Chapter 14

Wood Preservation

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Contents

When left untreated in many outdoor applications, wood becomes subject to degradation by a variety of natural causes. Although some trees possess naturally occurring resistance to decay (Ch. 3, Decay Resistance), many are in short supply or are not grown in ready proximity to markets. Because most commonly used wood species, such as Southern Pine, ponderosa pine, and Douglas-fir, possess little decay resistance, extra protection is needed when they are exposed to adverse environments. Wood can be protected from the attack of decay fungi, harmful insects, or marine borers by applying chemical preservatives. The degree of protection achieved depends on the preservative used and the proper penetration and retention of the chemicals. Some preservatives are more effective than others, and some are more adaptable to certain use requirements. Not only are different methods of treating wood available, but treatability varies among wood species—particularly their heartwood, which generally resists preservative treatment more than does sapwood. To obtain long-term effectiveness, adequate penetration and retention are needed for each wood species, chemical preservative, and treatment method.

Wood preservatives that are applied at recommended retention levels and achieve satisfactory penetration can greatly increase the life of wood structures. Thus, the annual replacement cost of treated wood in service is much less than that of wood without treatment. In considering preservative treatment processes and wood species, the combination must provide the required protection for the conditions of exposure and life of the structure. All these factors are considered by the consensus technical committees in setting reference levels required by the American Wood-Preservers’ Association (AWPA), the American Society for Testing and Materials (ASTM), and the Federal Specification Standards. Details are discussed later in this chapter.

Note that mention of a chemical in this chapter does not constitute a recommendation; only those chemicals registered by the U.S. Environmental Protection Agency (EPA) may be recommended. Registration of preservatives is under constant review by EPA and the U.S. Department of Agriculture. Use only preservatives that bear an EPA registration number and carry directions for home and farm use. Preservatives, such as creosote and pentachlorophenol, should not be applied to the interior of dwellings that are occupied by humans.

Because all preservatives are under constant review by EPA, a responsible State or Federal agency should be consulted as to the current status of any preservative.

Wood Preservatives

The EPA regulates pesticides, and wood preservatives are one type of pesticide. Preservatives that are not restricted by EPA are available to the general consumer for nonpressure treatments, and the sale of others is restricted to certified pesticide applicators. These preservatives can be used only in certain applications and are referred to as "restricted use." Restricted use refers to the chemical preservative and not to the treated wood product. The general consumer may buy and use wood products treated with restricted-use pesticides; EPA does not consider treated wood a toxic substance nor is it regulated as a pesticide.

Consumer Information Sheets (EPA-approved) are available from retailers of treated-wood products. The sheets provide information about the preservative and the use and disposal of treated-wood products. Consumer information sheets are available for three major groups of wood preservatives (Table 14–1):

- Creosote pressure-treated wood
- Pentachlorophenol pressure-treated wood
- Inorganic arsenical pressure-treated wood

Wood preservatives can be divided into two general classes: (1) oilborne preservatives, such as creosote and petroleum solutions of pentachlorophenol and (2) waterborne preservatives that are applied as water solutions. Many different chemicals are in each of these classes, and each has differing effectiveness in various exposure conditions. The three exposure categories for preservatives are (1) ground contact (high decay hazard that needs a heavy-duty preservative), (2) aboveground contact (low decay hazard that does not usually require pressure treatment), and (3) marine exposure (high decay hazard that needs a heavy-duty preservative or possibly dual treatment). In this chapter, both oilborne and waterborne preservative chemicals are described as to their potential and uses. See Table 14–2 for a summary of preservatives and their retention levels for various wood products. Some active ingredients can be used in both oilborne and waterborne preservatives.

Oilborne Preservatives

Wood does not swell from treatment with preservative oils, but it may shrink if it loses moisture during the treating process. Creosote and solutions with heavy, less volatile petroleum oils often help protect wood from weathering, but may adversely influence its cleanliness, odor, color, paintability, and fire performance. Volatile oils or solvents with oilborne preservatives, if removed after treatment, leave the wood cleaner than do the heavy oils but may not provide as much protection. Wood treated with some preservative oils can be glued satisfactorily, although special processing or cleaning may be required to remove surplus oils from surfaces before spreading the adhesive.

Coal-Tar Creosote

Coal-tar creosote (creosote) is a black or brownish oil made by distilling coal tar that is obtained after high temperature carbonization of coal. Advantages of creosote are (a) high toxicity to wood-destroying organisms; (b) relative insolubility in water and low volatility, which impart to it a great degree of permanence under the most varied use conditions; (c) ease of application; (d) ease with which its depth of penetration can be determined; (e) relative low cost (when purchased in wholesale quantities); and (f) lengthy record of satisfactory use.

The character of the tar used, the method of distillation, and the temperature range in which the creosote fraction is collected all influence the composition of the creosote. Therefore, the composition of the various coal-tar creosotes available may vary considerably. However, small differences in composition do not prevent creosotes from giving good service. Satisfactory results in preventing decay may generally be expected from any coal-tar creosote that complies with the requirements of standard specifications.

Several standards prepared by different organizations are available for creosote oils of different kinds. Although the oil obtained under most of these standards will probably be effective in preventing decay, the requirements of some organizations are more exacting than others. The American Society for Testing and Materials Standard D390 for coal-tar creosote has been approved for use by U.S. Department of Defense agencies. This standard covers new coal-tar creosote and creosote in use for the preservative treatment of piles, poles, and timber for marine, land, and fresh water use. Under normal conditions, requirements of this standard can be met without difficulty by most creosote producers. The requirements of this specification are similar to those of the AWPA standard P1/P13 for creosote, which is equally acceptable to the user.

Although coal-tar creosote (AWPA P1/P13) or creosote solutions (AWPA P2) are well-suited for general outdoor service in structural timbers, this creosote has properties that are undesirable for some purposes. The color of creosote and the fact that creosote-treated wood usually cannot be painted satisfactorily make this preservative unsuitable where appearance and paintability are important. Creosote is commonly used for heavy timbers, poles, piles, and railroad ties.

The odor of creosote-treated wood is unpleasant to some people. Also, creosote vapors are harmful to growing plants, and foodstuffs that are sensitive to odors should not be stored where creosote odors are present. Workers sometimes object to creosote-treated wood because it soils their clothes, and creosote vapor photosensitizes exposed skin. With normal precautions to avoid direct skin contact with creosote, there appears to be no danger to the health of workers handling or working near the treated wood. The EPA or the treater should be contacted for specific information on this subject.

Table 14–1. EPA-approved consumer information sheets for three major groups of preservative pressure-treated wood

Preservative treatment	Inorganic arsenicals	Pentachlorophenol	Creosote
Consumer information	This wood has been preserved by pressure-treatment with an EPA-registered pesticide containing inorganic arsenic to protect it from insect attack and decay. Wood treated with inorganic arsenic should be used only where such protection is important. Inorganic arsenic penetrates deeply into and remains in the pressure-treated wood for a long time. Exposure to inorganic arsenic may present certain hazards. Therefore, the following precautions should be taken both when handling the treated wood and in determining where to use or dispose of the treated wood.	This wood has been preserved by pressure-treatment with an EPA-registered pesticide containing pentachlorophenol to protect it from insect attack and decay. Wood treated with pentachlorophenol should be used only where such protection is important. Pentachlorophenol penetrates deeply into and remains in the pressure-treated wood for a long time. Exposure to pentachlorophenol may present certain hazards. Therefore, the following precautions should be taken both when handling the treated wood and in determining where to use and dispose of the treated wood.	This wood has been preserved by pressure treatment with an EPA-registered pesticide containing creosote to protect it from insect attack and decay. Wood treated with creosote should be used only where such protection is important. Creosote penetrates deeply into and remains in the pressure-treated wood for a long time. Exposure to creosote may present certain hazards. Therefore, the following precautions should be taken both when handling the treated wood and in determining where to use the treated wood.
Handling precautions	Dispose of treated wood by ordinary trash collection or burial. Treated wood should not be burned in open fires or in stoves, fireplaces, or residential boilers because toxic chemicals may be produced as part of the smoke and ashes. Treated wood from commercial or industrial use (e.g., construction sites) may be burned only in commercial or industrial incinerators or boilers in accordance with state and Federal regulations. Avoid frequent or prolonged inhalation of sawdust from treated wood. When sawing and machining treated wood, wear a dust mask. Whenever possible, these operations should be performed outdoors to avoid indoor accumulations of airborne sawdust from treated wood. When power-sawing and machining, wear goggles to protect eyes from flying particles. After working with the wood, and before eating, drinking, and using tobacco products, wash exposed areas thoroughly. If preservatives or sawdust accumulate on clothes, launder before reuse. Wash work clothes separately from other household clothing.	Dispose of treated wood by ordinary trash collection or burial. Treated wood should not be burned in open fires or in stoves, fireplaces, or residential boilers because toxic chemicals may be produced as part of the smoke and ashes. Treated wood from commercial or industrial use (e.g., construction sites) may be burned only in commercial or industrial incinerators or boilers rated at 20 million BTU/hour or greater heat input or its equivalent in accordance with state and Federal regulations. Avoid frequent or prolonged inhalation of sawdust from treated wood. When sawing and machining treated wood, wear a dust mask. Whenever possible, these operations should be performed outdoors to avoid indoor accumulations of airborne sawdust from treated wood. Avoid frequent or prolonged skin contact with pentachlorophenol-treated wood. When handling the treated wood, wear long-sleeved shirts and long pants and use gloves impervious to the chemicals (for example, gloves that are vinyl-coated). When power-sawing and machining, wear goggles to protect eyes from flying particles. After working with the wood, and before eating, drinking, and using tobacco products, wash exposed areas thoroughly. If oily preservatives or sawdust accumulate on clothes, launder before reuse. Wash work clothes separately from other household clothing.	Dispose of treated wood by ordinary trash collection or burial. Treated wood should not be burned in open fires or in stoves, fireplaces, or residential boilers, because toxic chemicals may be produced as part of the smoke and ashes. Treated wood from commercial or industrial use (e.g., construction sites) may be burned only in commercial or industrial incinerators or boilers in accordance with state and Federal regulations. Avoid frequent or prolonged inhalations of sawdust from treated wood. When sawing and machining treated wood, wear a dust mask. Whenever possible these operations should be performed outdoors to avoid indoor accumulations of airborne sawdust from treated wood. Avoid frequent or prolonged skin contact with creosote-treated wood; when handling the treated wood, wear long-sleeved shirts and long pants and use gloves impervious to the chemicals (for example, gloves that are vinyl-coated). When power-sawing and machining, wear goggles to protect eyes from flying particles. After working with the wood and before eating, drinking, and using tobacco products, wash exposed areas thoroughly. If oily preservative or sawdust accumulate on clothes, launder before reuse. Wash work clothes separately from other household clothing.

Table 14–1. EPA-approved consumer information sheets for three major groups of preservative pressure-treated wood—con.

