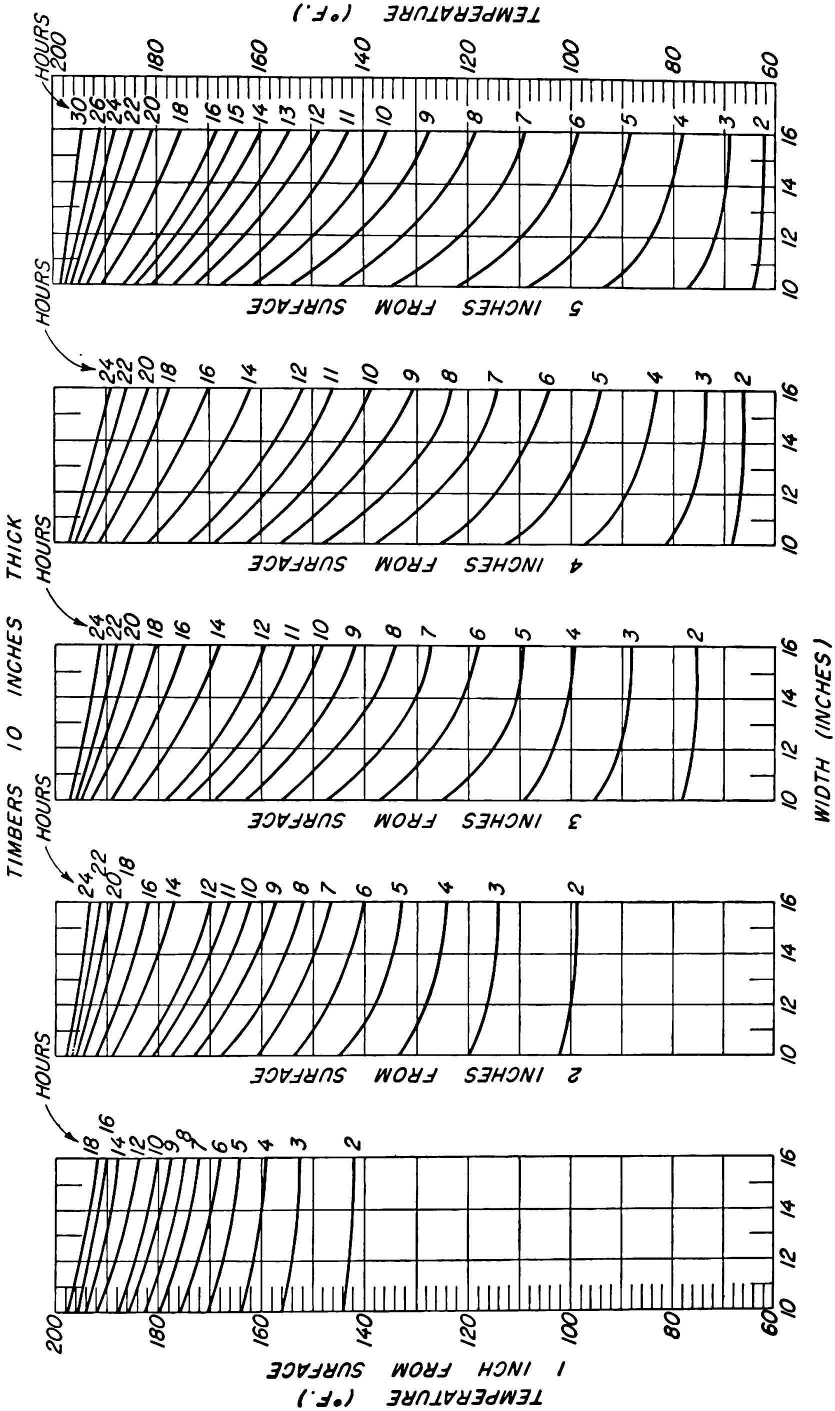

FIGURE 19.—Temperatures at distances of 1, 2, 3, 4, and 5 inches from the surface of timbers 10 inches thick after various heating periods. (Diffusivity = 0.00025; initial wood temperature = 60° F.; heating-medium temperature = 200° F.)

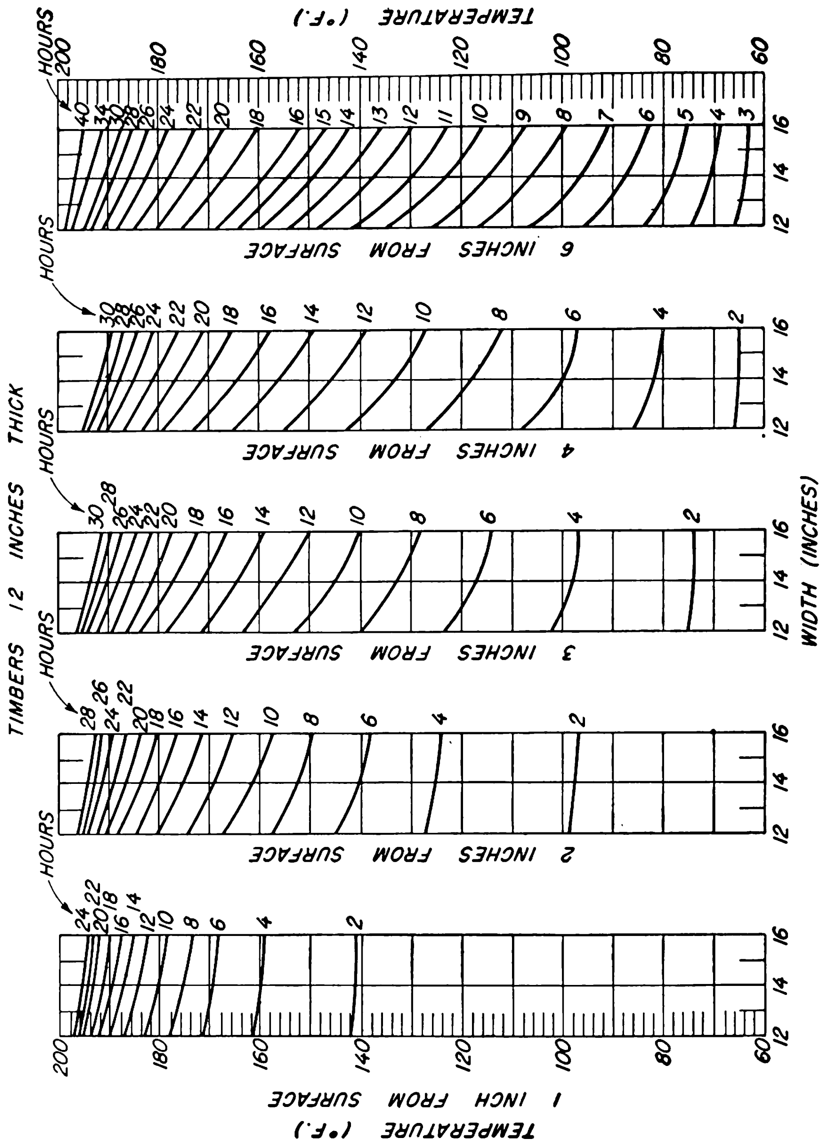

FIGURE 20.—Temperatures at distances of 1, 2, 3, 4, and 6 inches from the surface of timbers 12 inches thick after various heating periods. (Diffusivity = 0.00025; initial wood temperature = 60° F.; heating-medium temperature = 200° F.)

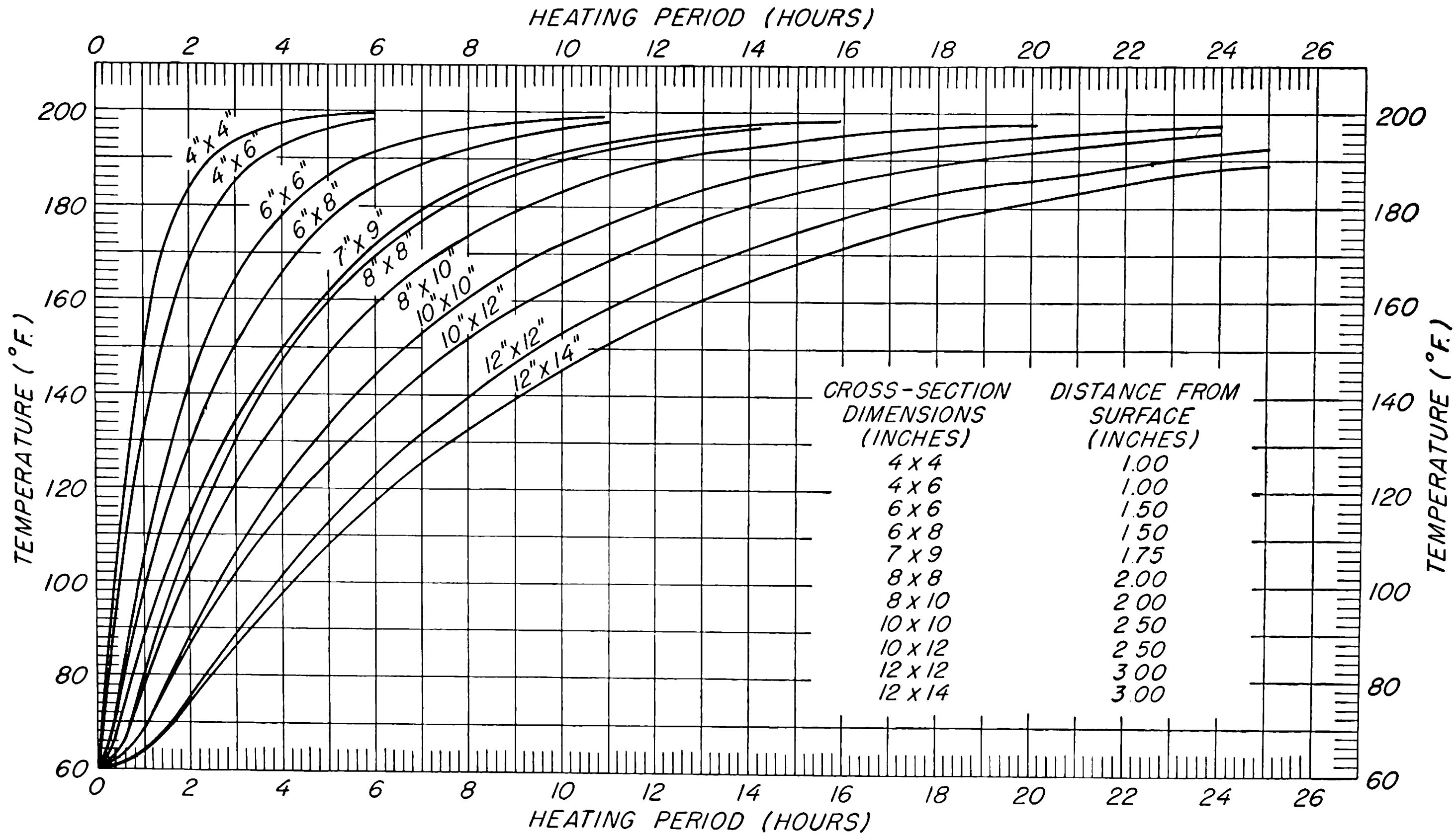

FIGURE 21.—Temperatures midway between the surface and center of sawed timbers of various cross-sectional dimensions (distance measured on the short axis when width is greater than thickness) heated at 200° F. for different periods of time. (Diffusivity = 0.00025; initial wood temperature = 60° F.)

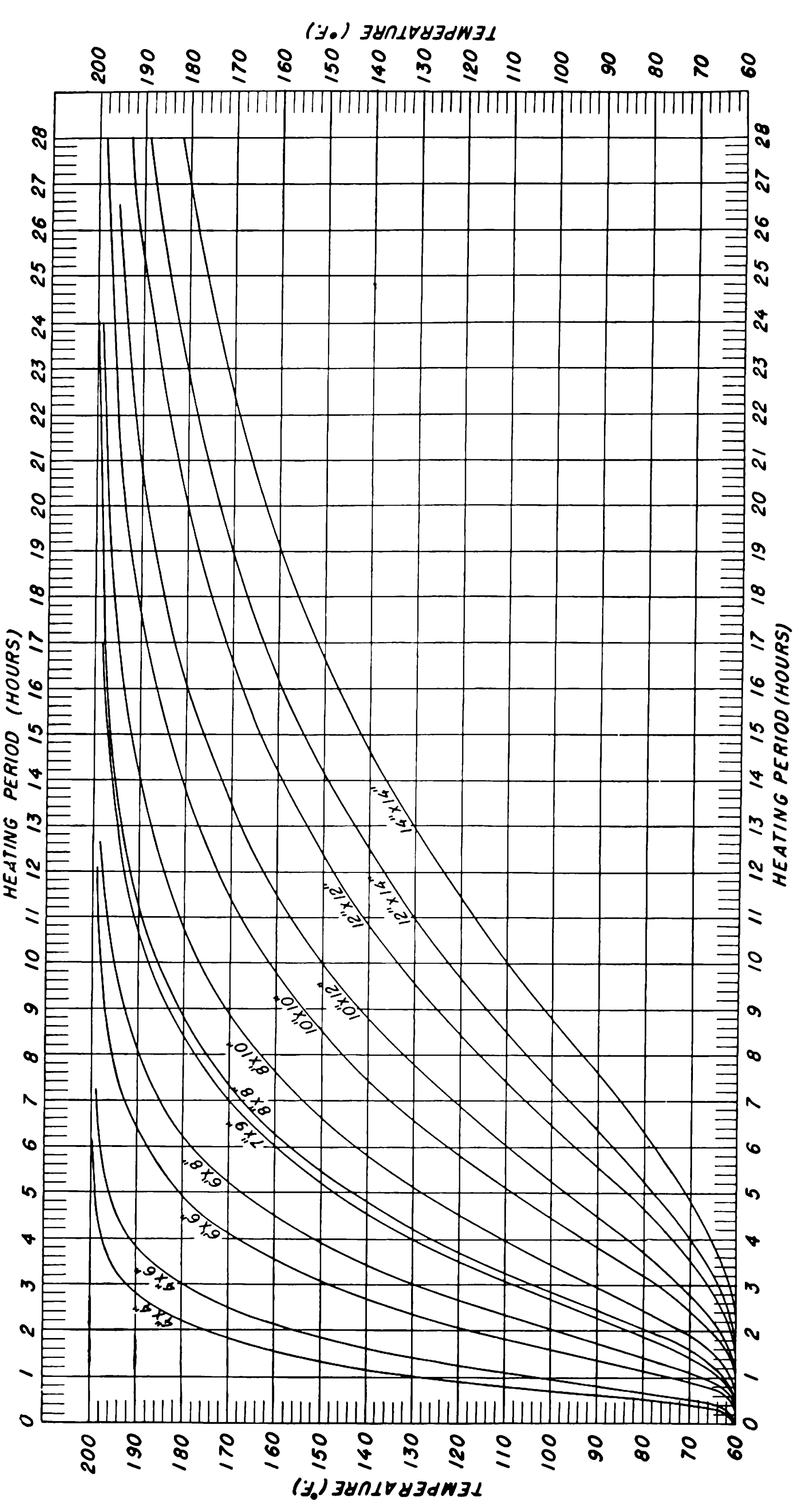

FIGURE 22.—Temperatures at center of sawed timbers of various cross-sectional dimensions heated at 200° F. for different periods of time. (Diffusivity = 0.00025; initial wood temperature = 60° F.)

TEMPERATURES REQUIRED TO STERILIZE WOOD

Laboratory studies (*6*, *15*) have shown that while heating conditions required to kill wood-destroying fungi depend both on the temperature and on the duration of heating, the required heating period decreases rapidly with increase in temperature. Results of these experiments indicate that it is not practical to sterilize wood at temperatures appreciably lower than 150° F., since the most resistant fungus tested was not killed even when heated for 12 hours at 140°. Following are the temperatures and times of application recommended to make sure that wood is effectively sterilized (*6*):

Temperature (°F.)	*Time (minutes)*
150	75
170	30
180	20
200	10
212	5

When the temperature of the wood at the interior of a timber is lower than that of the heating medium, it will continue to rise in the region near the center to a variable extent after heating is discontinued and cooling starts, since heat flows from the region of higher to the region of lower temperature. After cooling starts, heat will flow both toward the surface and toward the center as long as the temperature of the wood between the surface and center is higher than that at the center. The amount of temperature rise that occurs at the central portion of the timber will depend upon such factors as the surface temperature of the wood while heating, the temperature to which the center has been heated before cooling starts, the distance of the point under consideration from the surface, the cooling temperature, and the conditions of cooling. This subject is discussed more fully in another publication (*48*).

When the heating-medium temperature is 200° F. during the heating period, the temperature at the center may rise from 10 to 15 degrees or more if the center has been heated to a temperature around 130° to 135° before cooling starts. On the other hand, if the heating-medium temperature is 260° during the heating period and the center temperature is around 130° to 135° when cooling starts, the temperature may rise 25 to 30 degrees higher, roughly twice as much as when the heating-medium temperature is 200°.

INJECTING PRESERVATIVES

The character and viscosity of the preservative, and the preservative temperature, temperature of the wood, vacuum, air pressure, preservative pressure, and length of pressure periods all have a marked effect on treatment and are so closely interwoven that the relative influence of an individual factor is often unrecognized. Their importance is greatest in wood that is resistant to treatment or in treating mixtures of easily treated and resistant wood.

INFLUENCE OF VISCOSITY AND TEMPERATURE OF PRESERVATIVE

Preservatives differ considerably in the ease with which they can be made to penetrate resistant wood. One of the principal properties involved is viscosity (*4*, *25*, *26*, *27*, *29*). Other factors, such as surface tension or ability to wet the wood, are probably also of importance, but the extent to which their influence is different from that of viscosity has not been established.

The viscosity of a preservative varies with its temperature, and the two cannot be discussed independently.

Figure 23 illustrates variations in viscosity of different preservative oils. The figure gives temperature-viscosity curves for a representative coal-tar creosote, a petroleum oil, and mixtures of the creosote and petroleum oil. The petroleum and creosote were those used in making the treatments for which the data are given in table 8. The curve for 3 percent zinc-chloride solution has been added for comparison. The marked differences in viscosity between the creosote, the petroleum, and the mixtures stand out clearly. The low viscosity of the water solution, in comparison with the viscosities of the oils, is also noteworthy. The differences decrease greatly, however, as the temperature increases.

Liquids that are mobile or of low viscosity penetrate better, other things being equal, than more viscous liquids. Since temperature has such a pronounced effect on the viscosity of preservative oils and solutions, it affects their ease of penetration into wood. High preservative temperatures give better absorptions and penetrations than low temperatures.

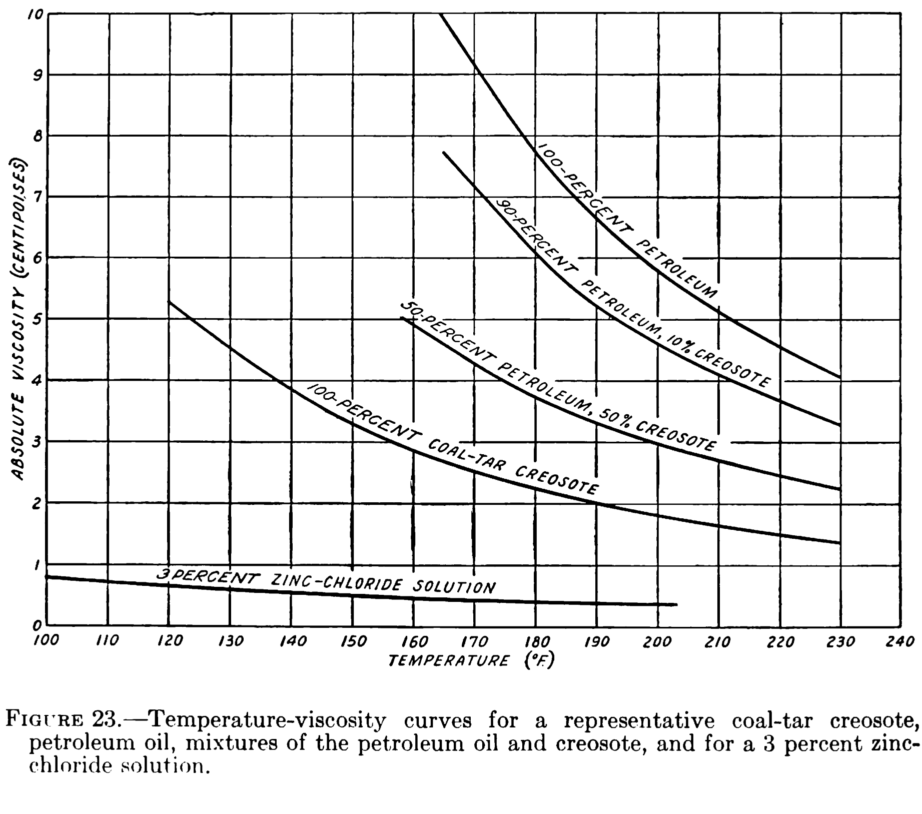

FIGURE 23.—Temperature-viscosity curves for a representative coal-tar creosote, petroleum oil, mixtures of the petroleum oil and creosote, and for a 3 percent zinc-chloride solution.

Coal-Tar Creosote and Mixtures of Petroleum or Tar with Creosote

Table 8 shows the effect of temperature on treatments of air-seasoned eastern hemlock ties with 100 percent coal-tar creosote, a 50-50 percent creosote-petroleum mixture, and a 90-percent petroleum and 10-percent creosote mixture. The preliminary vacuum, length of pressure period, and final vacuum were the same in all charges treated. With each pressure and preservative the only factor varied was the temperature of the preservative during the pressure period, which in turn varied the viscosity. Both the sapwood and heartwood of eastern hemlock are sufficiently resistant to prevent complete penetration under the conditions used.

In the treatments with creosote, increasing the temperature (lowering the viscosity) invariably increased the penetration and, in most cases, increased both the net and gross absorptions. Table 8 shows that a temperature of 180° F., which is a temperature that in the past was widely used in commercial creosoting, gives much better results than 140° or 160°. Still better results were obtained, however, at the higher temperatures. In the treatments with the petroleum mixtures, the penetration again was invariably greater at the higher temperatures, but the absorptions were not so consistent. The absorptions and penetrations of the creosote were much greater than those for the more viscous petroleum mixtures.

In order to compare the relative effect of different viscosities of the same preservative, which are a function of temperature, the side penetrations and absorptions obtained with creosote at each temperature (table 8) have been averaged for the three pressures. These averages are given in table 9 and show the marked influence that temperature and viscosity changes have on penetration and absorption.

Since the treatments with coal-tar creosote, covered by table 8, were made at the same preservative temperatures with each of the three pressures, the general effect of pressure alone is indicated by averaging the results of the six treatments made at different temperatures for each pressure. These averages are also shown in table 8. This gives an average based on 140 to 149 ties for each pressure. A comparison of the results thus obtained shows that the average of side penetration and gross absorption varied approximately in proportion to the increase in gage pressure.

Figure 24, which is based on data given in table 8, shows the penetrations obtained in the treatments made at 150 pounds' pressure when using the petroleum-creosote mixtures and creosote alone.

Figure 25 shows the effect of varying the viscosity without changing the temperature in a series of treatments of small, air-seasoned Douglas-fir heartwood specimens with creosote and creosote mixtures. The specimens were matched in quality and four were used in each treatment. No preliminary or final vacuum was used, the treating temperature was kept at about 185° F., the treating pressure was about 125 pounds gage, and the pressure period was 2 hours. The results shown in the figure are averages. It is clearly evident that a distinct relation exists between the penetration and the viscosity.

Table 10 shows the effect of changing the temperature without changing the viscosity. The results, which were obtained by varying the tempera-

TABLE 8.—*Effect of temperature on absorption and penetration in air-seasoned eastern hemlock ties treated by the full-cell process with creosote and creosote-petroleum mixtures* [1]

Preservative	Gage pressure	Ties in treatment	Average weight per cubic foot before treatment	Preservative temperature	Average net retention	Average gross absorption	Average side penetration		Absolute viscosity at temperature used in treatment		Average net retention per square foot of surface		Average gross absorption per square foot of surface	
	Pounds	*Number*	*Pounds*	°*F.*	*Pounds per cubic foot*	*Pounds per cubic foot*	*Inches*	*Percent*	*Centipoises*	*Percent*	*Pounds*	*Percent*	*Pounds*	*Percent*
Coal-tar creosote	125	25	29.3	140	9.5	9.8	0.26	100	3.80	100	1.31	100	1.35	100
	125	24	29.4	160	10.3	10.7	.32	123	2.81	74	1.41	108	1.46	108
	125	24	30.0	180	12.8	13.3	.39	150	2.22	58	1.75	134	1.82	135
	125	25	28.4	200	15.7	16.2	.43	165	1.80	47	2.14	163	2.21	164
	125	25	29.2	220	16.4	19.0	.48	185	1.50	40	2.25	172	2.60	193
	125	25	28.5	240	16.4	21.7	.49	188	1.22	32	2.22	170	2.93	217
Average	-------	-------	29.1	190	13.5	15.1	.40	-------	2.22	-------	1.85	-------	2.06	-------
Coal-tar creosote	150	25	30.7	140	8.2	8.6	.26	100	3.80	100	1.12	100	1.17	100
	150	25	29.4	160	12.7	13.5	.40	154	2.81	74	1.75	156	1.86	159
	150	25	30.2	180	14.7	15.9	.42	161	2.22	58	2.01	180	2.17	186
	150	24	29.8	200	16.2	19.2	.52	200	1.80	47	2.24	200	2.65	227
	150	25	30.3	220	18.5	24.5	.65	250	1.50	40	2.55	228	3.37	288
	150	25	30.3	240	18.1	27.6	.72	277	1.22	32	2.49	222	3.81	326
Average	-------	-------	30.1	190	14.7	18.2	.50	-------	2.22	-------	2.03	-------	2.50	-------

Coal-tar creosote	175	24	29.1	140	12.0	12.9	.35	100	3.80	100	1.64	100	1.76	100
	175	24	28.3	160	16.0	17.3	.44	126	2.81	74	2.18	133	2.35	134
	175	24	29.3	180	15.7	17.0	.53	151	2.22	58	2.26	138	2.45	139
	175	23	29.4	200	17.1	19.4	.57	163	1.80	47	2.43	148	2.76	157
	175	22	29.5	220	21.5	26.1	.71	203	1.50	40	2.93	179	3.57	203
	175	23	30.3	240	21.8	33.6	.81	231	1.22	32	3.13	191	4.82	274
Average			29.3	190	17.4	21.1	.57		2.22		2.43		2.95	
50-percent petroleum oil and 50-percent coal-tar creosote	150	24	32.7	160	10.7	11.2	.30	100	4.90	100	1.65	100	1.71	100
	150	24	32.5	180	11.1	11.5	.35	117	3.80	78	1.68	102	1.74	102
	150	24	32.2	200	13.4	14.0	.44	147	3.05	62	2.00	121	2.09	122
	150	24	34.0	220	11.8	13.0	.47	157	2.40	49	1.82	110	2.06	121
Average			32.9	190	11.8	12.4	.39		3.54		1.79		1.90	
90-percent petroleum oil and 10-percent coal-tar creosote	150	24	30.8	160	10.0	11.2	.24	100	8.30	100	1.35	100	1.50	100
	150	24	31.0	180	9.2	10.6	.33	138	6.05	73	1.26	93	1.37	91
	150	24	31.7	200	10.2	10.9	.37	154	4.60	55	1.52	113	1.64	109
	150	24	31.2	220	11.6	13.9	.45	188	3.62	44	1.66	123	1.98	132
Average			31.2	190	10.3	11.6	.35		5.64		1.45		1.62	

[1] Preliminary vacuum, 30 minutes; pressure period, 5 hours; final vacuum, 10 minutes. Wood not heated before applying treatment.

TABLE 9.—*Average*[1] *penetration and absorption of coal-tar creosote at six temperatures in air-seasoned eastern hemlock ties*[2]

Ties in average (*number*)	Preservative temperature	Absolute viscosity at temperature used in treatment	Average side penetration		Average net retention per square foot of surface		Average gross absorption per square foot of surface	
	°*F.*	*Centipoises*	*Inch*	*Percent*	*Pounds*	*Percent*	*Pounds*	*Percent*
74	140	3.80	0.29	100	1.36	100	1.43	100
73	160	2.81	.39	*235	1.78	131	1.89	132
73	180	2.22	.45	*255	2.01	148	2.15	150
72	200	1.80	.51	*276	2.27	167	2.54	178
72	220	1.50	.61	210	2.58	190	3.18	222
73	240	1.22	.67	231	2.61	192	3.85	269

[1] Data from table 8 averaged for pressures of 125, 150, and 175 pounds per square inch.
[2] Wood not heated before applying treatment.
[3] Percentages based on results obtained with lowest temperatures.

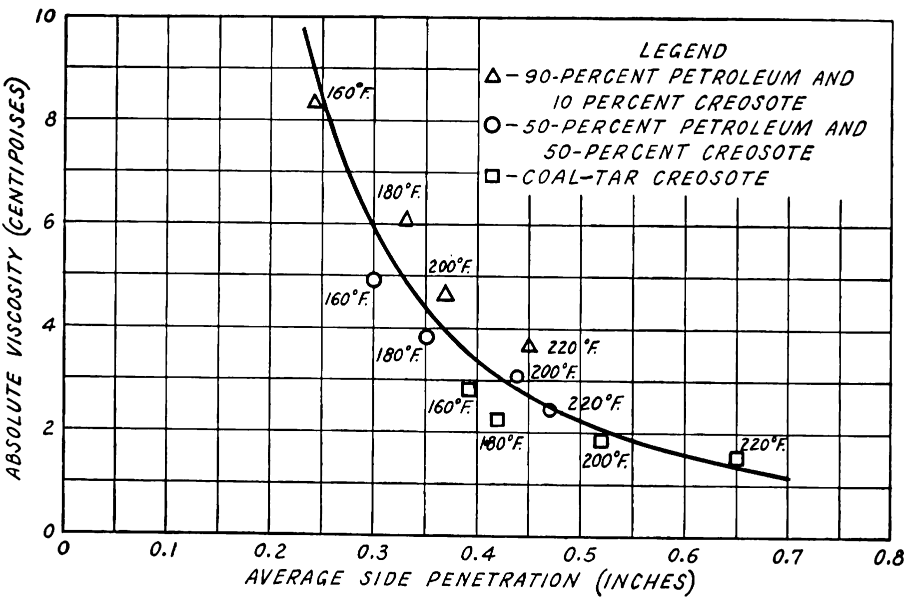

FIGURE 24.—Relation of absolute viscosity of preservative oils and penetration in air-seasoned eastern hemlock ties.

