



## Basic Treating Processes

H. Michael Barnes

The efficacy of a preservative treatment is highly dependent on the penetration of preservative into the wood. As wood swells and shrinks with moisture changes, cracks form and extend deep into the wood. If a preservative is only applied to the wood's surface, these cracks will expose untreated wood to deterioration by fungi and insects (Figure 2.1). To obtain deep penetration, most wood preservatives are applied by using pressure processes.

A look at current trends and technology in the wood-treating industry requires a historical perspective. A number of historical accounts and reviews are available in the literature (Hunt and Garratt 1953, Troxell 1961, Graham 1973, Richardson 1978, Thompson and Barnes 1978, Nicholas and Cockcroft 1982, Barnes 1985a, Barnes and

Murphy 1995, Evans 2003, Freeman et al. 2003). The impetus for the modern timber preservation industry originated in Britain with concerns over the longevity of ships of the Royal Navy and with the patenting of the Bethell (1838) process for treating wood with creosote.

Although a small Bethell plant was built in Somerset, MA in 1865, the modern wood preservation era in the United States began in 1875 with the construction of a plant in West Pascagoula (now Gautier), Mississippi by the Louisville and Nashville (L&N) Railroad. This plant used the Bethell process to treat ties and other stock with creosote. Most of the early growth in the industry in the U.S. was in response to the growth of utilities and the railroads. Until recently, commercial treatment technology had remained unchanged since the development of the Rueping (1902) and Lowry (1906) empty-cell processes. These processes were modifications of the full-cell processes patented by Bethell (1838) and Burnett (1838). The changes in preservative usage and treatment technology now underway worldwide have arisen primarily from two factors: (1) the energy crisis, especially with regard to oil and oil-based products; and (2) the environmental dilemma, including promulgated air and water effluent quality standards and the potential effects of treated wood on humans and other non-target organisms.

### 2.1 PRE-CONDITIONING OF STOCK FOR TREATMENT

#### 2.1.1 Debarking

In order to properly treat wood, it must be debarked. Bark retards seasoning of wood, is impermeable, and harbors insects and decay. Any of several methods (Figure 2.2) can be used to debark logs prior to treatment, including hand peeling, ring debarkers, machine shavers, high pressure water jets, and drum debarkers. For rectangular timbers, bark is usually removed in the sawing operation.



Figure 2.1 Typical core rot caused by fungi entering through a check across the well-treated shell into untreated wood.

The author is Warren S. Thompson Professor of Wood Science and Technology, Department of Forest Products, Mississippi State University, Mississippi State, MS 39762-9820. This paper was accepted as Journal Article FP-514, Forest & Wildlife Research Center, Mississippi State University, Mississippi State, MS.



Figure 2.2 Typical pole peeler (a, b, c) and Cambio ring debarker (d) used in de-barking operations.

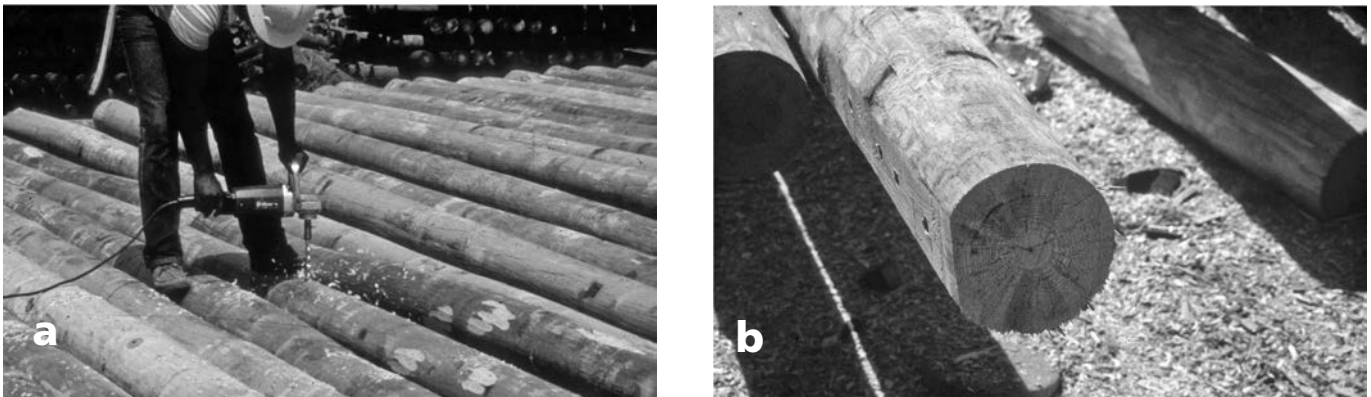


Figure 2.3 Pre-boring (a) and dapping (b) poles prior to treatment reduces the chance for exposing untreated wood.