Preservative treatment	Inorganic arsenicals	Pentachlorophenol	Creosote
Use site precautions	Wood pressure-treated with waterborne arsenical preservatives may be used inside residences as long as all sawdust and construction debris are cleaned up and disposed of after construction. Do not use treated wood under circumstances where the preservative may become a component of food or animal feed. Examples of such sites would be structures or containers for storing silage or food. Do not use treated wood for cutting boards or countertops. Only treated wood that is visibly clean and free of surface residue should be used for patios, decks, and walkways. Do not use treated wood for construction of those portions of beehives that may come into contact with the honey. Treated wood should not be used where it may come into direct or indirect contact with public drinking water, except for uses involving incidental contact such as docks and bridges.	Logs treated with pentachlorophenol should not be used for log homes. Wood treated with pentachlorophenol should not be used where it will be in frequent or prolonged contact with bare skin (for example, chairs and other outdoor furniture), unless an effective sealer has been applied. Pentachlorophenol-treated wood should not be used in residential, industrial, or commercial interiors except for laminated beams or building components that are in ground contact and are subject to decay or insect infestation and where two coats of an appropriate sealer are applied. Sealers may be applied at the installation site. Urethane, shellac, latex epoxy enamel, and varnish are acceptable sealers for pentachlorophenol-treated wood. Wood treated with pentachlorophenol should not be used in the interiors of farm buildings where there may be direct contact with domestic animals or livestock that may crib (bite) or lick the wood. In interiors of farm buildings where domestic animals or livestock are unlikely to crib (bite) or lick the wood, pentachlorophenol-treated wood may be used for building components which are in ground contact and are subject to decay or insect infestation and where two coats of an appropriate sealer are applied. Sealers may be applied at the installation site. Do not use pentachlorophenol-treated wood for farrowing or brooding facilities. Do not use treated wood under circumstances where the preservative may become a component of food or animal feed. Examples of such sites would be structures or containers for storing silage or food. Do not use treated wood for cutting boards or countertops. Only treated wood that is visibly clean and free of surface residue should be used for patios, decks, and walkways. Do not use treated wood for construction of those portions of beehives that may come into contact with the honey. Pentachlorophenol-treated wood should not be used where it may come into direct or indirect contact with public drinking water, except for uses involving incidental contact such as docks and bridges. Do not use pentachlorophenol-treated wood where it may come into direct or indirect contact with drinking water for domestic animals or livestock, except for uses involving incidental contact such as docks and bridges.	Wood treated with creosote should not be used where it will be in frequent or prolonged contact with bare skin (for example, chairs and other outdoor furniture) unless an effective sealer has been applied. Creosote-treated wood should not be used in residential interiors. Creosote-treated wood in interiors of industrial buildings should be used only for industrial building components that are in ground contact and are subject to decay or insect infestation and for wood-block flooring. For such uses, two coats of an appropriate sealer must be applied. Sealers may be applied at the installation site. Wood treated with creosote should not be used in the interiors of farm buildings where there may be direct contact with domestic animals or livestock that may crib (bite) or lick the wood. In interiors of farm buildings where domestic animals or livestock are unlikely to crib (bite) or lick the wood, creosote-treated wood may be used for building components that are in ground contact and are subject to decay or insect infestation if two coats of an effective sealer are applied. Sealers may be applied at the installation site. Coal-tar pitch and coal-tar pitch emulsion are effective sealers for creosote-treated wood-block flooring. Urethane, epoxy, and shellac are acceptable sealers for all creosote-treated wood. Do not use creosote-treated wood for farrowing or brooding facilities. Do not use treated wood under circumstances where the preservative may become a component of food or animal feed. Examples of such use would be structures or containers for storing silage or food. Do not use treated wood for cutting boards or countertops. Only treated wood that is visibly clean and free of surface residues should be used for patios, decks, and walkways. Do not use treated wood for construction of those portions of beehives that may come into contact with the honey. Creosote-treated wood should not be used where it may come into direct or indirect contact with public drinking water, except for uses involving incidental contact such as docks and bridges. Do not use creosote-treated wood where it may come into direct or indirect contact with drinking water for domestic animals or livestock, except for uses involving incidental contact such as docks and bridges.

Table 14–2. Creosote, oilborne, and waterborne preservatives and retention levels for various wood products[a]

Form of product and service condition	Creosote and oilborne preservative retention (kg/m^3 (lb/ft^3)) Creosote	Creosote solutions	Creosote-petroleum	Pentachloro-phenol, P9, Type A	Pentachloro-phenol, P9, Type E	Copper naphthenate	Oxine copper	AWPA standard
A. Ties (crossties and switch ties)	96–128 (6–8)	112–128 (7–8)	112–128 (7–8)	5.6–6.4 (0.35–0.4)	NR	NR	NR	C2/C6
B. Lumber, timber, plywood; bridge and mine ties								
(1) Salt water[b]	400 (25)	400 (25)	NR	NR	NR	NR	NR	C2/C9
(2) Soil and fresh water	160 (10)	160 (10)	160 (10)	8 (0.50)	NR	0.96 (0.06)	NR	C2/C9
(3) Above ground	128 (8)	128 (8)	128 (8)	6.41 (0.40)	6.4 (0.40)	0.64 (0.04)	0.32 (0.02)	C2/C9
C. Piles								
(1) Salt water[b]								C3/C14/C18
Borer hazard, moderate	320 (20)	320 (20)	NR	NR	NR	NR	NR	
Borer hazard, severe	NR	NR	NR	NR	NR	NR	NR	
Dual treatment	320 (20)	320 (20)	NR	NR	NR	NR	NR	
(2) Soil, fresh water, or foundation	96–272 (6–17)	96–272 (6–17)	96–272 (6–17)	4.8–13.6 (0.30–0.85)	NR	1.60 (0.10)	NR	C3/C14/C24
D. Poles (length >5 m (>16 ft))								
(1) Utility	120–256 (7.5–16)	120–256 (7.5–16)	120–256 (7.5–16)	4.8–12.8 (0.30–0.80)	NR	1.2–2.4 (0.075–0.15)	NR	C4
(2) Building, round and sawn	144–216 (9–13.5)	NR	NR	7.2–10.9 (0.45–0.68)	NR	NR	NR	C4/C23/C24
(3) Agricultural, round and sawn	120–256 (7.5–16)	120–256 (7.5–16)	NR, round (sawn, 192 (12))	6.1–9.6 (0.38–0.60)	NR	NR, round (sawn, 1.2 (0.075))	NR	C4/C16
E. Posts (length <5 m (<16 ft))								
(1) Agricultural, round and sawn, fence	128–160 (8–10)	128–160 (8–10)	128–160 (8–10)	6.4–8.0 (0.40–0.50)	NR	sawn, 0.96 (0.060)	round, 0.88 (0.055)	C2/C5/C16
(2) Commercial–residential construction, round and sawn	128–192 (8–12)	128–192 (8–12)	128–192 (8–12)	8–9.6 (0.50–0.60)	NR	NR	NR	C2/C5/C15/C23
(3) Highway construction								
Fence, guide, sign, and sight	128–160 (8–10)	128–160 (8–10)	128–160 (8–10)	6.4–8.1 (0.40–0.50)	NR	sawn four sides, 0.96 (0.06)	NR	C2/C5/C14
Guardrail and spacer blocks	160–192 (10–12)	160–192 (10–12)	160–192 (10–12)	8–9.6 (0.50–0.60)	NR	sawn four sides, 1.2 (0.075)	NR	C2/C5/C14
F. Glued-laminated timbers/laminates								
(1) Soil and fresh water	160 (10)	160 (10)	160 (10)	9.6 (0.60)	NR	9.6 (0.60)	NR	C28
(2) Above ground	128 (8)	128 (8)	128 (8)	4.8 (0.30)	NR	6.4 (0.40)	3.2 (0.20)	C28

Table 14–2. Creosote, oilborne, and waterborne preservatives and retention levels for various wood products[a]—con.

	Waterborne preservative retention (kg/m^3 (lb/ft^3))								
Form of product and service condition	ACC	ACZA or ACA	CCA Types I, II, or III	ACQ Type B	ACQ Type D	CDDC as Cu	CC	CBA Type A	AWPA standard
A. Ties (crossties and switch ties)	NR	NR	NR	NR	NR	NR	NR	NR	C2/C6
B. Lumber, timber, plywood; bridge and mine ties									
(1) Salt water[b]	NR	40 (2.50)	40 (2.50)	NR	NR	NR	40 (2.50)	NR	C2/C9
(2) Soil and fresh water	6.4 (0.40)	6.4 (0.40)	6.4 (0.40)	6.4 (0.40)	6.4 (0.40)	3.2 (0.20)	6.4 (0.40)	NR	C2/C9
(3) Above ground[c]	4.0 (0.25)	4.0 (0.25)	4.0 (0.25)	4.0 (0.25)	4.0 (0.25)	1.6 (0.10)	4.0 (0.25)	3.27 (0.20)	C2/C9
C. Piles									
(1) Salt water[b]									C3/C14/ C18
Borer hazard, moderate	NR	24 (1.5)	24.1 (1.5)	NR	NR	NR	NR	NR	
Borer hazard, severe	NR	40 (2.50)	40 (2.50)	NR	NR	NR	NR	NR	
Dual treatment	NR	16 (1.00)	16 (1.00)	NR	NR	NR	NR	NR	
(2) Soil, fresh water or foundation	NR	12–16 (0.80–1.0)	12–16 (0.80–1.0)	NR	NR	NR	NR	NR	C3/C14/ C24
D. Poles (length >5 m (>16 ft))									
(1) Utility	NR	9.6 (0.60)	9.6 (0.60)	9.6 (0.60)	NR	NR	NR	NR	C4
(2) Building, round and sawn timber	NR	9.6–12.8 (0.60–0.80)	9.6–12.8 (0.60–0.80)	9.6 (0.60)	9.6 (0.60)	3.2 (0.2)	NR	NR	C4/C23/ C24
(3) Agricultural, round and sawn	NR	9.6 (0.60)	9.6 (0.60)	9.6 (0.60)	NR	NR	NR	NR	C4/C16
E. Posts (length < 5 m (<16 ft))									
(1) Agricultural, round and sawn, fence	NR	6.4 (0.40)	6.4 (0.40)	6.4 (0.40)	NR	NR	NR	NR	C2/C5/ C16
(2) Commercial–residential con-struction, round and sawn	8 (0.50), (NR, sawn structural members)	6.4–9.6 (0.40–0.60)	6.4–9.6 (0.40–0.60)	6.4–9.6 (0.40–0.60)	6.4–9.6 (0.40–0.6)	3.2 (0.20)	6.4 (0.4), (NR, sawn structural members)	NR	C2/C5/ C15/ C23
(3) Highway construc-tion									
Fence, guide, sign, and sight	8–9.9 (0.50–0.62)	6.4 (0.40)	6.4 (0.40)	6.4 (0.40)	NR	NR	NR	NR	C2/C5/ C14
Guardrail and spacer blocks	NR	8 (0.50)	8 (0.50)	8 (0.50)	NR	NR	NR	NR	C2/C5/ C14
F. Glued- laminated timbers/laminates									
(1) Soil and fresh water	8 (0.50)[d]	6.4 (0.40)[d]	6.4 (0.40)[d]	NR	NR	NR	NR	NR	C28
(2) Above ground	3.2 (0.20)	4 (0.25)	4 (0.25)	NR	NR	NR	NR	NR	C28

[a]Retention levels are those included in Federal Specification TT–W–571 and Commodity Standards of the American Wood Preservers' Association. Refer to the current issues of these specifications for up-to-date recommendations and other details. In many cases, the retention is different depending on species and assay zone. Retentions for lumber, timber, plywood, piles, poles, and fence posts are determined by assay of borings of a number and location as specified in Federal Specification TT–W–571 or in the Standards of the American Wood Preservers' Association referenced in last column. Unless noted, all waterborne preservative retention levels are specified on an oxide basis. NR is not recommended.
[b]Dual treatments are recommended when marine borer activity is known to be high (see AWPA C2, C3, C14, and C18 for details).
[c]For use when laminations are treated prior to bonding.

In 1986, creosote became a restricted-use pesticide and is available only to certified pesticide applicators. For use and handling of creosote-treated wood, refer to the EPA-approved Consumer Information Sheet (Table 14–1).

Freshly creosoted timber can be ignited and burns readily, producing a dense smoke. However, after the timber has seasoned for some months, the more volatile parts of the oil disappear from near the surface and the creosoted wood usually is little, if any, easier to ignite than untreated wood. Until this volatile oil has evaporated, ordinary precautions should be taken to prevent fires. Creosote adds fuel value, but it does not sustain ignition.

Coal-Tar Creosotes for Nonpressure Treatments

Special coal-tar creosotes are available for nonpressure treatments, although these creosotes can only be purchased by licensed pesticide applicators. Special coal-tar creosotes differ somewhat from regular commercial coal-tar creosote in (a) being crystal-free to flow freely at ordinary temperatures and (b) having low-boiling distillation fractions removed to reduce evaporation in thermal (hot and cold) treatments in open tanks. Consensus standards do not exist for coal-tar creosote applied by brush, spray, or open-tank treatments.

Other Creosotes

Creosotes distilled from tars other than coal tar are used to some extent for wood preservation, although they are not included in current Federal or AWPA specifications. These include wood-tar creosote, oil-tar creosote, and water–gas-tar creosote. These creosotes protect wood from decay and insect attack but are generally less effective than coal-tar creosote.

Creosote Solution

For many years, either coal tar or petroleum oil has been mixed with coal-tar creosote, in various proportions, to lower preservative costs. These creosote solutions have a satisfactory record of performance, particularly for railroad ties and posts where surface appearance of the treated wood is of minor importance.