* 135 see errata
* 155 in front.
* 176

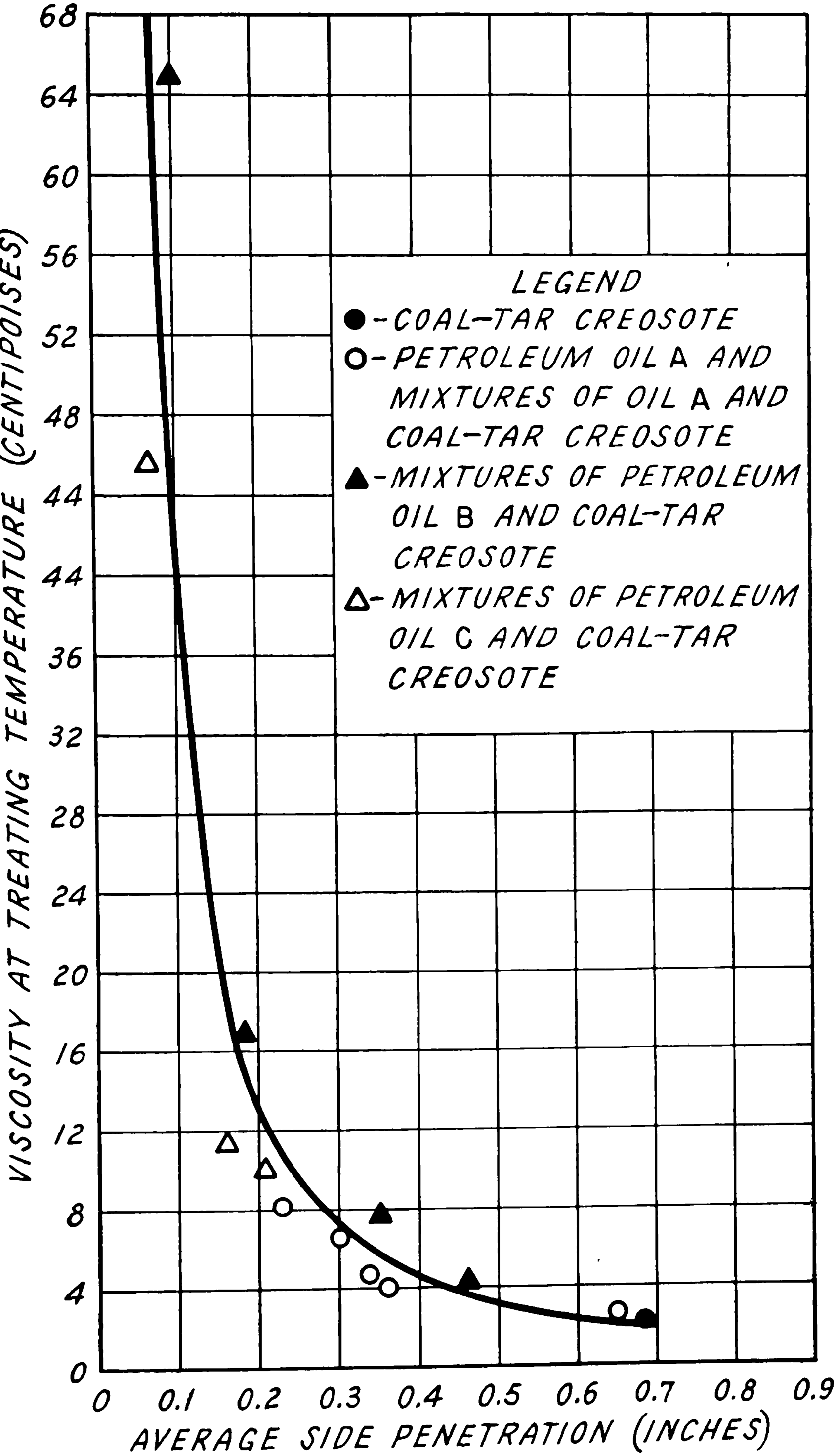

FIGURE 25.—Effect of varying viscosity (without changing temperature) upon the penetration of preservative oils in air-seasoned Douglas-fir heartwood specimens.

TABLE 10.—*Effect of changing temperature without changing viscosity in full-cell treatment*[1] *of air-seasoned eastern hemlock with creosote and creosote-petroleum mixtures*

Preservative	Specimens	Size of specimens	Viscosity	Pressure period	Treating temperature	Average net absorption per cubic foot	Average side penetration	Average longitudinal penetration
	Number	*Inches*	*Centipoises*	*Hours*	*°F.*	*Pounds*	*Inch*	*Inches*
Coal-tar creosote, grade 1	16	4 by 4 by 48	2.95	5	160	18.8	0.41	9.4
50-percent creosote and 50-percent petroleum oil	16	4 by 4 by 48	2.95	5	202	23.7	.46	10.7
10-percent creosote and 90-percent petroleum oil	16	4 by 4 by 48	2.95	5	235	20.6	.43	8.4
Coal-tar creosote, grade 1	19	3 by 4 by 47	2.81	3	160	19.4	.40	6.5
Mixtures of grade 1 coal-tar creosote and different proportions of a high-viscosity creosote	10	3 by 4 by 47	2.81	3	180	21.0	.36	6.2
	9	3 by 4 by 47	2.81	3	200	25.7	.44	7.3
	20	3 by 4 by 47	2.81	3	207	23.2	.40	7.1

[1] Preliminary vacuum, 30 minutes; treating pressure, 150 pounds; final vacuum, 10 minutes. Wood not heated before applying treatment.

ture of different preservative oils so as to obtain the same absolute viscosity while the other treating conditions were held constant (*26*, *27*), indicate that temperature alone may affect treatment, but that its effect is much more significant when the viscosity of the preservative is reduced.

Mixtures of coal tar and coal-tar creosote give results similar to those obtained with petroleum-creosote mixtures (*60*). The addition of coal tar to coal-tar creosote increases the resistance to penetration, depending both on the amount and the kind of tar added.

Water Solutions

The viscosity of water solutions, such as treating solutions of zinc chloride, is much lower than that of creosote and creosote mixtures, and it changes less with given changes in temperature. Nevertheless, experiments with zinc-chloride solution have shown that the small changes in viscosity that take place with increases in temperature have a marked effect on its penetration into wood. Although most of the water-borne preservatives in use today cannot safely be heated to the higher temperatures used with zinc chloride in these experiments, the data indicate the importance of using temperatures as high as permissible with water solutions.

Table 11 and figure 26 show the effect of viscosity and temperature of zinc-chloride solution on penetration in sawed specimens of coast-type Douglas-fir. The viscosity of the solution was varied by changing the temperature, and results were compared at four different pressures.

TABLE 11.—*Effect of viscosity and temperature of 3-percent zinc-chloride solution on penetration in sawed air-seasoned coast-type Douglas-fir heartwood* [1]

Pressure (*pounds per square inch*)	Temperature of solution	Average side penetration		Average longitudinal penetration		Specimens in average [2]
	°*F.*	*Inches*	*Percent* [3]	*Inches*	*Percent* [3]	*Number*
100	86	0.35	100	14.7	100	20
	120	.48	137	16.1	110	20
	160	.60	171	17.0	116	20
	200	.89	254	20.3	138	20
125	88	.36	100	16.4	100	13
	120	.52	144	21.3	130	13
	160	.67	186	19.8	121	13
	200	.97	269	22.5	137	13
150	79	.36	100	15.7	100	12
	120	.52	144	17.4	111	12
	160	.79	219	21.1	134	12
	200	1.30	361	26.8	171	12
175	83	.39	100	16.8	100	18
	120	.65	167	17.1	102	18
	160	.99	254	22.1	132	18
	200	1.48	379	24.1	143	18

[1] All treatments had a preliminary vacuum of 30 minutes and a pressure period of 3 hours. Wood not heated before applying treatment.

[2] Each treatment had seven to eight specimens 5 by 10 inches by 8 feet in size. Other specimens were 4 by 4 inches by 4 feet in size.

[3] Percentages based on results obtained at lowest temperature used at each pressure.

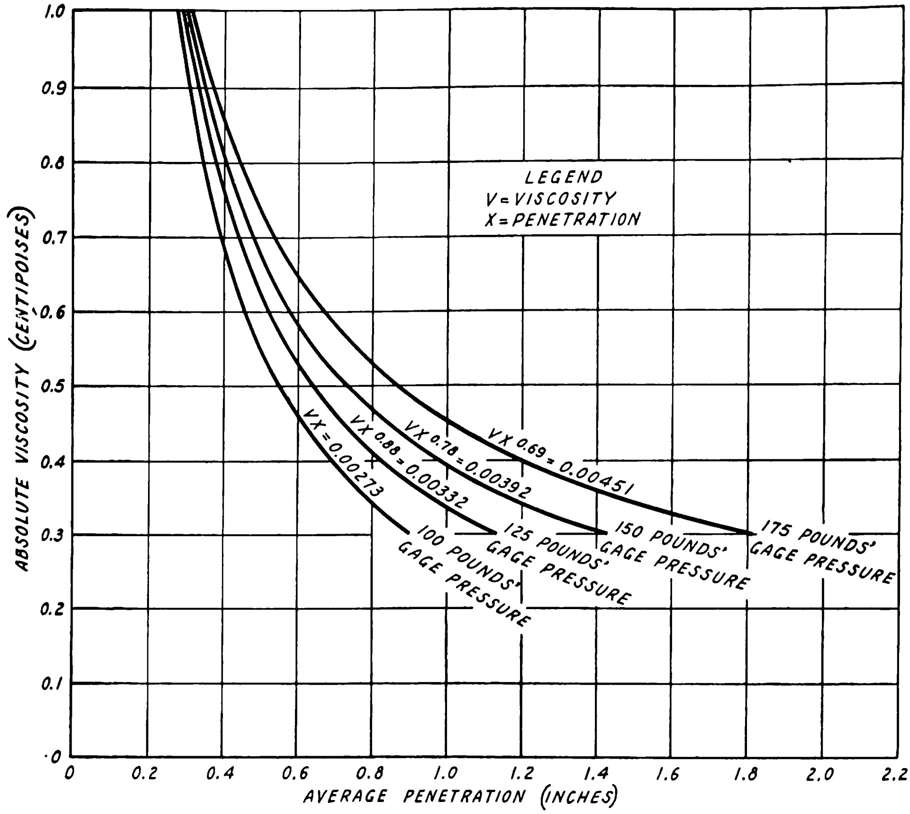

FIGURE 26.—Relation between absolute viscosity of zinc-chloride solution and penetration in air-seasoned coast-type Douglas-fir heartwood specimens.

Each charge contained seven or eight pieces 5 by 10 inches by 8 feet in size, and the remainder were 4 by 4 inches by 4 feet. At each pressure the same number and size of specimens were used, and they were matched as well as possible against each other.

Table 11 shows a consistent increase in penetration as the temperature was increased; the greatest penetration was obtained at the highest temperature. In other words, the 40-degree temperature change from 160° to 200° F. was more effective than a similar change between any two lower temperatures.

The relation between the absolute viscosity and the penetration obtained is expressed very closely by hyperbolic functions slightly different for each pressure. The empirical formulas with their respective curves are shown in figure 26. When plotted, the actual values obtained in experiments coincided closely with the mathematical curves, as may be noted by plotting the average penetration values given in table 11.

Figure 27 shows the effect of different pressures and temperatures on the gross and net absorptions of zinc-chloride solution into coast-type Douglas-fir. An increase in temperature always increased the gross absorption, but at the two higher pressures the kick-back, upon release of the pressure, was high in the charges treated at 200° F. This resulted in the net retentions in these two charges being lower than in their companion 160° charges. As would be expected, however, the greater

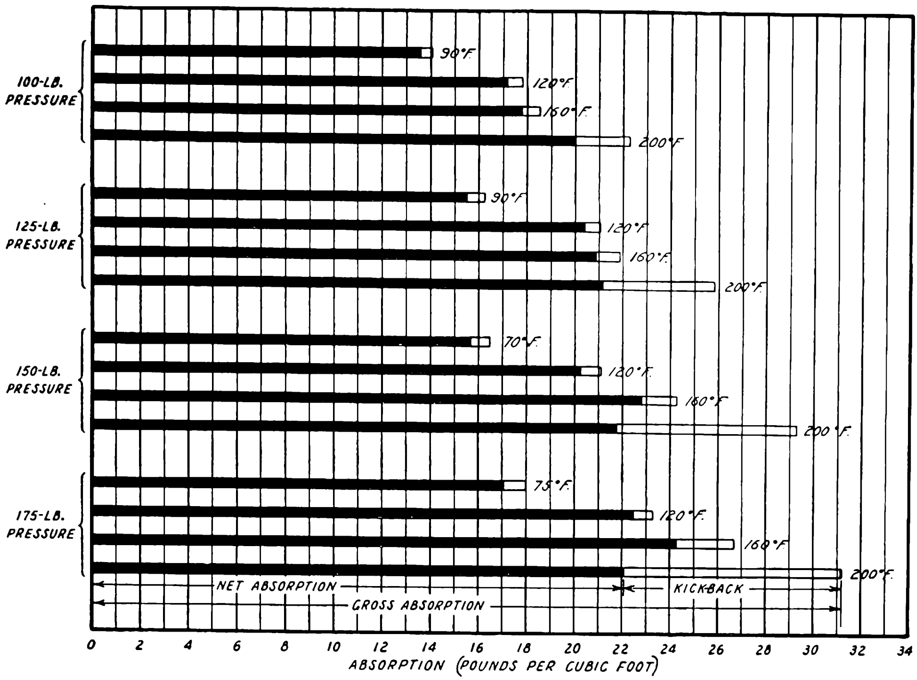

FIGURE 27.—Effect of different pressures and temperatures on gross and net absorptions of zinc-chloride solution in air-seasoned coast-type Douglas-fir heartwood. Full-cell treatment with 3-hour pressure period used in each run.

gross absorptions gave deeper penetrations despite the lower net absorptions.

Table 12 shows the results obtained in treatments of air-seasoned Rocky Mountain-type Douglas-fir ties using different solution temperatures in combination with different treating pressures. All ties were sawed transversely at the middle and lengthwise through the center for measurements of penetration. Most of the material was heartwood, although a few of the ties had a small amount of sapwood. Penetration measurements were made on heartwood only. Although this wood is the same species botanically as the coast-type Douglas-fir, it is far more difficult to penetrate than the latter and is one of the most resistant of the native conifers.

The 3-hour pressure period used for the treatments outlined in table 12 was the same as that used in the treatments of coast-type Douglas-fir (table 11). On account of the marked resistance of the Rocky Mountain-type Douglas-fir, however, this pressure period was too short to obtain appreciable penetrations except when the higher solution temperatures were used. As in the treatments made on coast-type Douglas-fir, the results show that the solution temperature and viscosity had a very pronounced effect on absorption and penetration at all pressures, and that the effectiveness of the treating pressures was considerably increased at the higher temperatures. None of the ties showed collapse or checking except those in the treatment made at 200° F. and 250 pounds' pressure.

TABLE 12.—*Results of treatments*[1] *on air-seasoned, sawed Rocky Mountain-type Douglas-fir ties with zinc-chloride solution when solution temperature and treating pressure were varied and treating period was kept constant at 3 hours*

Treating pressure (*pounds per square inch*)	Solution temperature	Average weight before treatment	Average net retention		Average kick-back	Average gross absorption		Average side penetration		Average longitudinal penetration	
			Amount	Increase over that obtained at lowest temperature		Amount	Increase over that obtained at lowest temperature	Depth	Increase over that obtained at lowest temperature	Depth	Increase over that obtained at lowest temperature
	°F.	*Pounds per cubic foot*	*Pounds per cubic foot*	*Percent*	*Pounds per cubic foot*	*Pounds per cubic foot*	*Percent*	*Inch*	*Percent*	*Inches*	*Percent*
50	80	33.6	5.2	----------	0.3	5.5	----------	0.11	----------	3.2	----------
	200	33.4	7.7	48	.5	8.2	49	.22	100	6.6	106
175	120	38.5	7.0	----------	.5	7.5	----------	.16	----------	6.7	----------
	160	33.9	10.3	47	.9	11.2	49	.30	88	9.5	42
	200	35.5	9.6	37	3.6	13.2	76	.31	94	10.0	49
200	120	32.1	8.4	----------	.7	9.1	----------	.25	----------	10.1	----------
	160	34.3	9.7	16	1.6	11.3	24	.30	20	12.5	24
	200	36.2	11.6	38	8.1	19.7	116	.33	32	14.0	39
225	95	36.9	6.4	----------	.5	6.9	----------	.15	----------	7.0	----------
	120	33.0	9.8	53	.7	10.5	52	.23	53	10.7	53
	160	35.6	10.2	59	1.6	11.8	71	.30	100	12.1	73
	200	34.3	14.9	133	11.0	25.9	275	.34	127	14.4	106
250	90	34.1	8.1	----------	.6	8.7	----------	.26	----------	10.0	----------
	120	36.8	9.4	16	.8	10.2	17	.25	----------	11.3	13
	160	36.9	10.5	30	1.5	12.0	38	.33	27	9.7	----------
	200	35.1	12.0	48	15.0	27.0	210	.60	131	15.6	56

[1] Preliminary vacuum 30 minutes at about 28 inches of mercury; no final vacuum. Wood not heated before pressure was applied. Ten ties in each treatment.

Similar data for yellow birch and eastern hemlock are shown in table 13. The effect of temperature and viscosity on penetration is conspicuous in the results with each species, although not so consistent in every case as the results in table 11. A small amount of sapwood was present on some of the yellow birch ties, and in making measurements of penetration an effort was made to eliminate all penetrations that might be in the sapwood.

From table 13 it may be noted that the absorptions in eastern hemlock ties treated with zinc-chloride solution were somewhat higher in proportion to the penetration than in those treated with preservative oils (table 8). This is probably on account of the deeper end penetration that occurs when water solutions are used, and also on account of water solution being absorbed by the cell walls in the treated portion.

Relation of Wood Temperature to Treatment

The data in tables 8 to 13, inclusive, show that the temperature of the preservative (and wood) has a most important effect on both the absorption and the penetration, and this is especially true in the treatment of resistant material. Except when a charge of timber is conditioned by the steaming or Boulton process, heating of the wood will depend on the preservative temperature and the time the wood is in contact with the preservative.

The question that naturally arises is: To what temperature should the wood be heated to obtain the most satisfactory conditions for pressure treatment? There is no direct answer. One consideration is the relative resistance of the wood to treatment, since the wood temperature is of less importance in the treatment of such fairly permeable material as the sapwood of various species. Since incipient decay may be present in some timbers, such as air-seasoned ties, without being visible, it may be desired to heat the center of all pieces to a temperature that will be sufficient to sterilize the wood. The time that a given temperature should be maintained to sterilize wood is given on page 67. It may be noted that the lowest temperature listed is 150° F., which should be held for about 75 minutes.

Small-dimension timbers that heat quickly and cool quickly should be heated to a temperature somewhat higher than 150° F. to allow for the more rapid cooling that takes place. Round timbers about 6 inches or less in diameter and sawed material about 6 inches or less in thickness could be placed in the latter category.

In view of the heating temperatures and length of conditioning periods commonly employed under commercial treating conditions, all material that is given a conditioning treatment would probably be well sterilized and only air-seasoned material that depends on the length of the pressure period for heating would need to be considered. For example, the time-temperature chart, figure 22, shows that a 7- by 9-inch air-seasoned tie should be in the preservative at 200° F. for about 4½ to 5 hours to sterilize the wood at the center. A somewhat longer heating period should be used when the wood is very cold before treatment, as in the winter months.

Preservative temperatures of 190° to 200° F. can be used satisfactorily, with preservatives that are not damaged thereby, even for woods that are susceptible to injury during treatment. Temperatures somewhat

TABLE 13.—*Effect of varying the temperature*[1] *of a 3-percent zinc-chloride solution on the absorption and penetration in air-seasoned yellow birch and eastern hemlock ties*

Species	Ties in treatment	Average weight before treatment	Pressure period	Treating temperature	Average net retention		Average gross absorption		Average side penetration in heartwood[2]		Absolute viscosity[2]	
	Number	*Pounds per cubic foot*	*Hours*	°*F.*	*Pounds per cubic foot*	*Pounds per square foot of surface*	*Pounds per cubic foot*	*Pounds per square foot of surface*	*Inch*	*Percent*	*Centipoises*	*Percent*
Yellow birch	25	46.6	4	140	22.1	3.0	22.6	3.1	0.32	100	0.54	100
	25	46.0	4	160	21.3	2.9	22.5	3.1	.38	119	.46	85
	25	46.3	4	180	22.6	3.1	24.4	3.3	.55	172	.39	72
	25	45.9	4	200	23.4	3.2	25.7	3.5	.75	234	.34	63
Eastern hemlock	25	30.3	4	160	19.6	2.8	20.6	3.0	.53	100	.46	100
	25	28.5	4	180	20.6	3.0	23.3	3.4	.69	130	.39	85
	24	28.6	4	200	23.0	3.3	28.6	4.1	.88	166	.34	74
	12	30.3	5	160	19.0	2.7	20.3	2.9	.71	100	.46	100
	25	30.6	5	200	18.5	2.7	25.8	37.7*	.84	118	.34	74

[1] Preliminary vacuum, 30 minutes at about 28 inches of mercury; treating pressure, 150 pounds; no final vacuum.

[2] Percentages for penetrations and viscosity based on data for lowest temperature used for each species.

* 3.7 see ERRATA, in front.

higher than 200° can be used to advantage for species like southern yellow pine, provided such temperatures are not applied too long and that the pressure is kept low enough to avoid checking or collapse.

Where there is a tendency for severe checking or collapse to occur with a given temperature-pressure combination, in wood that is resistant to penetration, the preservative temperature should be maintained at 190° to 200° F. and the pressure should be lowered until satisfactory results are obtained (*29*, *33*). With wood that is not resistant to treatment, high preservative temperatures are not so necessary. High temperatures may also prove undesirable when injecting water solutions of preservatives into resinous wood, because such temperatures may bring resin to the surface where it will interfere with painting or finishing if the wood is not resurfaced after treatment. It is a question in such cases whether it is better to accept the poorer penetrations and cleaner surfaces resulting from cold solutions or the resin exudation and the much better penetrations resulting from hot solutions. This difficulty does not arise with woods that do not exude resin. Preservative oils injected at the higher temperatures leave the wood cleaner after treatment than when lower treating temperatures are used.

High temperatures must not be used with some proprietary preservatives that are injected in water solution, for the heat will precipitate the preservative from its solution before it enters the wood. It is best to follow the recommendations of the manufacturers as to temperature conditions permissible with such preservatives.

RELATIVE PENETRATION OF PRESERVATIVE OILS AND WATER SOLUTIONS

Table 14 gives the relative penetrations and absorptions of zinc-chloride solution and coal-tar creosote obtained in two of the very refractory conifers. Similar results obtained in experiments with various other species show in a marked manner that resistant woods are considerably more difficult to penetrate with creosote and other oils than with water solutions A still greater difference in the relative penetration of water solutions and preservative oils would have been shown with longer pressure periods than those used with the refractory species. Water solutions are absorbed within the cell walls, while petroleum oils are not absorbed. Creosote oils are absorbed only slightly in the cell walls under normal treating conditions. This may account for the superiority of penetration by water solutions as compared with oils of the same viscosity.

THE USE OF VACUUM

In both the steaming-and-vacuum and the Boulton or boiling-under-vacuum processes the function of the vacuum is to help remove moisture from green wood (pp. 40, 41, 45). When seasoned timber is to be treated by a full-cell process, a preliminary vacuum is used to remove as much air as practicable from the wood before admitting the preservative. With full-cell oil treatments a final vacuum is usually employed to recover some of the surplus oil from and near the surface of the wood in order to reduce the amount of dripping after the charge is removed from the treating cylinder. A final vacuum is also used with water solutions for the same

TABLE 14.—*Comparison of absorptions and penetrations with coal-tar creosote and zinc-chloride solutions*

Species	Specimens	Preservative	Average weight before treatment	Treating pressure	Treating period[1]	Treating temperature	Average absorption		Average side penetration	
							Net	Gross	Heartwood	Sapwood
	Number		*Pounds per cubic foot*	*Pounds per square inch*	*Hours*	*°F.*	*Pounds per cubic foot*	*Pounds per cubic foot*	*Inch*	*Inch*
Douglas-fir: Rocky Mountain type.[2]	8	Coal-tar creosote	35.7	150	4	200	1.7	3.8	0.09	----
Do	8	Zinc-chloride solution	35.6	150	4	180	15.8	20.5	.42	----
Corkbark fir[3]	20	Coal-tar creosote	25.0	100	5	180	9.1	10.4	.12	0.81
Do	20	Zinc-chloride solution	24.8	100	5	180	15.4	19.8	.28	.92

[1] Preliminary vacuum of about 28 inches applied for 30 minutes before pressure period. No final vacuum after pressure period. The wood was not heated before pressure was applied.

[2] Air-seasoned specimens 4 by 4 by 48 inches in size.

[3] Sawed and hewed air-seasoned ties.

purpose; but when the solutions are used at reasonably high treating temperatures the final vacuum is of little value, for the surface of the wood dries quickly when the hot wood is withdrawn from the treating cylinder, and, as a result, there is very little drip. With cold or cool solutions the drip after treatment is greater and the final vacuum is more useful. In the empty-cell treating processes a final vacuum is employed, after the release of pressure and withdrawal of preservative, for the purpose of hastening the expulsion of the surplus preservative by the expansion of the air imprisoned and compressed in the wood.

In employing a preliminary vacuum in full-cell treatments to remove air from the wood, care should be exercised not to readmit the air by releasing the vacuum before the cylinder is full of preservative. Since the vacuum is not perfect, there is always some air left in the cylinder. The resistance of the wood to the outward movement of the confined air also makes it impossible to remove more than a limited amount, which will depend on the species, the size of timber, whether sapwood or heartwood, the moisture content, and other factors. As hot preservative is admitted to the bottom of the treating cylinder, it warms the wood and drives out more air, and this air, with that left in the space surrounding the wood, collects above the rising preservative. As the cylinder becomes nearly full of preservative, the amount of air collected may be sufficient to release the vacuum entirely in the space above the preservative and thus a moderate pressure may be produced. The amount of air that thus accumulates will, of course, be least with a high original vacuum.

This accumulation of air can be prevented by keeping the vacuum pump running during the filling process. Suction of preservative into the vacuum system during this period can be avoided by drawing the vacuum through a cylinder or drum of suitable size between the treating cylinder and the vacuum pump. Whether there is any advantage in continuing to operate the vacuum pump during the filling process has not been established by any known experimental evidence. If a high vacuum is first drawn, it would seem that so little air could collect above the preservative that running the pump during the filling process would have a negligible effect, but when a low initial vacuum is applied, there might be a noticeable effect on the air pressure in the upper timbers in the charge. The temperature of the preservative when admitted to the cylinder will also affect the results. At higher temperatures more air will come out of the wood during the filling process and more vapors will be given off by the preservative. Certainly, however, if the surging of preservative into the vacuum system is prevented, there can be no objection to keeping the pump running during the filling period.

Some specifications require that when air-seasoned wood is given a full-cell treatment the preliminary vacuum shall be held for a definite period after the maximum is reached. This seems to be an unnecessary requirement, for after the maximum vacuum is reached it is probable that little if any additional air is removed. This is indicated by the fact that when there are no air leaks in the treating equipment the vacuum can usually be held without appreciable drop when the vacuum pump is stopped. In general, it should be sufficient to specify that the preliminary vacuum be applied until the maximum is obtained.

When the vacuum is used after steaming or when the material is conditioned by the boiling-under-vacuum process (Boulton method), the air is removed more completely than when a vacuum is applied to cold, air-seasoned material. This is because the air in the cylinder can be more completely removed by the hot steam or vapors and because the expansion of the air in the wood cells by the heat makes it possible to evacuate the cells more completely than when the timber is cold. In addition, air does not have an opportunity to fill the space originally occupied by the water that is removed under the vacuum. In air-seasoned material the space originally filled with water, except as reduced by shrinkage, is full of air at the time of treatment.

Treating specifications sometimes specify the minimum vacuum requirements for sea level and allow a correction to be made by plants at higher elevations. This is commonly 22 inches of mercury, based on sea-level conditions. Figure 28 shows the vacuum correction in inches of mercury for different altitudes. The correction shown for any altitude must be subtracted from the minimum vacuum specified for sea level in order to give the corresponding vacuum for that altitude. Figure 28, which is based on the standard barometric pressures for the different

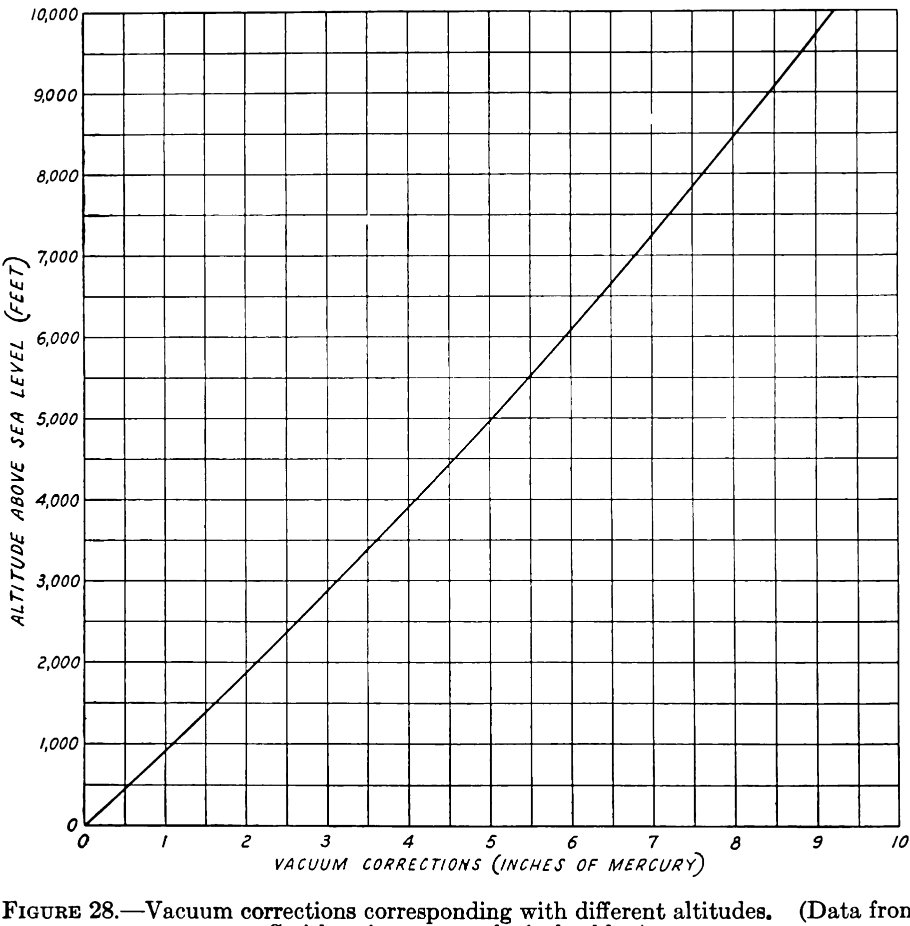

FIGURE 28.—Vacuum corrections corresponding with different altitudes. (Data from Smithsonian meteorological tables.)

altitudes, does not take into account the daily variations in barometric pressure due to weather changes. Such a degree of refinement, however, is unnecessary in injecting preservatives into wood.