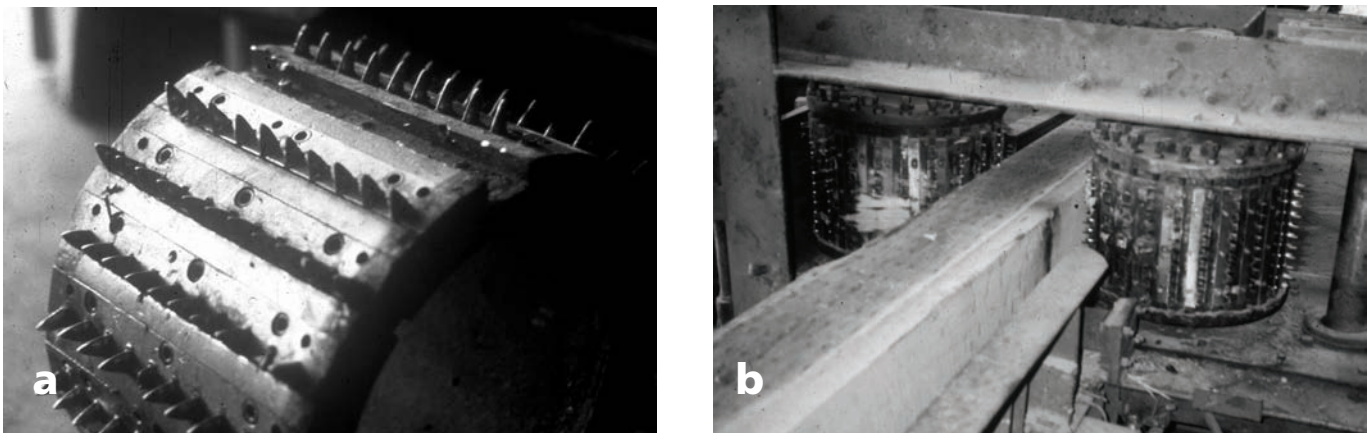


Figure 2.4 Typical oyster-tooth incising head (a) and tie incisor (b).



### 2.1.2 Mechanical preparation

Mechanical preparation may be used with refractory species to improve seasoning and treatability. In general, it is good practice to do all fabrication, cutting, drilling, or boring on stock prior to treatment. This greatly reduces the chance for exposing untreated wood (Figure 2.3).

Incising is a typical commercial practice with hardwood ties (Figure 2.4) and thin sapwood and refractory softwood species. Incising produces shallow, slit-like holes, which yield deeper, more uniform preservative penetration and reduce deep checking. An oyster-tooth incisor, 19–25-mm long and 19-mm deep and yielding 600 incisions/m<sup>2</sup>, is common for timbers and other large members. Some strength reductions have been found. Deep incising, boring, and kerfing techniques are also used to improve treatment of round members (Morrell 1996). Related reviews can be found in the literature (Perrin 1978, Morrell and Winandy 1987). Most of this work has centered in Canada for the treatment of spruce (*Picea* spp.). Ruddick (1985, 1986) demonstrated improved penetration in spruce and lodgepole pine (*Pinus contorta*) by using a needle incisor developed in Germany. Subsequently, a thin-toothed, self-cleaning system was developed to provide incised lumber with twice the incision density of conventional incisors (Morris 1991a, Morris et al. 1991). Excellent treatment for refractory white spruce (*Picea glauca*), lodgepole pine, and alpine fir (*Abies lasiocarpa*) was obtained, and strength losses were not considered an impediment to commercial use. Incising green material prior to drying and treatment led to better treatment (Morris 1991b, c). High density incising of green refractory material has become common for dimension lumber (Figure 2.5). The use of lasers for machining wood has been studied for several years. The feasibility of using laser-incising to improve the treatability of refractory species has been demonstrated (Goodell et al. 1991, Ruddick 1991).