The ASTM D391 "Creosote–Coal-Tar Solution" standard covers creosote–coal-tar solution for use in the preservative treatment of wood. This standard has been approved for use by agencies of the U.S. Department of Defense. This specification contains four grades of creosote solutions:

- A (land and fresh water), contains no less than 80% coal-tar distillate (creosote) by volume
- B (land and fresh water), contains no less than 70% coal-tar distillate (creosote) by volume
- C (land and fresh water), contains no less than 60% coal-tar distillate (creosote) by volume
- Marine

The AWPA standard P2 similarly describes the requirements for creosote solutions. The AWPA standard P3 (for creosote–petroleum oil solution) stipulates that creosote–petroleum oil solution shall consist solely of specified proportions of 50% coal-tar creosote by volume (which meets AWPA standard P1/P13) and 50% petroleum oil by volume (which meets AWPA standard P4). However, because no analytical standards exist to verify the compliance of P3 solutions after they have been mixed, the consumer assumes the risk of using these solutions.

Compared with straight creosote, creosote solutions tend to reduce weathering and checking of the treated wood. These solutions have a greater tendency to accumulate on the surface of the treated wood (bleed) and penetrate the wood with greater difficulty because they are generally more viscous than is straight creosote. High temperatures and pressures during treatment, when they can be safely used, will often improve penetration of high viscosity solutions.

Even though petroleum oil and coal tar are less toxic to wood-destroying organisms and mixtures of the two are also less toxic in laboratory tests than is straight creosote, a reduction in toxicity does not necessarily imply less preservative protection. Creosote–petroleum and creosote–coal-tar solutions help reduce checking and weathering of the treated wood. Posts and ties treated with standard formulations of these solutions have frequently shown better service than those similarly treated with straight coal-tar creosote.

Pentachlorophenol Solutions

Water-repellent solutions containing chlorinated phenols, principally pentachlorophenol (penta), in solvents of the mineral spirits type, were first used in commercial dip treatments of wood by the millwork industry about 1931. Commercial pressure treatment with pentachlorophenol in heavy petroleum oils on poles started about 1941, and considerable quantities of various products soon were pressure treated. The standard AWPA P8 defines the properties of pentachlorophenol preservative. Pentachlorophenol solutions for wood preservation shall contain not less than 95% chlorinated phenols, as determined by titration of hydroxyl and calculated as pentachlorophenol. The performance of pentachlorophenol and the properties of the treated wood are influenced by the properties of the solvent used.

The AWPA P9 standard defines solvents and formulations for organic preservative systems. A commercial process using pentachlorophenol dissolved in liquid petroleum gas (LPG) was introduced in 1961, but later research showed that field performance of penta/LPG systems was inferior to penta/P9 systems. Thus, penta/LPG systems are no longer used.

The heavy petroleum solvent included in AWPA P9 Type A is preferable for maximum protection, particularly when wood treated with pentachlorophenol is used in contact with the ground. The heavy oils remain in the wood for a long time and do not usually provide a clean or paintable surface.

Pentachlorophenol in AWPA P9, Type E solvent (dispersion in water), is only approved for aboveground use in lumber, timber, bridge ties, mine ties, and plywood for southern pines, coastal Douglas-fir, and redwood (Table 14–2; AWPA C2 and C9).

Because of the toxicity of pentachlorophenol, care is necessary when handling and using it to avoid excessive personal contact with the solution or vapor. Do not use indoors or where human, plant, or animal contact is likely. Pentachlorophenol became a restricted-use pesticide in November 1986 and is only available to certified applicators. For use and handling precautions, refer to the EPA-approved Consumer Information Sheet (Table 14–1).

The results of pole service and field tests on wood treated with 5% pentachlorophenol in a heavy petroleum oil are similar to those with coal-tar creosote. This similarity has been recognized in the preservative retention requirements of treatment specifications. Pentachlorophenol is effective against many organisms, such as decay fungi, molds, stains, and insects. Because pentachlorophenol is ineffective against marine borers, it is not recommended for the treatment of marine piles or timbers used in coastal waters.

Copper Naphthenate

Copper naphthenate is an organometalic compound that is a dark-green liquid and imparts this color to the wood. Weathering turns the color of the treated wood to light brown after several months of exposure. The wood may vary from light brown to chocolate-brown if heat is used in the treating process. The AWPA P8 standard defines the properties of copper naphthenate, and AWPA P9 covers the solvents and formulations for organic preservative systems.

Copper naphthenate is effective against wood-destroying fungi and insects. It has been used commercially since the 1940s for many wood products (Table 14–2). It is a reaction product of copper salts and naphthenic acids that are usually obtained as byproducts in petroleum refining. Copper naphthenate is not a restricted-use pesticide but should be handled as an industrial pesticide. It may be used for superficial treatment, such as by brushing with solutions with a copper content of 1% to 2% (approximately 10% to 20% copper naphthenate).

Chlorothalonil

Chlorothalonil (CTL) [tetrachloroisophthalonitrile] is an organic biocide that is used to a limited extent for mold control in CCA-treated wood (AWPA P8). It is effective against wood decay fungi and wood-destroying insects. The CTL has limited solubility in organic solvents and very low solubility in water, but it exhibits good stability and leach resistance in wood. This preservative is being evaluated for both aboveground and ground contact applications. The solvent used in the formulation of the preservative is AWPA P9 Type A.

Chlorothalonil/Chlorpyrifos

Chlorothalonil/chlorpyrifos (CTL/CPF) is a preservative system composed of two active ingredients (AWPA P8). The ratio of the two components depends upon the retention specified. CTL is an effective fungicide, and CPF is very effective against insect attack. The solvent used for formulation of this preservative is specified in AWPA P9.

Oxine Copper (copper-8-quinolinolate)

Oxine copper (copper-8-quinolinolate) is an organometalic compound, and the formulation consists of at least 10% copper-8-quinolinolate, 10% nickel-2-ethylhexanoate, and 80% inert ingredients (AWPA P8). It is accepted as a stand-alone preservative for aboveground use for sapstain and mold control and is also used for pressure treating (Table 14–2). A water-soluble form can be made with dodecylbenzene sulfonic acid, but the solution is corrosive to metals.

Oxine copper solutions are greenish brown, odorless, toxic to both wood decay fungi and insects, and have a low toxicity to humans and animals. Because of its low toxicity to humans and animals, oxine copper is the only EPA-registered preservative permitted by the U.S. Food and Drug Administration for treatment of wood used in direct contact with food. Some examples of its uses in wood are commercial refrigeration units, fruit and vegetable baskets and boxes, and water tanks. Oxine copper solutions have also been used on nonwood materials, such as webbing, cordage, cloth, leather, and plastics.

Zinc Naphthenate

Zinc naphthenate is similar to copper naphthenate but is less effective in preventing decay from wood-destroying fungi and mildew. It is light colored and does not impart the characteristic greenish color of copper naphthenate, but it does impart an odor. Waterborne and solventborne formulations are available. Zinc naphthenate is not used for pressure treating and is not intended as a stand-alone preservative.

Bis(tri-n-butyltin) Oxide

Bis(tri-n-butyltin) oxide, commonly called TBTO, is a colorless to slightly yellow organotin compound that is soluble in many organic solvents but insoluble in water. It is not used for pressure treating or as a stand-alone preservative for in-ground use. TBTO concentrate contains at least 95% bis(tri-n-butyltin) oxide by weight and from 38.2% to 40.1% tin (AWPA P8). This preservative has lower mammalian toxicity, causes less skin irritation, and has better paintability than does pentachlorophenol, but it is not effective against decay when used in ground contact. Therefore, TBTO is recommended only for aboveground use, such as millwork. It has been used as a marine antifoulant, but this use has been almost eliminated because of the environmental impact of tin on shellfish.

3-Iodo-2-Propynyl Butyl Carbamate

3-Iodo-2-propynyl butyl carbamate (IPBC) is a preservative that is intended for nonstructural, aboveground use only (for example, millwork). It is not used for pressure treating applications such as decks. The IPBC preservative is included as the primary fungicide in several water-repellent-preservative formulations under the trade name Polyphase and marketed by retail stores. However, it is not an effective insecticide. Waterborne and solventborne formulations are available. Some formulations yield an odorless, treated product that can be painted if dried after treatment. IPBC is also being used in combination with didecyldimethylammonium chloride in a sapstain–mold formulation (NP–1). IPBC contains 97% 3-iodo-2-propynyl butyl carbamate, with a minimum of 43.4% iodine (AWPA P8).

Alkyl Ammonium Compound

Alkyl ammonium compound (AAC) or didecyldimethylammonium chloride (DDAC) is a compound that is effective against wood decay fungi and insects. It is soluble in both organic solvents and water and is stable in wood as a result of chemical fixation reactions. It is currently being used as a component of ammoniacal copper quat (ACQ) (see section on Waterborne Preservatives) for aboveground and ground contact and is a component of NP–1 for sapstain and mold control.

Propiconazole

Propiconazole is an organic triazole biocide that is effective against wood decay fungi but not against insects (AWPA P8). It is soluble in some organic solvents, but it has low solubility in water and is stable and leach resistant in wood. It is currently being used commercially for aboveground and sapstain control application in Europe and Canada. Solvents used in the formulation of the preservative are specified in either AWPA P9 Type C or Type F.

4,5-Dichloro-2-N-Octyl-4-Isothiazolin-3-One

4,5-dichloro-2-N-octyl-4-isothiazolin-3-one is a biocide that is effective against wood decay fungi and insects. It is soluble in organic solvents, but not in water, and is stable and leach resistant in wood. This biocide is not currently being used as a wood preservative. The solvent used in the formulation of the preservative is specified in AWPA P9 Type C.

Tebuconazole

Tebuconazole (TEB) is an organic triazole biocide that is effective against wood decay fungi, but its efficacy against insects has not yet been evaluated. It is soluble in organic solvents but not in water, and it is stable and leach resistant in wood. Currently, TEB has no commercial application. The solvents used in the formulation of this preservative are specified in either AWPA P9 Type C or Type F.

Chlorpyrifos

Chlorpyrifos (CPF) is a preservative recently put into standard (AWPA P8). It is very effective against insect attack but not fungal attack. If fungal attack is a concern, then CPF should be combined with an appropriate fungicide, such as chlorothalonil/chlorpyrifos or IPBC/chlorpyrifos.

Water-Repellent and Nonpressure Treatments

Effective water-repellent preservatives will retard the ingress of water when wood is exposed above ground. Therefore, these preservatives help reduce dimensional changes in the wood as a result of moisture changes when the wood is exposed to rainwater or dampness for short periods. As with any wood preservative, the effectiveness in protecting wood against decay and insects depends upon the retention and penetration obtained in application. These preservatives are most often applied using nonpressure treatments like brushing, soaking, or dipping.

Preservative systems containing water-repellent components are sold under various trade names, principally for the dip or equivalent treatment of window sash and other millwork. Many are sold to consumers for household and farm use. Federal specification TT–W–572 stipulates that such preservatives (a) be dissolved in volatile solvents, such as mineral spirits, (b) do not cause appreciable swelling of the wood, and (c) produce a treated wood product that meets a performance test on water repellency.

The preservative chemicals in Federal specification TT–W–572 may be one of the following:

- Not less than 5% pentachlorophenol
- Not less than 1% copper in the form of copper naphthenate
- Not less than 2% copper in the form of copper naphthenate for tropical conditions
- Not less than 0.045% copper in the form of oxine copper for uses when foodstuffs will be in contact with the treated wood

The National Wood Window and Door Association (NWWDA) standard for water-repellent preservative nonpressure treatment for millwork, IS 4–94, permits other preservatives, provided the wood preservative is registered for use by the EPA under the latest revision of the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) and that all water-repellent preservative formulations are tested for effectiveness against decay according to the soil block test (NWWDA TM1).

The AWPA Standard N1 for nonpressure treatment of millwork components also states that any water-repellent preservative formulation must be registered for use by the EPA under the latest revision of FIFRA. The preservative must also meet the *Guidelines for Evaluating New Wood Preservatives for Consideration by the AWPA* for nonpressure treatment.

Water-repellent preservatives containing oxine copper are used in nonpressure treatment of wood containers, pallets, and other products for use in contact with foods. When combined with volatile solvents, oxine copper is used to pressure-treat lumber intended for use in decking of trucks and cars or related uses involving harvesting, storage, and transportation of foods (AWPA P8).

Waterborne Preservatives

Waterborne preservatives are often used when cleanliness and paintability of the treated wood are required. Several formulations involving combinations of copper, chromium, and arsenic have shown high resistance to leaching and very good performance in service. Waterborne preservatives are included in specifications for items such as lumber, timber, posts, building foundations, poles, and piling.