In using the steaming or the boiling-under-vacuum process at any plant above sea level, it may be desirable to know the boiling points of water corresponding to different vacuums at that location. Figure 29 shows the boiling points of water under different vacuums at sea level and the corresponding saturated-vapor or absolute pressure. The vacuum required at a given altitude for a specified boiling point is equal to the vacuum required for that boiling point at sea level minus the vacuum correction for the altitude under consideration.

Example of the Use of Figures 28 and 29.—Green timber is conditioned by the Boulton process at a plant where the altitude is 5,000 feet. The temperature of the creosote is 185° F. What minimum vacuum will be required to reach the boiling point of water?

Figure 29 shows that at sea level a vacuum of about 13 inches is required to boil water at 185° F. The vacuum correction for an altitude of 5,000 feet (fig. 28) is approximately 5 inches of mercury. Therefore, the vacuum required at a 5,000-foot altitude to boil water at 185° is 13 minus 5, or 8 inches of mercury. The right-hand scale of figure 29 shows that the saturated-vapor pressure is about 8.4 pounds per square inch when the boiling point of water is 185°.

The temperature at which water boils under atmospheric pressure at a 5,000-foot altitude is the same as that at sea level when the vacuum is approximately 5 inches. Figure 29 shows this temperature to be about 203° F. The right-hand scale of this figure shows that the corresponding absolute or saturated-vapor pressure is about 12.3 pounds per square inch.

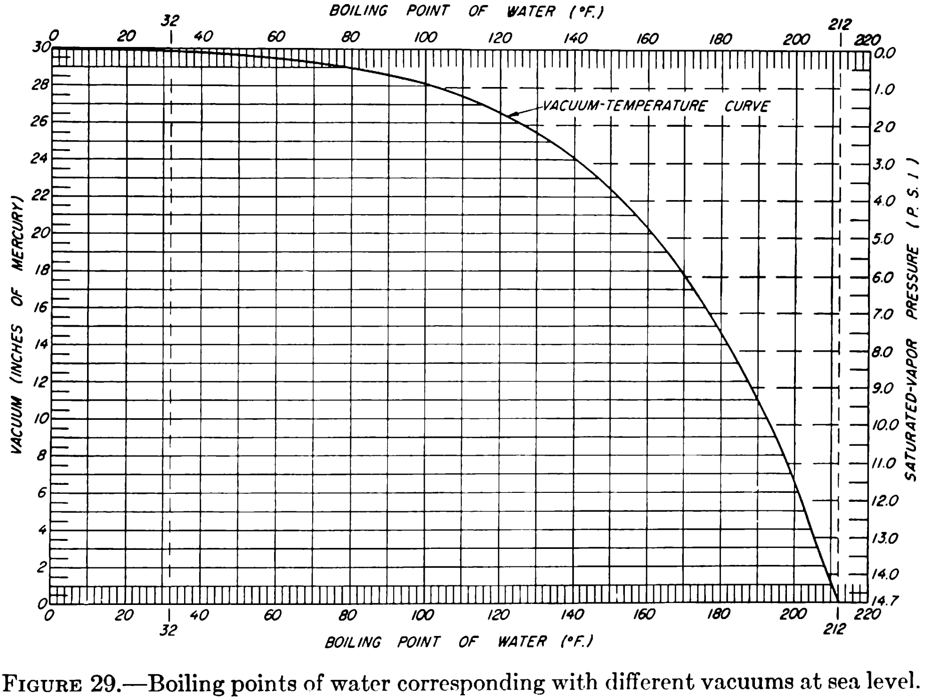

FIGURE 29.—Boiling points of water corresponding with different vacuums at sea level.

A curve, similar to figure 29 but corrected for the altitude of the individual plant, would answer directly the question answered in the computation shown.

In applying the Boulton process, preservative temperatures higher than the boiling temperature of water corresponding with the maximum vacuum obtained should be used in order to overcome the resistance of the wood to moisture movement, to heat the wood more rapidly, and to compensate for the reduction in vacuum caused by the hydrostatic pressure of the preservative above the timbers.

Little experimental work has been done to determine the effect of the preliminary vacuum on the net retention or the effect of the final vacuum on the recovery of preservative after the cylinder has been emptied of preservative.

Experiments have shown, however, that when air-seasoned timbers are to be treated by the full-cell process the vacuum is much more effective in removing air from the wood if the timbers are first heated in steam or in the hot preservative. For example, if air-seasoned Douglas-fir piling is to be treated to refusal for marine use, heavier retentions will be obtained if the charge is boiled under vacuum a sufficient length of time to heat the wood and expand the air so that a greater amount of the air can be withdrawn by the vacuum. When the vacuum is applied to a charge of cold timber, it will generally remove little air from the wood cells, particularly if the material is fairly resistant.

In commercial practice preliminary vacuums are commonly applied for 15 to 30 minutes when air-seasoned material is given a full-cell treatment. The longer period is more commonly used because specifications frequently call for it. Final vacuums used with coast-type Douglas-fir vary from about ½ to 3 hours, but in most cases are about 1 to 2 hours. Final vacuums used on air-seasoned and steamed material of other species vary from about ¼ to 2 hours, with an average of about 1 hour. The maximum vacuums usually obtained are about 22 to 26 inches of mercury, based on sea level.

PRELIMINARY AIR PRESSURE

As previously stated, the purpose in using a preliminary air pressure is to take advantage of the compressed air to force out a part of the gross absorption when the preservative pressure is released. Within certain limits this favors improved penetrations, as compared with full-cell treatment, because of the greater amount of preservative that can be injected without leaving an undesirably high retention of preservative in the timber. The use of preliminary air pressure is more effective in the treatment of timbers that have a considerable amount of sapwood that is not distinctly resistant to penetration, or in the treatment of heartwood timbers that are reasonably permeable. When there is the possibility of undesirably heavy end penetration in heartwood material, the use of preliminary air pressure may be desirable. Preliminary air pressure probably also causes greater reduction of gross absorption in the easily treated pieces than in the more resistant pieces and thus helps to reduce the differences in net retention between the different pieces. Preliminary air pressure, however, is much less effective in the pressure treatment of heartwood or sapwood that is difficult to penetrate.

For this reason it cannot be assumed that the same retention will give equally good penetrations in the sapwood of round timbers of one species as in those of another species, even when the more resistant timbers have less sapwood based on the total volume. In fact, considerably heavier net retentions may be required to obtain satisfactory penetrations in material having a fairly resistant sapwood, although the proportion of sapwood is much less than in more easily treated poles or piling of another species. Increasing the preliminary air pressure will not remedy this difficulty, since increasing the air pressure in the wood cells increases the resistance to penetration and this added resistance may result in erratic penetration in refractory material. The optimum conditions for penetration in very resistant material would naturally be obtained by removing as much air as possible from the wood before applying the preservative pressure, as is done when the so-called full-cell treatment is employed.

If the retention must be limited, however, a full-cell treatment is impractical when the wood is not particularly resistant and a large proportion of the total volume can be penetrated.

A further discussion of the effect of preliminary air pressure is given later under the heading "Kick-back," p. 90.

The Lowry and Rueping processes are widely used in the treatment of railway ties and poles and, to a somewhat less extent, in sawed timbers and land piling. They are not used for treating marine piling or for other timbers where heavy net retentions are required. When the Boulton process is employed to condition the timber before treatment by an empty-cell process, it is necessary to drain the cylinder after the vacuum period is completed. Air is then admitted at atmospheric pressure or at a higher pressure, depending upon whether the Lowry or Rueping method is used.

Most plants using the Rueping process for Douglas-fir apply preliminary air pressures of 20 to 60 pounds, which are held for ¼ to 1 hour. Plants using the Rueping process for Rocky Mountain species generally apply preliminary air pressures of 50 to 80 pounds, which are held for about ¼ to ½ hour. Most of the plants employing this process for southern yellow pine poles and piling and for hardwood ties, such as oak, gum, maple, birch, and beech, use air pressure of 50 to 75 pounds. Preliminary air pressures used in the Rueping process for southern yellow pine ties vary from about 65 to 80 pounds, although a few plants use lower pressures of 30 to 60 pounds. Most of the plants treating southern yellow pine and hardwood timbers run the preservative into the cylinder as soon as the required air pressure is reached. The wide variations in the use of preliminary air pressure result in part from differences in the wood being treated and in part from lack of evidence as to what are the most satisfactory air pressures and air-pressure periods for different requirements.

At the present time comparatively little is known about the rate at which air diffuses in the wood of different species or what the effect of moisture or intensity of pressure is on the transmission of air in the timber. Some preliminary laboratory experiments on the rate of air transmission across the grain were made on heartwood specimens of green Douglas-fir. With an air pressure of 100 pounds in the treating cylinder, a pressure period of more than 5 hours was required to obtain between 4 and 5 pounds' gage pressure in a hole three-eighths of an inch in diameter, bored longitudinally, at a distance of about three-quarters of an inch from the surface. Under the same air-pressure conditions a pressure of less than 2½ pounds gage was obtained in 5 hours at a distance of about 1¾ inches from the surface. Changes in air pressure occur more slowly and to a lesser depth in green than in seasoned timbers, provided checks do not affect the results.

Very little experimental work has been done to study the relation of preliminary air pressure to preservative pressure. It has been a commonly accepted view that in the empty-cell treatment the preservative pressure should be increased somewhat in proportion to the preliminary air pressure used. As an illustration, with timber that would be treated at 150 pounds' pressure by the full-cell process, the plant operator would probably apply 200 pounds' preservative pressure after using a preliminary air pressure of 50 pounds, or 175 pounds' preservative pressure after a 25-pound preliminary air pressure.

The difference between the preservative pressure and the preliminary air pressure, however, does not necessarily represent the pressure effective in forcing the preservative into the wood. Except for material that is very easily penetrated, such as the sapwood of various species or timbers of small dimension, the air pressure is not uniform throughout the timber. In resistant woods subjected to preliminary air pressures, the intensity of air pressure in the wood may decrease rapidly and the air may penetrate only a short distance from the surface. Experiments on timbers of various refractory species showed that although a given preservative pressure may cause no checking or collapse when used in full-cell treatments or when no preliminary air or vacuum is employed, severe checking and collapse may occur if a preliminary air pressure is used and the preservative pressure is increased by an amount equal to the preliminary air pressure. This general practice, therefore, is not safe to follow; rather, the amount of increase in preservative pressure needed should be worked out by experience and observation at each plant.

PRESERVATIVE PRESSURE

At some plants the maximum preservative pressure is applied as soon as it can be reached, whereas at others it is applied gradually, reaching the maximum in from ½ to 2 hours, depending on the kind of material and species treated. When pressures of 200 pounds or greater are used, they are generally approached gradually during the entire pressure period so that the average pressure is considerably less than the maximum. No study has been made, so far as is known, to determine the relative merits of applying pressure gradually in comparison with a constant pressure applied over the entire pressure period. Possibly plants using pressures gradually raised to a relatively high maximum could obtain similar results if the average pressure, or even one somewhat lower than the average, were maintained during the entire pressure period.

Resistance of the wood to the transmission of liquids and gases necessarily makes the effectiveness of the preservative pressure decrease as the depth of penetration increases. This effect may be noted in sawed timbers or pole ties where both sapwood and heartwood faces are exposed. Penetration is, of course, deeper in the exposed heartwood faces than in the heartwood covered by the sapwood, since the resistance of the sapwood reduces the effect of pressure on the heartwood beneath it.

In the discussion relating to the effect of preservative temperature attention has been directed to the fact that the treating pressure must be carefully controlled when the timber shows evidence of checking or collapse under the treating conditions employed. Higher treating pressures can be used on seasoned wood or cold wood than on wood that is green or that has been heated for a long time.

PRESSURE PERIOD

The length of pressure period required to obtain a given absorption depends largely upon the ease with which the timber can be impregnated and upon the treating conditions employed. In the treatment of resistant material the pressure period should be long enough to obtain the maximum benefit of the pressure employed and to allow sufficient heating of the wood to produce favorable conditions for treatment. Attempting to shorten the treating period by the use of high pressures frequently results in erratic penetrations or unsatisfactory absorptions. Treatment is sometimes discontinued when the rate of absorption becomes slow, since it is assumed nothing much can be gained by using a longer pressure period. In some cases the rate of absorption is slow because the wood has not had time to become heated enough for the best penetration to be obtained.

Experiments have shown that better penetrations are usually obtained with moderate treating pressures and moderately long pressure periods than by very high pressures for short periods. On the other hand, little is to be gained by holding the pressure after absorption has practically ceased and, from the standpoint of treating costs, a reasonable balance must be established between treating time and treating pressure.

A few plants treating resistant woods preheat the charge in the hot preservative for a time before applying pressure. Whether this is as effective as applying pressure from the start, and thereby obtaining a longer pressure period without increasing the total time of treatment, is a question on which there is some disagreement. When pressure is applied, the preservative helps carry heat into the wood as it penetrates. It therefore appears that an advantage would be gained by applying pressure as soon as possible after the cylinder is filled with the preservative, in order to help increase the rate of heating and also to have the benefit of a longer pressure period. So far as is known, however, no definite data have been obtained on this subject.

The pressure periods required for Douglas-fir timbers that have been conditioned by the Boulton process are, in general, considerably shorter than are required to obtain a similar treatment in air-seasoned wood. The Boulton-processed wood has a higher preliminary temperature at the beginning of the pressure period than seasoned wood that has not been heated, and this higher wood temperature is apparently of considerable assistance in reducing the length of the pressure period.

It has been observed in experiments on air-seasoned wood in which different pressure periods are employed that the tendency toward checking and collapse increases as the length of the pressure period increases, other treating conditions being constant. In such cases the difficulty has been overcome by lowering the treating pressure and, when necessary, by using a somewhat longer pressure period to compensate for the lower pressure.

Results of treatments made on Rocky Mountain-type Douglas-fir ties when pressure and treating period varied and solution temperature was constant (table 15) show that the penetrations and absorptions were very much better in 6- and 8-hour treatments than those obtained with pressure periods of 2 and 4 hours. In general, an increase of 2 hours in the pressure period gave better results than an increase of 50 pounds in pressure with the treating period constant. A solution temperature of 175° F. was used in these tests so that a wider range of pressure could be used in the study of the relative effect of pressure and pressure period. If a higher solution temperature had been used, it would have been necessary to use lower pressures to avoid collapse and checking. All ties excepting those in the 4- and 6-hour treatments at 250 pounds' pressure were apparently uninjured by the treating conditions used. About half of those in the 4-hour treatment at 250 pounds pressure showed considerable collapse and checking, and all of those in the 6-hour treatment at this pressure were badly injured by collapse and internal checking. These results show that both the pressure and the length of the pressure period affected the condition of the timber.

KICK-BACK

When the pressure is released at the end of the pressure period, some of the preservative flows out of the wood and the treating cylinder and returns to the working tank. The quantity of preservative that flows back into the tank is called the "kick-back." The total quantity of preservative injected into the wood during the treating operation is called the "gross absorption." In other words, the gross absorption includes the amount of preservative absorbed by the wood while the cylinder is being filled [12] as well as that injected during the pressure period. The difference between the gross absorption and the kick-back, plus the preservative recovered during the final vacuum, gives the net absorption or net retention.

The most important factor causing kick-back under moderate pressure conditions is the expansion of air compressed in the wood during the pressure period. The outstanding characteristics of the empty-cell processes, as distinguished from the full-cell, is that a larger part of the gross absorption is expelled by the imprisoned air after the pressure period. This expulsion usually permits reasonably large gross absorptions and deep penetrations with comparatively small net retentions. The net retention, however, may vary widely for any particular gross absorption, depending within certain limits on the preliminary air pressure, the resistance of the species, whether sapwood or heartwood, the moisture content, and other variables.

As the preservative is forced into the wood during the empty-cell treatment, some of the confined air becomes mixed with the preservative; although, when penetration is not complete, some of the air must obviously occupy space in the untreated portion. It is probable that the air in the wood cells that are partly filled with preservative is largely responsible for the kick-back. A proof that small air bubbles must be trapped in the preservative is shown in the empty-cell treatment of sapwood material and of other easily treated material that takes complete

[12] The amount absorbed while the cylinder is being filled is called the initial absorption, which is discussed on page 110.

TABLE 15.—*Results of treatments*[1] *on air-seasoned, sawed Rocky Mountain-type Douglas-fir ties with 3-percent zinc-chloride solution when treating period and treating pressure were varied and temperature was kept constant at 175° F.*

Treatment No.	Treating pressure	Treating period	Average weight before treatment	Average net retention		Average kick-back	Average gross absorption		Average side penetration		Average longitudinal penetration	
				Amount	Increase over that in 2-hour treatment		Amount	Increase over that in 2-hour treatment	Depth	Increase over that in 2-hour treatment	Depth	Increase over that in 2-hour treatment
	Pounds per square inch	*Hours*	*Pounds per cubic foot*	*Pounds per cubic foot*	*Percent*	*Pounds per cubic foot*	*Pounds per cubic foot*	*Percent*	*Inch*	*Percent*	*Inches*	*Percent*
1	100	2	33.5	5.5	----	0.4	5.9	----	0.20	----	6.8	----
2	100	4	36.8	7.8	42	.3	8.1	37	.20	0	8.8	29
3	100	6	34.4	10.2	85	.5	10.7	81	.29	45	13.0	91
4	100	8	33.1	11.5	109	.5	12.0	103	.32	60	15.9	134
5	150	2	33.2	8.4	----	.6	9.0	----	.25	----	10.5	----
6	150	4	36.0	9.6	14	.8	10.4	16	.25	0	9.5	----
7	150	6	35.0	14.2	69	1.3	15.5	72	.27	8	16.1	53
8	150	8	33.5	15.0	79	2.1	17.1	90	.38	52	18.2	73
9	200	2	33.8	9.1	----	2.4	11.5	----	.25	----	9.8	----
10	200	4	32.8	11.5	26	4.2	15.7	37	.31	24	16.9	72
11	200	6	36.7	13.5	48	3.9	17.4	51	.39	56	17.0	73
12	250	2	33.7	8.9	----	5.2	14.1	----	.20	----	13.4	----
13	250	4	32.9	13.3	49	10.2	23.5	67	.34	70	19.4	45
14	250	6	33.1	16.0	80	11.2	27.2	93	.41	105	30.0	124

[1] Preliminary vacuum, 30 minutes at about 28 inches of mercury; no final vacuum. The ties were not heated before pressure was applied. Ten ties in each treatment.

penetration. If the air were merely compressed and forced farther into the timber, it would not be practical to penetrate the wood completely in the region occupied by the entrapped air.

In addition to the effect of air pressure on kick-back, if the timbers have a high moisture content at the time of treatment, vaporization of the water in the wood when the final vacuum is applied may also force out more or less preservative. This may reduce the net retention, especially in round timbers, even when the full-cell treatment is employed. In some cases this may be particularly objectionable when high retentions are needed, as in the treatment of marine timbers. Much of this difficulty can be avoided by more thorough seasoning of the material before treatment.

Another factor that influences the kick-back, depending on the material and treating conditions employed, is the compression of the wood during the pressure period and its expansion upon release of pressure. This effect is greatest with woods that are resistant to treatment, especially if they are of low compressive strength and if the timber has been conditioned by the steaming or Boulton process. When these processes are used with green timber, the wood has a high moisture content and is well heated, so that it is more pliable when pressure is applied than colder or drier wood. The tendency of the wood to compress is naturally greater with high treating pressures and long treating periods. In experiments conducted at the Forest Products Laboratory on the ties of low density and high resistance to penetration, the ties practically recovered their normal volume when pressure was released immediately after treatment. Similar ties when held under a pressure that gradually dropped from 150 to 125 pounds while the preservative cooled, showed a permanent reduction of 6 to 7 percent of the original volume. A combination of high temperature and high pressure is likely to cause considerable permanent reduction in volume, accompanied by checking and collapse.

The kick-back resulting from compression of the wood has often been overlooked in treating practice. This compression of the wood will also indicate a higher gross absorption than is actually obtained. A charge of timber on which a high treating pressure is used may appear to have a much higher gross absorption than another charge treated under a lower pressure, yet the true gross absorption may be greater in the case where the lower pressure is used. When this is not recognized, the treating-plant operator may believe that he is obtaining a high kick-back and a correspondingly high gross absorption while the actual kick-back of preservative from the wood cells may be much less than that indicated.

Unfortunately, there is no way in which the kick-back caused by compression of the wood can be determined in the normal treating operation. Kick-back is less in timbers having a high moisture content, as might be expected, since the amount of air in the wood decreases as the amount of water increases. The relation of air volume and moisture content is shown in figure 11. An approximate determination of the maximum amount of preservative that can be absorbed in the available air space of the treated wood (pp. 29 and 104) may help in finding whether kick-back is partly caused by compression of the wood.

Increasing the preservative temperature, the treating pressure, or the length of the pressure period also increases the amount of kick-back.

The effect of temperature and pressure on kick-back is shown in figure 27 and also by the data given in tables 8, 9, 12, and 13.

A comparison of the results obtained at each pressure given in table 15 shows that the general effect of increasing the pressure period was to increase the kick-back. This is indicated by comparing the averages of all the 2-, 4-, and 6-hour periods, respectively.

Naturally there is a large variation in the relative penetrability of different woods, and kick-back caused by expansion of compressed air in the wood will be less from resistant timbers than from sapwood material or from species that are more pervious to the passage of air and liquids. Thus, while in empty-cell treatments of air-seasoned southern yellow pine timbers that are largely sapwood the kick-back often amounts to a large part of the gross absorption, it is usually much less in material that is largely heartwood. The kick-back from resistant sapwood will also be considerably less than that from easily penetrated sapwood.

Even when the full-cell process is employed, there is always a certain amount of kick-back because more or less air is left in the wood after the preliminary vacuum is applied. This kick-back will be greater from air-seasoned timbers on which the preliminary vacuum is applied when the charge is cold.

In experimental full-cell treatments on air-seasoned ties of different species containing a considerable amount of sapwood, the kick-back varied from about 4 to 10 percent, whereas for ties of resistant woods the kick-back varied from about 6 to 25 percent of the apparent gross absorption. This higher kick-back from the resistant woods was partly caused by compression of the timber under the treating conditions employed. Preservative oils were used in these treatments. The kick-back was somewhat higher for similar treating conditions when zinc-chloride solution was used, probably largely because of the greater compression of the wood under pressure.

FINAL HEATING AND VACUUM, USING STEAM OR EXPANSION BATH

Use of Final Steaming and Vacuum

A preliminary steaming-and-vacuum treatment is used to aid in removing moisture from the wood and to help heat the material to a favorable treating temperature. In addition a short final steaming-and-vacuum treatment is often permitted for the purpose of cleaning the wood surfaces of surplus preservative and to reduce the tendency of the timbers to exude the preservative after treatment. A clean surface is of particular interest in treating poles, since an oily surface is objectionable to the linemen, and often to the public when the poles are used on city streets.

In treating some timbers—steam-conditioned poles, for example—a final steaming has sometimes been applied for 3 to 4 hours, on the assumption that the steam pressure will help force the absorbed preservative farther into the wood. It is questionable, however, whether this final steaming accomplishes much from the standpoint of improving the penetration, since the moisture in the wood develops a back pressure that reduces the effective steam pressure, which is relatively low in any case.

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Use of Expansion Bath and Vacuum

The preservative pressure is released at the end of the pressure period in what is called the expansion bath, used largely in the treatment of Douglas-fir poles, and with the charge of timber still submerged the temperature of the preservative is raised from 10° to 20° F. above the temperature maintained during the pressure period. A vacuum is commonly applied during this heating period to assist in removing air and some excess preservative. The duration of the expansion bath depends upon the kind of material treated and similar factors and may vary from about 2 to 6 hours. After the expansion bath, the preservative is withdrawn from the cylinder and a final vacuum is applied in the usual manner.

Pressure from the expansion of air and formation of steam at the lowered boiling temperature probably help force out some of the preservative during the expansion bath, but removal of air is probably an important factor affecting subsequent bleeding. If the vacuum is released while the wood is submerged, a small reabsorption of preservative is possible, but it is probably insignificant, since the atmospheric pressure is low compared with the pressure applied during the treating period, and the time during which the cylinder is being emptied is short.

ABSORPTION AND PENETRATION

The effectiveness of treatment depends on both the depth of penetration and the amount of preservative injected. The net amount of preservative retained by the wood (net retention) cannot be taken alone as a measure of effectiveness, for there may be considerable differences in penetration and distribution of preservative in different timbers or in different charges having the same retention. Results are most nearly comparable when the treating conditions are similar and the timbers are of the same size, character, sapwood content, and degree of seasoning.

The following are some of the more important reasons why the net retention alone does not necessarily indicate whether the wood has been properly treated:

1. The treating conditions may be controlled, as in the empty-cell processes, so that a large gross absorption and, consequently, a deep penetration will be obtained with subsequent recovery of a considerable proportion of the original or gross absorption. On the other hand, treating conditions may be used where only a small amount of kick-back occurs, such as in the full-cell process, and therefore a much heavier net retention is required to obtain an equally good penetration. Kick-back is much less when the wood is resistant to treatment, and in such material there may be little gained by the use of an empty-cell treatment from the standpoint of penetration.

2. Some woods take a deep end penetration and very small side penetration, while in others the ratio of end to side penetration is not so high. In the first case the absorption may be largely at the ends of the timbers, particularly when they are fairly short and the end-surface area is large in proportion to the side-surface area.

3. When the timbers in a charge have varying amounts of sapwood and heartwood, or are of mixed species that vary widely in their relative resistance to treatment, the more easily treated sapwood or more easily

treated species may absorb a disproportionate amount of the average retention indicated for the charge.

4. Timbers that have not had fairly uniform seasoning may take heavy absorptions and deep penetrations in some portions and have poor treatment in other portions.

5. In timbers that vary considerably in size and in those that cannot be completely penetrated, the penetration for a given retention is greatly influenced by differences in ratio of surface area to volume (p. 96).

Penetration is more nearly a measure of effectiveness of treatment than is retention, but, with the same penetration, higher retentions indicate that the treatment is better because it results in a greater concentration of preservative in the wood. The gross absorption is also a better measure of treatment than net absorption (net retention) since good gross absorptions are necessary to obtain satisfactory penetrations. Unfortunately, the true gross absorption is difficult to determine accurately for reasons mentioned.

FULL-CELL AND EMPTY-CELL ABSORPTIONS

In the empty-cell treatment of poles of southern yellow pine, which in the more commonly used sizes are largely sapwood, the net retention of preservative varies from about 25 to 75 percent of the gross absorption, depending on the air pressure in the wood, the character and condition of the timber, and other factors. With an 8-pound empty-cell treatment and an average net retention of 50 percent, the gross absorption would be 16 pounds per cubic foot. If a full-cell treatment of 12 pounds were applied, a kick-back of about 25 percent of the gross absorption, or 4 pounds per cubic foot, for the same gross absorption as that obtained in an 8-pound empty-cell treatment, would be necessary. This kick-back, however, is considerably higher than would ordinarily be obtained with a full-cell treatment of such timbers. As deep penetrations should therefore not be expected in southern pine poles with a full-cell treatment of 12 pounds, as with an 8-pound empty-cell treatment.

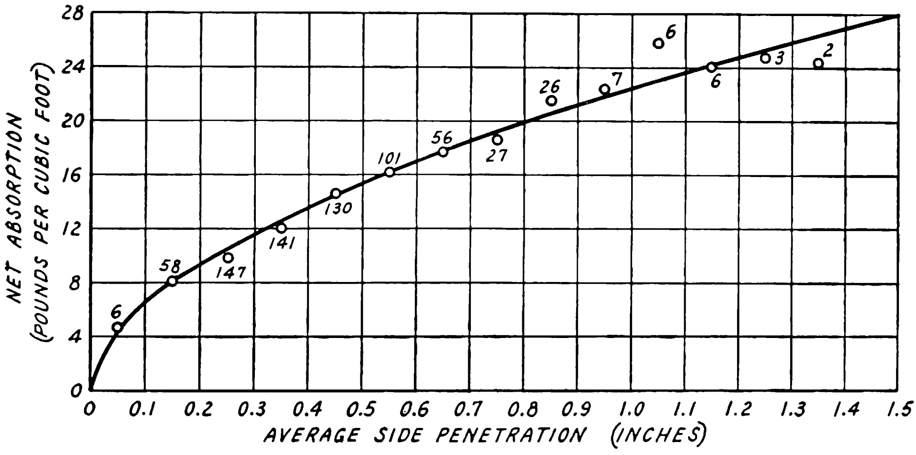

FIGURE 30.—Relation observed between penetration and absorption of preservative oils in air-seasoned eastern hemlock ties treated by full-cell process. (Numbers opposite the points indicate the number of ties averaged in the group. The ties were grouped for differences of 0.1-inch penetration.)