In crosstie production, adzing and boring prior to treatment yields smooth, even bearing surfaces, which reduces mechanical wear (Figure 2.6). Pre-boring results in a decrease in crushing and tearing, an increase in spike-withdrawal resistance, and less spike kill in the resultant tie. Machining of profiles, such as for crossing plank (Figure 2.6), reduces the exposure of untreated wood. Pre-framing (boring, cutting, dapping, planning, roofing) of pole stock will increase the service life of the treated pole stock.

Transverse compression has been used experimentally to improve the treatability of refractory wood and heartwood (Cech and Huffman 1970, 1972), but has not been used commercially. More recently, a process combining vibration and compression has been used to improve treatability of wood (Amburgey et al. 2007). A modified compression technique utilizing roll pressing while the wood is immersed in treating solution yielded large increases in uptake in Japanese cedar (*Cryptomeria japonica*) (Inoue et al. 2001, Inoue and Adachi 2003). Earlier work by Fry (1976) showed that compression roll technology

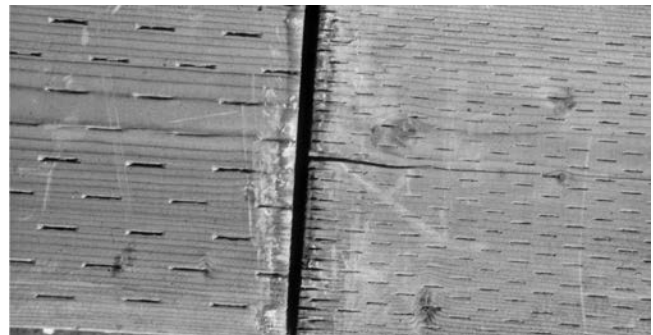


Figure 2.5 Typical conventional (left) and double density (right) incising patterns for dimension lumber



Figure 2.6 Adzed and bored tie plate area (a) and machined stock (b) will increase service life of crossties (a) and crossing plank (b).

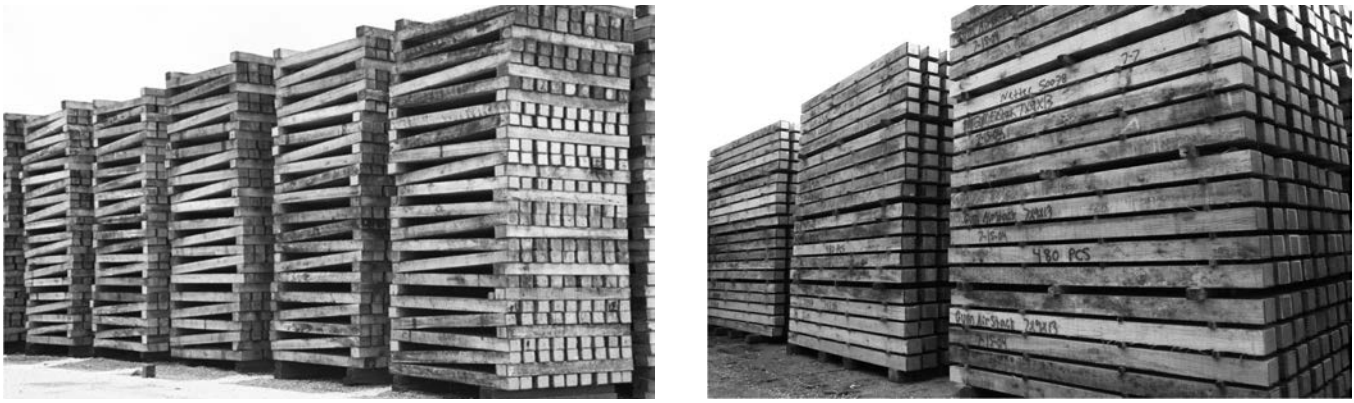


Figure 2.7 Air seasoning of ties showing good stacking and yard procedures.