Test results based on sea water exposure have shown that dual treatment (waterborne copper-containing salt preservatives followed by creosote) is possibly the most effective method of protecting wood against all types of marine borers. The AWPA standards have recognized this process as well as the treatment of marine piles with high retention levels of ammoniacal copper arsenate (ACA), ammoniacal copper zinc arsenate (ACZA), or chromated copper arsenate (CCA). The recommended treatment and retention in kilograms per cubic meter (pounds per cubic foot) for round timber piles exposed to severe marine borer hazard are given in Table 14–3. Poorly treated or untreated heartwood faces of wood species containing "high sapwood" that do not require heartwood penetration (for example, southern pines, ponderosa pine, and red pine) have been found to perform inadequately in marine exposure. In marine applications, only sapwood faces should be allowed for waterborne-preservative-treated pine in direct sea water exposure.

Waterborne preservatives leave the wood surface comparatively clean, paintable, and free from objectionable odor. CCA and acid copper chromate (ACC) must be used at low treating temperatures (38ºC to 66ºC (100ºF to 150ºF)) because they are unstable at higher temperatures. This restriction may involve some difficulty when higher temperatures are needed to obtain good treating results in woods such as Douglas-fir. Because water is added to the wood in the treatment process, the wood must be dried after treatment to the moisture content required for the end use intended.

Inorganic arsenicals are a restricted-use pesticide. For use and handling precautions of pressure-treated wood containing inorganic arsenicals, refer to the EPA-approved Consumer Information Sheet (Table 14–1).

Standard wood preservatives used in water solution include ACC, ACZA, and CCA (Types A and C). Other preservatives in AWPA P5 include alkyl ammonium compound (AAC) and inorganic boron. Waterborne wood preservatives, without arsenic or chromium, include ammoniacal copper quat (ACQ) (Types B and D), copper bis(dimethyldithiocarbamate) (CDDC), ammoniacal copper citrate (CC), and copper azole–Type A (CBA–A), for aboveground use only.

Acid Copper Chromate

Acid copper chromate (ACC) contains 31.8% copper oxide and 68.2% chromium trioxide (AWPA P5). The solid, paste, liquid concentrate, or treating solution can be made of copper sulfate, potassium dichromate, or sodium dichromate. Tests on stakes and posts exposed to decay and termite attack indicate that wood well-impregnated with ACC gives acceptable service, but it is more prone to leaching than are most other waterborne preservatives. Use of ACC is generally limited to cooling towers that cannot allow arsenic leachate in cooling water.

Ammoniacal Copper Zinc Arsenate

Ammoniacal copper zinc arsenate (ACZA) is used in the United States but not in Canada. It is commonly used on the West Coast for the treatment of Douglas-fir. The penetration

Table 14–3. Preservative treatment and retention necessary to protect round timber piles from severe marine borer attack

Treatment	Retention (kg/m³ (lb/ft³)) Southern Pine, red pine	Retention (kg/m³ (lb/ft³)) Coastal Douglas-fir	AWPA standard
Limnoria tripunctata only			
Ammoniacal copper arsenate	40 (2.50), (24 (1.5))[a]	40 (2.50)	C3, C18
Ammoniacal copper zinc arsenate	40 (2.50), (24 (1.5))[a]	40 (2.50)	C3, C18
Chromated copper arsenate	40 (2.50) (24 (1.5))[a]	Not recommended	C3, C18
Creosote	320 (20), (256 (16))[a]	320 (20)	C3, C18
Limnoria tripunctata and Pholads (dual treatment)			
First treatment			
Ammoniacal copper arsenate	16 (1.0)	16 (1.0)	C3, C18
Ammoniacal copper zinc arsenate	16 (1.0)	16 (1.0)	C3, C18
Chromated copper arsenate	16 (1.0)	16 (1.0)	C3, C18
Second treatment			
Creosote	320 (20.0)	320 (20.0)	C3, C18
Creosote solution	320 (20.0)	Not recommended	C3, C18

[a]Lower retention levels are for marine piling used in areas from New Jersey northward on the East Coast and north of San Francisco on the West Coast in the United States.

of Douglas-fir heartwood is improved with ACZA because of the chemical composition and stability of treating at elevated temperatures. Wood treated with ACZA performs and has characteristics similar to those of wood treated with CCA (Table 14–2).

ACZA should contain approximately 50% copper oxide, 25% zinc oxide, and 25% arsenic pentoxide dissolved in a solution of ammonia in water (AWPA P5). The weight of ammonia is at least 1.38 times the weight of copper oxide. To aid in solution, ammonium bicarbonate is added (at least equal to 0.92 times the weight of copper oxide).

A similar formulation, ammoniacal copper arsenate (ACA), is used in Canada. This preservative is used most commonly to treat refractory species, such as Douglas-fir. Service records on structures treated with ACA show that this preservative provides protection against decay and termites. High retention levels of preservative will provide extended service life to wood exposed to the marine environment, provided pholad-type borers are not present. ACZA replaced ACA in the United States because ACZA has less arsenic and is less expensive than ACA.

Chromated Copper Arsenate

Three types of chromated copper arsenate (CCA)—Types A, B, C—are covered in AWPA P5, but Type C is by far the most commonly used formulation. The compositions of the three types are given in Table 14–4. Standard P5 permits substitution of potassium or sodium dichromate for chromium trioxide; copper sulfate, basic copper carbonate, or copper hydroxide for copper oxide; and arsenic acid, sodium arsenate, or pyroarsenate for arsenic pentoxide.

1. CCA Type A (Greensalt)—Currently, CCA Type A is only being used by a few treaters in California. CCA Type A is high in chromium. Service data on treated poles, posts, and stakes installed in the United States since 1938 have shown that CCA Type A provides excellent protection against decay fungi and termites.

2. CCA Type B (K–33) —Commercial use of this preservative in the United States started in 1964, but it is no longer used in significant quantities. CCA Type B is high in arsenic and has been commercially used in Sweden since 1950. It was included in stake tests in the United States in 1949 and has been providing excellent protection.

3. CCA Type C (Wolman)—Currently, Type C is by far the most common formulation of CCA being used because it has the best leach resistance and field efficacy of the three CCA formulations. CCA Type C composition was selected by AWPA technical committees to encourage a single standard for CCA preservatives. Commercial preservatives of similar composition have been tested and used in England since 1954, then in Australia, New Zealand, Malaysia, and in various countries of Africa and Central Europe; they are performing very well.

High retention levels (40 kg/m^3 (2.5 lb/ft^3)) of the three types of CCA preservative will provide good resistance to *Limnoria* and *Teredo* marine borer attack. In general, Douglas-fir heartwood is very resistant to treatment with CCA.

Ammoniacal Copper Quat

There are basically two types of ammoniacal copper quat (ACQ) preservatives (AWPA P5):

- Type B (ACQ–B) [ammoniacal]
- Type D (ACQ–D) [amine-based]

The compositions of these two types are given in Table 14–5. ACQ is used for many of the same applications as are ACZA and CCA, but it is not recommended for use in salt water. ACQ–B, the ammoniacal formulation, is better able to penetrate difficult to treat species such as Douglas-fir; ACQ–D provides a more uniform surface appearance. Wood products treated with ACQ Type B and D are included in the AWPA Commodity Standards (Table 14–2).

Copper bis(dimethyldithiocarbamate)

Copper bis(dimethyldithiocarbamate) (CDDC) is a reaction product formed in wood as a result of the dual treatment of two separate treating solutions. The first treating solution contains a maximum of 5% bivalent copper–ethanolamine (2-aminoethanol), and the second treating solution contains a minimum of 2.5% sodium dimethyldithiocarbamate

Table 14–4. Composition of the three types of chromated copper arsenate[a]

	Chromated copper arsenate (parts by weight)		
Component	Type A	Type B	Type C
Chromium trioxide	65.5	35.3	47.5
Copper oxide	18.1	19.6	18.5
Arsenic pentoxide	16.4	45.1	34.0

[a]As covered in AWPA P5.

Table 14–5. Composition of two types of ammoniacal copper quat[a]

	Ammoniacal cooper quat (parts by weight)	
Component	Type B	Type D
Copper oxide	66.7	66.7
Quat as DDAC[b]	33.3	33.3
Formulation	ammoniacal	amine

[a]As covered in AWPA P5.
[b]DDAC is didecyldimethylammonium chloride.

(AWPA P5). CDDC-treated wood products are included in the AWPA Commodity Standards (Table 14–2) for uses such as residential construction. Like CCA and ACQ–D, CDDC is not recommended for treatment of refractory species such as Douglas-fir.

Ammoniacal Copper Citrate

Ammoniacal copper citrate (CC) has 62.3% copper as copper oxide and 35.8% citric acid dissolved in a solution of ammonia in water (AWPA P5). CC-treated wood products are included in the AWPA Commodity Standards (Table 14–2). Like other ammonia-based preservatives, CC can be used to treat refractory species such as Douglas-fir.

Copper Azole–Type A

Copper azole–Type A (CBA–A) has 49% copper as Cu, 49% boron as boric acid, and 2% azole as tebuconazole dissolved in a solution of ethanolamine in water (AWPA P5). Wood products treated with CBA–A are included in the AWPA Commodity Standards for aboveground use only (Table 14–2).

Inorganic Boron (Borax/Boric Acid)

Borate preservatives are readily soluble in water, are highly leachable, and should only be used above ground where the wood is protected from wetting. When used above ground and protected from wetting, this preservative is very effective against decay, termites, beetles, and carpenter ants. Borates are odorless and can be sprayed, brushed, or injected. They will diffuse into wood that is wet; therefore, these preservatives are often used as a remedial treatment. Borates are widely used for log homes, natural wood finishes, and hardwood pallets.

The solid or treating solution for borate preservatives (borates) should be greater than 98% pure, on an anhydrous basis (AWPA P5). Acceptable borate compounds are sodium octaborate, sodium tetraborate, sodium pentaborate, and boric acid. These compounds are derived from the mineral sodium borate, which is the same material used in laundry additives.

Preservative Effectiveness

Preservative effectiveness is influenced not only by the protective value of the preservative chemical, but also by the method of application and extent of penetration and retention of the preservative in the treated wood. Even with an effective preservative, good protection cannot be expected with poor penetration or substandard retention levels. The species of wood, proportion of heartwood and sapwood, heartwood penetrability, and moisture content are among the important variables that influence the results of treatment. For various wood products, the preservatives and retention levels listed in Federal Specification TT–W–571 and the AWPA Commodity Standards are given in Table 14–2.

Few service tests include a variety of preservatives under comparable conditions of exposure. Furthermore, service tests may not show a good comparison between different preservatives as a result of the difficulty in controlling the previously mentioned variables. Such comparative data under similar exposure conditions, with various preservatives and retention levels, are included in the USDA Forest Service, Forest Products Laboratory, stake test study on Southern Pine sapwood (Gutzmer and Crawford 1995). A summary of these test results is included in Table 14–6.

In the same manner, a comparison of preservative treatments in marine exposure (Key West, Florida) of small wood panels is included in Johnson and Gutzmer (1990). These preservatives and treatments include creosotes with and without supplements, waterborne preservatives, waterborne preservative and creosote dual treatments, chemical modifications of wood, and various chemically modified polymers. In this study, untreated panels were badly damaged by marine borers after 6 to 18 months of exposure while some treated panels have remained free of attack after 19 years in the sea.

Effect of Species on Penetration

The effectiveness of preservative treatment is influenced by the penetration and distribution of the preservative in the wood. For maximum protection, it is desirable to select species for which good penetration is best assured.

The heartwood of some species is difficult to treat. There may be variations in the resistance to preservative penetration of different wood species. Table 14–7 gives the relative resistance of the heartwood to treatment of various softwood and hardwood species (MacLean 1952).

In general, the sapwood of most softwood species is not difficult to treat under pressure. Examples of species with sapwood that is easily penetrated when it is well dried and pressure treated are the pines, coastal Douglas-fir, western larch, Sitka spruce, western hemlock, western redcedar, northern white-cedar, and white fir (*A. concolor*). Examples of species with sapwood and heartwood somewhat resistant to penetration are the red and white spruces and Rocky Mountain Douglas-fir. Cedar poles are commonly incised to obtain satisfactory preservative penetration. With round members, such as poles, posts, and piles, the penetration of the sapwood is important in achieving a protective outer zone around the heartwood.