Figure 30 shows the relation observed between penetration and net retention in air-seasoned, sawed, eastern hemlock ties treated with preservative oils by the full-cell process. In this figure the individual ties in various treatments are grouped according to differences of 0.1-inch penetration. All ties having from 0- to 0.1-inch penetration form the first group. The average gross absorption obtained in the treatments was about 2 pounds greater than the net retention.

RELATION OF DIMENSIONS OF TIMBER TO ABSORPTION AND PENETRATION

Heartwood Timbers

For many years preservative treatment was largely confined to cross ties and larger material. Since ties do not vary widely in dimensions, the volumetric absorptions necessary to give satisfactory results with timbers of this kind have been fairly well established from experience. In the application of preservative treatment to many different types of timber having widely different cross-sectional dimensions, the tendency of many purchasers is to specify the same retentions regardless of dimensions. If all of the wood could be penetrated, the dimensions would not need consideration. Very few species, however, are sufficiently permeable in the heartwood to permit complete penetration, even when the timbers have relatively small cross-sectional dimensions. In large timbers the ratio of surface area to volume is much smaller than in pieces of small dimensions. Since there is less surface area per cubic foot in the large timbers than in small ones, a given quantity of preservative per cubic foot can penetrate deeper in the larger sizes.

The following example will illustrate the disparity in treatment that may result if the same retention is specified for heartwood timbers having the same volume but different surface areas. Assume a 7- by 9-inch by 8-foot heartwood tie is to be treated with a net retention of preservative of 8 pounds per cubic foot. A tie of this size will have a volume of 3½ cubic feet and a total surface area of about 22.2 square feet, or about 6.35 square feet per cubic foot. If the same timber should be cut into four pieces 3½ by 4½ inches by 8 feet in size, the volume would still be the same but the total surface area would be 43.54 square feet or about 12.4 square feet per cubic foot. This is an increase of about 96 percent in surface area over that of the tie. Naturally, the 8 pounds of preservative will penetrate deeper when injected through 6.35 square feet of surface than when the same amount of preservative is used for 12.4 square feet of surface.

If the average ratio of end to side penetration were determined, it would be possible to compute the approximate amount or percentage of treated wood in a timber of any given size. With this information it would be a simple matter to specify volumetric absorptions that should give similar average penetrations and concentrations of preservative in heartwood timbers of different dimensions. This could be done as follows:

Let V = Total volume of the timber in cubic feet

V_t = Volume of treated wood in cubic feet

V_s = Volume of wood treated by side penetration only

L = Length of the timber in feet

L_1 = Average depth of end-surface penetration in inches
A = Width of timber in inches
B = Thickness of timber in inches
p = Average depth of side-surface penetration in inches
np = Longitudinal penetration where n is the ratio of depth of end to depth of side-surface penetration $= L_1$
A_t = Square inches of penetrated wood in cross-section beyond average depth of end penetration

Figure 31 is a sketch showing the dimensions named.

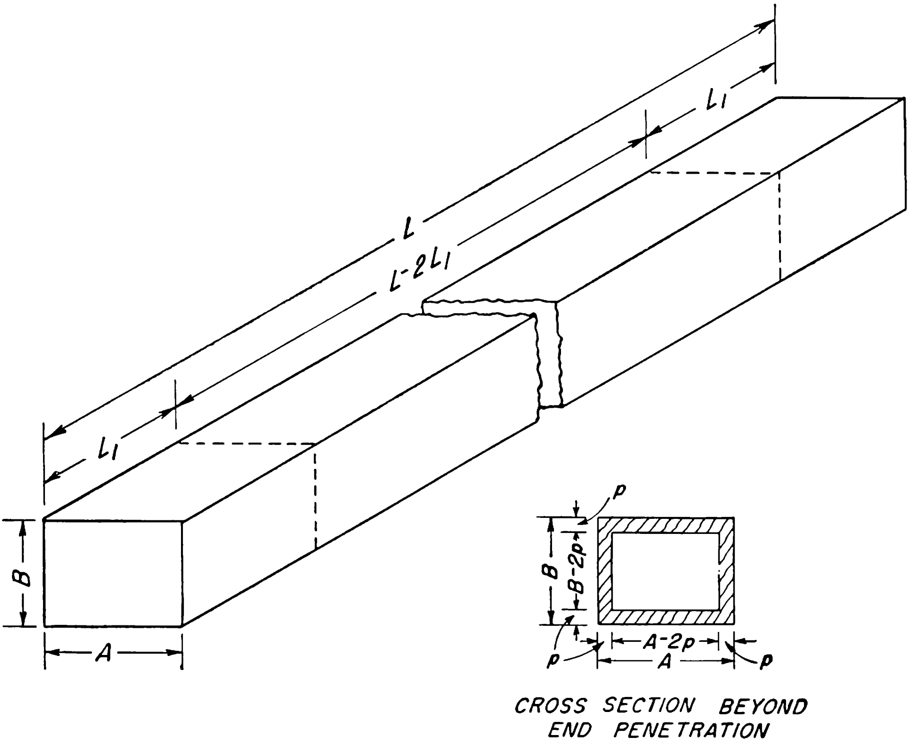

FIGURE 31.—Sketch showing dimensions used in computing the volume of treated wood in a sawed heartwood timber.

The volume of penetrated wood at the ends with the dimensions ABL_1, where $L_1 = np$, is evidently $\frac{ABL_1}{1728}$ cubic feet at each end, or for both ends $\frac{ABL_1}{864}$.

The area A_t, or the number of square inches of treated wood in a cross section where all penetration is from the side surfaces, is $2p\,(A+B-2p)$; hence the volume of wood, in cubic feet, that is penetrated entirely from side penetration is

$$V_s = \left(\frac{2p\,(A+B-2p)}{144}\right)\left(\frac{L-2L_1}{12}\right) = \frac{(p)(A+B-2p)(6L-L_1)}{432}$$

The total volume of treated wood (V_t), including that penetrated by both end and side penetration, is therefore:

$$V_t = \left(\frac{ABL_1}{864}\right) + \left(\frac{(p)(A+B-2p)(6L-L_1)}{432}\right)$$

If a timber such as a tie is taken as a standard and has V_1 cubic feet and the volume of treated wood in the tie is V_2 cubic feet, for comparable treatments the required retention in a timber having a total volume V and treated volume V_t would be computed as

$$\left[\frac{V_t}{V} \div \frac{V_2}{V_1}\right](W_p) = \left[\frac{(V_t)(V_1)}{(V)\ (V_2)}\right](W_p),$$

where W_p is the absorption in pounds per cubic foot specified for the tie.

The average side and longitudinal penetrations have been measured in a large number of air-seasoned heartwood specimens of several different woods, such as southern pine and Douglas-fir, which take only a limited heartwood penetration (*31*, *32*). In general, the longitudinal penetration of creosote was found to be from 10 to 20 times as deep as the side penetration and that of zinc-chloride solution from 15 to 25 times as deep. Table 16 has been prepared to serve as a guide in specifying absorptions for heartwood timbers and shows the approximate amount by which volumetric absorption should be increased or decreased to give a treatment equivalent to that obtained in a 7- by 9-inch by 8-foot timber. This timber of tie size is taken as a standard for the comparison of absorptions in timber of other dimensions, since the necessary volumetric absorptions for ties are better known than those for timbers of any other size.

Many measurements of the average side penetration in unincised heartwood timbers of the commonly treated species indicate that a fair average value for general conditions would be about ½ inch. The computations for table 16 were therefore made on the assumption that the values for the ratio of end to side penetrations are 15 and 20, respectively, for preservative oils and water solutions, and that the value for side penetration is ½ inch. On this basis the average end penetration of preservative oils would be roughly about 7 to 8 inches and that of water solutions about 10 inches. These values should give results that are reasonably close and will apply to treatment with either the full-cell or empty-cell processes, since the same gross absorption obtained by either process should give similar penetrations. As table 16 includes a variety of sizes, a close estimate can be made for intermediate dimensions.

If the ratio of end to side penetration is taken as 15 for preservative oils and 20 for water solutions, the volume of treated wood in a 7- by 9-inch by 8-foot tie would be 1.25 cubic feet for preservative oils and 1.4 cubic feet for water solutions. With the penetrations as assumed, about 36 percent of the total volume of a heartwood tie, having an average side penetration of ½ inch, would then be treated with preservative oils and about 40 percent of the volume would be treated when water solutions were used. A somewhat deeper average penetration is obtained when heartwood timbers are incised, and this would help increase the percentage of treated wood.

Mixed Sizes in a Charge of Heartwood Timbers

If a charge of heartwood timber contains pieces of different dimensions but of the same species and similar moisture content, the larger sizes

TABLE 16.—*Amount by which net retentions in various sizes of timber should be increased or decreased to give a treatment equivalent to that obtained with a given retention in a 7- by 9-inch by 8-foot timber*

[For heartwood timbers or those that contain only a small amount of sapwood]

Nominal cross section	Length	Increase or decrease in retention [1] for preservative oils	Increase or decrease in retention [2] for water solutions	Nominal cross section	Length	Increase or decrease in retention [1] for preservative oils	Increase or decrease in retention [2] for water solutions
Inches	*Feet*	*Percent* [3]	*Percent* [3]	*Inches*	*Feet*	*Percent* [3]	*Percent* [3]
2 by 4	All lengths [4]	+74	+56	8 by 8	4	+33	+40
2 by 6	do	+64	+48		8	−1	0
2 by 8	do	+58	+42		12	−12	−14
2 by 12	do	+51	+36		16	−18	−21
3 by 6	4	+73	+70	8 by 12	4	+26	+34
	8	+49	+41		8	−10	−8
	12	+41	+32		12	−21	−22
	16	+37	+27		16	−27	−29
3 by 10	4	+65	+64	8 by 16	4	+22	+32
	8	+38	+33		8	−14	−12
	12	+30	+22		12	−26	−26
	16	+25	+17		16	−32	−33
4 by 4	4	+72	+70	10 by 12	4	+21	+31
	8	+47	+40		8	−15	−12
	12	+39	+30		12	−27	−27
	16	+35	+25		16	−33	−34
4 by 8	4	+54	+56	10 by 16	4	+18	+28
	8	+26	+21		8	−19	−16
	12	+16	+10		12	−32	−31
	16	+11	+4		16	−38	−38
4 by 12	4	+48	+51	12 by 14	4	−16	+27
	8	+18	+15		8	−21	−18
	12	+8	+3		12	−34	−33
	16	+3	−3		16	−40	−40

See footnotes at end of table.

TABLE 16.—*Amount by which net retentions in various sizes of timber should be increased or decreased to give a treatment equivalent to that obtained with given retention in a 6- by 9-inch by 8-foot timber—Continued*

Nominal cross section	Length	Increase or decrease in retention [1] for preservative oils	Increase or decrease in retention [2] for water solutions	Nominal cross section	Length	Increase or decrease in retention [1] for preservative oils	Increase or decrease in retention [2] for water solutions
Inches	*Feet*	*Percent* [3]	*Percent* [3]	*Inches*	*Feet*	*Percent* [3]	*Percent* [3]
6 by 8	4	+40	+45	14 by 14	4	+14	+25
	8	+ 8	+ 7		8	−24	−20
	12	− 3	− 6		12	−36	−35
	16	− 8	−12		16	−42	−43
6 by 12	4	+33	+40	16 by 16	4	+11	+23
	8	0	0		8	−28	−23
	12	−12	−14		12	−40	−39
	16	−17	−20		16	−47	−46
6 by 16	4	+30	+37				
	8	− 5	− 4				
	12	−16	−18				
	16	−22	−24				

[1] Unit end penetration assumed to be 15 times unit side penetration.
[2] Unit end penetration assumed to be 20 times unit side penetration.
[3] Plus sign indicates increase; minus sign indicates decrease.
[4] End penetration in timbers 2 inches thick is negligible.

will naturally absorb less than the average volumetric absorption specified, while the smaller sizes will take a heavier absorption. Theoretically, the penetration would be the same in all timbers, assuming equal resistance to treatment. If it is necessary to treat more than one size of timber in a charge, the approximate proportional absorption should be determined for all timbers of each size. The total absorption for the charge will then be the sum of the absorptions required for the material in each group.

Example of Computation of Absorption in Mixed Sizes in a Charge of Heartwood Timbers

Suppose that a charge has approximately 1,500 cubic feet of timbers 4 by 8 inches by 16 feet and 1,000 cubic feet of timbers 10 by 12 inches by 16 feet in size. All are to be treated with a net retention of creosote equivalent in penetration to an 8-pound-per-cubic-foot treatment in a tie. What is the total absorption for the charge?

From table 16 it is found that the 4- by 8-inch by 16-foot timbers should have about 111 percent of the absorption required for the tie, or 8.9 pounds per cubic foot. Similarly, the 10- by 12-inch by 16-foot timbers should have 67 percent of the 8-pound absorption, or about 5.4 pounds per cubic foot. The total absorption to be specified for the charge would then be $(8.9\times 1{,}500)+(5.4\times 1{,}000)=18{,}750$ pounds, or an average absorption of about 7.5 pounds per cubic foot. An 8-pound absorption in such a mixed charge should be better than would be expected from an 8-pound treatment in ties. If the small-size pieces constituted a much higher proportion of the total volume, calculation would show that it was desirable to specify an average absorption of somewhat more than 8 pounds per cubic foot. Since, however, the smaller-dimension timbers will be heated to a higher temperature, which is more favorable for treatment, the larger pieces will usually be more difficult to penetrate satisfactorily. It is therefore desirable, whenever possible, to avoid treating mixed charges of timbers that vary widely in cross-sectional dimensions.

Sapwood Timbers and Easily Treated Woods

Timbers that have fairly easily penetrated heartwood, that are practically all sapwood, or that contain a large proportion of sapwood, should have heavier volumetric absorptions (retentions) than heartwood timbers that take only a small penetration. If the proportion of treated wood in a heartwood tie is assumed as approximately 36 percent when impregnated with preservative oils and 40 percent when water solutions are used, then in order to obtain the same concentration of preservative per unit volume of treated wood in a timber that can be completely penetrated, the net retention should be increased by an amount equal to 1/0.36, or about 2.8 times, when treated with a preservative oil, and by 1/0.4, or about 2.5 times, when treated with a water solution. In most cases, however, the same concentration would not be necessary or justified, although some increase would be desirable over the retention required in heartwood timbers. There is evidence from service-test records to show that a given retention that may be found satisfactory for heartwood timbers may be entirely inadequate for similar material that is largely sapwood or that can be fairly easily penetrated in both the heartwood and sapwood portion. For example, a large proportion of a group of experimental ties of red oak, sapwood gum, and sapwood southern yellow pine treated by the empty-cell method with 5 to 6 pounds of coal-tar creosote per cubic foot were badly decayed after 7 years of service. Other ties in the same group and of the same species that had a net retention of about 12 pounds of creosote per cubic foot showed no signs of decay within the same period. These ties were installed in the South, where conditions are particularly favorable to decay. Under similar service conditions the lower retentions have been considered satisfactory for heartwood ties.

A discussion of retentions recommended for sapwood timbers will be found on pages 130, 132.

In round timbers such as poles and piling the end-surface area is so small a percentage of the total-surface area that the influence of end absorption is generally negligible, and only in exceptional cases is it practical to penetrate much more than the sapwood.

Absorptions and Penetrations in Round Timbers

For any given species the average diameter and the average depth of sapwood must be considered in computing equivalent treatments in round timbers of different dimensions. An equivalent treatment is one that will give a retention proportional to the amount of penetrated wood in the total volume. This naturally assumes that the treated wood has a similar concentration of preservative. It is not sufficient to consider the surface area only, since the proportion of sapwood in the total volume depends both on the average diameter and on the average depth of sapwood, and in timbers of most species used for poles or piling penetration is usually limited by the depth of sapwood.

If R_s represents the ratio of surface area to volume and D is the average diameter of the timber, then $R_s=\frac{4}{D}$. When D is in inches, R_s is the number of square inches per cubic inch; and when D is in feet, R_s is the number of square feet of surface area per cubic foot. If P_s represents the percent of sapwood in the total volume, T the average sapwood thickness, and D the diameter, then

$$P_s=100\left(\frac{4T\ (D-T)}{D^2}\right)=100\left[1-\left(1-\frac{T}{R}\right)^2\right].$$

If, from this equation, T is determined in terms of P_s and D, it will be found that

$$T=D\left(0.5-0.05\ \sqrt{100-P_s}\right)$$

or

$$\frac{T}{D}=0.5-0.05\ \sqrt{100-P_s}.$$

Figure 7, which has been produced by using the outlined equation, shows the percentage of sapwood, based on the total volume, plotted against the sapwood thickness divided by the diameter, that is, the ratio T/D. In order to determine from figure 7 the percent of sapwood in a timber of any diameter, divide the sapwood thickness by the diameter and, above this ratio, found on the horizontal scale, read the percent of sapwood, based on the total volume, on the vertical scale. For example, assume that a timber has an average diameter of 11 inches and that the sapwood thickness averages 1.3 inches. In this case the ratio $T/D = 1.3/11$, which is approximately 0.118. The corresponding percent of sapwood for this value of T/D is found on the left-hand scale to be about 42.

Figure 7 will be found convenient for comparing the relative sapwood depth in timbers of different diameters for any ratio T/D, or for finding the required sapwood depth in timbers of any diameter to give the same percentage of sapwood P_s. If, for example, the proportion of sapwood is assumed as 65 percent, the chart shows that the corresponding value of T/D is 0.205. The average sapwood thickness that would give 65 percent sapwood based on the total volume would then be $T = 0.205D$, where T is the sapwood thickness and D is the diameter.

The ratio of the surface area per unit volume of a smaller-diameter timber to one of a larger diameter is always greater than the ratio of the percent of sapwood P_s in the smaller timber to the percent of sapwood in the larger timber when both have the same sapwood thickness. As the depth of sapwood decreases, however, the ratio of the percents of sapwood in timbers of different diameters approaches as a limit the ratio of the surface areas.

Similar concentrations of preservatives cannot be expected to give as good protection to the pieces of round timber with thin sapwood as to pieces with thick sapwood. Poles or piling with thin sapwood will normally lose preservative more rapidly from leaching and evaporation than timbers with deeper sapwood. For this reason it would be logical to insure heavier concentrations of the preservative in the thinner sapwood than in the thicker sapwood to help compensate for the more rapid loss of preservative, since both depth of penetration and concentration of preservative are important factors affecting the service life.

Furthermore, poles or piling of one species might have an average sapwood depth considerably less than that of another species and, depending on the diameter, might require a much smaller retention to give a similar concentration of preservative. If the sapwood of the two species was about equally permeable, the depletion of preservative would probably be considerably faster in the thinner sapwood pieces and higher retentions might be needed to help compensate for this more rapid loss. On the other hand, if the species with the thinner sapwood was more resistant to penetration, the higher sapwood resistance would probably help materially in retarding preservative losses from leaching and evaporation. These factors should be given careful study in specifying retentions in round timbers. In the case of poles, also, it might be necessary to consider the matter of bleeding depending on the preservative used and other variables.

Disadvantages of Treating Both Large- and Small-diameter Timbers in the Same Charge

Although it is often necessary to treat both large- and small-diameter timbers in the same charge, this practice should be avoided as much as possible, especially when some timbers have a much larger cross section than others.

When mixed sizes are treated in the same charge, the smaller-diameter pieces will usually take more than their share of the preservative because the percentage of sapwood in the smaller timbers usually comprises a greater percentage of the total volume; however, the depth of sapwood in the smaller pieces may be considerably less than in the larger pieces. The smaller timbers will be heated to a higher temperature when treatment is applied. Care must be exercised to make sure that in treating large- and small-diameter timbers, the more favorable conditions for treatment of the smaller-diameter timbers do not result in poor treatment in the larger pieces. The trouble is considerably aggravated if the sapwood is fairly resistant to treatment and the larger timbers have deeper sapwood than the smaller ones.

When the specified retention is relatively low, the problem is particularly difficult, for the large pieces with fairly deep sapwood (that, in addition, may be more or less resistant to treatment) will retain a large proportion of the gross absorption, regardless of the initial air pressure used. In fact, too high initial air pressures may retard rather than improve penetration, and they become less effective as the resistance of the wood increases.

A point too often overlooked is that the required retention cannot be based alone on the proportion of sapwood or on the proportion of surface area. Other considerations such as the depth of sapwood, resistance of the wood to treatment, and proportion of the gross absorption retained after treatment, are very important factors affecting the final retention.

Maximum Absorptions in Round Timbers

Figure 7 is also useful in estimating the maximum amount of preservative that poles or piling having different average depths of sapwood can absorb, since in general only the sapwood is treated. The approximate percentage of air space P can be found from figure 11 for the species treated. If P_s is the percent of sapwood found from figure 7 and W is the weight in pounds per cubic foot of the preservative at the treating temperature, the maximum amount of preservative that could be absorbed, assuming all the available air space is filled, is

$$\left(\frac{P}{100}\right)\left(\frac{P_s}{100}\right)\left(W\right) \textit{pounds per cubic foot.}$$

The maximum absorption will necessarily be somewhat less than this because all the air space in the treated sapwood cannot be completely filled regardless of the method of treatment used.

Table 17 shows the surface area and volume per foot of length of different sizes of sawed and round timbers. The areas given in this table are actual surface areas for timbers of the dimensions shown and do not take into account relations of end to side penetration. In the table the nominal sizes are used; that is, in computations of volume and surface area for the sawed timbers account is not taken of the fact that the actual dimensions of lumber and timber are usually somewhat less than the nominal dimensions. For simplicity, the round timbers were assumed to be cylindrical in shape, which, although not correct, is sufficiently close for practical purposes, since the average diameter can be used in computing volumes or percentages of sapwood.

TABLE 17.—*Surface area* [1] *and volume per foot of length of different sizes of timber (Nominal dimensions)*

SAWED MATERIAL

Nominal size of timber (inches)	Total side-surface area, per foot length	Total end-surface area (both ends)	Volume per foot length	Nominal size of timber (inches)	Total side-surface area, per foot length	Total end-surface area, (per ends)	Volume per foot length
Lumber and dimension sizes:	*Square feet*	*Square feet*	*Cubic feet*	Tie sizes commonly used—Continued	*Square feet*	*Square feet*	*Cubic feet*
2 by 4	1.000	0.111	0.056	6 by 8	2.333	0.667	0.333
2 by 6	1.333	.167	.083	7 by 7	2.333	.681	.340
2 by 8	1.667	.222	.111	7 by 8	2.500	.778	.389
2 by 10	2.000	.278	.139	7 by 9	2.667	.875	.438
2 by 12	2.333	.333	.167	7 by 10	2.833	.972	.486
3 by 4	1.167	.167	.083	Timber sizes:			
3 by 6	1.500	.250	.125	6 by 6	2.000	.500	.250
3 by 8	1.833	.333	.167	6 by 8	2.333	.667	.333
3 by 10	2.167	.417	.208	6 by 10	2.667	.833	.417
3 by 12	2.500	.500	.250	6 by 12	3.000	1.000	.500
4 by 4	1.333	.222	.111	6 by 14	3.333	1.167	.583
4 by 6	1.667	.333	.167	6 by 16	3.666	1.333	.667
4 by 8	2.000	.444	.222	8 by 8	2.667	.889	.444
4 by 10	2.333	.556	.278	8 by 10	3.000	1.111	.556
4 by 12	2.667	.667	.333	8 by 12	3.333	1.333	.667
Boards and strips:				8 by 14	3.667	1.556	.778
1 by 2	.500	.028	.014	8 by 16	4.000	1.778	.889
1 by 3	.667	.042	.021	10 by 10	3.333	1.389	.694
1 by 4	.833	.056	.028	10 by 12	3.667	1.667	.833
1 by 5	1.000	.069	.035	10 by 14	4.000	1.944	.972
1 by 6	1.167	.083	.042	10 by 16	4.333	2.222	1.111
1 by 8	1.500	.111	.056	12 by 12	4.000	2.000	1.000
1 by 10	1.833	.139	.069	12 by 14	4.333	2.333	1.167
1 by 12	2.167	.167	.083	12 by 16	4.667	2.667	1.333
Tie sizes commonly used:				14 by 14	4.667	2.722	1.361
6 by 6	2.000	.500	.250	14 by 16	5.000	3.111	1.555
6 by 7	2.067*	.583	.292	16 by 16	5.333	3.555	1.778

See footnotes at end of table.

*2.167 see ERRATA.

TABLE 17.—*Surface area*[1] *and volume per foot of length of different sizes of timber (Nominal dimensions)*—Continued

ROUND TIMBERS

Mean diameter (inches)	Total side-surface area, per foot length	Total end-surface area (both ends)	Volume per foot length	Mean diameter (inches)	Total side-surface area, per foot length	Total end-surface area (both ends)	Volume per foot length
	Square feet	*Square feet*	*Cubic feet*		*Square feet*	*Square feet*	*Cubic feet*
4	1.047	0.175	0.087	18	4.712	3.534	1.768
5	1.309	.273	.136	19	4.974	3.938	1.969
6	1.571	.393	.196	20	5.236	4.363	2.182
7	1.833	.535	.267	21	5.498	4.811	2.405
8	2.094	.698	.349	22	5.760	5.280	2.640
9	2.356	.884	.442	23	6.021	5.771	2.885
10	2.618	1.090 *	.545	24	6.283	6.283	3.142
11	2.880	1.320	.660	25	6.545	+ 6.808	3.409
12	3.142	1.571	.785	26	6.807	7.374	3.687
13	3.403	1.844	.922	27	7.069	7.952	3.976
14	3.665	2.138	1.069	28	7.330	8.552	4.276
15	3.927	2.454	1.227	29	7.592	9.174	4.587
16	4.189	2.792	1.396	30	7.854	9.818	4.909
17	4.451	3.152	1.576				

[1] The areas given are the actual areas for timbers of the dimensions given and do not take into consideration relations of end to side penetration.

* 1.091 See ERRATA, in front.

+ 6.818 See ERRATA, in front.

MEASUREMENT OF ABSORPTION

In making preservative treatments the absorptions are usually determined by one of the following methods: (1) By taking gage readings and determining the difference in the volume of preservative contained in the working tank before and after treatment; (2) by using a working tank mounted on scales and weighing the total amount of preservative absorbed, or (3) by taking weights of the charge of timber before and after it is treated. The oldest and most commonly used method of determining absorption is to reduce the volumetric measurement of the amount of preservative absorbed to pounds per cubic foot.

The advantages of the weighing-tank method as compared with tank-gage readings in measuring absorption are: More accurate determinations of the absorption can be made because the method reduces the possibility of errors that may be introduced by such factors as the expansion of preservative, cylinder, and measuring tanks due to change in temperature, friction affecting the movement of the gage, and the difficulty of making accurate readings in the measuring or working tank of small changes in the height of the liquid. Weighing the wood on track scales before and after treatment is a very dependable method of measuring absorption in well-seasoned material, but it has the disadvantage when the wood has a high moisture content or when the charge is given a preliminary steaming treatment, that the moisture content and hence the weight of the wood is changed by the steaming. The weight of the timber cannot be conveniently determined after completing the vacuum following steaming and before the preservative is admitted to the cylinder. When the charge contains wood at a high moisture content, some of the moisture is lost when pressure is released and a final vacuum is applied. This will introduce an error when the final weight is taken on track scales.

The same objection applies when the material is conditioned by the Boulton method, unless the amount of water withdrawn from the wood during the vacuum period is measured accurately. The amount of water condensed during the Boulton treatment is not a true measure of the amount of moisture removed from the wood unless the oil is free from water when it is admitted to the cylinder and all of the vapors withdrawn by the vacuum pump are condensed.

Unless proper care is exercised, absorption measurements made by taking gage readings or by weighing the working tank may be subject to considerable error. Small leaks in valves may allow a large amount of preservative to pass out of the cylinder during the pressure period; and unless this preservative is returned to the working tank before treatment is completed, a false reading of absorption will be obtained.

Specifications of the American Wood-Preservers' Association [13] require that in all tank-volume readings the temperature be recorded and the reading be reduced to that of the preservative at 100° F.

Figure 32 will be found convenient to use in determining the volumetric absorption, in percent of the total volume of the charge, for a given specified retention in pounds or in gallons per cubic foot. The range of specific gravities shown is from 0.92 to 1.12 for differences of 0.04 in each

[13] American Wood-Preservers' Association Manual of Recommended Practice, Instructions for the Inspection of Preservative Treatment of Wood.

interval. Intermediate values can be easily determined by interpolating. The readings are net absorptions (retentions). Since there is always a kick-back after treatment, the gross absorption should be proportionately increased.

Example of the use of figure 32.—Suppose than an absorption of 15 pounds per cubic foot is specified, and the specific gravity of the preservative at the temperature used is 1.04. What is the required net retention in percentage of total volume of charge and in gallons per cubic foot?

Starting in figure 32 on the horizontal scale with the specified absorption of 15 pounds per cubic foot, follow vertically until an intersection is made with the diagonal line labeled specific gravity 1.04. The reading on the left vertical scale corresponding to the intersection point is found to be about 23.2 percent, which indicates that for each cubic foot of wood in the charge 0.232 cubic foot of preservative should be injected; projecting horizontally across to the diagonal dotted line labeled gallons per cubic foot and then directly above to the horizontal scale, it is found that the required retention is about 1.73 gallons per cubic foot. The lines with arrows (fig. 32) shows the procedure for this example. If in this case it is found from experience that a gross absorption of 18 pounds is necessary to obtain the net retention of 15 pounds, the chart shows that this absorption (18 pounds) requires about 28 percent, or 0.28 cubic foot, of preservative per cubic foot of wood. Expressed in gallons, the gross absorption is found to be about 2.1 gallons per cubic foot of wood.

It may be noted that when absorptions are specified in pounds per cubic foot of wood, a greater volumetric absorption of the preservative will be obtained with a preservative having a low specific gravity than with one having a high specific gravity, since the absorptions by volume are inversely proportional to the specific gravities.

Assume for illustration that a creosote-petroleum mixture has a specific gravity of 0.94 at the treating temperature and that a creosote-tar solution has a specific gravity of 1.08 at the same temperature. For a given absorption in pounds per cubic foot the ratio of the volumetric absorption of the creosote-tar solution to that of the creosote-petroleum mixture will be $0.94 \div 1.08$, or about 87 percent. In other words, the unit volumetric absorption of the preservative oil with the higher specific gravity will be about 13 percent less than that of the oil with the lower specific gravity.