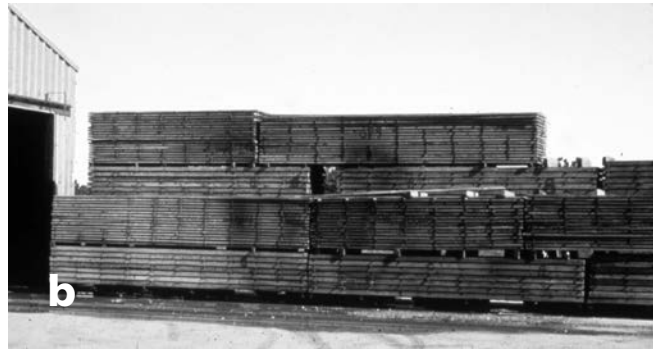


Figure 2.8 Stacked poles (a) and lumber (b) being prepared for a batch kiln.

could assist both drying and treating of southern pine and other species.

### 2.1.3 Seasoning

Green wood must be seasoned prior to treatment in order to get adequate penetration and retention of preservative. Various seasoning techniques are used prior to preservative treatment (Henry 1973). Of these, air seasoning, kiln-drying, Boultonizing, and steam conditioning are used in commercial operations. Air seasoning is the simplest method and has the lowest energy costs. The drying rate is climate dependent; the method requires a large inventory and land area and is subject to deterioration from decay and insects. Fire can also be a problem. Good seasoning practices should be used and spacing should be appropriate for the climate. Stacks should be properly stickered, free of weeds and debris, and off of the ground on treated piles (Figure 2.7).

Kiln-drying (Figure 2.8) is currently the fastest growing method of conditioning, primarily because of the increased use of waterborne preservatives, the reduction of wastewater volumes generated, and the rapid turnover of inventory. Kiln drying is used for drying commodities

such as lumber, poles, and piles. Generally batch kilns operating in the 60°–110°C range are used, depending upon the species being dried. Time varies according to species and commodity. Kiln drying has the advantage of speed, allows for process control, yields a reduced weight with fewer storage problems, and gives an increase in permeability with more uniform treatment.

In the Boulton process (Boulton 1884), the wood is literally boiled in oil under vacuum (Figure 2.9). Green or partially seasoned stock is covered with a hot oil or oilborne treating solution, a vacuum is applied, and the water is removed. Boulton-drying of green ties began in 1978 and has grown rapidly. Many plants are Boultonizing partially seasoned ties, and Boulton-drying is used extensively for Douglas-fir (*Pseudotsuga menziesii*) poles/piles treated with oilborne preservatives. Typically, 32–192 kg/m<sup>3</sup> of water are removed in this process. Temperatures ranging from 82°–99°C for 10–50 h are used. The process minimizes checking and improves treatability, but is not good for thick sapwood species.

The major advance in steam conditioning has been a move toward closed steaming (Thompson and Barnes 1978) in order to reduce process wastewater. In this pro-