The heartwood of most species resists penetration of preservatives, but well-dried white fir, western hemlock, northern red oak, the ashes, and tupelo are examples of species with heartwood that is reasonably easy to penetrate. The southern pines, ponderosa pine, redwood, Sitka spruce, coastal Douglas-fir, beech, maples, and birches are examples of species with heartwood that is moderately resistant to penetration.

Table 14–6. Results of Forest Products Laboratory studies on 5- by 10- by 46-cm (2- by 4- by 18-in.) Southern Pine sapwood stakes, pressure-treated with commonly used wood preservatives, installed at Harrison Experimental Forest, Mississippi

Preservative	Average retention (kg/m^3 (lb/ft^3))[a]	Average life (year) or condition at last inspection
Control (untreated stakes)		1.8 to 3.6 years
Acid copper chromate	2.08 (0.13)	11.6 years
	2.24 (0.14)	6.1 years
	4.01 (0.25)	70% failed after 24 years
	4.17 (0.26)	60% failed after 46 years
	4.65 (0.29)	4.6 years
	5.93 (0.37)	50% failed after 46 years
	8.01 (0.50)	40% failed after 24 years
	12.18 (0.76)	20% failed after 24 years
Ammoniacal copper borate	2.72 (0.17)	65% failed after 16 years
	3.52 (0.22)	30% failed after 16 years
	5.29 (0.33)	10% failed after 16 years
	7.21 (0.45)	5% failed after 16 years
	.41 (0.65)	5% failed after 16 years
	21.31 (1.33)	No failures after 16 years
Ammoniacal copper arsenate	2.56 (0.16)	60% failed after 16 years
	3.52 (0.22)	10% failed after 16 years
	3.84 (0.24)	67% failed after 47 years
	4.01 (0.25)	20% failed after 24 years
	7.37 (0.46)	10% failed after 24 years
	8.17 (0.51)	10% failed after 47 years
	15.54 (0.97)	No failures after 47 years
	20.02 (1.25)	No failures after 47 years
Chromated copper arsenate	2.40 (0.15)	70% failed after 46 years
Type I	3.52 (0.22)	30% failed after 24 years
	4.65 (0.29)	30% failed after 46 years
	7.05 (0.44)	10% failed after 24 years
	7.05 (0.44)	10% failed after 46 years
Type II	3.68 (0.23)	30% failed after 24 years
	4.17 (0.26)	10% failed after 42 years
	5.93 (0.37)	No failures after 42 years
	8.33 (0.52)	No failures after 42 years
	12.66 (0.79)	No failures after 42 years
	16.66 (1.04)	No failures after 42 years
Type III	2.24 (0.14)	No failures after 12-1/2 years
	3.20 (0.20)	No failures after 20 years
	4.01 (0.25)	No failures after 14 years
	4.33 (0.27)	No failures after 12-1/2 years
	6.41 (0.40)	No failures after 20 years
	6.41 (0.40)	No failures after 14 years
	6.41 (0.40)	No failures after 12-1/2 years
	9.61 (0.60)	No failures after 20 years
	9.93 (0.62)	No failures after 12-1/2 years
	12.34 (0.77)	No failures after 14 years
	12.66 (0.79)	No failures after 12-1/2 years
Chromated zinc arsenate	1.76 (0.11)	22.1 years
	3.52 (0.22)	33.0 years
	4.65 (0.29)	89% failed after 51-1/2 years
	3.20 (0.20)	10% failed after 40 years
	6.41 (0.40)	No failures after 40 years
	8.49 (0.53)	No failures after 40 years
	6.09 (0.38)	40% failed after 51-1/2 years
	8.33 (0.52)	10% failed after 51-1/2 years
	11.21 (0.70)	No failures after 51-1/2 years

Table 14–6. Results of Forest Products Laboratory studies on 5- by 10- by 46-cm (2- by 4- by 18-in.) Southern Pine sapwood stakes, pressure-treated with commonly used wood preservatives, installed at Harrison Experimental Forest, Mississippi—con.

Preservative	Average retention (kg/m³ (lb/ft³))[a]	Average life (year) or condition at last inspection
Chromated zinc chloride	4.81 (0.30)	14.2 years
	7.53 (0.47)	20.2 years
	7.37 (0.46)	13.7 years
	10.09 (0.63)	20.1 years
	9.93 (0.62)	14.9 years
	14.74 (0.92)	23.4 years
	15.38 (0.96	90% failed after 24 years
	28.52 (1.78)	32.7 years
		90% failed after 38 years
	58.79 (3.67)	No failures after 38 years
Oxine copper	0.16 (0.01)	5.3 years
(Copper-8-quinolinoate)	0.32 (0.02)	4.2 years
Stoddard solvent	0.96 (0.06)	5.6 years
	1.92 (0.12)	7.8 years
Oxine copper	0.22 (0.014)	80% failed after 28 years
(Copper-8-quinolinolate)	0.48 (0.03)	70% failed after 28 years
AWPA P9 heavy petroleum	0.95 (0.059)	20% failed after 28 years
	1.99 (0.124)	No failures after 28 years
Copper naphthenate		
0.11% copper in No. 2 fuel oil	0.19 (0.012)	15.9 years
0.29% copper in No. 2 fuel oil	0.46 (0.029)	21.8 years
0.57% copper in No. 2 fuel oil	0.98 (0.061)	27.2 years
0.86% copper in No. 2 fuel oil	1.31 (0.082)	29.6 years
Creosote, coal-tar	52.87 (3.3)	24.9 years
	65.68 (4.1)	14.2 years
	67.28 (4.2)	17.8 years
	73.69 (4.6)	21.3 years
	124.96 (7.8)	70% failed after 49-1/2 years
	128.24 (8.0)	80% failed after 51-1/2 years
	132.97 (8.3)	40% failed after 42 years
	160.2 (10.0)	90% failed after 51 years
	189.04 (11.8)	30% failed after 51-1/2 years
	211.46 (13.2)	20% failed after 49-1/2 years
	232.29 (14.5)	No failures after 51 years
	264.33 (16.5)	No failures after 51-1/2 years
Low residue, straight run	128.16 (8.0)	17.8 years
Medium residue, straight run	128.16 (8.0)	18.8 years
High residue, straight run	124.96 (7.8)	20.3 years
Medium residue, low in tar acids	129.76 (8.1)	19.4 years
Low in naphthalene	131.36 (8.2)	21.3 years
Low in tar acids and naphthalene	128.16 (8.0)	18.9 years
Low residue, low in tar acids and naphthalene	128.16 (8.0)	19.2 years
High residue, low in tar acids and naphthalene	131.36 (8.2)	20.0 years
English vertical retort	84.91 (5.3)	80% failed after 44 years
	128.16 (8.0)	18.9 years
	161.80 (10.1)	80% failed after 44 years
	240.30 (15.0)	No failures after 44 years
English coke oven	75.29 (4.7)	16.3 years
	126.56 (7.9)	13.6 years
	161.80 (10.1)	70% failed after 44 years
	237.10 (14.8)	70% failed after 44 years

Table 14–6. Results of Forest Products Laboratory studies on 5- by 10- by 46-cm (2- by 4- by 18-in.) Southern Pine sapwood stakes, pressure-treated with commonly used wood preservatives, installed at Harrison Experimental Forest, Mississippi—con.

Preservative	Average retention (kg/m³ (lb/ft³))[a]	Average life (year) or condition at last inspection
Fluor chrome arsenate phenol type A	1.92 (0.12)	10.2 years
	3.04 (0.19)	18.0 years
	3.52 (0.22)	18.3 years
	4.97 (0.31)	18.5 years
	6.09 (0.38)	24.1 years
Pentachlorophenol (various solvents)		
Liquefied petroleum gas	2.24 (0.14)	90% failed after 30-1/2 years
	3.04 (0.19)	15.9 years
	5.45 (0.34)	No failures after 30-1/2 years
	5.45 (0.34)	70% failed after 28 years
	7.85 (0.49)	No failures after 28 years
	9.29 (0.58)	No failures after 30-1/2 years
	10.41 (0.65)	No failures after 28 years
Stoddard solvent (mineral spirits)	2.24 (0.14)	13.7 years
	2.88 (0.18)	15.9 years
	3.20 (0.20)	9.5 years
	3.20 (0.20)	13.7 years
	6.09 (0.38)	40% failed after 30-1/2 years
	6.41 (0.40)	15.5 years
	10.73 (0.67)	No failures after 30-1/2 years
Heavy gas oil (Mid-United States)	3.20 (0.20)	67% failed after 44-1/2 years
	6.41 (0.40)	60% failed after 44-1/2 years
	9.61 (0.60)	10% failed after 44-1/2 years
No. 4 aromatic oil (West Coast)	3.36 (0.21)	21.0 years
	6.57 (0.41)	50% failed after 42 years
AWPA P9 (heavy petroleum)	1.76 (0.11)	80% failed after 30-1/2 years
	3.04 (0.19)	No failures after 30-1/2 years
	4.65 (0.29)	No failures after 30-1/2 years
	8.49 (0.53)	No failures after 28 years
	10.73 (0.67)	No failures after 30-1/2 years
Tributyltin oxide		
Stoddard solvent	0.24 (0.015)	6.3 years
	0.40 (0.025)	4.5 years
	0.48 (0.030)	7.2 years
	0.72 (0.045)	7.4 years
	0.75 (0.047)	7.0 years
AWPA P9 (heavy petroleum)	0.38 (0.024)	20.8 years
	0.77 (0.048)	24.0 years
Petroleum solvent controls	64.08 (4.0)	7.6 years
	65.68 (4.1)	4.4 years
	75.29 (4.7)	12.9 years
	123.35 (7.7)	14.6 years
	126.56 (7.9)	90% failed after 44-1/2 years
	128.16 (8.0)	19.7 years
	128.16 (8.0)	23.3 years
	128.16 (8.0)	14.6 years
	129.76 (8.1)	3.4 years
	136.17 (8.5)	90% failed after 28 years
	157.00 (9.8)	6.3 years
	192.24 (12.0)	17.1 years
	193.84 (12.1)	20% failed after 44-1/2 years
	310.79 (19.4)	9.1 years

[a]Retention values are based on preservative oxides or copper metal.

Table 14–7. Penetration of the heartwood of various softwood and hardwood species[a]

Ease of treatment	Softwoods	Hardwoods
Least difficult	Bristlecone pine (*Pinus aristata*)	American basswood (*Tilia americana*)
	Pinyon (*P. edulis*)	Beech (white heartwood) (*Fagus grandifolia*)
	Pondersosa pine (*P. pondersosa*)	Black tupelo (blackgum) (*Nyssa sylvatica*)
	Redwood (*Sequoia sempervirens*)	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 lenia*)
		Water tupelo (*Nyssa aquatica*)
		White ash (*Fraxinus americana*)
Moderately difficult	Baldcypress (*Taxodium distichum*)	Black willow (*Salix nigra*)
	California red fir (*Abies magnifica*)	Chestnut oak (*Quercus montana*)
	Douglas-fir (coast) *(Pseudotsuga taxifolia)*)	Cottonwood (*Populus* sp.)
	Eastern white pine (*Pinus strobus*)	Bigtooth aspen (*P. grandidentata*)
	Jack pine (*P. banksiana*)	Mockernut hickory (*Carya tomentosa*)
	Loblolly pine (*P. taeda*)	Silver maple (*Acer saccharinum*)
	Longleaf pine (*P. palustris*)	Sugar maple (*A. saccharum*)
	Red pine (*P. resinosa*)	Yellow birch (*Betula lutea*)
	Shortleaf pine (*P. echinata*)	
	Sugar pine (*P. lambertiana*)	
	Western hemlock (*Tsuga heterophylla*)	
Difficult	Eastern hemlock (*Tsuga canadensis*)	American sycamore (*Platanus occidentalis*)
	Engelmann spruce (*Picea engelmanni*)	Hackberry (*Celtis occidentalis*)
	Grand fir (*Abies grandis*)	Rock elm (*Ulmus thomoasi*)
	Lodgepole pine (*Pinus contorta* var. *latifolia*)	Yellow-poplar (*Liriodendron tulipifera*)
	Noble fir (*Abies procera*)	
	Sitka spruce (*Picea sitchensis*)	
	Western larch (*Larix occidentalis*)	
	White fir (*Abies concolor*)	
	White spruce (*Picea glauca*)	
Very difficult	Alpine fir (*Abies lasiocarpa*)	American beech (red heartwood) (*Fagus grandifolia*)
	Corkbark fir (*A. lasiocarpa* var. *arizonica*)	American chestnut (*Castanea dentata*)
	Douglas-fir (Rocky Mountain) (*Pseudotsuga taxifolia*)	Black locust (*Robinia pseudoacacia*)
	Northern white-cedar (*Thuja occidentalis*)	Blackjack oak (*Quercus marilandica*)
	Tamarack (*Larix laricina*)	Sweetgum (redgum) (*Liquidambar styraciflua*)
	Western redcedar (*Thuja plicata*)	White oaks (*Quercus* spp.)