Differences in the specific gravity of oils used in preservative mixtures made by volume will affect the proportion of each absorbed by weight. For example, assume that a petroleum oil having a specific gravity of 0.9 at the treating temperature is mixed with an equal volume of creosote having a specific gravity of 1.02 at the same temperature. If W is the specified absorption in pounds per cubic foot, then the weight of petroleum injected per cubic foot will be

$$W\left(\frac{0.9}{0.9+1.02}\right)=0.469W$$

The weight of creosote will be

$$W\left(\frac{1.02}{0.9+1.02}\right)=\underline{.0531W}\,*$$

* 0.531 W
See ERRATA

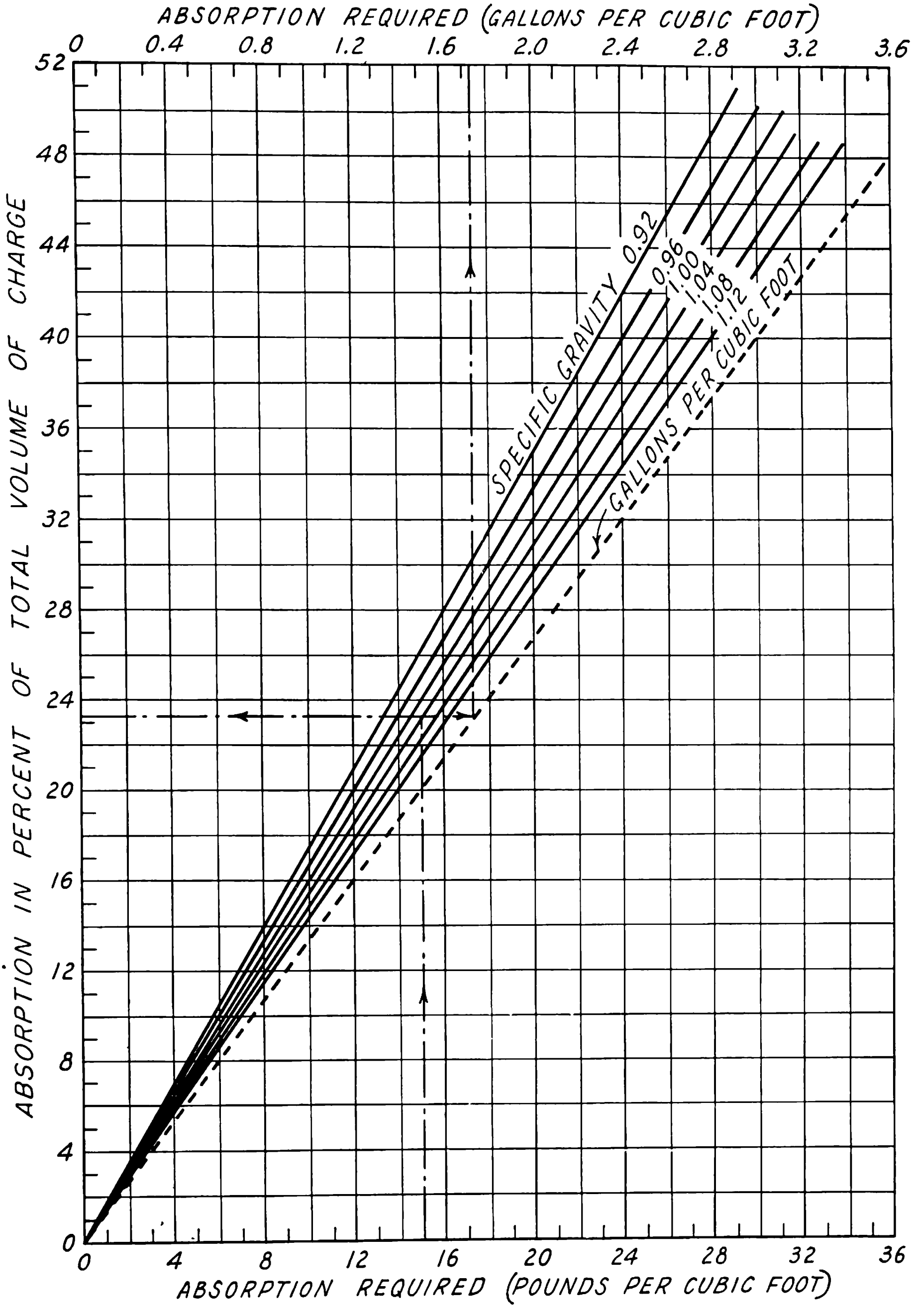

FIGURE 32.—Volumetric absorption, in percent of total volume of the charge, required for preservatives at different specific gravities to obtain a given absorption in pounds or gallons per cubic foot. (Dotted line is for absorptions in gallons per cubic foot. Scale for absorptions in pounds per cubic foot is at bottom of figure, and scale for absorptions in gallons per cubic foot is at top.)

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An 8-pound treatment of the 50–50 mixture would then contain 3.75 pounds of petroleum and 4.25 pounds of creosote per cubic foot.

If the mixture contained 45 percent of petroleum and 55 percent of creosote, the weight of petroleum per pound of absorption of the mixture would be

$$\frac{(0.9)\,(0.45)}{(0.9)\,(0.45)+(1.02)\,(.055)} = 0.42 \text{ pound} \ *$$

and the weight of creosote (1−0.42), or 0.58 pound. With a mixture of this proportion the 8-pound treatment would therefore give an absorption of 3.36 pounds of petroleum and 4.64 pounds of creosote per cubic foot. In the first case the absorption of creosote is more than 13 percent greater by weight than the absorption of petroleum, while in the second case, when the difference in volumetric proportions is 10 percent, the absorption of creosote is more than 38 percent greater by weight than that of the petroleum.

Initial Absorption

During the filling of the cylinder with the preservative, when air-seasoned or steamed material is treated, and also during the boiling-under-vacuum period when the Boulton process is employed, there is more or less absorption of preservative, known as initial absorption. The amount of this initial absorption will vary, depending on the treating conditions and similar factors.

Experimental air-seasoned hemlock ties, when treated by the full-cell process with preservative oils and water solutions, had an initial absorption ranging from about 1.5 to 3 pounds and averaging about 2 pounds per cubic foot. The initial absorption in several charges of seasoned red oak ties, impregnated by the full-cell process with water solutions and preservative oils, ranged from about 3.5 to 6 pounds per cubic foot and averaged about 4 pounds. The allowance that should be made for the initial absorption and kick-back can usually be estimated fairly closely after a few charges of timber have been treated.

EFFECT OF TREATMENT ON THE STRENGTH AND PHYSICAL PROPERTIES OF THE WOOD

EFFECT OF PRESERVATIVES

Experiments indicate that the preservatives commonly used for the treatment of wood have no significant effect on the wood properties. Preservative oils such as creosote, creosote-coal tar, or creosote-petroleum mixtures do not contain chemical substances that would have a harmful effect on the wood, and this is substantiated by results obtained in strength tests.

Very strong solutions of some water-borne salt preservatives may affect the strength, depending on the concentration, but the concentrations used for protection against decay and insect attack are usually so low that the salt retention in the wood should not have an important effect on the strength or other wood properties.

* "0.55"
See ERRATA,

VARIABLES AFFECTING THE STRENGTH PROPERTIES

There are a large number of variables that determine the effect of treatment on the strength properties. Some of the more important are (1) species, (2) heating medium used, (3) temperature of the heating medium, (4) length of the heating period, (5) dimensions of the timber, (6) preservative pressure used, (7) moisture content of the wood, and (8) length of the pressure period.

Some species are more susceptible to injury under any given heating conditions than are others. The heating medium is also an important factor, for the surface coefficient of heat transfer varies for different mediums and this affects the rate at which the wood is heated.

Both the temperature and the duration of heating naturally have an important bearing on the results, since the two variables are interrelated. Increasing the temperature will decrease rapidly the time required to produce a given effect on the strength properties of wood.

Laboratory studies have shown that the effect of temperature on both the strength properties and on the rate of deterioration, as indicated by loss in oven-dry weight, is accelerated as the temperature is increased. For example, the effect of raising the temperature from 250° to 300° F. is considerably greater than the corresponding effect on strength that occurs when the temperature is raised from 200° to 250° F. In general, it is better practice to use moderate heating temperatures and a somewhat longer heating period than to use high temperatures in order to hasten the rate of heating. Points near the surface of a timber quickly approach the temperature of the heating medium, while much of the wood at the interior is still at a relatively low temperature. It is therefore necessary to bear in mind that the wood at and near the surface is exposed to a temperature close to that of the heating medium for most of the heating period, unless water is being evaporated while the timber is in contact with the heating medium.

Experiments have shown that the size of the timber has a bearing on the results obtained. In strength tests it was found that the strength properties of timbers of large dimension were more easily injured by high temperatures and long-continued heating than those of timbers of smaller sizes. On the other hand, both air-seasoned and steamed timbers with small cross-sectional dimensions were apparently more easily collapsed during the preservative treatment.

Similarly different results are obtained with water solutions than with oils. Timbers treated with water solutions showed a greater tendency to collapse than the same kind of material impregnated with preservative oils under the same treating conditions. This is probably because the water solutions soften the wood more than do preservative oils. Figure 33 shows cross sections from the centers of 4- by 4- by 48-inch heartwood Douglas-fir specimens treated with a water solution under pressures of 150 and 175 pounds. The shaded portion indicates the original size of each specimen. The two specimens shown in the figure were the most severely collapsed of those treated, but the results demonstrate that the pressures used were too high for the species and size of specimens. Nearly all of the pieces treated under these pressures were more or less severely injured, but little or no collapse occurred in specimens treated under the same conditions but with pressures of 100 and 125 pounds.

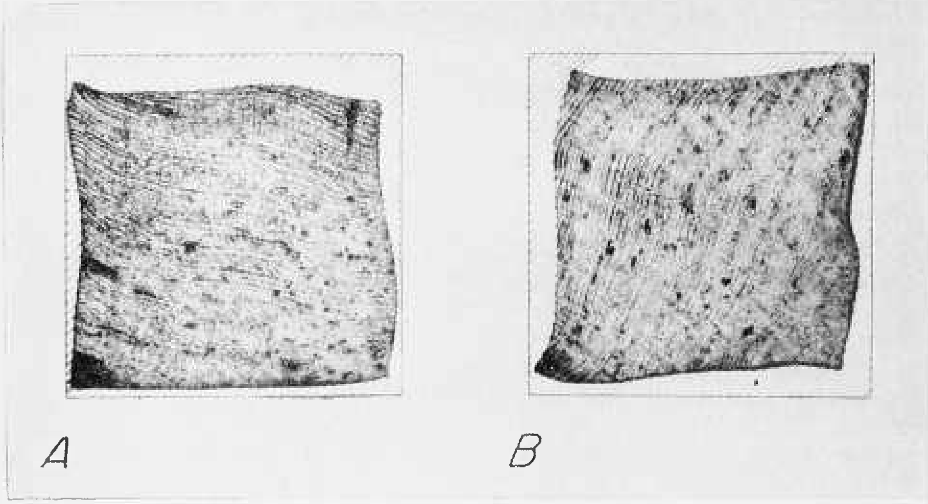

FIGURE 33.—Collapse in 4- by 4- by 48-inch Douglas-fir specimens treated with a water solution: *A*, At 150 pounds' pressure; *B*, at 175 pounds' pressure.

Although these specimens were collapsed by the treating conditions used, less easily injured woods might show no indication of collapse under the same treatment. Some woods can be treated at much higher pressures than others, particularly when dry. As previously mentioned, it is important to keep the preservative pressure low enough to avoid collapse and checking under the temperature conditions necessary for satisfactory treatment and for the species being treated. In general, the denser woods, such as many of the hardwoods, show less tendency to check and collapse under high pressures than the lower-density woods.

The moisture content of the wood is a factor, since hydrolysis is increased when the moisture content is high.

EFFECT OF STEAMING ON STRENGTH AND PHYSICAL CONDITION OF THE WOOD

Steaming at temperatures that are too high for the species treated or steaming for long periods may materially reduce the strength of the wood (*13, 14*). The effect of steaming on the strength of wood is influenced by so many variables that no way has yet been found to determine the loss in strength to be expected in timbers of different size, shape, or character for any given set of steaming conditions. Furthermore, some strength properties are more affected than others. In using the steaming process, the aim should always be to employ steam temperatures and steaming periods that are as mild as consistent with good absorption and penetration. Some woods are more adversely affected than southern yellow pine, but in present practice steaming is not used much with other species. When it is used for other woods, it is usually for relatively short periods to help remove excess preservative from the surface of timbers after treatment or to assist in heating the wood prior to treatment. In such cases lower temperatures or considerably shorter heating periods are generally used than are specified for conditioning southern pine.

Since the effect of steaming on the strength of the wood may not be evident to the eye, there may be considerable loss in strength in timbers that appear to be entirely unaffected. Both the visible and the invisible damage should be avoided so far as possible.

From the standpoint of checking and collapse the sapwood of most species is less likely to be damaged by steaming than the heartwood. For this reason round timbers, such as poles and piling, particularly those that are largely sapwood, are able to withstand steaming treatments that would cause serious checking and collapse in sawed material having exposed heartwood faces. The end surfaces of round timbers, however, may check badly in the heartwood, and objectionable ring shakes may develop if the steaming conditions are too severe. The same is true of sawed timbers that are largely sapwood but have boxed heartwood. The ends are exposed to more severe conditions than any other part of the timber because they are heated in a longitudinal direction as well as from the sides. Heating also takes place most rapidly from the ends.

In some timbers the growth conditions apparently affect the resistance of the heartwood to checking and collapse. In one instance sawed timbers of rapid-growth wood were found badly end-checked and collapsed after steaming and treatment in a commercial charge, whereas slower-growth material of the same species treated in the same charge was not visibly damaged. It is possible that other characteristics than the rate of growth also had an important bearing on the results observed. Very often wood that has been steamed will appear uninjured if examined immediately after the steaming-and-vacuum treatment, but serious checking and collapse may occur during the subsequent pressure treatment. This indicates that the wood has been at least temporarily weakened by the steaming treatment. The remedy is to lower the pressure of the preservative to a point where appreciable checking and collapse will be avoided and, if necessary, to lengthen the pressure period to some extent. Contrary to common belief, reducing the preservative temperature below 200° F. is not necessary.

In experiments on several species of conifers it has been found that wood having a high moisture content at the time it is steamed usually shows less tendency to check and collapse during the preservative treatment than air-seasoned material that has been similarly steamed before treatment. On the other hand, some woods, like the oaks, usually check severely even when the timber is green at the time of steaming. Experiments indicate that steaming may increase checking and shakes, depending on the species, on the treating pressures used, and on the steaming conditions (*23*).

EFFECT OF BOULTON PROCESS ON STRENGTH

One of the principal reasons for using the Boulton process on Douglas-fir and for some hardwood timbers is to overcome the damaging effects that would result from the higher temperatures normally used in the steaming process or from boiling in creosote at high temperatures, as was formerly the practice. With the milder heating conditions used in the Boulton process, these effects are much less (*63*). In the use of the Boulton process, as in the steaming-and-vacuum method, the preservative temperature and the length of the heating period should be restricted as much as practicable, consistent with good treatment.

BLEEDING OF TREATED WOOD

In wood treated with creosote or creosote mixtures the oil may sometimes "bleed" or ooze to the surface after the wood is in use and thus cause inconvenience under certain conditions of service. The phenomenon is not encountered with water solutions, except perhaps for a very brief time immediately after removal from the treating cylinder; for the water evaporates in a short time, leaving no free liquid that can bleed from the wood. Bleeding may occur, however, with any oil sufficiently liquid to flow at atmospheric temperatures. This trouble is sometimes of concern in poles, cross arms, or timbers used in places where the dripping preservative or the oily surface may cause damage or public complaint, but it is seldom of importance in cross ties or piling.

The causes of bleeding are not well understood, but it is apparently influenced chiefly by the intensity of exposure to sunshine or to other sources of heat. The dark color of the treated wood causes it to absorb considerable heat from the sun. Temperatures as high as 140° F. have been measured at the surface of a creosoted timber in direct sunshine. It is quite possible that higher temperatures may be reached under favorable conditions. The bleeding may occur either in summer or winter, but it is usually greatest in the summer. Although this oozing of the preservative is usually at its worst during the first year after treatment, it may occur to a certain extent on some poles over a period of several years. In a pole or other timber the bleeding will usually be confined to the surface facing the sun. Apparently, it is a direct result of the heating and expansion of air and oil in the affected portion and of the inability of the expanded oil to flow in any direction except toward the surface. Bleeding, of course, would not occur if the preservative could not flow at the temperatures reached by the wood in the sunshine.

The character of the preservative used has an important influence upon bleeding. Straight coal-tar creosote is less likely to cause trouble than mixtures of creosote with tar or petroleum. Perhaps the mixtures do not bleed more, but they remain on the surface longer and are more troublesome that straight creosote. Similarly, low-boiling creosotes are, in general, less troublesome than high-boiling creosotes or those that show a high residue above 355° C.

The quantity of preservative injected affects bleeding. Very high absorptions are more likely to bleed than lower absorptions injected by the same method. Differences in method of injection, however, must also be considered. In experiments with paving blocks (*58*) it was found that the amount of air in the wood had a very marked effect on bleeding. Blocks treated by the Rueping process bled much more than those treated by the full-cell process. Those treated by the full-cell process, after preliminary steaming and vacuum, bled least. The air used in empty-cell treatments of heartwood timbers does not all escape with the completion of the treating process. The expansion of the air that remains in the wood apparently adds to the effect of the expansion of the oil on exposure of the treated wood to strong sunshine. This is not such an important factor in the more easily treated sapwood, since the resistance to the movement of air through the sapwood is much less than in the heartwood.

Heartwood and resistant woods in general appear more subject to bleeding than easily penetrated sapwood, but it is true that sapwood may also bleed copiously. On sawed surfaces, however, on which both heartwood and sapwood may be exposed, the heartwood seems to have the greater tendency to bleed. Resistant sapwood is also much more inclined to bleed than that which is less resistant to treatment.

It must not be assumed from the above statements that all creosoted wood gives trouble from bleeding. Many pole lines and structures of various kinds have been built of creosoted wood that have given no trouble whatever from bleeding. The difficulty is not that the wood always bleeds, but that the treating-plant operator is unable to guarantee that his treated material will be entirely free from bleeding.

Methods generally used in an effort to reduce bleeding are the application of an expansion bath, as discussed on page 94, or the application of a final steaming-and-vacuum treatment. When final steaming is employed, the cylinder is emptied of preservative when the pressure treatment is completed. Steam is then admitted until a pressure of 10 to 20 pounds is reached, and this is held for 30 minutes or longer, depending on the steam temperature used and the material treated. A final vacuum is applied after the steam treatment. This final steaming treatment, like the expansion bath, is intended to reduce the amount of air in the wood cells and to remove some of the free oil near the surface. It also helps to clean off the surface of the wood.

A third method employed to a very limited extent by a few plants in an effort to reduce bleeding has been to use a final air pressure after the preservative has been withdrawn from the cylinder. Air at pressures as high as 150 pounds or more has been applied for a period of 3 to 4 hours for the purpose of forcing the free oil farther into the wood. There is considerable question whether the use of a final air pressure would be effective as a means of reducing bleeding. As far as known, adequate experiments have not been made to settle the question.

A considerable amount of observation and study will be necessary to catalog and determine the relative importance of the several factors that encourage bleeding and to find the most effective means of preventing it.

TREATING CONDITIONS USED IN COMMERCIAL PRACTICE

Tables 18 to 20, inclusive, summarize the commercial treating methods employed for various species and different kinds of material. These tables include data obtained from a large number of the wood-preserving plants operating in the United States, as well as from some of those in Canada, and show representative treating practices for different regions. These data were obtained in 1949 and 1950. The diversity in conditions used in treating the same or similar material reflects some of the lack of information and difference of opinion as to conditions that are considered most satisfactory.

TABLE 18.—*Commercial treating conditions and retentions in use for coast-type Douglas-fir*

Plants studied (number)	Preliminary air pressure	Preservative used: Coal-tar creosote	Preservative used: Petroleum	Maximum treating pressure	Preservative temperature	Pressure period	Final hot bath in preservative		Final vacuum	Net retention	Remarks
	Pounds per square inch	*Percent*	*Percent*	*Pounds per square inch*	*°F.*	*Hours*	*Hours*	*°F.*	*Hours*	*Pounds per square inch*	
GREEN TIES (conditioned by Boulton process)[1]											
1		100		120	190–200	2 –3	1	220	1	8	Full-cell treatment.
1		50	50	80	190	½–1			2	8	Do.
1		50	50	120	180	–2	2¼	220	1	7	Do.
1	35	100		125	200	1 –1½			1	8	
1	40	25	75	120	190	3 –6			1½	10	
1	30	50	50	140–150	190	1 –3			2	8	
1	40	50	50	140–150	190–200	4 –5			½	7	
AIR-SEASONED TIES											
1	40	50	50	140–150	195–200	4–5			½	7	
1	50	50	50	150	195–200	4–4½			½	7	
1		100		120	190–200	2–3	1	220	1	8	Full-cell treatment.
1		50	50	100–110	200	4–5			1	8	Full-cell treatment. Boiled under vacuum 3 hours.
1	40	25	75	150	200	9–10			2	10–10½	
1		50	50	125	195–200	4–5			1–2	8	Lowry process.
1	50	50	50	150	200	4	2	220	1	8	Boiled under vacuum 4 hours at 200° F.
1	30	50	50	125	200	5			½	8	
GREEN LUMBER AND BRIDGE TIMBERS (conditioned by Boulton process)[1]											
1		100		75–100	190	1 –2	1	195	2	8–12	Full-cell treatment. Initial air of 50 pounds used for low retention.
1		100		130	190–200	2½–4			½–1	8–12	Full-cell treatment.
1	25–30	100		140–165	175–190	½–2	2	220	1½–2	8–12	
1		50	50	150	200–210	6			½	10–10½	Lowry process.

AIR-SEASONED LUMBER AND BRIDGE TIMBERS

1---	50	100	---	110–120	200	¼–½	2½	225	2	10–12	Boiled under vacuum 2 hours at 200° F. (small dimension material.)
1---	---	100	---	75–100	190	1–2	1	195	2	8–12	Full-cell treatment. Boiled under vacuum 4 to 8 hours at 190° F.
1---	---	45	55	100	200	12	---	---	1	12–14	Full-cell treatment. Heated in oil (before pressure treatment) for 6 hours at 200° F.
1---	---	50	50	125	195–200	5–6	---	---	2	9–10	Full-cell treatment. Heated in oil (before pressure treatment) for 5 to 8 hours.
1---	---	50	50	150	200–210	6	---	---	½	10–10½	Lowry process.
1---	50	50	50	135	200	1–5	---	---	½	8	Heated in oil (before pressure treatment) for 10 to 12 hours at 200° F.

GREEN PILING (conditioned by Boulton process) [1]

1---	20	100	---	150	200	¼–½	2	235	2	8	
1---	30	100	---	125	200	1–1¾	2½	225	¾	8–10	
1---	---	100	---	90	190	¾–2	---	---	1	12	Full-cell treatment.
1---	---	100	---	140	200	4½–5	---	---	½	12	Do.
1---	---	100	---	120	200	1–2	---	---	1	12–14	Do.
1---	---	100	---	150	220	2–3	---	---	2	12–16	Do.
1---	---	100	---	150	185–190	½–2	---	---	2	12–16	Do.

AIR-SEASONED OR PARTLY AIR-SEASONED PILING (full-cell treatment)

1---	---	100	---	135	200	10–12	---	---	1	12–16	Boiled under vacuum for 4 hours at 200° F.
1---	---	100	---	110	190	3–6	---	---	1	8–12	Boiled under vacuum for 12 hours at 190° F.
1---	---	100	---	140	200	6	---	---	½	12	Boiled under vacuum for 8 to 9 hours at 200° F.
1---	---	100	---	140	190	9–15	---	---	1	12–13	Boiled under vacuum for 10 to 12 hours at 190° F.
1---	---	100	---	120	220	5–6	---	---	2–3	10–12	Boiled under vacuum for 7 to 8 hours at 220° F.
1---	---	45	55	125	200	16	---	---	1	10–12	Heated in oil at 200° F. for 6 hours.
1---	---	100	---	130	200–205	8–10	---	---	½	12	Boiled under vacuum at 205° to 210° F. for 8 to 10 hours.

See footnote at end of table.

TABLE 18.—*Commercial treating conditions and retentions in use for coast-type Douglas-fir*—Continued

GREEN POLES (conditioned by Boulton process)[1]

Plants studied (number)	Preliminary air pressure	Preservative used: Coal-tar creosote	Preservative used: Petroleum	Maximum treating pressure	Preservative temperature	Pressure period	Final hot bath in preservative: Hours	Final hot bath in preservative: °F.	Final vacuum	Net retention	Remarks
	Pounds per square inch	*Percent*	*Percent*	*Pounds per square inch*	°F.	*Hours*	*Hours*	°F.	*Hours*	*Pounds per cubic foot*	
1	25	15	85	140	200–210	5 –6			1	8	5 percent pentachlorophenol in petroleum.
1	30	100		125	200	1 –1¾	2	220	¾	8	
1		100		90	190	½–1	2	200	2	8	Full-cell treatment.
1	60	100		145	180	5	3½	220	1	8	
1	70	100		170	200	3	4	200	1	8	

AIR-SEASONED AND PARTLY AIR-SEASONED POLES[2]

Plants studied (number)	Preliminary air pressure	Preservative used: Coal-tar creosote	Preservative used: Petroleum	Maximum treating pressure	Preservative temperature	Pressure period	Final hot bath in preservative: Hours	Final hot bath in preservative: °F.	Final vacuum	Net retention	Remarks
1	30	50	50	150	220	1 – 3			1	8	Short final steaming.
1	25–30	100		165	175–190	½– 1	2	220	1½–2	8	
1	25	15	85	140	195–200	4 – 5			1	8	5-percent pentachlorophenol in petroleum.
1	50	50	50	135	180–190	10 –12			½	8	Do.
1	50	50	50	150	195–200	1 – 2			1	8	Short final steaming.
1	30–50	50	50	120	220	½– 1	2–3	220	2 –3	8	

[1] See table 5 for conditions employed in using the Boulton process for coast-type Douglas-fir.

[2] Most seasoned and partly seasoned poles are conditioned for several hours by the Boulton process, but for shorter periods than are used for green poles.

TABLE 19.—*Commercial treating conditions and retentions in use for air-seasoned material of species grown in the Central and Rocky Mountain States*

TIES [1]

Plants studied (number)	Species treated	Preservative		Preliminary air pressure	Treating pressure	Preservative temperature	Net retention of preservative	Remarks
		Coal-tar creosote	Petroleum					
		Percent	*Percent*	*Pounds per square inch*	*Pounds per square inch*	*°F.*	*Pounds per cubic foot*	
1	Lodgepole pine	50	50	(2)	125	200	8	
1	do	50	50	(3)	125	195	8	
1	Douglas-fir (Rocky Mountain)	50	50	(2)	150	190–200	3–4	
1	do	100		35	160	195–200	3–4	
1	do	50	50	(3)	125	195–200	3–4	
1	do	50	50	(2)	140	195–200	3–4	
1	Ponderosa pine	50	50	70	150	195–200	8	
1	do	50	50	60	140	200	8	
1	do	50	50	(2)	80	195–200	8	
1	Western larch	50	50	(2)	125	195–200	8	
1	do	50	50	(2)	125	195–200	8	
1	do	50	50	(2)	140–150	190–200	7	
1	Red oak	25	75	(3)	125	195–200	10	
1	Yellow birch	50	50	40	150	185	7	
1	Hard maple	50	50	40	150	185	7	
1	Western hemlock	100		(3)	110	185–190	8	

See footnotes at end of table.

TABLE 19.—*Commercial treating conditions and retentions in use for air-seasoned material of species grown in the Central and Rocky Mountain States.*—Continued

Plants studied (number)	Species treated	Preservative		Preliminary air pressure	Treating pressure	Preservative temperature	Net retention of preservative	Remarks
		Coal-tar creosote	Petroleum					
		POLES AND POSTS [4]						
		Percent	*Percent*	*Pounds per square inch*	*Pounds per square inch*	°*F.*	*Pounds per cubic foot*	
1	Ponderosa pine poles	50	50	50	150	195–200	8	Short final steaming
1	Douglas-fir (Rocky Mountain) and ponderosa pine posts.	25	75	(3)	125	195–200	8 –9	
1	Lodgepole pine poles	50	50	(2)	130	195–200	4½–5	Short final steaming
1	do	15	85	35	140	195–200	8	
1	do	50	50	35	140	205–210	8	
1	do	50	50	70–75	145	175–190	6	
		GREEN POLES [4]						
1	Lodgepole pine poles	50	50	(3)	80	195	4	Steam-conditioned.
1	do	50	50	30–35	140	200–210	8	Do.
1	do	50	50	(2)	50–90	195–200	4½–5	Do.

[1] Pressure periods for lodgepole pine, western larch, and red oak, about 5 to 6 hours; yellow birch and maple, about ½ hour following heating in preservative at 212° F. for 2 hours; ponderosa pine and western hemlock, 3 to 4 hours; Rocky Mountain type of Douglas-fir, 8 to 12 hours. Final vacuum periods, ½ to 2 hours with average about 1¼ hours.

[2] Lowry process.

[3] Full-cell treatment.

[4] Pressure periods, about 1 to 3 hours for posts and poles; final vacuum periods, ½ to 2 hours, with average about 1 hour.