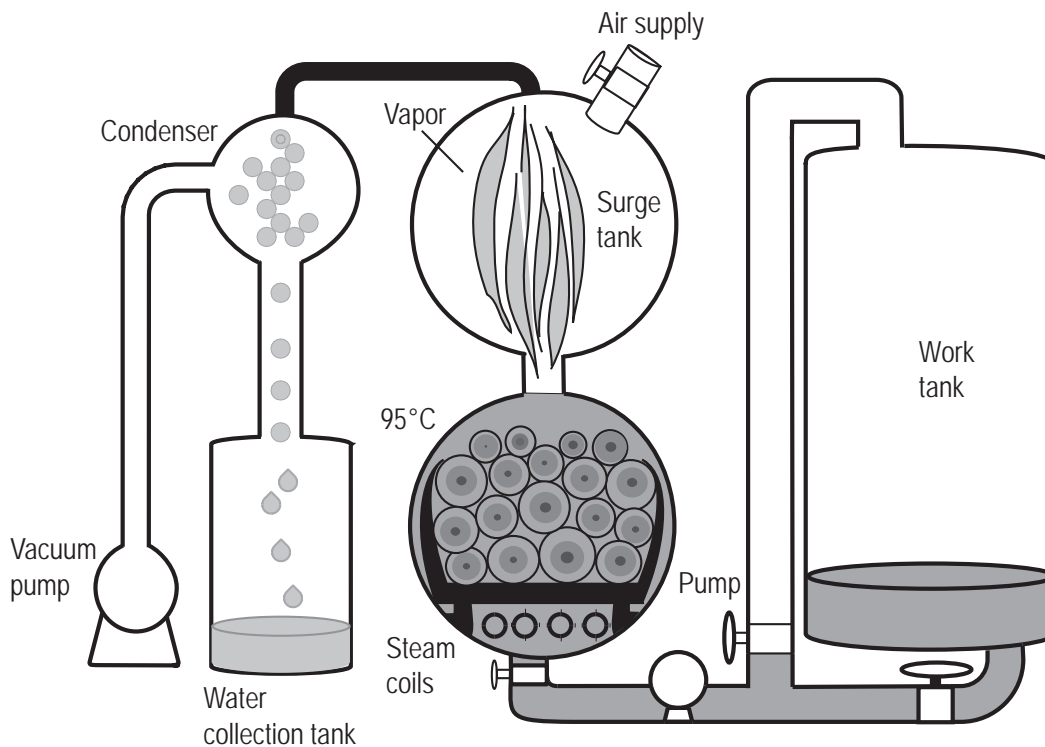


Figure 2.9 Schematic showing the Boulton drying process (adapted from Koppers, Inc.).

cess, green stock [typically southern pine (*Pinus* spp.)] is heated with steam, and water is removed by the application of a vacuum (Figure 2.10). Steaming temperatures range from 104°–118°C for 1–16 h. AWPA limits the length of the steaming periods to prevent damage to the wood (AWPA 2008).

Typically, 64–80 kg/m<sup>3</sup> of water are removed and the process is used with oilborne preservative systems. Southern pine is the major species conditioned in this manner. The process yields lighter stock and leads to less bleeding and vapor loss.

Vapor drying of green stock, developed by Hudson in 1942, has been discontinued. In this process, the wood/water matrix was heated using the latent heat of organic solvents. As the solvent condensed on the wood, its heat was given up to the wood, and the water and solvent were removed by vacuum and separated.

Pressure steam drying (PSD) has the potential for rapid seasoning of stock with minimal degrade, and it seems readily adaptable to existing treating facilities (Rosen 1980, 1981). Other techniques, discussed later, allow for the treatment of green wood with preservative systems that fix in wood.

## 2.2 PRESSURE PROCESSES

Most wood is treated by using pressure processes. The wood is placed onto trams that are rolled into large steel cylinders (Figure 2.11). Combinations of pressure and/or vacuum are used to force preservative into the wood and remove excess preservative at the end of the treatment.

### 2.2.1 Conventional cycles

This section discusses the major pressure/vacuum cycles used in commercial production today. Times and magnitude are given for reference only as both can vary greatly from treating plant to plant.

#### 2.2.1.1 Waterborne preservatives

The Bethell (full-cell) process was the first pressure process used to treat wood. In the classic Bethell process (Figure 2.12), wood is introduced into a treating cylinder and evacuated under a vacuum of 71 kPa or higher. Preservative is introduced under vacuum, the cylinder is filled, and the pressure increased up to a maximum of 1380 kPa. After a specified time or uptake, the pressure is reduced to atmospheric and the solution withdrawn. The process provides