[a]As covered in MacLean (1952).

Preparation of Timber for Treatment

For satisfactory treatment and good performance, the timber must be sound and suitably prepared. Except in specialized treating methods involving unpeeled or green material, the wood should be well peeled and either seasoned or conditioned in the cylinder before treatment. It is also highly desirable that all machining be completed before treatment. Machining may include incising to improve the preservative penetration in woods that are resistant to treatment, as well as the operations of cutting or boring of holes.

Peeling

Peeling round or slabbed products is necessary to enable the wood to dry quickly enough to avoid decay and insect damage and to permit the preservative to penetrate satisfactorily. Even strips of the thin inner bark may prevent penetration. Patches of bark left on during treatment usually fall off in time and expose untreated wood, thus permitting decay to reach the interior of the member.

Careful peeling is especially important for wood that is to be treated by a nonpressure method. In the more thorough processes, some penetration may take place both longitudinally and tangentially in the wood; consequently, small strips of bark are tolerated in some specifications. Processes in which a preservative is forced or permitted to diffuse through green wood lengthwise do not require peeling of the timber. Machines of various types have been developed for peeling round timbers, such as poles, piles, and posts (Fig. 14–1).

Drying

Drying of wood before treatment is necessary to prevent decay and stain and to obtain preservative penetration. However, for treatment with waterborne preservatives by certain diffusion methods, high moisture content levels may be permitted. For treatment by other methods, however, drying before treatment is essential. Drying before treatment opens up the checks before the preservative is applied, thus increasing penetration, and reduces the risk of checks opening after treatment and exposing unpenetrated wood. Good penetration of heated organic-based preservatives may be possible in wood with a moisture content as high as 40% to 60%, but severe checking while drying after treatment can expose untreated wood.

For large timbers and railroad ties, air drying is a widely used method of conditioning. Despite the increased time, labor, and storage space required, air drying is generally the most inexpensive and effective method, even for pressure treatment. However, wet, warm climatic conditions make it difficult to air dry wood adequately without objectionable infection by stain, mold, and decay fungi. Such infected wood is often highly permeable; in rainy weather, infected wood can absorb a large quantity of water, which prevents satisfactory treatment.

Figure 14–1. Machine peeling of poles. The outer bark has been removed by hand, and the inner bark is being peeled by machine. Frequently, all the bark is removed by machine.

How long the timber must be air dried before treatment depends on the climate, location, and condition of the seasoning yard, methods of piling, season of the year, timber size, and species. The most satisfactory seasoning practice for any specific case will depend on the individual drying conditions and the preservative treatment to be used. Therefore, treating specifications are not always specific as to moisture content requirements.

To prevent decay and other forms of fungal infection during air drying, the wood should be cut and dried when conditions are less favorable for fungus development (Ch. 13). If this is impossible, chances for infection can be minimized by prompt conditioning of the green material, careful piling and roofing during air drying, and pretreating the green wood with preservatives to protect it during air drying.

Lumber of all species, including Southern Pine poles, is often kiln dried before treatment, particularly in the southern United States where proper air seasoning is difficult. Kiln drying has the important added advantage of quickly reducing moisture content, thereby reducing transportation charges on poles.

Conditioning of Green Products

Plants that treat wood by pressure processes can condition green material by means other than air and kiln drying. Thus, they avoid a long delay and possible deterioration of the timber before treatment.

When green wood is to be treated under pressure, one of several methods for conditioning may be selected. The steaming-and-vacuum process is used mainly for southern pines, and the Boulton or boiling-under-vacuum process is used for Douglas-fir and sometimes hardwoods.

In the steaming process, the green wood is steamed in the treating cylinder for several hours, usually at a maximum of 118ºC (245ºF). When steaming is completed, a vacuum is immediately applied. During the steaming period, the outer part of the wood is heated to a temperature approaching that of the steam; the subsequent vacuum lowers the boiling point so that part of the water is evaporated or forced out of the wood by the steam produced when the vacuum is applied. The steaming and vacuum periods used depend upon the wood size, species, and moisture content. Steaming and vacuum usually reduce the moisture content of green wood slightly, and the heating assists greatly in getting the preservative to penetrate. A sufficiently long steaming period will also sterilize the wood.

In the Boulton or boiling-under-vacuum method of partial seasoning, the wood is heated in the oil preservative under vacuum, usually at about 82ºC to 104ºC (180ºF to 220ºF). This temperature range, lower than that of the steaming process, is a considerable advantage in treating woods that are especially susceptible to injury from high temperatures. The Boulton method removes much less moisture from heartwood than from sapwood.

Incising

Wood that is resistant to penetration by preservatives may be incised before treatment to permit deeper and more uniform penetration. To incise, lumber and timbers are passed through rollers equipped with teeth that sink into the wood to a predetermined depth, usually 13 to 19 mm (1/2 to 3/4 in.). The teeth are spaced to give the desired distribution of preservative with the minimum number of incisions. A machine of different design is required for deeply incising the butts of poles, usually to a depth of 64 mm (2.5 in.) (Fig. 14–2).

The effectiveness of incising depends on the fact that preservatives usually penetrate into wood much farther in the longitudinal direction than in a direction perpendicular to the faces of the timber. The incisions open cell lumens along the grain, which greatly enhances penetration. Incising is especially effective in improving penetration in the heartwood areas of sawn surfaces.

Incising is practiced primarily on Douglas-fir, western hemlock, and western larch ties and timbers for pressure treatment and on cedar and Douglas-fir poles. Incising can result in significant reductions in strength (Ch. 4).

Cutting and Framing

All cutting and boring of holes should be done prior to preservative treatment. Cutting into the wood in any way after treatment will frequently expose the untreated interior of the timber and permit ready access to decay fungi or insects.

Figure 14–2. Deep incising permits better penetration of preservative.

In some cases, wood structures can be designed so that all cutting and framing is done before treatment. Railroad companies have followed this practice and have found it not only practical but economical. Many wood-preserving plants are equipped to carry on such operations as the adzing and boring of crossties; gaining, roofing, and boring of poles; and framing of material for bridges and specialized structures, such as water tanks and barges.

Treatment of the wood with preservative oils results in little or no dimensional change. With waterborne preservatives, however, some change in the size and shape of the wood may occur even though the wood is redried to the moisture content it had before treatment. If precision fitting is necessary, the wood is cut and framed before treatment to its approximate final dimensions to allow for slight surfacing, trimming, and reaming of bolt holes. Grooves and bolt holes for timber connectors are cut before treatment and can be reamed out if necessary after treatment.

Application of Preservatives

Wood-preserving methods are of two general types: (a) pressure processes, in which the wood is impregnated in closed vessels under pressures considerably above atmospheric, and (b) nonpressure processes, which vary widely in the procedures and equipment used.

Pressure Processes

In commercial practice, wood is most often treated by immersing it in a preservative in a high pressure apparatus and applying pressure to drive the preservative into the wood. Pressure processes differ in details, but the general principle is the same. The wood, on cars or trams, is run into a long steel cylinder (Fig. 14–3), which is then closed and filled with preservative. Pressure forces the preservative into the wood until the desired amount has been absorbed. Considerable preservative is absorbed, with relatively deep penetration. Three pressure processes are commonly used: full-cell, modified full-cell, and empty-cell.

Full-Cell

The full-cell (Bethel) process is used when the retention of a maximum quantity of preservative is desired. It is a standard procedure for timbers to be treated full-cell with creosote when protection against marine borers is required. Waterborne preservatives are generally applied by the full-cell process, and control over preservative retention is obtained by regulating the concentration of the treating solution. Steps in the full-cell process are essentially the following:

1. The charge of wood is sealed in the treating cylinder, and a preliminary vacuum is applied for a half-hour or more to remove the air from the cylinder and as much as possible from the wood.
2. The preservative, at ambient or elevated temperature depending on the system, is admitted to the cylinder without breaking the vacuum.
3. After the cylinder is filled, pressure is applied until the wood will take no more preservative or until the required retention of preservative is obtained.
4. When the pressure period is completed, the preservative is withdrawn from the cylinder.
5. A short final vacuum may be applied to free the charge from dripping preservative.

When the wood is steamed before treatment, the preservative is admitted at the end of the vacuum period that follows steaming. When the timber has received preliminary conditioning by the Boulton or boiling-under-vacuum process, the cylinder can be filled and the pressure applied as soon as the conditioning period is completed.

Modified Full-Cell

The modified full-cell process is basically the same as the full-cell process except for the amount of initial vacuum and the occasional use of an extended final vacuum. The modified full-cell process uses lower levels of initial vacuum; the actual amount is determined by the wood species, material size, and final retention desired.

Empty-Cell

The objective of the empty-cell process is to obtain deep penetration with a relatively low net retention of preservative. For treatment with oil preservatives, the empty-cell process should always be used if it will provide the desired retention. Two empty-cell processes, the Rueping and the Lowry, are commonly employed; both use the expansive force of compressed air to drive out part of the preservative absorbed during the pressure period.

The Rueping empty-cell process, often called the empty-cell process with initial air, has been widely used for many years in Europe and the United States. The following general procedure is employed:

1. Air under pressure is forced into the treating cylinder, which contains the charge of wood. The air penetrates some species easily, requiring but a few minutes application of pressure. In treating the more resistant species, common practice is to maintain air pressure from 1/2 to 1 h before admitting the preservative, but the necessity for lengthy air-pressure periods does not seem fully established. The air pressures employed generally range between 172 to 689 kPa (25 to 100 lb/in^2), depending on the net retention of preservative desired and the resistance of the wood.
2. After the period of preliminary air pressure, preservative is forced into the cylinder. As the preservative is pumped in, the air escapes from the treating cylinder into an equalizing or Rueping tank, at a rate that keeps the pressure constant within the cylinder. When the treating cylinder is filled with preservative, the treating pressure is increased above that of the initial air and is maintained until the wood will absorb no more preservative, or until enough has been absorbed to leave the required retention of preservative in the wood after the treatment.

Figure 14–3. Interior view of treating cylinder at wood-preserving plant, with a load about to come in.

3. At the end of the pressure period, the preservative is drained from the cylinder, and surplus preservative is removed from the wood with a final vacuum. The amount of preservative recovered can be from 20% to 60% of the gross amount injected.

The Lowry is often called the empty-cell process without initial air pressure. Preservative is admitted to the cylinder without either an initial air pressure or a vacuum, and the air originally in the wood at atmospheric pressure is imprisoned during the filling period. After the cylinder is filled with the preservative, pressure is applied, and the remainder of the treatment is the same as described for the Rueping treatment.

The Lowry process has the advantage that equipment for the full-cell process can be used without other accessories that the Rueping process usually requires, such as an air compressor, an extra cylinder or Rueping tank for the preservative, or a suitable pump to force the preservative into the cylinder against the air pressure. However, both processes have advantages and are widely and successfully used.

With poles and other products where bleeding of preservative oil is objectionable, the empty-cell process is followed by either heating in the preservative (expansion bath) at a maximum of 104ºC (220ºF) or a final steaming for a specified time limit at a maximum of 116ºC (240ºF) prior to the final vacuum.

Treating Pressures and Preservative Temperatures

The pressures used in treatments vary from about 345 to 1,723 kPa (50 to 250 lb/in^2), depending on the species and the ease with which the wood takes the treatment; most commonly, pressures range from about 862 to 1,207 kPa (125 to 175 lb/in^2). Many woods are sensitive to high treating pressures, especially when hot. For example, AWPA standards permit a maximum pressure of 1,034 kPa (150 lb/in^2) in the treatment of Douglas-fir, 862 kPa (125 lb/in^2) for redwood, and 1,723 kPa (250 lb/in^2) for oak. In commercial practice, even lower pressures are frequently used on such woods.