TABLE 20.—*Commercial treating conditions and retentions in use for species in the Eastern and Southern States*

Species treated and number of plants studied	Preservative: Coal-tar creosote	Preservative: Coal tar	Preliminary air pressure	Maximum treating pressure	Preservative temperature	Net retention
AIR-SEASONED TIES [1]						
	Percent	*Percent*	*Pounds per square inch*	*Pounds per square inch*	*°F.*	*Pounds per cubic foot*
Pine, southern yellow:						
2	100	---	70–90	175	200	6, 8
1	70	30	90–100	200	212	6
1	[2] 25	---	30	125	195–200	10
1	[3] 50	---	45–90	200	200	9½
1	70	30	65–90	200	200	7
1	100	---	90–100	200	200	8
1	100	---	75–80	200	200	6
1	60	40	75–80	200	200	8
2	100	---	60–85	175	200–210	6, 8
1	100	---	60	200	200	8
3	80	20	70–80	200	200–210	8
Gum:						
1	100	---	80	175	200	6
2	70	30	65–80	200	200–210	6, 8
1	80	20	100	200	200–210	10
1	70	30	65–80	200	200	7
1	60	40	75–80	195–200	200	8
1	80	20	60	200	200	9
Oak:						
1	100	---	25	175	200	6
1	100	---	70	200	200	6, 7
1	70	30	(4)	200	200	8½
1	100	---	(4)	175	190–200	7
1	100	---	90	200	200	6
1	100	---	50	175	200	6
1	80	20	80	225	205	8
1	60	40	80	225	205	8
1	80	20	70	200	200	8
1	80	20	20	200	200	8
STEAMED GREEN CROSS ARMS [5]						
Pine, southern yellow:						
1	100	---	60	200	200	10
1	100	---	80	200	200	6
1	100	---	60	175	200	6, 8
STEAMED GREEN LUMBER AND TIMBERS [6]						
Pine, southern yellow:						
1	100	---	50	140	210	8
1	100	---	70–75	150	185–200	8
1	100	---	60–70	175	200	8–12
1 *	100	---	50–70	175	200	8, 10, 12
1	100	---	40–75	150	200	8, 10
1	100	---	25–50	175	200–205	8–16
1	100	---	40–50	200	205	12
1	100	---	50	200	200	12
STEAMED GREEN POSTS [7]						
Pine, southern yellow:						
1	100	---	50	130	200	6
1	100	---	70–80	150	185–200	8
1	100	---	75–80	150	200	6
1	100	---	70–75	150	200	6
1	100	---	85	200	200	8

* see ERRATA, in front.

TABLE 20.—*Commercial treating conditions and retentions in use for species in the Eastern and Southern States.*—Continued

AIR-SEASONED POSTS [7]

Species treated and number of plants studied	Preservative: Coal-tar creosote	Preservative: Coal tar	Preliminary air pressure	Maximum treating pressure	Preservative temperature	Net retention
	Percent	*Percent*	*Pounds per square inch*	*Pounds per square inch*	*°F.*	*Pounds per cubic foot*
Pine, southern yellow:						
1	100	--------	60	175	200	8
1	100	--------	80	180	200	5
STEAMED GREEN PILING AND POLES [8]						
Pine, southern yellow:						
4	100	--------	70–80	175	190–200	8
3	100	--------	50–60	175	200	8, 10
1	100	--------	40	175	200	12
2	100	--------	50–60	200	190–200	8, 10, 12
1	100	--------	40–80	200	210	8, 12
1	100	--------	50–60	160	190–200	8
1	100	--------	40–50	160	190–200	10, 12
1	100	--------	20	200	200	18
1	100	--------	75–80	250	200–210	8
2	100	--------	70–80	150	185–200	8
2	100	--------	70–75	175	200	8, 10, 12
1	100	--------	40–50	200	200	10, 12
1	100	--------	60–80	200	200	8
3	100	--------	(9)	175	200–210	16, 18, 20
4	100	--------	60–70	200	200–205	8, 10
1	100	--------	35	125	200	12
3	100	--------	55	175	200–210	8, 10
2	100	--------	50–60	175	185–200	8, 10
1	100	--------	(4)	175	185–200	16
1	100	--------	80	175	200–210	8
2	100	--------	60–75	175	200–205	8, 10
1	100	--------	50	175–200	200	8, 10, 12
AIR-SEASONED POLES [10]						
Pine, southern yellow:						
1	100	--------	80–90	175	200	8
1	100	--------	60–80	175	205	8
1	100	--------	75–80	200	200	8, 10
1	100	--------	70	200	205	8, 10
2	100	--------	70–80	200	200–210	8, 10

[1] Pressure periods for southern yellow pine ties, 2 to 4 hours; gum ties, 2 to 5 hours; oak ties, 4 to 6 hours. Final vacuum periods range from ½ to maximum of 2 hours, with average about 1 hour.

[2] Remaining 75 percent is petroleum oil.

[3] Remaining 50 percent is petroleum oil.

[4] Lowry process.

[5] Pressure periods, 1½ to 2 hours; final vacuum period, ½ hour.

[6] Pressure periods, 2 to 6 hours; final vacuum periods, ½ to 2½ hours.

[7] Pressure periods, 1 to 2½ hours for green and seasoned posts; final vacuum periods, ½ to 1 hour.

[8] Pressure periods for poles, 2 to 4 hours; piles, 4 to 6 hours. Final vacuum periods, ½ to 1 hour.

[9] Full-cell treatment.

[10] Pressure periods, 2 to 4 hours; final vacuum periods, ¾ to 1 hour.

SPECIFICATIONS FOR TREATMENT

GENERAL CONSIDERATIONS

A large proportion of the wood that is treated commercially is treated under purchasers' specifications. Sometimes the specifications employed are the general specifications developed by various associations that are interested. In other cases the purchaser develops his own specifications and puts into them the provisions that he considers important. Frequently, whatever the source, the specification fails to protect the purchaser or contains provisions that are actually harmful to the wood or unnecessarily increase the cost of the treatment. Competent inspectors placed at the treating plants by the purchaser can enforce compliance with most of the requirements of a specification, but even then the treatment will be unsatisfactory unless the specification is properly prepared or the treating-plant operator gives good treatment despite the specification.

As far as is practicable, the author of a treating specification should take into consideration the following items: Species, form, and dimensions of the timber to be treated, proportion of heartwood and sapwood, degree of seasoning at the time of treatment, method of seasoning or conditioning for treatment, purpose for which the treated timber is to be used, kind of preservative, retention, penetration, and the details of the treating process. The specification, however, should avoid unnecessarily fixing the details of the treating operation. Provision should be made against the use of temperatures, pressures, and treating periods that are likely to damage the wood, but within these limits the plant operator should be given as much freedom as practicable.

As far as possible, the specification should cover the finished product rather than minor details of the treating process. It should also clearly define the methods that will be used in judging the quality of the finished product. In developing new specifications or improvements to old specifications, there should be cooperation and thorough understanding between the purchaser and the treating-plant operator to be sure that the requirements of the specification are reasonable and can be fulfilled. The general specifications that have been adopted by the Federal Government, the American Wood-Preservers' Association, and other associations afford a good starting point, but they are necessarily quite general in character and must often be modified or limited in some respects in order to meet the needs of the individual purchaser.

AVOIDING INJURIOUS TREATING CONDITIONS

While the knowledge of wood-impregnating technic is still too incomplete to show the dividing line between safe and unsafe conditions, enough is known to permit some definite limitations. In the steaming-and-vacuum process of conditioning green timber, various steaming pressures and lengths of steaming periods have been used. With our present state of knowledge, however, there appears to be no good reason why steaming pressures higher than 20 pounds' gage pressure (about 259° F.) should be employed in treating green pine timber. No advantage that might be gained by higher pressures is known that would offset the greater danger that the higher temperatures might damage the timber. Further study and experience may show that the use of pressures lower than 20 pounds will be practical and preferable for the pines. With other species, specifications customarily greatly limit the use of steaming and usually do not permit higher steam temperatures than 240° F.

The data given in figures 13 to 22 can be useful as a guide in selecting a steaming period. From these temperature curves it may be noted that material of small dimension, such as that 3 inches or less in thickness, can be heated in a very short time, so that the temperature at the center is nearly equal to that of the outside steam temperature. With a steam pressure of 20 pounds, about 4 to 5 hours of steaming should be ample for timbers about 6 to 7 inches in diameter, about 1½ to 2 hours for lumber 2 inches in thickness, about 2 to 3 hours for lumber 3 inches in thickness, and 3 to 4 hours for material 4 inches in thickness. The foregoing time intervals assume that full steam temperature is applied at once. In actual practice, from ½ to 1 hour additional may be required to reach the maximum steam temperature. It is important that sawed material be properly spaced or "stickered" in loading the trams so that the steam can circulate freely around every piece; otherwise longer steaming periods will be required and uniform distribution of heat throughout the charge may not be obtained.

In the larger sizes it becomes impractical and also unnecessary to heat the center to a temperature approaching that of the heating medium. It is impractical because of the very long heating periods required and of the injury that might result to the wood. It is unnecessary because the heat at the interior of the large timber cannot be very effective in evaporating moisture during the subsequent vacuum period. Although it is not known just what the wood temperature should be at a given distance from the surface to obtain the most effective results in steam conditioning, it is probable that very little would be gained by heating the wood much above 200° F. at a distance of about 3 inches from the surface. In some of the larger sizes of timber it would be necessary to be satisfied with even lower temperatures at this depth because of the undesirably long steaming periods otherwise required. If particularly long steaming periods are employed, they should be used only with the full knowledge of both operator and purchaser that the risk of damage increases as the steaming period is lengthened. In steaming timbers to sterilize the wood, it is important to bear in mind that the temperature at the central portion will rise to a considerable extent after cooling starts, depending on the surface temperature conditions. This is discussed on page 67.

When conditioning wood by the Boulton process, time and temperature are again the important factors to control in avoiding damage. The specifications of the American Wood-Preservers' Association permit a maximum oil temperature of 220° F. during the boiling-under-vacuum period when treating green Douglas-fir poles and piling, and of 210° F. when treating Douglas-fir lumber and sawed timbers. In the light of present information these temperatures should not be exceeded when conditioning green wood by the Boulton method.

Treating pressures specified should be maximum allowable pressures; not required pressures. The plant operator should be allowed to use any pressure within the maximum limit that will give the required retention and penetration and avoid damage to the timber.

The maximum pressures employed in practice for various species are given in tables 18 to 20 inclusive. Some of these pressures, however, have been found to be too high if applied for a considerable period or when used with preservative temperatures that are more favorable for treatment. With preservative temperatures of 195° to 200° F., gage pressures of 100 to 125 pounds are generally as high as should be used in the full-cell treatment of low-density species such as the spruces and true firs. This also applies to other species that show susceptibility to checking and collapse during treatment. In the empty-cell treatment of such woods the maximum preservative pressure will depend somewhat on the initial air pressure, but it should always be less than an amount equal to the pressures recommended for a full-cell treatment plus the initial air pressure. For example, if an initial air pressure of 50 pounds per square inch is used, the preservative pressure in most cases should not be more than 150 pounds as a maximum with low-density woods or with those that are susceptible to checking and collapse. The more dense woods can, of course, withstand somewhat higher pressures, but if it is found that collapse or checking occurs during treatment, the preservative pressure should be lowered.

SELECTION OF TREATING PROCESS

There is often considerable misunderstanding regarding the relative merits of the full-cell and the empty-cell methods of treatment. The effectiveness of treatment depends upon the preservative, and the retention and depth of penetration, and not upon the treating process, except as the process used may affect the penetration and the retention specified.

The terms "full-cell" and "empty-cell," as applied to treatment, are very misleading, since the so-called full-cell process does not leave the wood cells completely filled with preservative even when an effort is made to obtain this objective, nor does empty-cell treatment leave the cells empty. As previously mentioned in the discussion of the effect of initial air on penetration, the empty-cell process loses much of its value when applied in the treatment of wood that is fairly resistant under normal pressure-treating conditions. The empty-cell treatment is most effective when employed in the treatment of reasonably permeable sapwood, such as that of the pines or the penetrable heartwood of species like the red oaks, black tupelo, or ponderosa pine. In selecting the treating process, the object in all cases should be to obtain the maximum penetration practicable with the absorption specified.

This important consideration has been frequently overlooked in many specifications. Some specifications formerly used required full-cell treatment of timbers that were largely sapwood, and with this stipulated that all sapwood be penetrated. These specifications at the same time named net retentions that would not permit complete sapwood penetration by the full-cell method. An empty-cell treatment should be employed whenever the penetration can be improved thereby, and the purchaser harms himself in restricting the plant operator to the use of the full-cell process when a limited retention is specified. Full-cell treatment should be specified only when, because of a limited amount of sapwood, resistance of the material, or for other reasons, the specified net retention cannot be obtained by an empty-cell treatment.

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In preparing specifications, it is also important to specify retentions that are not too low to give the required penetration. For the same depth of penetration, resistant material such as heartwood timber or round timbers with resistant sapwood generally require a higher concentration of preservative than material that is easily penetrated. Even when an initial air pressure is used, only a limited kick-back can be obtained from resistant wood.

UNNECESSARY REQUIREMENTS

A serious fault with some specifications is that they attempt to fix all the details of treatment regardless of the fact that, even when the same species and the same class of timber are treated, each charge may require some modification of the treating conditions to obtain satisfactory results. For example, in the treatment of green material some timbers will require different steaming or boiling-under-vacuum periods, depending on the size of the timber, moisture content, amount of sapwood and heartwood, and other variables. Similarly, a certain degree of latitude should be permitted in the treating pressures and pressure periods employed because pressure conditions that give good results for some timbers may prove unsatisfactory for others. Specifications, however, should set maximum limits on the steaming pressure, steaming periods, preservative pressures, and similar treating operations that may affect the condition of the timber.

An attempt has sometimes been made to insure deep penetrations by specifying the gross absorption as well as the net retention. Since the net retention may vary widely for any given gross absorption, such specifications are impractical and often impossible to meet. Again, if the sapwood is not very deep or if the wood has a high moisture content when treated, it may be impossible to get the required gross absorption. In any case, it is sufficient to specify the net retention and whatever penetration can reasonably be required.

Specifications sometimes severely limit the amount of sapwood permitted in the timber. As a rule, this merely adds to the cost of the timber, makes it more difficult to get, and may result in poorer treatment than if no limit is placed on the amount of sapwood. This provision is evidently carried over from specifications covering timber to be used without preservative treatment, when the proportion of heartwood had a marked influence on the decay resistance of the wood. Preservatives, however, make sapwood as durable as heartwood; and, since sapwood takes better absorptions and penetrations than heartwood, there is seldom good cause to require a high percentage of heartwood in timber that is to be treated. Since the mechanical properties of sapwood average as high as those of heartwood, strength requirements afford no basis for discriminating against sapwood.

With good vacuum pumps, long vacuum periods are apparently unnecessary at any stage in the treating operation with the exception of the boiling-under-vacuum process. Preliminary vacuum for full-cell treatment of air-seasoned material needs to be extended little, if any, beyond the point at which approximately the maximum vacuum is reached. In order to allow sufficient time for the excess preservative to drip from the wood, final vacuums after full-cell or empty-cell treatments sometimes need to be held longer than a preliminary vacuum.

The vacuum applied after steaming should not be held longer than necessary to obtain a practicable moisture reduction, since after a time the effect is merely to cool the wood to a less favorable treating temperature without appreciably lowering the moisture content. Sufficient experimental work has not yet been done to determine the most effective vacuum periods for various sizes of timber, but the data at hand indicate that some plants use vacuum periods that are appreciably longer than needed to accomplish the best results.

RETENTIONS

The net retentions that should be specified for various types of material such as ties, poles, posts, piling, lumber, and structural timbers of different types will depend on a number of variables. These include kind of material, dimensions, species, service conditions, preservative used, amount of sapwood and heartwood in the timbers, the degree to which the wood is subject to mechanical wear, kind of wood-destroying agencies to which the material is exposed, cost of renewal, possibility of obsolescence, and the like.

The tendency of some purchasers is to specify relatively low retentions in the hope of reducing the cost to the lowest safe minimum. This proves to be false economy in many cases, for the minimum safe retention cannot be named with exactness for any form or use of treated timber. The cost of a little additional preservative is relatively small in comparison with the total cost of the treated timber in place in the finished structure, and the saving in cost that may result from the use of low retentions is very small in comparison to the risk of poor service from inadequate treatment. When long service is required, it is better to specify retentions somewhat above the minimum in common practice.

Most of the general specifications, such as those of the American Wood-Preservers' Association, state the minimum retention required. Engineers preparing specifications for the treatment of timbers, however, may overlook the fact that the figures stipulated are minimum values and may specify retentions even lower than the minimum named. Although it is desirable to avoid the use of retentions that are higher than necessary for satisfactory service and economical treatment, it is important to consider all the variables involved, for, under certain conditions, retentions considerably higher than the minimum may be needed from the standpoint of economy in use.

It is quite natural for one to assume that most timbers in a charge will have about the average volumetric retention specified. This assumption, however, is not justified because of the large number of variables that affect the results. There is often a wide variation in both the retention and the penetration obtained in individual timbers in the same charge; some will have considerably less and others considerably more than the average retention or penetration for the charge as a whole.

Some of the important factors that affect the treatment of individual timbers are differences in dimensions, presence of incipient decay in some pieces, differences in the temperature of the preservative in contact with the various pieces while pressure is applied, variations in moisture content, variable growth conditions that affect the relative resistance to penetration of the preservative, proportion of sapwood and heartwood, depth of sapwood, type of preservative used, method of treatment employed, and similar variables.

Because of these variables it is not practicable to conclude from sample timbers or from sections cut from sample pieces that the charge has received the specified average retention. Even a careful determination of the amount of preservative in the treated portion of the sample would be of little value in estimating the average retention per unit volume of the entire charge with which the sample timbers were treated. In other words, it is necessary to determine the average retentions at the time of treatment, for there is no satisfactory way to obtain this information at a later date. Penetrations, however, can usually be measured at any time, especially when preservative oils are used, and this is one of the most important means of determining whether timbers have been properly treated.

Following are some of the advantages of specifying retentions that are higher than the minimum it is believed will be "just enough."

(1) The higher retentions provide a better reserve against depletion by leaching and evaporation.

(2) They usually result in better distribution and deeper penetration of the preservative.

(3) When the preservative has an uncertain toxicity, the heavier absorptions help protect against a deficiency in this property.

(4) There is less danger of inadequate retention because of careless treatment.

(5) Good retentions help protect against the possibility of not providing sufficient treatment for the more resistant timbers in a charge. Likewise, they help protect against failure to give sufficient treatment to timbers of the larger sizes when the charge contains timbers of different dimensions.

(6) Ample retentions reduce the danger of wide variations between the maximum and minimum penetrations obtained in the same or in different timbers.

The principal disadvantages of using heavier retentions are: The initial cost of treatment is somewhat higher and there is a possibility that objectionable bleeding will take place when oily preservatives are used, as in the case of poles. A higher initial cost of treatment, however, is not necessarily a criterion of the ultimate cost. Under certain circumstances, somewhat higher retentions than commonly specified may result in marked economy by substantially increasing the life in service and thereby reducing the annual charge.

Ties

Coal-tar creosote, solutions of coal-tar creosote and coal tar, and solutions of coal-tar creosote and petroleum oil are the preservatives most widely used for ties. The preservative solutions containing petroleum or tar have been extensively used for many years to help reduce the cost of the preservative and have proved very satisfactory. Table 21 shows the preservatives used and the average retentions specified by various railroads in the United States and Canada as found in a survey made in 1948.

The creosote-petroleum mixtures are extensively used in the Far Western and Rocky Mountain States, and the solutions of creosote and coal tar in the Eastern and Southern States. Most of the ties impregnated with preservative oils are treated by the empty-cell method

TABLE 21—*Preservatives and absorptions used for ties by various railroads in the United States and Canada in 1948* [1]

Number of railroad companies	Coal-tar creosote	Mixtures of coal-tar creosote and petroleum		Mixtures of coal tar creosote and coal tar		Specified retention		
		Coal-tar creosote	Petroleum	Coal tar creosote	Coal tar	Per cubic foot		Per tie
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Pounds*	*Gallons*	*Gallons*
1	100					5.0		
2	100					6.5		
1	100					7.0		
2	100					8.0		
1		30	70			10.0		
3		50	50			7.0, 8.0		
5		50	50			7.0		
6		50	50			8.0		
2		50	50			8.5		
2		50	50			9.0		
1		50	50			9.5		
1		40	60			8.0		
2		40	60			8.0–10.0		
1		70	30			11.0		
1		25	75			9.5		
5				80	20	6.0		
3				80	20	7.0		
1				80	20	8.0		
1				60	40		0.86	
1				60	40			2.5–3.0
1				60	40	7.5		
1				60	40	7.0–8.0		
3				60	40	8.0		
1				60	40	6.0		
4				70	30	8.0		
1				70	30			2.5–3.0
1				70	30			2.5
1				70	30		0.75	
1				70	30	7		
1				50	50	6.0–8.0		
1				50	50			2.5
2				50	50	8		
1				50	50	6.0–7.0		
1				50	50	9.5		
1		40	10	40	10			3.0

[1] Preservative Survey, 1948. Amer. Ry. Engin. Assoc. Bul. 474, p. 402. 1948.

(Lowry or Rueping process), and the specified net retentions usually vary from about 5 to 8 pounds per cubic foot. Retentions of 5 to 6 pounds appear to be too low for ties that can be deeply penetrated, such as red oak or sapwood material.

Although the empty-cell treatment may give good penetrations when the wood has been properly seasoned, the possibility of erratic penetrations is great when low net retentions are used. The chance of erratic penetration decreases with higher retentions. The question also arises whether, even with complete penetration, the concentration of pre-

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servative with these low retentions is sufficient to protect the ties over the period of service that should be expected of properly treated wood. Ties with a considerable proportion of heartwood, treated with the lower retentions, would naturally show a greater concentration of preservative in the treated part than those that take practically complete penetration. The life obtained from the heartwood ties having a heavy concentration of preservative might be much longer than would be obtained from sapwood material or woods that take practically complete penetration, unless the absorption in the latter was increased to compensate for the greater amount of wood treated. In view of the unsatisfactory results that have been noted in some installations of ties treated with the low net retentions of 5 to 6 pounds of preservative oil per cubic foot, it is recommended that, for general use, specifications should require a net retention of at least 8 pounds per cubic foot in ties having 50 percent or more sapwood or when the species is one that can be well penetrated in the heartwood.

If the ties are used under tropical or semitropical conditions, minimum retentions of 10 to 12 pounds of preservative per cubic foot, or treatment with the maximum absorption obtainable, are recommended regardless of whether the creosote is used alone or in mixtures. Some specifications call for 5 to 6 pounds of creosote per cubic foot on the assumption that the greater toxicity of creosote, as compared with that of creosote mixtures containing coal tar or petroleum, will permit these lower retentions when creosote alone is used. Successful results are not assured by a consideration of toxicity only, since permanence plays a very important part. Data on leaching and evaporation indicate that doubling the retention should increase permanence fourfold.

Marine Timbers

The protection of wood against marine borers is a much more difficult problem than protection against decay and insects and requires much higher concentration of the preservative. The Forest Products Laboratory has tested a large number of preservatives to study their effectiveness in protecting wood against marine borers (*41*, *49*). Results obtained in these experiments, as well as experience in general, have shown that heavy retentions of coal-tar creosote are essential if the best protection is to be obtained. The heavy retentions insure better penetrations and also furnish a reserve supply of creosote to provide against early depletion by leaching. Over much of the coastal region of the United States, marine timbers are exposed to severe borer attack, and it is poor economy to specify retentions that will not give the maximum protection under such conditions. Specifications for such timbers should require treatment to refusal by the full-cell process, and the specified retention should be the minimum that will be accepted. No maximum should be specified.

The species most commonly used for marine timbers in the United States are southern yellow pine and coast Douglas-fir. Southern yellow pine piling treated with the maximum retention practicable by the full-cell process usually has average net retentions of 20 to 25 pounds of creosote per cubic foot, provided the moisture content of the wood is not too high at the time of treatment. Since the depth of sapwood on Douglas-fir piling is usually less than that on southern yellow pine, the net retentions are somewhat less in the Douglas-fir for the same treatment. The maximum retention that can be conveniently obtained in the Douglas-fir piling may vary from about 12 to 16 pounds per cubic foot, depending on the size, moisture content, and depth of sapwood.

Posts

Although posts are exposed to service conditions similar to those under which poles are used, the cost of post replacements is small compared with the cost of pole renewals. Furthermore, unlike poles, posts are relatively cheap, and they can usually be replaced at any convenient time and without use of the special equipment and skilled labor commonly required for poles. Preservative retentions specified for posts are therefore usually somewhat less than those for poles and similar timbers that have a high initial cost and that are difficult and costly to replace.

Since posts are exposed to conditions in which leaching is important, preservative oils are generally specified for post treatment. Preservative salts or some of the chemicals carried in suitable nonaqueous solutions may be used when the posts are to be painted. Minimum retentions of about 6 pounds of coal-tar creosote or of creosote and coal-tar solution per cubic foot, or about 7 pounds of creosote-petroleum solution, are usually specified. Some plants, however, treat southern pine posts with retentions of 8 pounds of creosote per cubic foot. Specified retentions of preservative salts or chemicals carried in a nonaqueous solution vary, depending on the preservative used.

Poles

Prior to World War II, most of the pressure-treated poles used in the United States were treated with American Wood-Preservers' Association specification grade 1 coal-tar creosote with a specified distillation residue above 355° C. of not more than 20 to 25 percent.

In recent years solutions of pentachlorophenol have attracted attention as substitutes for creosote or for use in mixtures with creosote, and large quantities have been used. Thousands of poles have been treated with pentachlorophenol dissolved in the lighter petroleum oils or with solutions containing various proportions of coal-tar creosote and pentachlorophenol dissolved in a petroleum-oil solvent. These poles have not been in service for sufficient time to determine how the results will compare ultimately with those obtained from creosoted poles. Experimental installations under observation, however, are giving excellent results, so that this preservative may find a wide field of use in the future.

Most of the poles that have been pressure-treated and on which the best service records are available, are southern yellow pine and coast Douglas-fir. Of these two woods, southern pine has been much more extensively used. Other pine species have also been used to a variable extent during recent years, particularly lodgepole, red, jack, and some ponderosa. Several pole users have also started using pressure-treated western larch poles in varying quantities.

Retentions of 8 to 10 pounds of preservative oil per cubic foot for southern yellow pine and about 8 pounds per cubic foot for coast Douglas-fir have been commonly specified. Poles with these absorptions are treated by the empty-cell processes. Some specifications require retentions of 12 to 14 pounds per cubic foot in southern yellow pine and 10 to 12 pounds in coast Douglas-fir poles.

In some cases lodgepole pine, jack pine, and western larch poles have been treated with retentions of 4.5 to 6 pounds per cubic foot, although 8-pound retentions are more commonly specified. The low retentions have been used partly because of the thinner sapwood in poles of these species and partly because many of the poles are used in regions where decay conditions are not so severe, as in the South where southern pine poles are most extensively employed. Another reason for using the lower retentions is to reduce the possibility of objectionable bleeding as much as possible. Some poles treated with these lower retentions have given good results, but most of them have not been in use a sufficient time to show what service life will be obtained.

Piles

The principal woods used for piling are southern pine and coast Douglas-fir, although a few other woods, such as red pine, lodgepole pine, western larch, and oak, are used in some localities.

Specifications for most species used for land piling generally require retentions of about 10 to 16 pounds of creosote solution, creosote and coal-tar solution, or creosote-petroleum solution per cubic foot of wood. When particularly heavy concentrations of the preservative are needed, retentions should be specified that will insure good sapwood penetration with the full-cell treatment.

Pile renewals are very expensive compared with renewal costs of many other types of timber, such as ties or medium-size poles. In fact, the cost of renewal may be considerably more than the cost of the treated timber. Furthermore, as in the case of bridge structures, traffic obstruction that commonly occurs while repairs are being made, may be an important problem. For this reason it is not good economy to specify retentions that may later prove to be too low to insure a satisfactory service life.

Lumber and Timbers

Coal-tar creosote and its mixtures are commonly employed for sawed material, such as bridge timbers, used under relatively severe conditions. Retentions specified for such timbers vary from about 6 to 20 pounds per cubic foot, about 10 to 12 pounds being most common. Both empty-cell and full-cell methods are employed, depending on the amount of sapwood, retention required, size of timbers, and similar factors. The full-cell process is commonly employed in the treatment of resistant heartwood timbers and timber for use in salt water.

Water-borne salts are widely applied in the treatment of sawed lumber under conditions that make it impractical to employ preservative oils.

Specifications for retentions of both preservative oils and water-borne salts often fail to take into consideration the relation of the timber dimensions to penetration and retention (p. 96). Frequently the treating plant has been blamed for unsatisfactory treatment when the fault lies in the specification, which does not call for a sufficient retention to insure a good penetration. Again, the specifications may require a net retention in large heartwood timbers that cannot be obtained because of the small ratio of surface area to volume, although the same retention might be obtained without difficulty in heartwood timbers of tie size or smaller or in large-size timbers containing a large proportion of sapwood. Table 16 will be found useful in estimating the proportional retention for various sizes of heartwood timbers. In timbers containing 50 percent or more sapwood, it is recommended that at least 10 pounds of preservative oil be specified per cubic foot of wood.[14]

Small and large sizes of heartwood timber should not be treated in the same charge if it can be avoided, but sometimes the total volume of timber in an order is less than enough for one charge and it would be uneconomical to make more than one charge. In such cases the average absorption should be calculated on the proportions of small and large sizes, as shown on p. 101.

PENETRATION

Whenever practicable, the minimum acceptable penetration should be specified, but this should be done with considerable care or the requirement may be impracticable. Complete sapwood penetration is obtained many times in various sizes and shapes of timber, but a strict enforcement of this requirement on every piece of timber treated would generally prove impractical. There should be a definite understanding between purchaser and plant operator as to what will be acceptable and what will not. A complication in this connection is that it is not always easy to locate in treated timber the dividing line between heartwood and sapwood. To say that "as much of the heartwood as practicable shall be penetrated" is too indefinite and adds nothing of value in the specification. It is possible to require minimum penetrations in heartwood faces that are practical to obtain by good treating methods and that are suitable for the service desired of the timber. This is not often done, however, except in incised timber. It is, of course, impractical to demand deep penetrations in boards or timber of small dimensions when insufficient retentions are specified. This is especially true for heartwood material because of the smaller amount of kick-back from heartwood in comparison with that obtained from sapwood.

In the treatment of some kinds of timber, such as posts, ties, and lumber, it is not practical to make penetration measurements on all pieces. For such material it is common practice to specify that a certain number of pieces from each charge shall be bored for penetration measurements and that some high percentage of them shall meet the minimum penetration specified. In such material it is not always practical to require that every piece meet the minimum penetration requirement. In larger, more costly material, however, it is often required that every piece be bored for penetration and that only those meeting the minimum requirement shall be acceptable.