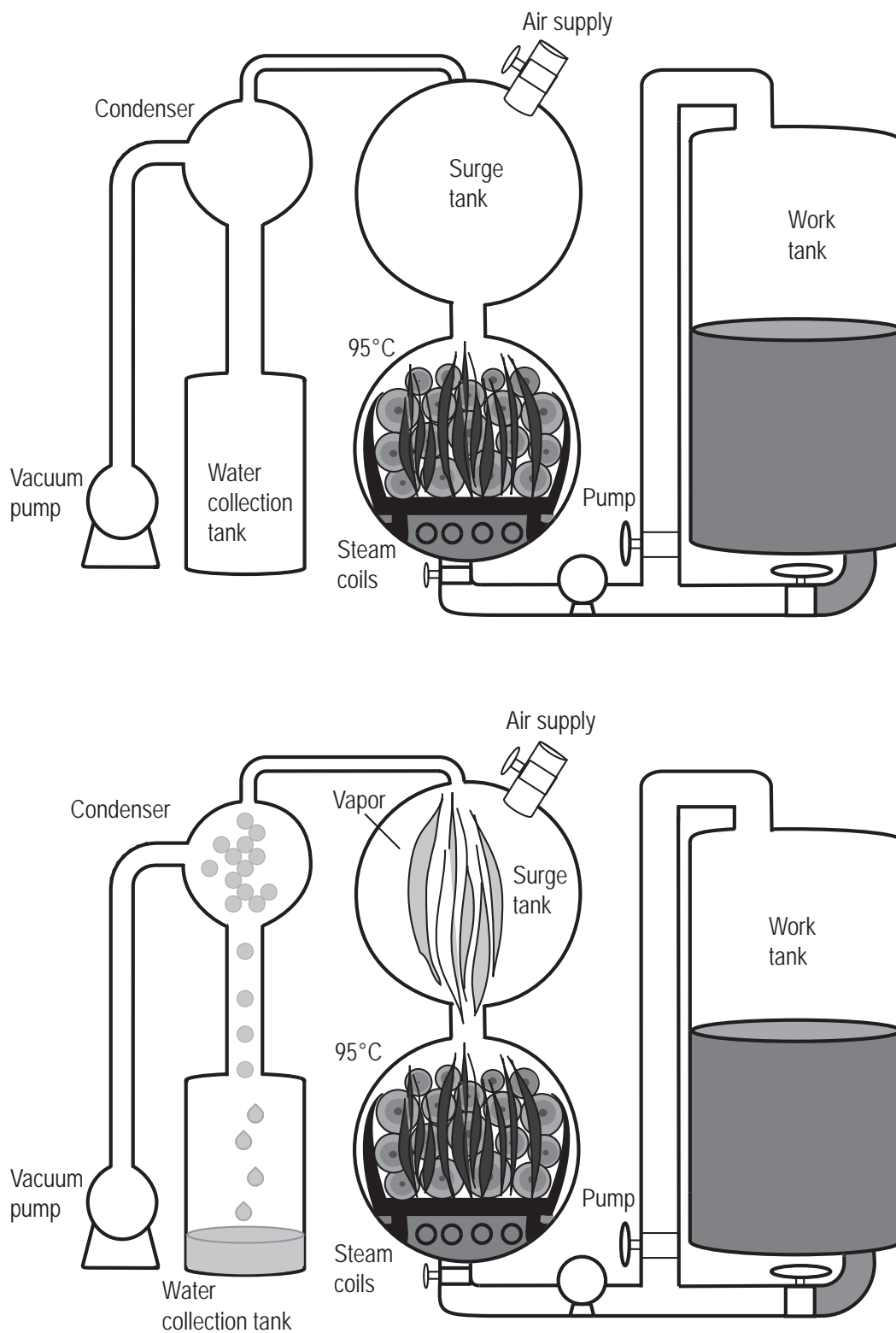


Figure 2.10 Schematic showing closed steaming (top) and water removal by vacuum (bottom) in the steam conditioning process (adapted from Koppers, Inc.).