The AWPA C1 standard requires that the temperature of creosote and creosote solutions, as well as that of the oil-borne preservatives, during the pressure period shall not be greater than 93ºC (200ºF) for Western redcedar and 99ºC (210ºF) for all other species. With a number of waterborne preservatives, especially those containing chromium salts, maximum temperatures are limited to avoid premature precipitation of the preservative. The AWPA specifications require that the temperature of the preservative during the entire pressure period not exceed the maximum of 49ºC (120ºF) for ACC and CCA and 60ºC (150ºF) for ACA, CC, ACQ Type B, ACQ Type D, ACZA, CBA–A, and CDDC. The limit for inorganic boron is 93ºC (200ºF).

Penetration and Retention

Penetration and retention requirements are equally important in determining the quality of preservative treatment. Penetration levels vary widely, even in pressure-treated material. In most species, heartwood is more difficult to penetrate than sapwood. In addition, species differ greatly in the degree to which their heartwood may be penetrated. Incising tends to improve penetration of preservative in many refractory species, but those highly resistant to penetration will not have deep or uniform penetration even when incised. Penetration in unincised heart faces of these species may occasionally be as deep as 6 mm (1/4 in.) but is often not more than 1.6 mm (1/16 in.).

Experience has shown that even slight penetration has some value, although deeper penetration is highly desirable to avoid exposing untreated wood when checks occur, particularly for important members that are costly to replace. The heartwood of coastal Douglas-fir, southern pines, and various hardwoods, although resistant, will frequently show transverse penetrations of 6 to 12 mm (1/4 to 1/2 in.) and sometimes considerably more.

Complete penetration of the sapwood should be the ideal in all pressure treatments. It can often be accomplished in small-size timbers of various commercial woods, and with skillful treatment, it may often be obtained in piles, ties, and structural timbers. Practically, however, the operator cannot always ensure complete penetration of sapwood in every piece when treating large pieces of round material with thick sapwood, for example, poles and piles. Therefore, specifications permit some tolerance. For instance, AWPA C4 for Southern Pine poles requires that 63 mm (2-1/2 in.) or 85% of the sapwood thickness be penetrated for 96 kg/m^3 (6 lb/ft^3) retention of creosote. This applies only to the smaller class of poles. The requirements vary, depending on the species, size, class, and specified retention levels.

At one time, all preservative retention levels were specified in terms of the weight of preservative per cubic foot (0.028 m^3) of wood treated, based on total weight of preservative retained and the total volume of wood treated in a charge. This is commonly called gauge retention. However, specifications for most products now stipulate a minimum retention of preservative as determined from chemical analysis of borings from specified zones of the treated wood, known as a “assay-retention” or results-type specification.

The preservatives and retention levels listed in Federal Specification TT–W–571 and the AWPA Commodity Standards are shown in Table 14–2. The retention levels are often a range. The current issues of these specifications should be referenced for up-to-date recommendations and other details. In many cases, the retention level is different depending on species and assay zone. Higher preservative retention levels are justified in products to be installed under severe climatic or exposure conditions. Heavy-duty transmission poles and items with a high replacement cost, such as structural timbers and house foundations, are required to be treated to higher retention levels. Correspondingly, deeper penetration or heartwood limitations are also necessary for the same reasons.

It may be necessary to increase retention levels to ensure satisfactory penetration, particularly when the sapwood is either unusually thick or is somewhat resistant to treatment. To reduce bleeding of the preservative, however, it may be desirable to use preservative-oil retention levels less than the stipulated minimum. Treatment to refusal is usually specified for woods that are resistant to treatment and will not absorb sufficient preservative to meet the minimum retention requirements. However, such a requirement does not ensure adequate penetration of preservative, should be avoided, and must not be considered as a substitute for results-type specification in treatment.

Nonpressure Processes

The numerous nonpressure processes differ widely in the penetration and retention levels of preservative attained, and consequently in the degree of protection they provide to the treated wood. When similar retention and penetration levels are achieved, wood treated by a nonpressure method should have a service life comparable to that of wood treated by pressure. Nevertheless, results of nonpressure treatments, particularly those involving surface applications, are not generally as satisfactory as those of pressure treatment. The superficial processes do serve a useful purpose when more thorough treatments are impractical or exposure conditions are such that little preservative protection is required.

Nonpressure methods, in general, consist of (a) surface application of preservatives by brushing or brief dipping,

(b) soaking in preservative oils or steeping in solutions of waterborne preservatives, (c) diffusion processes with waterborne preservatives, (d) vacuum treatment, and (e) a variety of miscellaneous processes.

Surface Applications

The simplest treatment is to apply the preservative to the wood with a brush or by dipping. Preservatives that are thoroughly liquid when cold should be selected, unless it is possible to heat the preservative. The preservative should be flooded over the wood rather than merely painted. Every check and depression in the wood should be thoroughly filled with the preservative, because any untreated wood left exposed provides ready access for fungi. Rough lumber may require as much as 40 L of oil per 100 m^2 (10 gallons of oil per 1,000 ft^2) of surface, but surfaced lumber requires considerably less. The transverse penetration obtained will usually be less than 2.5 mm (1/10 in.), although in easily penetrated species, end-grain (longitudinal) penetration is considerably greater. The additional life obtained by such treatments over that of untreated wood will be affected greatly by the conditions of service. For wood in contact with the ground, service life may be from 1 to 5 years.

Compared with brushing, dipping for a few seconds to several minutes in a preservative gives greater assurance that all surfaces and checks are thoroughly coated with the preservative; it usually results in slightly greater penetration. It is a common practice to treat window sash, frames, and other millwork, either before or after assembly, by dipping the item in a water-repellent preservative. Such treatment is covered by NWWDA IS 4–94, which also provides for equivalent treatment by the vacuum process. AWPA also has a new nonpressure standard, N1, that includes preservative treatments by nonpressure processes for all millwork products.

In some cases, preservative oil penetrates the end surfaces of ponderosa pine sapwood as much as 25 to 76 mm (1 to 3 in.). However, end penetration in such woods as the heartwood of Southern Pines and Douglas-fir is much less. Transverse penetration of the preservative applied by brief dipping is very shallow, usually only less than a millimeter (a few hundredths of an inch). The exposed end surfaces at joints are the most vulnerable to decay in millwork products; therefore, good end penetration is especially advantageous. Dip applications provide very limited protection to wood used in contact with the ground or under very moist conditions, and they provide very limited protection against attack by termites. However, they do have value for exterior woodwork and millwork that is painted, not in contact with the ground, and exposed to moisture only for brief periods.

Cold Soaking and Steeping

Cold soaking well-seasoned wood for several hours or days in low viscosity preservative oils or steeping green or seasoned wood for several days in waterborne preservatives has provided varying success on fence posts, lumber, and timbers.

Pine posts treated by cold soaking for 24 to 48 h or longer in a solution containing 5% of pentachlorophenol in No. 2 fuel oil have shown an average life of 16 to 20 years or longer. The sapwood in these posts was well penetrated, and preservative solution retention levels ranged from 32 to 96 kg/m^3 (2 to 6 lb/ft^3). Most species do not treat as satisfactorily as do the pines by cold soaking, and test posts of such woods as birch, aspen, and sweetgum treated by this method have failed in much shorter times.

Preservative penetration and retention levels obtained by cold soaking lumber for several hours are considerably better than those obtained by brief dipping of similar species. However, preservative retention levels seldom equal those obtained in pressure treatment except in cases such as sapwood of pines that has become highly absorptive through mold and stain infection.

Steeping with waterborne preservatives has very limited use in the United States but it has been used for many years in Europe. In treating seasoned wood, both the water and the preservative salt in the solution soak into the wood. With green wood, the preservative enters the water-saturated wood by diffusion. Preservative retention and penetration levels vary over a wide range, and the process is not generally recommended when more reliable treatments are practical.

Diffusion Processes

In addition to the steeping process, diffusion processes are used with green or wet wood. These processes employ waterborne preservatives that will diffuse out of the water of the treating solution or paste into the water of the wood.

The double-diffusion process developed by the Forest Products Laboratory has shown very good results in fence post tests and standard 38- by 89-mm (nominal 2- by 4-in.) stake tests, particularly for full-length immersion treatments. This process consists of steeping green or partially seasoned wood first in one chemical solution, then in another (Fig. 14–4). The two chemicals diffuse into the wood, then react to precipitate an effective preservative with high resistance to leaching. The process has had commercial application in cooling towers and fence posts where preservative protection is needed to avoid early replacement of the wood.

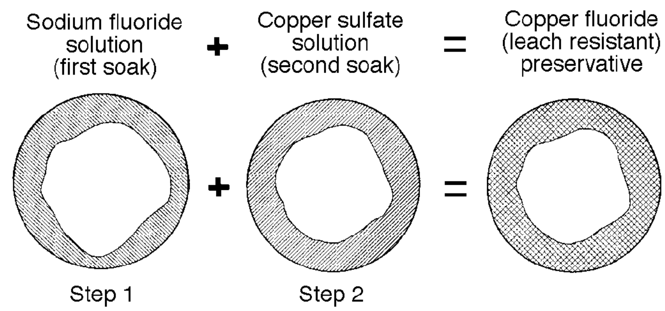


Figure 14–4. Double-diffusion steps for applying preservatives.

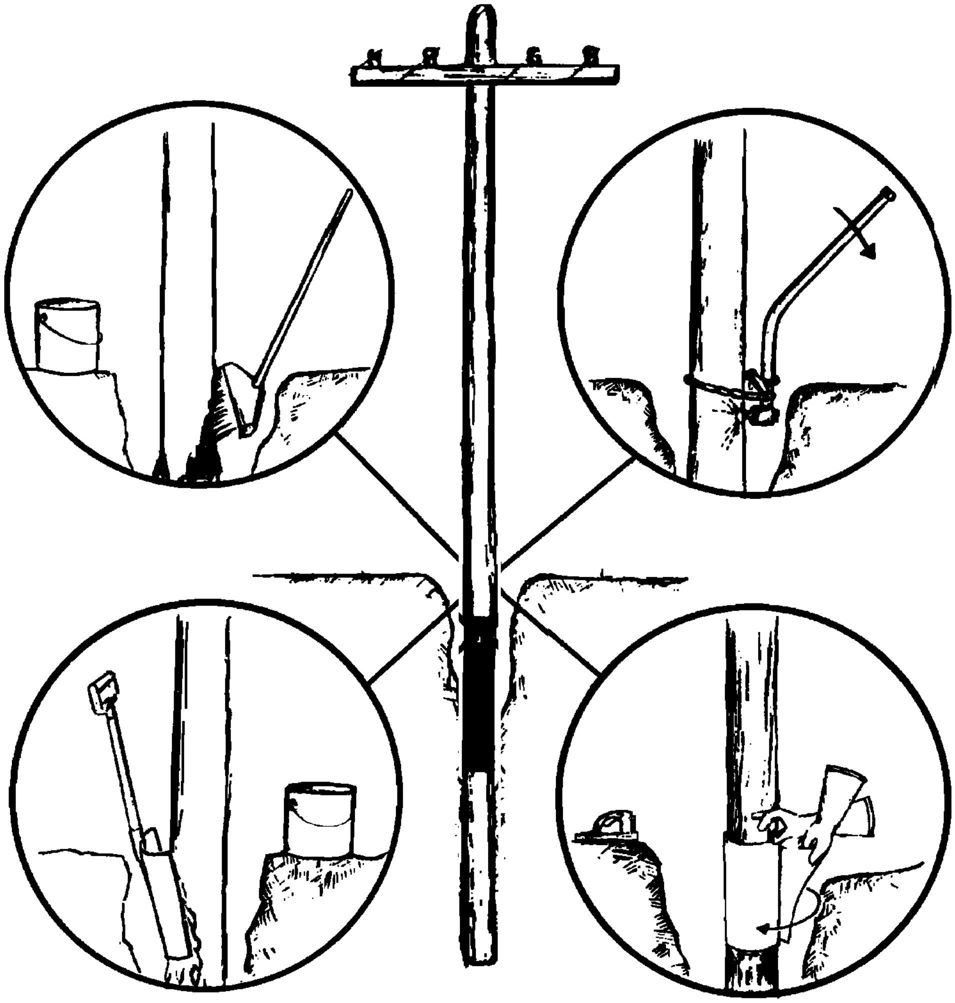


Figure 14–5. Methods of applying groundline treatment to utility poles. Preservative is injected into the pole at the groundline with a special tool or applied on the pole surface as a paste or bandage.