Penetrations of creosote and other dark-colored oils can be measured on increment borings or bit holes made at a sufficient distance from the ends of the piece to escape the effect of end penetration. The oil has a tendency to creep over the surface of the wood in a short time, so that the observation should be made promptly after boring. With sufficient

[14] Specifications of the American Wood-Preservers' Association and Federal specification TT-W-571C include various preservative salts and give retentions recommended.

skill and a sharp knife or blade, the core taken out by the increment borer may be split open lengthwise and a more accurate determination made of the penetration. This avoids the effect of oil creeping along the surface during the boring operation.

The benzidine stain is very satisfactory for showing the demarcation between the heartwood and sapwood of the pines. This is prepared in two separate solutions as follows: Solution 1 is made by dissolving 1 gram of benzidine in 5 grams of 25-percent hydrochloric acid and 194 grams of water. Three parts of commercial hydrochloric acid mixed with 1 part water will give the 25 percent strength required. Solution 2 is made by dissolving 20 grams of sodium nitrite in 80 grams of water. When ready to use, mix 50 percent of solution 1 with 50 percent of solution 2 by volume. Immerse the increment-borer core in the mixture for a few seconds or spray the mixture on the surface of the timber to show the sapwood region. The heartwood turns a dark red, while the sapwood is yellow.

The penetration on borings from timber treated with water-borne salts can usually be shown by spraying the boring with a solution that gives a distinct color reaction with the preservative. If a timber treated with water-borne salts is sawed for penetration measurements before it is seasoned, the saw may carry some of the solution over the cut surface. This could very easily give an indicated penetration much deeper than is actually obtained. Even well-seasoned wood may have particles of sawdust carried over the surface from the treated portion, which would give misleading results. It is therefore important to guard against conditions that will spread the preservative over unpenetrated wood when the timber is either bored or sawed for penetration measurements.

All holes made in treated timber for observing penetration should be tightly plugged with thoroughly treated plugs.

FRAMING AND BORING

Insofar as is practical, the specifications should provide for complete framing and boring before treatment. This is much more practical than is ordinarily supposed (*9*, *62*). Cutting into timber after treatment is very likely to expose untreated wood and thus to permit the entrance of decay or insects beneath the treatment. Cutting after treatment is especially dangerous in timber that will be exposed to marine borers.

APPENDIX

SYMBOLS USED IN FORMULAS RELATING TO PHYSICAL PROPERTIES OF WOOD

C = Percentage shrinkage per unit volume.
D = Average diameter of timber in inches.
M = Percentage moisture based on oven-dry weight.
m = Percentage moisture based on original weight.
M_1 and M_2 = Percentage moisture-content values below the fiber saturation point where moisture-content range is M_1 to M_2, and M_1 is less than M_2.
M_f = Maximum percentage moisture wood will hold when all void space is filled with water.
M_h = Percentage moisture of heartwood (when considered separately from that of the sapwood) based on oven-dry weight.
M_s = Percentage moisture of sapwood (when considered separately from that of the heartwood) based on oven-dry weight.
P = Percentage air space in wood.
P_w = Percentage volume occupied by water in wood.
P_s = Percentage sapwood in timber based on total volume.
ρ_w = Density of water in wood.
S = Specific gravity based on the weight when oven-dry and the volume at current moisture content.
S_a and S_b = Specific gravity values when wood has moisture contents of M_1 and M_2, respectively. S_a greater than S_b and M_1 less than M_2.
S_d = Specific gravity based on the weight of the oven-dry wood and the volume when oven-dry.
S_g = Specific gravity based on the weight of the oven-dry wood and the volume when green.
S_h = Specific gravity of heartwood (when considered separately from that of the sapwood).
S_s = Specific gravity of sapwood (when considered separately from that of the heartwood).
T = Average thickness of sapwood in inches.
W = Original weight of moisture specimen.
W_a = Weight of moisture specimen when oven-dried.
* W_d = Weight of oven-dry per unit volume at moisture content M.
W_m = Weight of water in wood at moisture content M (weight per unit volume).
W_o = Weight per unit volume of wood at moisture content M = weight per unit volume of wood before oven-drying.
W_w = Weight per unit volume of water at maximum density. ($W_w = 1$ in C.G.S. system and equals 0.0361 pound per cubic inch or 62.4 pounds per cubic foot in the English system.)
1.46 = Specific gravity of wood substance determined in helium gas.
1.53 = Specific gravity of wood substance determined in water.

* see Errata, in front.

FORMULAS RELATING TO PHYSICAL PROPERTIES OF WOOD

Moisture Content in Percent

Moisture content based on weight when oven-dry $=M$

$$M=100\left(\frac{W-W_a}{W_a}\right)=100\left(\frac{W_o-W_d}{W_d}\right)=100\left(\frac{W_o}{S(W_w)}-1\right) \qquad (1)$$

Moisture content based on original weight (weight before oven-drying) $=m$

$$m=100\left(\frac{W_o-W_d}{W_o}\right)=100\left(1-\frac{W_d}{W_o}\right) \qquad (2)$$

M expressed in terms of m

$$M=\frac{100\ m}{100-m} \qquad (3)$$

m expressed in terms of M

$$m=\frac{100\ M}{100+M} \qquad (4)$$

Maximum Moisture Content in Percent

(All air space filled)

$$M_f=100\left[\left(W_w-\frac{W_d}{1.53}\right)\div W_d\right]=100\left(\frac{1}{S_g}-\frac{1}{1.53}\right) \qquad (5)$$

If the weights are expressed in pounds per cubic foot,

$$M_f=100\left(\frac{62.4}{W_d}-\frac{1}{1.53}\right) \qquad (6)$$

Specific Gravity

Specific gravity based on weight when oven-dry and volume at current moisture content $=S$

$$S=\frac{W_d}{W_w}=\frac{W_o}{W_w\left(1+\frac{M}{100}\right)} \qquad (7)$$

If the weights are expressed in pounds per cubic foot,

$$S=\frac{W_d}{62.4}=\frac{W_o}{62.4\left(1+\frac{M}{100}\right)} \qquad (8)$$

Specific gravity at any moisture content M, below the fiber saturation point, determined from the specific-gravity values based on weight when oven-dry and volume when green and on weight and volume when oven-dry.

$$S_a=S_d-(S_d-S_g)\frac{M}{30} \qquad (9)$$

Weight of Water per Unit Volume of Wood

$$W_m = (W_o - W_d) = W_d\left(\frac{M}{100}\right) = W_w\left(\frac{MS}{100}\right) \qquad (10)$$

If the weights are expressed in pounds per cubic foot,

$$W_m = 62.4\left(\frac{MS}{100}\right) \qquad (11)$$

Percentage of Volume Occupied by Water

$$P_w = 100\left(\frac{W_o - W_d}{W_w \quad \rho_w}\right) = \frac{\overline{MS}}{\rho_w} \qquad (12)$$

If the weights are expressed in pounds per cubic foot,

$$P_w = 100\left(\frac{W_o - W_d}{(62.4)\rho_w}\right) \qquad (13)$$

Values of ρ_w can be found from figure 8 for moisture-content values up to the fiber saturation point. Above the fiber saturation point

$$\rho_w = \frac{M}{M - 3.1}.$$

Total Weight of Wood and Water at Any Moisture Content

$$W_o = W_d\left(1 + \frac{M}{100}\right) = S\ (W_w)\left(1 + \frac{M}{100}\right) \qquad (14)$$

When W_o and W_d are in pounds per cubic foot:

$$W_o = S\ (62.4)\left(1 + \frac{M}{100}\right) \qquad (15)$$

When the moisture content and specific gravity of the heartwood and sapwood are to be considered separately:

$$W_o = W_w\left[S_s\left(\frac{P_s}{100}\right)\left(1 + \frac{M_s}{100}\right) + S_h\left(1 - \frac{P_s}{100}\right)\left(1 + \frac{M_h}{100}\right)\right] = (W_s + W_h) \qquad (16)$$

where W_s and W_h are the proportional weight of sapwood and heartwood, respectively, per unit volume.

If the specific gravity of the sapwood S_s is assumed to be the same as the specific gravity of the heartwood, which is usually sufficiently accurate for green timbers,

$$W_o = (S)(W_w)\left[\left(\frac{P_s}{100}\right)\left(\frac{M_s}{100} - \frac{M_h}{100}\right) + \left(1 + \frac{M_h}{100}\right)\right] \qquad (17)$$

Percentage of Sapwood in Total Volume

$$P_s = 100\left[\frac{4T\ (D - T)}{D^2}\right] \qquad (18)$$

Percentage of shrinkage in volume in seasoning from moisture content M_2 to a moisture content M_1 (where M_2 is greater than M_1 and not more than 30):

$$C=100\left(\frac{S_a-S_b}{S_a}\right) \tag{19}$$

Percentage of Air Space in Wood

If M_k is the percentage of moisture content at or below the fiber saturation point (taken as 30 percent) and M_a is the percentage of moisture content above the fiber saturation point,

$$P=100\left[1-S\left(\frac{1}{1.46}+\frac{M_k}{100\rho_w}+\frac{M_a}{100}\right)\right] \tag{20}$$

When the moisture content is at or above the fiber saturation point and $M=M_k+M_a$, or the total amount of moisture in the wood, equation 20 may be written:

$$P=100\left[1-S\left(\frac{1}{1.46}+\frac{M-3.1}{100}\right)\right]=100\left[1-S\left(\frac{1}{1.53}+\frac{M}{100}\right)\right] \tag{21}$$

METHOD OF USING FIGURES WHEN FINDING TEMPERATURES TO BE EXPECTED IN TIMBERS HEATED UNDER ANY GIVEN CONDITIONS

A list of symbols employed in the following discussion relating to temperature changes in wood is given on pp. 149–150. Temperatures are designated by using the letter t with various subscripts, while heating periods, expressed in hours, are designated by using Greek letter θ, also with corresponding subscripts.

All computed temperatures plotted in figures 13 to 22, inclusive, are designated as t_c, and the corresponding heating periods found from these figures are designated as θ_c.

In computing the time-temperature curves, the initial wood temperature was taken as 60° F., the heating-medium temperature as 200° F., and the diffusivity a as 0.00025.

If θ_c represents the time required to obtain a temperature t_c at some particular distance from the surface of a timber when the diffusivity is $a=0.00025$, then the time θ_x required to obtain the same temperature under the same heating conditions in the same size timber and at the same distance from the surface when the diffusivity is a_1 is shown by the relation:

$$\theta_x\, a_1=\theta_c a \text{ or } \theta_x=\left(\frac{0.00025}{a_1}\right)\left(\theta_c\right) \text{ and } \left(\theta_c\right)=\frac{a_1}{0.00025}\left(\theta_x\right)$$

Since the diffusivity was assumed as 0.00025 in computing temperature data plotted in the figures, the required heating period θ_x for wood with any other diffusivity designated as a_1 is easily determined by multiplying the ratio $\frac{(0.00025)}{a_1}=f$ by the time θ_c found from the proper chart for the temperature desired. Likewise, when θ_x is given,

$$\theta_c=\left(\frac{a_1}{0.00025}\right)\left(\theta_x\right)=f_1\,\theta_x.$$

TABLE 22.—*Average diffusivity factors for various species and diffusivity ratios to be used as multiplying factors*

Species	Green wood						Seasoned wood, heated in creosote		
	Heated in steam			Heated in creosote					
	Diffusivity a_1	Multiplying factors [1]		Diffusivity a_1	Multiplying factors [1]		Diffusivity a_1	Multiplying factors [1]	
		f	f_1		f	f_1		f	f_1
Slash pine, sugar maple, red oak, beech, rock elm	0.00027	0.93	1.08	0.00023	1.09	0.92	0.00020	1.25	0.8
Longleaf pine, yellow birch, white ash	.00028	.89	1.12	.00024	1.04	.96	.00020	1.25	.8
Shortleaf and loblolly pine, larch and tamarack	.00032	.78	1.28	.00026	.96	1.04	.00022	1.14	.88
Coast Douglas-fir, red pine, black tupelo, sweetgum, American elm	.00033	.76	1.32	.00027	.93	1.08	.00024	1.04	.96
Jack, lodgepole, and ponderosa pine, yellow-poplar, eastern and western hemlock, redwood, Sitka spruce, white fir, eastern spruce	.00036	.70	1.43	.00029	.86	1.16	.00026	.96	1.04
Northern white-cedar, western redcedar, Engelmann spruce, American basswood, northern black cottonwood	.00039	.64	1.56	.00032	.78	1.28	.00028	.89	1.12

* [1] Factor $f = \frac{0.00025.}{a1}$ Factor $f^1 = \frac{a1}{0.00025} = \frac{1}{f}$.

* see errata,

For convenience table 22 has been prepared showing the multiplying factors f and f_1 for both green and seasoned wood of different species when heated in steam or in creosote. As an example, this table shows the multiplying factor f for green longleaf pine heated in steam as $0.89 = \frac{0.00025}{0.00028}$ while for green shortleaf or loblolly pine it is about 0.78. For practical purposes these factors may be taken to the nearest decimal, which gives 0.9 and 0.8, respectively. The simple adjustment in the treating period for differences in the diffusivity of different woods can thus easily be made by using the multiplying factor f in finding θ_x when θ_c is known or the multiplying factor f_1 when θ_x is known and θ_c is to be determined.

For commercial treating conditions the desired information relating to temperature changes in timbers may be obtained either (1) by finding the time θ_x required to obtain a desired temperature t_x at any particular point in a timber when the initial wood temperature t_a and the heating temperature t_b are known, or (2) by finding the temperature t_x obtained at a given point in a timber when the heating period θ_x is

TABLE 23.—*Corresponding wood temperatures t_x obtained with different heating-medium temperatures*

Temperature t_c[1] (°F.)	Corresponding temperature t_x when heating-medium temperature is—					
	210° F.	220° F.	230° F.	240° F.	250° F.	260° F.
	°F.	*°F.*	*°F.*	*°F.*	*°F.*	*°F.*
60	60	60	60	60	60	60
65	65	66	66	66	67	67
70	71	71	72	73	74	74
75	76	77	78	79	80	81
80	81	83	84	86	87	89
85	87	89	90	92	94	96
90	92	94	96	99	101	103
95	97	100	102	105	108	110
100	103	106	109	111	114	117
105	108	111	115	118	121	124
110	114	117	121	124	128	131
115	119	123	127	131	135	139
120	124	129	133	137	141	146
125	130	134	139	144	148	153
130	135	140	145	150	155	160
135	140	146	151	156	162	167
140	146	151	157	163	168	174
145	151	157	163	169	175	181
150	156	163	169	176	182	189
155	162	169	175	182	189	196
160	167	174	181	189	196	203
165	172	180	187	195	202	210
170	178	186	194	201	209	217
175	183	191	200	208	216	224
180	189	197	206	214	223	231
185	194	203	212	221	229	239
190	199	209	218	227	236	246
195	205	214	224	234	243	253
200	210	220	230	240	250	260

[1] From figures based on heating-medium temperature of 200° F.

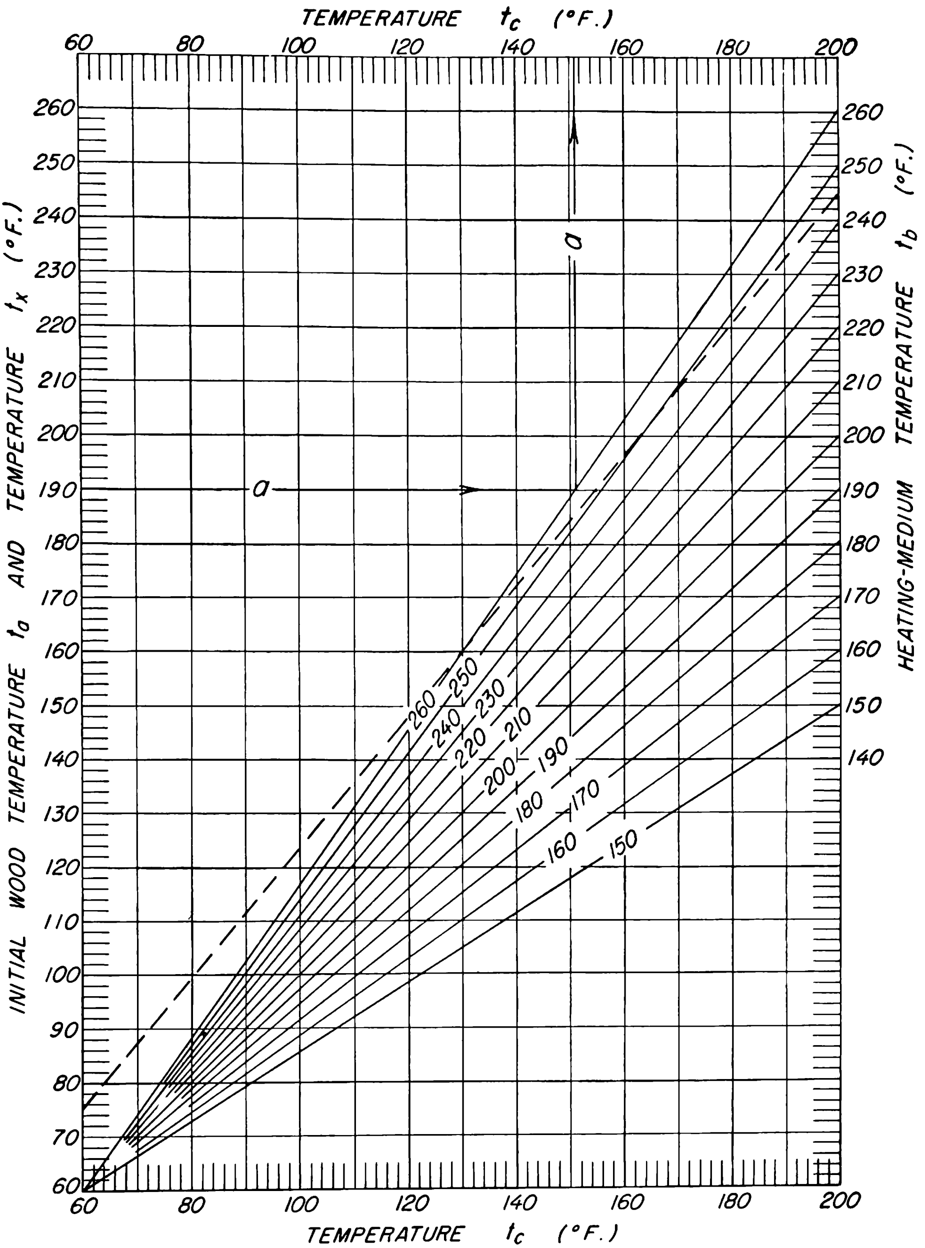

FIGURE 34.—Chart for finding the corresponding temperature t_x within the timber when the initial wood temperature t_a, the heating-medium temperature t_b, or both, are different from those assumed in computing the plotted temperature. (Temperature t_c taken from figs. 13 to 22, inclusive.)

known. In the first case, $\theta_x = f\ \theta_c$, and in the second case, when θ_x is assumed, $\theta_c = \frac{1}{f}\theta_x = f_1\ \theta_x$.

Either table 23 or figure 34 can be used in finding the corresponding wood temperature t_x when the heating conditions are different from those assumed in making the temperature computations. In most cases it will be sufficient to assume that the average initial wood temperature t_a is about 60° F. (as has been done in preparing table 23 and figure 34), but the heating-medium temperature t_b may differ for any charge treated.

A simple algebraic expression that can be used in finding the corresponding wood temperatures t_x when the initial wood temperature is any value t_a, which in winter may be well below 60° F. (the lowest temperature shown in figure 34), is given on page 150, with examples illustrating how to use it.

ADJUSTING FOR DIFFERENT HEATING-MEDIUM TEMPERATURES

In table 23 the first column shows temperatures t_c (temperatures found from the figures) in 5° intervals up to the assumed heating-medium temperature of 200° F. The other columns, 2 to 7, show the corresponding wood temperatures t_x for heating-medium temperatures of 210°, 220°, 230°, 240°, 250°, and 260° F. In this tabulated form, which covers the range of heating temperatures most commonly used, it is easy to compare the increase in wood temperature t_x for each increase in heating-medium temperature listed. The data in table 23 show that the rate of temperature rise at any point will be proportional to the temperature of the heating medium. For example, with a heating-medium temperature of 260° F. the rise in temperature will be $\frac{260-60}{200-60}$, or 1.43° for each 1° temperature rise when the heating-medium temperature is 200° F. and the initial wood temperature is assumed as 60° F. Similarly, when the heating-medium temperature is 250° F., the temperature will rise $\frac{250-60}{200-60}$, or 1.36° for each degree rise when the heating-medium temperature is 200° F., and so on.

A general expression for any value of t_a and t_b is $\frac{t_b-t_a}{140}$ = the temperature change for each 1° temperature rise for the temperature conditions assumed in computing time-temperature data plotted in the figures. Although the rate of temperature rise will be faster or slower than shown for t_c (column 1, table 23), depending on values of t_a and t_b, it will be more convenient and sufficiently accurate to neglect these differences in the 5° intervals of t_c when using this table.

For example, assume $t_x=170°$ and $t_b=260°$ F. In using table 23 to find the corresponding value of t_c, column 7 ($t_b=260°$) reveals that 170° lies between the tabulated temperature of 167°, corresponding to $t_c=135°$, and 174°, corresponding to $t_c=140°$. The required temperature $t_x=170°$ is 3° higher than 167. Adding 3° to 135° gives 138° as the value for t_c. On the other hand, by assuming t_c is given as 143°, the corresponding temperature t_x from column 7 would be taken as 174° plus 3°=177°.

Figure 34 can be used if desired instead of table 23. This figure provides a convenient means of finding the corresponding temperature t_x for any assumed initial wood temperature t_a between 60° and 260° F. or for any heating-medium temperature t_b within the same temperature range.

In using this figure, connect the initial wood temperature t_a on the left-hand scale with the heating-medium temperature t_b on the right-hand scale. This can be done conveniently by means of a straightedge. Values of t_c, which are temperatures found from the time-temperature charts, are to be read on either the bottom or top scale, which are the same.

The lines connecting the initial wood temperatures of 60° F. and various heating-medium temperatures are merely drawn in for convenience in using the chart. The dotted line drawn from the initial wood temperature $t_a=75°$ to the heating-medium temperature $t_b=245°$ shows how the chart can be used for different assumed heating conditions. In this case the dotted line shows how the chart would be used when the initial wood temperature t_a is 75° and the heating-medium temperature t_b is 245°. If initial wood temperatures lower than 60° are to be considered, the corresponding temperatures t_x or t_c can be computed from the simple equation (A) given on page 150.

In figure 34 the line a drawn from $190°=t_x$ (found on left-hand scale) to the line connecting the initial wood temperature $t_a=60°$ F. and the heating-medium temperature $t_b=260°$, shows how to find the corresponding temperature t_c, the plotted temperature to be found from the proper figure. In this case where t_x is 190, the desired wood temperature t_c is found to be 151°. The heating period θ_c can then be found when t_c is determined.

TEMPERATURES IN ROUND TIMBERS

Since timbers such as posts, poles, and piling can be assumed to have approximately a circular cross section, it is possible to compute the temperature in timbers of various diameters after any heating period when the temperature distribution is computed for any given diameter D and for any assumed heating conditions. (See p. 149 for list of symbols used.) This is done by expressing the radial distance from the circumferential surface as a proportion of the radius. In this case the proportional radial distance from the surface is simply the distance F from the surface to the point at which the temperature is to be determined, divided by the radius R. Figure 35 will be convenient to use for this purpose, as it shows either the distance F from the surface (in inches) for any assumed proportional radial distance $\frac{F}{R}$ of timbers ranging in diameter from 4 to 22 inches, or the corresponding proportional radial distance $\frac{F}{R}$ for any assumed distance F from the surface. The two formulas (B) and (C), p. 150, are simple algebraic relations that are the only formulas needed in using figure 13. Since figure 13 is based on a heating-medium temperature of 200° F., table 23 or figure 34 can be used, as explained on pages 140–141, to find t_x when other heating temperatures are used.

The time required to obtain the same temperature at the same proportional radial distance in any two timbers of diameters d and D inches, respectively, will be directly proportional to the squares of the diameters or squares of the radii. For example, assuming the same kind of wood and same heating conditions, if θ_c represents the time required to obtain a given temperature t_c at a proportional radial distance $\frac{F}{r}=\frac{2F}{d}$, where

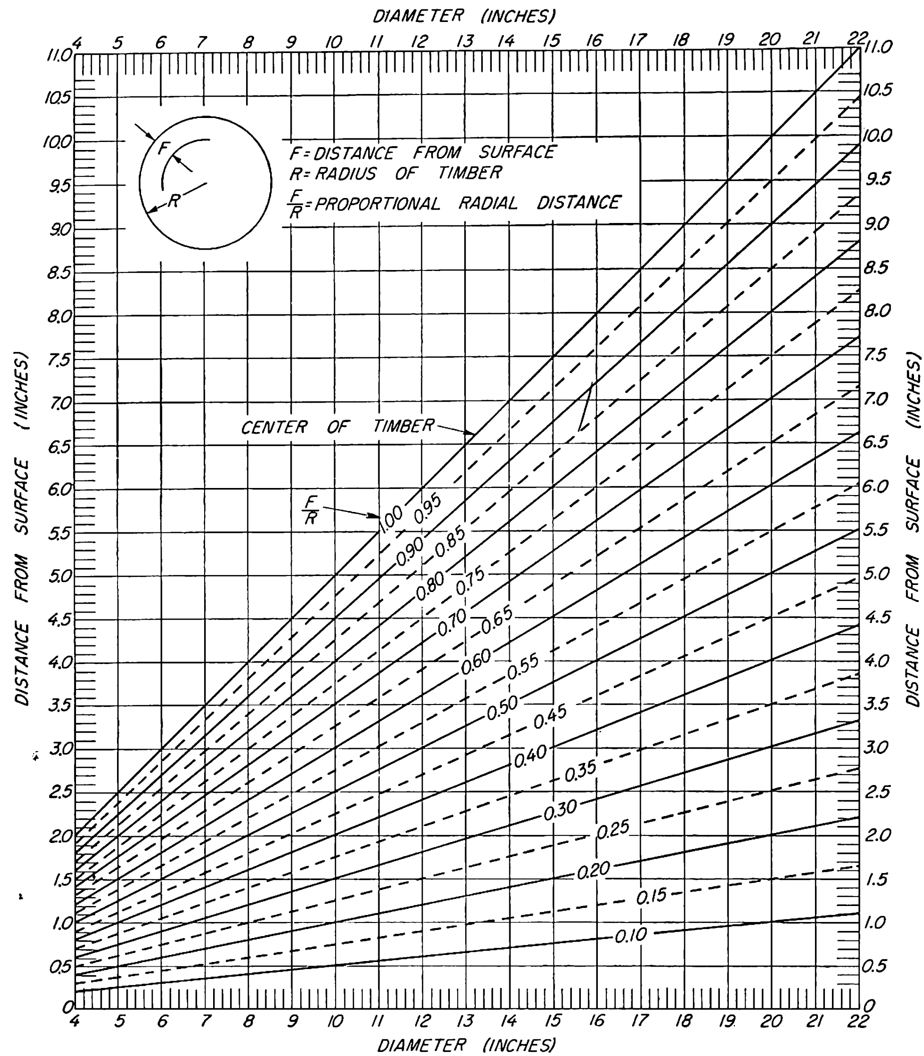

FIGURE 35.—Chart showing relation among distance from surface, proportional radial distance, and diameter of round timbers.

$r=\frac{d}{2}$, in a timber d inches in diameter, and if θ_x represents the time required to reach the same temperature at the same proportional radial distance $\frac{F_1}{R}=\frac{2F_1}{D}$, where $R=\frac{D}{2}$, then $\frac{\theta_c}{\theta_x}=\frac{d^2}{D^2}$. One may then write, $\theta_c=\left(\frac{d^2}{D^2}\right)\theta_x$, and $\theta_x=\left(\frac{D^2}{d^2}\right)\theta_c$. When the proportional radial distances are equal, $\frac{2F}{d}=\frac{2F_1}{D}$, or the distance F_1 from the surface of the timber having a diameter $D=F\left(\frac{D}{d}\right)$.

Figure 13 has been computed for a timber diameter of 10 inches, and because of the foregoing relation, can be used for timbers of any diameter D if the time θ_c computed for the 10-inch diameter is multiplied by $\left(\frac{D^2}{100}\right)$. It is because of this fact that it is an advantage to express the distances from the circumference as a proportion of the radius.

The relation between diffusivity and heating period as given on page 138 is $\theta_x = \left(\frac{0.00025}{a_1}\right) \theta_c$ and $\theta_c = \left(\frac{a_1}{0.00025}\right) \theta_x$. If the temperature t_x is to be calculated at any given proportional radial distance $\frac{F}{R}$ for a timber of diameter D that is greater or less than 10 inches, the required heating period θ_x can be calculated easily by using the simple algebraic relation (B), page 150, which is $\theta_x = \left(\frac{D^2}{100}\right) (f) \left(\theta_c\right)$. Values of f are found in table 22.

On the other hand, if the heating period θ_x is given and it is desired to compute the temperature t_x obtained at any proportional radial distance $\frac{F}{R}$, this can be computed from the relation (C) given on page 150, which is $\theta_c = \left(\frac{100}{D^2}\right) (f_1) \theta_x$.

Values of f and f_1 are given in table 22 for various species. In using the foregoing equation (B), the value t_c corresponding to the required temperature t_x for the given heating-medium temperature t_b is first found from table 23 or figure 34. If the initial wood temperature t_a is greater that 60° (the initial wood temperature assumed in preparing table 23), either figure 34 or the algebraic expression (A), page 150, can be used to find t_c. Equation (A) can be used for any assumed values of t_a and t_b.

Next, find from figure 13 the heating period θ_c corresponding to the temperature t_c for the proportional radial distance $\frac{F}{R}$. Then substitute in (B) the factors $\frac{D^2}{100}$, f, and θ_c, and from the expression determine the required heating period θ_x. (See example 1, p. 146.)