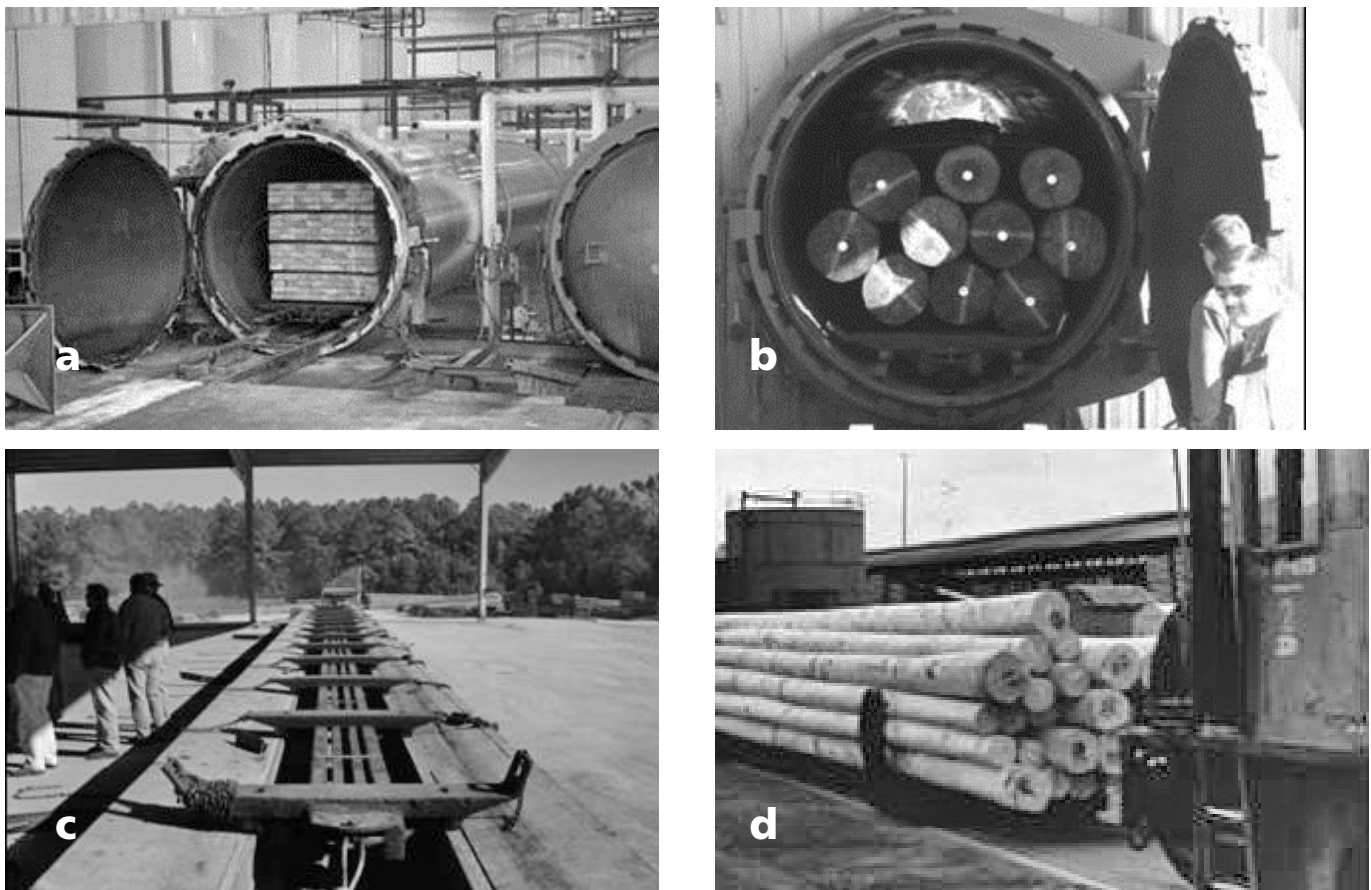


Figure 2.11 Typical single (a) and double (b) opening treating cylinders for the pressure treatment of wood and trams (c, d) for raw material in-feed and out-feed. Photo (a) courtesy of Thunderbolt Wood Treating.

for the maximum solution uptake of  $400 \text{ kg/m}^3$  or greater and is used primarily with waterborne systems.

A modern enhancement is the use of a lower initial vacuum of shorter duration (for instance  $50 \text{ kPa}$  for 8–15 min) and the addition of a final vacuum to reduce weight and drippage. This process is known as the modified full-cell (MFC) process (Figure 2.12), and is used to treat the vast majority of dimension lumber treated with water-based preservatives. Wood exits the treating cylinder at a significantly lower moisture content, and post-treatment dripping of preservative, a major environmental concern, is minimized. Problems with sludging are mitigated by rapid turnover of working solutions and the cooling of working solutions using refrigeration (McIntyre and Eakin 1984) or deep well water. A similar process in Germany is known as a modified Lowry process (modifizierten Lowry-Verfahrens) (Anonymous 1991).