Other diffusion processes involve applying preservatives to the butt or around the groundline of posts or poles. In treatments of standing poles, the preservative can be injected into the pole at groundline with a special tool, applied on the pole surface as a paste or bandage (Fig. 14–5), or poured into holes bored in the pole at the groundline. These treatments have recognized value for application to untreated standing poles and treated poles where preservative retention levels are determined to be inadequate.

Vacuum Process

The vacuum process, or "VAC–VAC" as referred to in Europe, has been used to treat millwork with water-repellent preservatives and construction lumber with waterborne and water-repellent preservatives.

In treating millwork, the objective is to use a limited quantity of water-repellent preservative and obtain retention and penetration levels similar to those obtained by dipping for 3 min. The vacuum process treatment is included in NWWDA IS–94 for "Water-Repellent Preservative Nonpressure Treatment for Millwork." In this treatment, a quick, low initial vacuum is followed by filling the cylinder under vacuum, releasing the vacuum and soaking, followed by a final vacuum. The treatment is better than the 3-min dip treatment because of better penetration and retention, and the surface of the wood is quickly dried, thus expediting glazing, priming, and painting. The vacuum treatment is also reported to be less likely than dip treatment to leave objectionably high retention levels in bacteria-infected wood referred to as "sinker stock."

Lumber intended for buildings has been treated by the vacuum process, either with a waterborne preservative or a water-repellent pentachlorophenol solution, with preservative retention levels usually less than those required for pressure treatment. The process differs from that used in treating millwork in employing a higher initial vacuum and a longer immersion or soaking period.

In a study by the Forest Products Laboratory, an initial vacuum of −93 kPa (27.5 inHg) was applied for 30 min, followed by a soaking for 8 h, and a final or recovery vacuum of −93 kPa (27.5 inHg) for 2 h. Results of the study showed good penetration of preservative in the sapwood of dry lumber of easily penetrated species such as the pines. However, in heartwood and unseasoned sapwood of pine and heartwood of seasoned and unseasoned coastal Douglas-fir, penetration was much less than that obtained by pressure treatment. Preservative retention was less controllable in vacuum than in empty-cell pressure treatment. Good control over retention levels is possible in vacuum treatment with a waterborne preservative by adjusting concentration of the treating solution.

Miscellaneous Nonpressure Processes

Several other nonpressure methods of various types have been used to a limited extent. Many of these involve the application of waterborne preservatives to living trees. The Boucherie process for the treatment of green, unpeeled poles has been used for many years in Europe. This process involves attaching liquid-tight caps to the butt ends of the poles. Then, through a pipeline or hose leading to the cap, a waterborne preservative is forced under hydrostatic pressure into the pole.

A tire-tube process is a simple adaptation of the Boucherie process used for treating green, unpeeled fence posts. In this treatment, a section of used inner tube is fastened tight around the butt end of the post to make a bag that holds a solution of waterborne preservative. There are limitations for application of this process in the United States because of the loss of preservative to the soil around the treatment site.

Effect on Mechanical Properties

Coal-tar creosote, creosote solutions, and pentachlorophenol dissolved in petroleum oils are practically inert to wood and have no chemical influence that would affect its strength. Chemicals commonly used in waterborne salt preservatives, including chromium, copper, arsenic, and ammonia, are reactive with wood. Thus, these chemicals are potentially damaging to mechanical properties and may also promote corrosion of mechanical fasteners.

Significant reductions in mechanical properties may be observed if the treating and subsequent drying processes are not controlled within acceptable limits. Factors that influence the effect of the treating process on strength include (a) species of wood, (b) size and moisture content of the timbers treated, (c) type and temperature of heating medium, (d) length of the heating period in conditioning the wood for treatment and time the wood is in the hot preservative, (e) post-treatment drying temperatures, and (f) amount of pressure used. Most important of those factors are the severity and duration of the in-retort heating or post-treatment redrying conditions used. The effect of wood preservatives on the mechanical properties of wood is covered in Chapter 4.

Handling and Seasoning of Timber After Treatment

Treated timber should be handled with sufficient care to avoid breaking through the treated areas. The use of pikes, cant hooks, picks, tongs, or other pointed tools that dig deeply into the wood should be prohibited. Handling heavy loads of lumber or sawn timber in rope or cable slings can crush the corners or edges of the outside pieces. Breakage or deep abrasions can also result from throwing or dropping the lumber. If damage results, the exposed places should be retreated, if possible.

Wood treated with preservative oils should generally be installed as soon as practicable after treatment to minimize lateral movement of the preservative, but sometimes cleanliness of the surface can be improved by exposing the treated wood to the weather for a limited time before installation. Waterborne preservatives or pentachlorophenol in a volatile solvent are best suited to uses where cleanliness or paintability is of great importance.

Lengthy, unsheltered exterior storage of treated wood before installation should be avoided because such storage encourages deep and detrimental checking and can also result in significant loss of some preservatives. Treated wood that must be stored before use should be covered for protection from the sun and weather.

Although cutting wood after treatment is highly undesirable, it cannot always be avoided. When cutting is necessary, the damage can be partly overcome in timber for land or freshwater use by a thorough application of copper naphthenate (2% copper) to the cut surface. This provides a protective coating of preservative on the surface that may slowly migrate into the end grain of the wood. A special device is available for pressure treating bolt holes that are bored after treatment. For wood treated with waterborne preservatives, a 2% (as copper) solution of copper naphthenate should be used. Thoroughly brushing cut surfaces with two coats of hot creosote (applicator license required) is also helpful, although brush coating of cut surfaces provides little protection against marine borers.

For treating the end surfaces of piles where they are cut off after driving, at least two generous coats of creosote should be applied. A coat of asphalt or similar material may be thoroughly applied over the creosote, followed by some protective sheet material, such as metal, roofing felt, or saturated fabric, fitted over the pile head and brought down the sides far enough to protect against damage to the treatment and against the entrance of storm water. AWPA M4 contains instructions for the care of pressure-treated wood after treatment.

With waterborne preservatives, seasoning after treatment is important for wood that will be used in buildings or other places where shrinkage after placement in the structure would be undesirable. Injecting waterborne preservatives puts large amounts of water into the wood, and considerable shrinkage is to be expected as subsequent seasoning takes place. For best results, the wood should be dried to approximately the moisture content it will ultimately reach in service. During drying, the wood should be carefully piled and, whenever possible, restrained by sufficient weight on the top of the pile to prevent warping.

With some waterborne preservatives, seasoning after treatment is recommended. During this seasoning period, volatile chemicals can escape and chemical reactions are completed within the wood. Thus, the resistance of the preservative to leaching by water is increased. This physical or chemical process whereby a wood preservative system is rendered leach resistant in both water and soil application is called "fixation." In this process, the active ingredient or ingredients maintain fungal or insecticidal efficacy.

The Western Wood Preservers' Institute and the Canadian Institute of Treated Wood (1996) have developed a publication to address best management practices (BMPs) for the use of treated wood in aquatic environments. Their purpose is to protect the quality of the water and diversity of the various life forms found in the lakes, streams, estuaries, bays, and wetlands of North America. The document is continually updated as better methods for risk assessment and research are developed.

Quality Assurance for Treated Wood

Treating Conditions and Specifications

Specifications on the treatment of various wood products by pressure processes have been developed by AWPA. These specifications limit pressures, temperatures, and time of conditioning and treatment to avoid conditions that will cause serious injury to the wood. The specifications also contain minimum requirements for preservative penetration and retention levels and recommendations for handling wood after treatment to provide a quality product.

Specifications are broad in some respects, allowing the purchaser some latitude in specifying the details of individual requirements. However, the purchaser should exercise great care so as not to hinder the treating plant operator from doing a good treating job and not to require treating conditions so severe that they will damage the wood. Federal Specification TT–W–571 lists treatment practices for use on U.S. Government orders for treated wood products; other purchasers have specifications similar to those of AWPA.

The AWPA is working on the development of a Use Category System (UCS), which is a new way to organize the Commodity Standards. The system utilizes seven different exposure categories for treated-wood products, with each exposure category representing a different degree of biodeterioration hazard and/or product expectation. Product users will be able to specify treated-wood products based on the biodeterioration risk to which the product will be exposed. The UCS is expected to appear in the 1998 AWPA Book of Standards for information only and with standardization parallel to the current C-Standards in 1999.

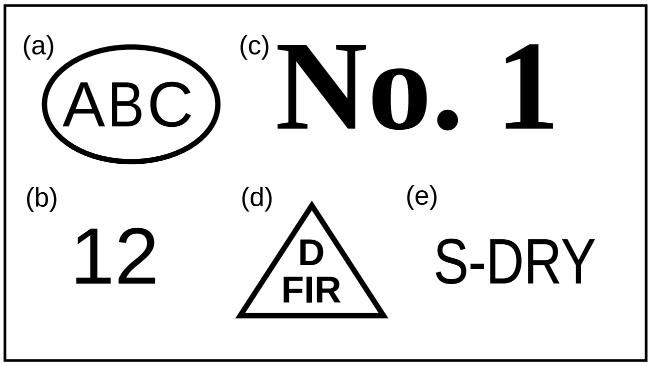
Inspection

There are two important factors to consider depending upon the intended end use of preservative-treated wood: (a) the grade or appearance of the lumber and (b) the quality of the preservative treatment in the lumber. The U.S. Department of Commerce American Lumber Standard Committee (ALSC), an accrediting agency for treatment quality assurance, has an ink stamp or end tag for each grade stamp (Fig. 14–6) and quality mark (Fig. 14–7). These marks indicate that the producer of the treated-wood product subscribes to an independent inspection agency. However, there are non-ALSC end tags or ink stamps that are similar to ALSC tags. Only end tags or ink stamps with the logo of an accredited ALSC–QA agency are acceptable. (A current list is available from ALSC.)

Quality control overview by ALSC is preferable to simple treating plant certificates or other claims of conformance made by the producer without inspection by an independent agency. These third-party agencies verify for customers that the wood was properly treated in accordance with AWPA standards. Thus, the purchaser may either accept the stamps as their quality assurance or have an independent inspector inspect and analyze the treated products to ensure compliance with the specifications. The latter is recommended for treated-wood products used for critical structures. Railroad companies and other corporations that purchase large quantities of treated timber usually maintain their own inspection services.

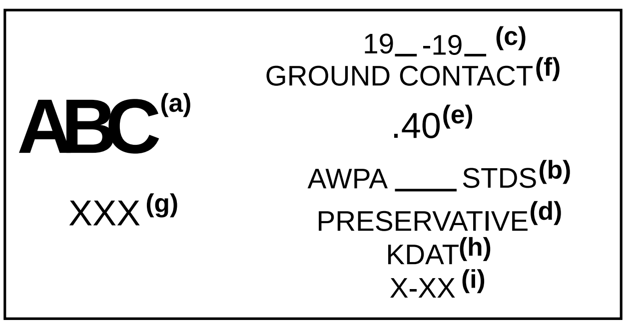
Purchase of Treated Wood

To obtain a treated-wood product of high quality, the purchaser should use the appropriate specifications. Specifications and standards of importance here are Federal Specification TT–W–571, "Wood Preservation—Treating Practices;" Federal Specification TT–W–572, "Fungicide: Pentachlorophenol;" and the *AWPA Book of Standards*. The inspection of material for conformity to the minimum requirements listed in these specifications should be in accordance with the American Wood Preservers' M2, "Standard for Inspection of Treated Timber Products."



a Trademark indicates agency quality supervision.
b Mill Identification—firm name, brand, or assigned mill number
c Grade Designation—grade name, number, or abbreviation
d Species Identification—indicates species individually or in combination
e Condition of Seasoning at time of surfacing
S-DRY — 19% max. moisture content
MC 15 — 15% max. moisture content
S-GRN — over 19% moisture content (unseasoned)

Figure 14–6. Typical lumber grade stamp as approved by ALSC and its interpretation for Douglas Fir lumber.



a Identifying symbol, logo, or name of the accredited agency.
b Applicable American Wood Preservers' Association (AWPA) commodity standard.
c Year of treatment, if required by AWPA standard.
d Preservative used, which may be abbreviated.
e Preservative retention.
f Exposure category (e.g. Above Ground, Ground Contact, etc.).
g Plant name and location, plant name and number, or plant number.
h If applicable, moisture content after treatment.
i If applicable, length, and/or class.

Figure 14–7. Typical quality mark for preservative-treated lumber to conform to the ALSC accreditation program.

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