In using equation (C), when θ_x is given and θ_c is to be determined, substitute f_1, from table 22, and the assumed heating period θ_x and compute θ_c. Next find from figure 13, for the proportional radial distance under consideration, the temperature t_c corresponding to the computed heating period θ_c. (See example 2, p. 146.)

Third, find the value of t_x from figure 34 or table 23 that corresponds to t_c for the heating-medium temperature used.

The following two examples illustrate the use of figure 13 in computing temperatures obtained in round timbers when different heating temperatures and different heating mediums are used. (See relation of θ_x, θ_c, and diameter D given in (B) and (C), for round timbers, p. 150).

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Example 1

Data given

Material—Green shortleaf pine timbers with average diameter assumed as 12.5 inches ($=D$).

Heating medium—Steam.

Steam temperature=260° F. ($=t_b$).

Initial wood temperature=60° F. (t_a).

Required data

Find the heating period θ_x needed to obtain a temperature t_x, of approximately 212° F. in the timber at the proportional radial distance of 0.3 $(=\frac{F}{R})$ .This is equal to a distance from the surface of 0.3 $\left(\frac{12.5}{2}\right)$ or 1⅞ inches.

In this example the required heating period θ_x is easily found by using equation (B), page 150.

From table 23 or figure 34 it is found that if the heating-medium temperature is 260° F. when $t_x=212°$, the corresponding value of t_c (given in the first column of table 23) is about 167°.

The heating period θ_c corresponding to 167° when $\frac{F}{R}=0.3$, is found from figure 13 to be about 4.9 hours.

The factor f is found from table 22 to be 0.78 (or approximately 0.80) for green steamed shortleaf pine, and the required value of θ_x is then computed as $(0.80)\left(\frac{(12.5)^2}{100}\right)(4.9)=6.1$ hours.

Example 2

Assume that air-seasoned Douglas-fir piles, with an average diameter of about 14 inches are heated in creosote at 200° F. for 8 hours and that the initial wood temperature t_a is taken as 60°. Compute the temperature at 0.5, 1.5, 2.5, and 3.5 inches from the surface and at the center. In this case $t_b=200°$, $\theta_x=8$ hours, and $\frac{F}{R}=\frac{0.5}{7}$ or 0.07 for 0.5 inch from the surface, $\frac{1.5}{7}$ or 0.21 for 1.5 inches, $\frac{2.5}{7}$ or about 0.36 for 2.5 inches, and $\frac{3.5}{7}$ or 0.50 for 3.5 inches from the surface, and 1.00 at the center. These ratios could also be found by using figure 35.

First find the heating period θ_c from equation (C), p. 150, which gives $\theta_c=\frac{100}{D^2}(f_1)\ \theta_x$.

From table 22 the factor f_1 is found to be 0.96 for seasoned Douglas-fir heated in creosote. By substituting the numerical values, $\theta_c=\frac{100}{196}(0.96)(8)$, or approximately 3.9 hours. Next find from figure 13 the temperature t_c obtained in 3.9 hours for the proportional radial distances. These temperatures t_c are found to be approximately 190° F. for $\frac{F}{R}=0.07$, 171° for $\frac{F}{R}=0.21$, 150° for $\frac{F}{R}=0.36$, 133° for $\frac{F}{R}=0.50$, and 103° at the center.

Since the initial wood temperature and heating-medium temperature have been assumed as 60° and 200° F., respectively (the same as were used in computing the data for fig. 13), $t_c=t_x$. It is therefore unnecessary in this case to use table 23 or figure 34 to adjust for a difference in heating-medium temperature.

It is easy to compare the temperatures that would be obtained if different heating-medium temperatures were employed. For example, after t_c had been determined, table 23 or figure 34 would show that if the creosote temperature t_b had been 220° F. instead of 200°, the computed temperatures at 0.5, 1.5, 2.5, and 3.5 inches from the surface would be about 209°; 187°, 163°, and 143° F. instead of 190°, 171°, 150°, and 133° F., while the temperature at the center would be about 109° instead of 103° F.

Examples (1) and (2), pp. 150–151, show how to find the temperatures t_x or t_c when the initial wood temperature t_a is any temperature below 60° F., the value used in preparing table 23 and as the minimum initial wood temperature for figure 34.

TEMPERATURES IN SAWED TIMBERS

The relative symmetry of material in the round form such as in posts, poles, and piling makes it possible to compute the approximate temperatures for timbers of different diameters when the temperature distribution has been computed for any particular diameter (for example, 10 inches). This possibility has been shown in the discussion of temperature data for round timbers.

A similar relation holds for square timbers, but it does not apply, however, for sawed material when the width and thickness are not equal. It is therefore necessary to compute temperatures at various assumed distances from the surface for sawed timbers of different dimensions.

Figures 14 to 20, inclusive, show computed time-temperature curves for lumber and timbers, 1, 2, 3, 4, 6, 8, 10, and 12 inches in thickness and having widths varying from the square dimensions to 16 inches. Figures 21 and 22 show the computed temperatures midway between the surface and the center, and at the center of timbers 4 by 4, 4 by 6, 7 by 9, 8 by 8, 8 by 10, 10 by 10, 10 by 12, 12 by 12, and 12 by 14 inches in cross section. These time-temperature curves for sawed timbers, like those shown for round timbers in figure 13, were computed by assuming an initial wood temperature of 60° F., a heating-medium temperature of 200° F., and a diffusivity of 0.00025. The data given in tables 22 and 23 will therefore apply for sawed as well as for round timbers.

The temperatures given in figures 14 to 22, inclusive, for sawed timbers and lumber are temperatures obtained along the transverse axis on which the temperature changes take place most slowly. In square timbers the temperature would normally be the same along either transverse axis perpendicular to two parallel faces, since the rate of temperature change may be assumed to be the same in both the radial and tangential directions. In all timbers, however, in which the width and thickness are different, temperature changes will take place more slowly along the axis perpendicular to the wider faces, which is the shorter axis. For example, in a timber 2 by 4 inches in cross section, temperature changes will be slower along the 2-inch axis.

The following examples will illustrate the use of the temperature curves shown in figures 14 to 22, inclusive. (See relation of θ_x and θ_c given in (D) and (E) for sawed timbers, p. 150.)

Example 1

Data given

Material—Green loblolly or shortleaf pine.
Cross-sectional dimension of timber—8 by 10 inches.
Initial wood temperature = 60° F. $(=t_a)$.
Heating medium—Steam.
Steam temperatures 250° F. $(=t_b)$.

Data required

Find steaming period needed to obtain a temperature t_x of 200° F. at a distance of 2 inches from the surface. Table 23 or figure 34 shows that this would correspond to a temperature t_c of approximately 163°. The corresponding heating period θ_c is found from figure 18 to be about 6½ hours. Table 22 shows that the correction factor f for the difference in diffusivity is about 0.8; and since the required time $\theta_x = f\theta_c$, this equals (0.8) 6.5 or about 5.2 hours.

Example 2

Data given

Material—Air-seasoned coast Douglas-fir.
Cross-sectional dimensions—10 by 12 inches.
Heating medium—Coal-tar creosote.
Creosote temperature—210° F. $(=t_b)$.
Initial wood temperature—60° F. $(=t_a)$.

Data required

Find (1) the heating period θ_x required to reach a temperature t_x of 190° F. at a distance of 1 inch from the surface, and (2) find the temperature t_x obtained at the center when the timber has been heated for the time determined.

For part (1) table 23 or figure 34 shows that a temperature t_x of 190° F., when $t_b = 210°$, corresponds to a temperature of about 182° $(=t_c)$ when the heating-medium temperature is 200°. Figure 19 shows that the heating period θ_c required to reach a temperature of 182° at 1 inch from the surface is about 9 hours.

In table 22 the correction factor f to correct for differences in diffusivity is shown as 1.04. The required heating period θ_x is then $f\theta_c = (1.04)\ (9) = 9.36$, or about 9.4 hours.

For part (2) figure 19 shows that a temperature of about 142° F. $(=t_c)$ is obtained at the center when $\theta_c = 9$ hours, corresponding to $\theta_x = 9.4$ hours. This temperature corresponds to a temperature of about 147° when $t_b = 210°$, as shown by table 23 or figure 34.

Example 3

Data given

Material—Air-seasoned red oak ties 7 by 9 inches in cross section.
Heating medium—Coal-tar creosote.
Creosote temperature during pressure period = 200° F. ($=t_b$).
Initial wood temperature = 60° F. ($=t_a$).

Date required

Assuming that the wood is heated only during the pressure period, which is 4 hours long ($=\theta_x$), what temperature t_x can be expected at the center of the ties when the pressure period is completed, neglecting the effect of any heat that might be carried in by penetration of the preservative?

Since the heating-medium temperature is assumed to be 200° F. (which was the temperature used in computing the time-temperature curves), $t_c=t_x$.

Table 22 shows that the factor f_1 for air-seasoned red oak is 0.8; then $\theta_c=(0.8)\ (4)=3.2$ hours. In this case the temperature that can be expected at the center would be the temperature shown in figure 22 after heating for 3.2 hours. This is found to be about 112° F.

If the ties were coast Douglas-fir, black tupelo, or sweetgum, table 22 would show that $f_1=0.96$ for these woods. The heating period θ_c corresponding to $\theta_x=4$ hours is then (0.96) (4), or about 3.8 hours. The temperature t_x that can be expected at the center of ties of these species will then be the temperature shown in figure 14 after heating for 3.8 hours. This is found to be about 126° F.

Computations such as those in example 3 are of interest to determine whether air-seasoned timbers, such as ties, have been heated long enough during the pressure period to sterilize the wood at the center if there is danger of incipient decay being present at the time of treatment.

SYMBOLS AND FORMULAS RELATING TO TEMPERATURE CHANGE IN WOOD

a = Diffusivity factor (0.00025) used in computing temperature curves shown in figures 13 to 22, inclusive. (Diffusivity $=\frac{K}{C\rho}$ where K is conductivity through unit area of a layer of the substance having unit thickness, C is the specific heat, and ρ is the density.)

a_1 = Apparent diffusivity for the wood and heating medium under consideration found from figure 12.

D = Diameter of timber $=2R$.

F = Distance from surface of timber to point at which wood temperature is to be determined. F is measured on radius for round timbers and along axis of sawed timbers. This is measured along the shorter axis if width is different from thickness.

$\frac{F}{R}$ = Proportional radial distances where R is radius of timber.

t = Any wood temperature.

t_a = Any initial wood temperature.

t_b = Any heating-medium temperature.

t_c = Temperature found from figures 13 to 22, inclusive, which were computed by assuming $t_a = 60°$ F., $t_b = 200°$, and diffusivity $a = 0.00025$.

t_x = Wood temperature to be determined at any given point when the heating period θ_x, diffusivity a_1, initial wood temperature t_a, and heating-medium temperature t_b are assumed. If t_x is assumed, θ_x is to be determined.

The relation (A) of t_x, t_c, t_a, and t_b, when 60° and 200° F. are the assumed initial wood temperature and heating-medium temperature, respectively, used in computing the plotted temperature curves in figures 13 to 22, is the following:

$$\frac{t_b - t_x}{t_b - t_a} = \frac{200 - t_c}{140} = \text{(A)}. \quad * +$$

Since t_b, t_a, and either t_x or t_c are assumed to be known, the unknown value of t_x or t_c can be readily determined from the foregoing expression. For most normal ranges of initial wood temperature t_a, or of heating-medium temperature t_b, the temperatures t_x and t_c can be found conveniently by using figure 34 or table 23. *

Examples (1) and (2), pp. 149–150, illustrate the use of formula (A). This formula applies for both round and sawed timbers.

In figures 13 to 22 the computed temperature t_c is plotted against the corresponding heating period θ_c for round timbers of different diameters and for different proportional radial distances $\frac{F}{R}$. Similarly, for sawed timbers the temperature t_c is plotted for different distances from the surface measured along the axis.

For Round Timbers

$$\theta_x = f\left(\frac{D^2}{100}\right)\theta_c \qquad \text{(B)}$$

$$\theta_c = f_1\left(\frac{100}{D^2}\right)\theta_x \qquad \text{(C)}$$

For Sawed Timbers

$$\theta_x = f\theta_c \qquad \text{(D)}$$

$$\theta_c = f_1\theta_x \qquad \text{(E)}$$

Values of f and f_1 are given in table 22 for various species. Figure 13 can be used for timbers of any diameter and for computing the temperature at any proportional radial distance $\frac{F}{R}$. (See list of symbols, p. ~~150~~ 149.) * +

Example 1

(1) Assume the heating-medium temperature $t_b = 250°$ F., the initial wood temperature $t_a = 0°$, and t_c found from one of the figures = 85°. Find the corresponding temperature t_x by using equation (A). (2) With the same assumed temperatures for t_a and t_b, 0° and 250° F., respectively, find the temperature when $t_x = t_c$ and the time θ_x required to reach this

* 150-151
+ * See errata, in front.

temperature at a distance of $\frac{F}{R}$ = 0.3, or 1.8 inches from the surface of a shortleaf pine timber 12 inches in diameter when heated in steam at 250°.

For part (1), substituting in equation (A),

$$\frac{250-t_x}{250-0}=\frac{200-85}{140}$$

$$\therefore \qquad t_x=250-\left[\frac{(250-0)\quad(200-85)}{140}\right]=45°\text{ F.}$$

For part (2), substituting in equation (A),

$$\text{Since } t_c=t_x,\text{ then } \frac{250-t_x}{250-0}=\frac{200-t_x}{140}$$

$$\therefore \qquad t_x=250-\left[\frac{(250-0)\quad(200-t_x)}{140}\right]\text{ ,which gives } t_x=136°\text{ F.}$$

In this case the temperature t_c is the temperature obtained at some particular point in a timber when $t_a=60°$ and $t_b=200°$ F., while t_x is the temperature obtained at the same point in the same time when $t_a=0°$ and $t_b=250°$. Although t_x at the start is lower than t_c, because the initial wood temperature is assumed to be zero instead of 60°, the higher heating-medium temperature of 250° and the greater temperature difference make t_x increase more rapidly than t_c. After reaching 136°, $t_x=t_c$ at $\frac{F}{R}=0.3$, or 1.8 inches from the surface, and will then continue to increase faster than t_c and reach the heating-medium temperature of 250° when t_c reaches the corresponding heating-medium temperature of 200°. From table 22, f is found to be about 0.8, and from figure 13, for $\frac{F}{R}=0.3$, it is found that θ_c is approximately 2.2 hours when $t_c=136°$.

Then $\theta_x=\left(\frac{12^2}{100}\right)(0.8)\ (2.2)=2.53$, or about 2.5 hours, which is the steaming period required to reach a temperature of 136° in the 12-inch-diameter timber when $t_a=0°$, $t_b=250°$ F., and $\frac{F}{R}=0.3$, or 1.8 inches from the surface.

Example 2

Assume the heating-medium temperature $t_b=220°$ F., the initial wood temperature $t_a=75°$, and the temperature $t_x=190°$. Find temperature t_c.

Substituting in the equation (A) gives $\frac{220-190}{220-75}=\frac{200-t_c}{140}$

$$\therefore \qquad t_c=200-\left[\frac{(220-190)\ (140)}{(220-75)}\right]=171°\text{ F.}$$

LITERATURE CITED

(1) Baechler, R. H.
1947. REPORT OF COMMITTEE 4—PRESERVATIVES. Amer. Wood-Preservers' Assoc. Proc. 43: 58–93, illus.

(2) ———
1948. REPORT OF COMMITTEE 4—PRESERVATIVES. Amer. Wood-Preservers' Assoc. Proc. 44: 19–38, illus.

(3) Bailey, I. W.
1915. THE EFFECT OF THE STRUCTURE OF WOOD UPON ITS PERMEABILITY—THE TRACHEIDS OF CONIFEROUS TIMBERS. Amer. Ry. Engin. Assoc. Proc. 16: 835–853, illus.

(4) Bateman, E.
1920. RELATION BETWEEN VISCOSITY AND PENETRANCE OF CREOSOTE INTO WOOD. Chem. & Metall. Eng. 22: 359–360, illus.

(5) Blew, J. O.
1949. WOOD PRESERVATIVES. U. S. Forest Serv. Forest Prod. Lab. Rpt. R149, 5 pp. [Processed.]

(5a) Blew, J. Oscar, Jr., and Champion, Francis J.
1952. PRESERVATIVE TREATMENT OF FENCE POSTS AND FARM TIMBERS. U. S. Dept. Agr. Farmers' Bul. 2049, 33 pp., illus.

(6) Chidester, M. S.
1939. FURTHER STUDIES ON TEMPERATURES NECESSARY TO KILL FUNGI IN WOOD. Amer. Wood-Preservers' Assoc. Proc. 35: 319–324.

(7) Fobes, E. W.
1949. BARK-PEELING MACHINES AND METHODS. U. S. Forest Serv. Forest Prod. Lab. Rpt. D1730, 35 pp., illus. [Processed.]

(8) Gerry, E.
1914. TYLOSES: THEIR OCCURRENCE AND PRACTICAL SIGNIFICANCE IN SOME AMERICAN WOODS. Jour. Agr. Research 1:455-470, illus.

(9) Geyer, C. J.
1938. THE PREFRAMING OF TIMBERS BEFORE TREATMENT FOR USE IN BRIDGES AND BUILDINGS. Amer. Wood-Preservers' Assoc. Proc. 34: 176-182.

(10) Gibbs, R. D.
1935. STUDIES OF WOOD II, ON THE WATER CONTENT OF CERTAIN CANADIAN TREES AND ON CHANGES IN THE WATER-GAS SYSTEM DURING SEASONING AND FLOTATION. Canadian Jour. Res. 12: 727–760.

(11) Griffin, G. J.
1919. BORDERED PITS IN DOUGLAS-FIR: A STUDY OF THE POSITION OF THE TORUS IN MOUNTAIN AND LOWLAND SPECIMENS IN RELATION TO CREOSOTE PENETRATION. Jour. Forestry 17: 813–822, illus.

(12) ———
1924. FURTHER NOTE ON THE POSITION OF THE TORI IN BORDERED PITS IN RELATION TO PENETRATION OF PRESERVATIVES. Jour. Forestry 22: 82–83, illus.

(13) Hatt, W. K.
1906. EXPERIMENTS ON THE STRENGTH OF TREATED TIMBER. U. S. Dept. Agr. Forest Serv. Cir. 39, 31 pp., illus.

(14) ———
1927. REPORT ON THE EFFECT OF STEAMING ON WOOD. Amer. Ry. Engin. Assoc. Bul. 295: 1164–1186.

(15) Hubert, E. E.
1924. EFFECT OF KILN-DRYING, STEAMING, AND AIR-SEASONING ON CERTAIN FUNGI IN WOOD. U. S. Dept. Agr. Bul. 1262, 20 pp., illus.

(16) Hudson, M. S.
1946. POLES SEASONED QUICKLY IN HYDROCARBON ATMOSPHERE. Elect. World 126(11): 90–93, illus.; 126(13): 107–108, illus.

(17) ———
1947. VAPOR-DRYING; THE ARTIFICIAL SEASONING OF WOOD IN VAPOR OF ORGANIC CHEMICALS. Forest Products Research Soc. Proc. 1: 124–146, illus.

(18) Hunt, G. M.
1915. TEMPERATURE CHANGES IN WOOD UNDER TREATMENT. Amer. Wood-Preservers' Associ. Proc. 11: 85–99, illus.

(20) ———
1923–26. REPORT OF COMMITTEE (8, 8–1)—STEAM TREATMENTS. Amer. Wood-Preservers' Assoc. Proc. 19: 340–357, illus., 1923; 20: 265–284, illus., 1924; 22: 225–230, illus., 1926.

(21) ——— and GARRATT, G. A.
1938. WOOD PRESERVATION. 457 pp., illus., New York.

(22) KOEHLER, A.
1924. THE PROPERTIES AND USES OF WOOD. 354 pp., illus. New York.

(23) ———
1933. EFFECT OF HEATING WET WOOD ON ITS SUBSEQUENT DIMENSIONS. Amer. Wood-Preservers' Assoc. Proc. 29: 376–388, illus.

(24) LOUGHBOROUGH, W. K.
1931. VARIATION OF THE SWELLING AND SHRINKING OF WOOD. Amer. Soc. Mech. Engin. Trans. WD1-53-2: 17–20.

(25) MACLEAN, J. D.
1924. RELATIONS OF TEMPERATURE AND PRESSURE TO THE ABSORPTION AND PENETRATION OF ZINC-CHLORIDE SOLUTION INTO WOOD. Amer. Wood-Preservers' Assoc. Proc. 20: 44–73, illus.

(26) ———
1926. EFFECT OF TEMPERATURE AND VISCOSITY OF WOOD PRESERVATIVE OILS ON PENETRATION AND ABSORPTION. Amer. Wood-Preservers' Assoc. Proc. 22: 147–167, illus.

(27) ———
1927. RELATION OF TREATING VARIABLES TO THE PENETRATION AND ABSORPTION OF PRESERVATIVES INTO WOOD. PART III: EFFECT OF TEMPERATURE AND PRESSURE ON THE PENETRATION AND ABSORPTION OF COAL-TAR CREOSOTE INTO WOOD. Amer. Wood-Preservers' Assoc. Proc. 23: 52–70, illus.

(28) ———
1927. REPORT OF COMMITTEE (8-1)—STEAM TREATMENTS. Amer. Wood-Preservers' Assoc. Proc. 23: 189–195, illus.

(29) ———
1928. RELATION OF TREATING VARIABLES TO THE PENETRATION AND ABSORPTION OF PRESERVATIVES INTO WOOD. PART IV: EXPERIMENTS ON MOUNTAIN DOUGLAS-FIR, EASTERN HEMLOCK AND CORK BARK FIR. Amer. Wood-Preservers' Assoc. Proc. 24: 52–77, illus.

(30) ———
1928. REPORT OF COMMITTEE (8-2)—BOILING TREATMENTS. Amer. Wood-Preservers' Assoc. Proc. 24: 171–177, illus.

(31) ———
1929. ABSORPTION OF WOOD PRESERVATIVES SHOULD BE BASED ON THE DIMENSIONS OF THE TIMBER. Amer. Wood-Preservers' Assoc. Proc. 25: 129–142, illus.

(32) ———
1929. ABSORPTION OF WOOD PRESERVATIVES. Engin. News-Record 102: 176–179, illus.

(33) ———
1930. PRESERVATIVE TREATMENT OF ENGELMANN SPRUCE TIES. Amer. Wood-Preservers' Assoc. Proc. 26: 164–183, illus.

(34) ———
1930. STUDIES OF HEAT CONDUCTION IN WOOD. RESULTS OF STEAMING GREEN ROUND SOUTHERN PINE TIMBERS. Amer. Wood-Preservers' Assoc. Proc. 26: 197–219, illus.

(35) ———
1932. STUDIES OF HEAT CONDUCTION IN WOOD—PART II: RESULTS OF STEAMING GREEN SAWED SOUTHERN PINE TIMBERS. Amer. Wood-Preservers' Assoc. Proc. 28: 303-330, illus.

(36) ———
1933. EXPERIMENTS WITH THE BOULTON PROCESS IN THE TREATMENT OF GREEN SOUTHERN PINE POLES. Amer. Wood-Preservers' Assoc. Proc. 29: 343–366, illus.

(37) ———
1935. TEMPERATURE AND MOISTURE CHANGES IN COAST DOUGLAS-FIR. Amer. Wood-Preservers' Assoc. Proc., pp. 77–103, illus.

(38) ———
1936. AVERAGE TEMPERATURE AND MOISTURE REDUCTION CALCULATIONS FOR STEAMED ROUND SOUTHERN PINE TIMBERS. Amer. Wood-Preservers' Assoc. Proc., pp. 256–279, illus.

(39) ———
1938. WEIGHTS AND ABSORPTION LIMITATIONS OF ROUND TIMBERS. Amer. Wood-Preservers' Assoc. Proc. 34: 325–349, illus.

(40) ———
1940 RELATION OF WOOD DENSITY TO RATE OF TEMPERATURE CHANGE IN WOOD IN DIFFERENT HEATING MEDIUMS. Amer. Wood-Preservers' Assoc. Proc. 36: 220–248, illus.

(41) ———
1941. INFORMATION OBTAINED FROM MARINE PILING EXPERIMENTS ON THE GULF COAST. Amer. Wood-Preservers' Assoc. Proc. 37: 107–117, illus.

(42) ———
1941. THERMAL CONDUCTIVITY OF WOOD. Trans. Amer. Soc. Heating and Ventilating Engin. 47: 323–354. [Abstract in Mech. Engin. 63: 734–736.]

(43) ———
1942. THE RATE OF TEMPERATURE CHANGE IN WOOD PANELS HEATED BETWEEN HOT PLATES. U. S. Forest Serv. Forest Prod. Lab. Rpt. 1299, 21 pp., illus. [Processed.]

(44) ———
1943. METHOD OF COMPUTING THE RATE OF TEMPERATURE CHANGE IN WOOD AND PLYWOOD PANELS WHEN THE TWO OPPOSITE SURFACES ARE MAINTAINED AT DIFFERENT TEMPERATURES. U. S. Forest Serv. Forest Prod. Lab. Rpt. R1406, 26 pp., illus.

(45) ———
1943. RATE OF TEMPERATURE CHANGE IN LAMINATED TIMBERS HEATED IN AIR UNDER CONTROLLED RELATIVE-HUMIDITY CONDITIONS. U. S. Forest Serv. Forest Prod. Lab. Rpt. R1434, 33 pp., illus. [Processed.]

(46) ———
1944. EFFECT OF MOISTURE CHANGES ON THE SHRINKING, SWELLING, SPECIFIC GRAVITY, AIR OR VOID SPACE, WEIGHT, AND SIMILAR PROPERTIES OF WOOD. U. S. Forest Serv. Forest Prod. Lab. Rpt. R1448, 44 pp., illus. [Processed.]

(47) ———
1946. RATE OF TEMPERATURE CHANGE IN SHORT-LENGTH ROUND TIMBERS. Amer. Soc. Mech. Engin. Trans. 68 (1): 1–16.

(48) ———
1946. TEMPERATURES OBTAINED IN TIMBERS WHEN THE SURFACE TEMPERATURE IS CHANGED AFTER VARIOUS PERIODS OF HEATING. Amer. Wood-Preservers' Assoc. Proc. 42: 87–139, illus.

(49) ———
1949. RESULTS OF EXPERIMENTS ON THE EFFECTIVENESS OF VARIOUS PRESERVATIVES IN PROTECTING WOOD AGAINST MARINE BORER ATTACK. U. S. Forest Serv. Forest Prod. Lab. Rpt. D1773, 49 pp., illus. [Processed.]

(50) ———
1951. RATE OF DISINTEGRATION OF WOOD UNDER DIFFERENT HEATING CONDITIONS. Amer. Wood-Preservers' Assoc. Proc. 47: 155–168, illus.

(51) MATHEWSON, J. S., MORTON, C. S., AND BESCHER, R. H.
1949. AIR-SEASONING OF RED OAK CROSS TIES. Amer. Wood-Preservers' Assoc. Proc. 45: 216–230, illus.

(52) MCMILLEN, JOHN M.
1950. METHODS OF DETERMINING THE MOISTURE CONTENT OF WOOD. U. S. Forest Serv. Forest Prod. Lab. Rpt. R1649, 15 pp., illus. [Processed].

(53) PHILLIPS, E. W. J.
1933. MOVEMENT OF THE PIT MEMBRANE IN CONIFEROUS WOODS, WITH SPECIAL REFERENCE TO PRESERVATIVE TREATMENT. [Gt. Brit.] Forestry Jour. Soc. Foresters 7: 109–120, illus.

(54) STAMM, A. J.
1929. THE FIBER SATURATION POINT OF WOOD AS OBTAINED FROM ELECTRICAL-CONDUCTIVITY MEASUREMENTS. Indus. and Engin. Chem. Analyt. Ed. 1 (2): 94–97.

(55) ——— AND HANSEN, L. A.
1937. THE BONDING FORCE OF CELLULOSIC MATERIALS FOR WATER. (From specific volume and thermal data.) Jour. Phys. Chem. 41 (7): 1007–1016.

(56) ——— AND SEBORG, R. M.
1935. ABSORPTION COMPRESSION OF CELLULOSE AND WOOD. 1. DENSITY MEASUREMENTS IN BENZINE. Jour. Phys. Chem. 39 (1): 133–141.

(57) ———
1943. COATINGS THAT PREVENT END CHECKS. U. S. Forest Serv. Forest Prod. Lab. Tech. Note 186, 4 pp. [Processed.]

(58) TEESDALE, C. H.
1915. THE BLEEDING AND SWELLING OF PAVING BLOCKS. Amer. Wood-Preservers' Assoc. Proc. 11: 372–397, illus.

(59) ——— AND MACLEAN, J. D.
1918. RELATIVE RESISTANCE OF VARIOUS HARDWOODS TO INJECTION WITH CREOSOTE. U. S. Dept. Agr. Bul. 606, 36 pp., illus.

(60) ——— AND MACLEAN, J. D.
1918. TESTS OF THE ABSORPTION AND PENETRATION OF COAL-TAR CREOSOTE INTO LONGLEAF PINE. U. S. Dept. Agr. Bul. 607. 433 pp., illus.

(61) TIEMANN, H. D.
1910. THE PHYSICAL STRUCTURE OF WOOD IN RELATION TO ITS PENETRABILITY BY PRESERVATIVE FLUIDS. Amer. Ry. Engin. and Maintenance of Way Assoc. Proc. Bul. 120: 781–796, illus.

(62) TROUT, G. H.
1940. PREFRAMING OF TREATED TIMBER FOR USE IN BRIDGES. Amer. Wood-Preservers' Assoc. Proc. 36: 200–205.

(63) WILSON, T. R. C.
1930. THE EFFECT OF CREOSOTE ON STRENGTH OF FIR TIMBERS. Timberman 31(8): 50–52, 54–56, illus.

(64) WIRKA, R. M.
1924. TEMPERATURE CHANGES IN WOOD UNDER TREATMENT. Amer. Wood-Preservers' Assoc. Proc. 20: 285–303, illus.

(65) ———
1925. TEMPERATURE AND MOISTURE CHANGES IN WOOD UNDER STEAMING TREATMENT. Amer. Wood-Preservers' Assoc. Proc. 21: 271–289, illus.

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