### 2.2.1.2 Oil-type preservatives

Empty cell treatments are commonly used when wood is treated with oil-type preservatives such as pentachloro-

phenol, creosote, or copper naphthenate. Conventional empty-cell treatments include Rueping (1902) and Lowry (1906) processes (Figure 2.12). In the former, an initial pressure (e.g.,  $138\text{--}276 \text{ kPa}$ ) is applied to the charge before introduction of the preservative. Pressure is then increased to a maximum and held until the desired gross retention is achieved. The cylinder is then vented to atmospheric pressure and the solution removed. When the pressure drops below the initial air pressure, the pressure inside the wood, being higher than the applied pressure, forces the excess preservative from the wood. This excess preservative is known as “kickback.” A final vacuum completes the process. In Germany, a double Rueping process (Doppelrueping-Verfahren) is used (Anonymous 1991).

The Lowry process starts at atmospheric pressure, rather than at an increased initial pressure. The remaining steps are the same as with the Rueping process. Net nominal solution uptakes of the order of  $140 \text{ kg/m}^3$  for the Rueping process and  $200 \text{ kg/m}^3$  for the Lowry process are produced. The advantage of the initial air pressure is that the net solution injection can be controlled.

## 2.2.2 Processes attempted for difficult-to-treat wood species

Some wood species, such as Douglas-fir, are difficult to penetrate with liquid preservatives; various processes have been proposed or used to assist in treatment of wood species that resist preservative penetration. At this time the processes discussed in this section are not widely used.

### 2.2.2.1 Oil-type preservatives sonic wave treatments

The application of a saw-toothed sonic wave during the pressure period has reduced treatment time for pine poles by over 80% (Page and Reed 1969). Researchers at Oregon State University have investigated sonic wave pressure. Nair and Simonsen (1994, 1995) were able to increase the absorption of water in Douglas-fir by using sonic wave pressure. The authors consistently obtained injection rates 1.5 times that obtained when conventional hydraulic pressure was employed.

### 2.2.2.2 High energy jet treatment

Using Bryan's work on machining with high-energy water jets (Bryan 1963) as a basis, Nearn and Megraw (1972) used high-pressure jets to treat composite products with fire retardants. Nozzle pressures as high as 413 MPa have been used to treat refractory softwoods such as western hemlock (*Tsuga heterophylla*) and ponderosa pine (*Pinus ponderosa*) with ammoniacal copper arsenate (ACA). Douglas-fir was less well treated, but field trial samples performed adequately after 13 y of ground contact exposure (Jewell et al. 1985). Lower pressure jets have been used successfully in Japan (Saburo 2001), and Misawa Home Co. Ltd. is using the technique to produce sill plates (dodai).

### 2.2.2.3 Vapor phase treatment

There has been considerable interest in recent years in the development of vapor phase treatments for wood and wood composites, a concept put forward by Scheurch (1968). Treatment with gas-phase components would eliminate the problems that exist with the liquid tension interface in current treatment practices. All treatments in the liquid phase depend upon the movement of liquid preservative into the wood. Two problems must be overcome in order to get deep, uniform treatment. First, tension forces at the liquid-air and liquid-wood interfaces must be overcome (Skaar 1972). Second, transverse movement is dictated by the permeability of pit membranes (Hunt

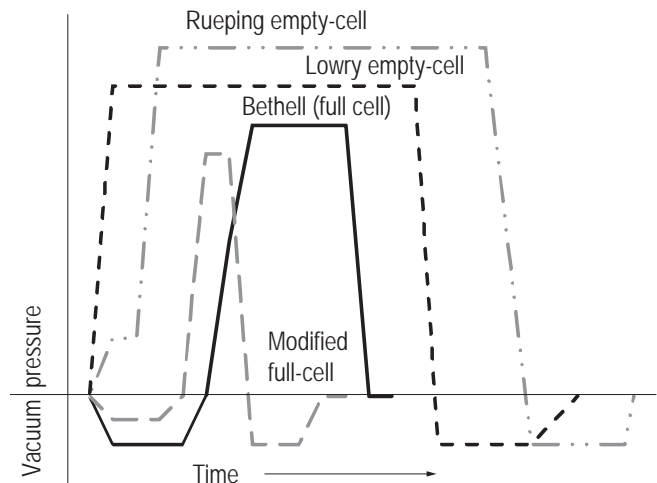


Figure 2.12 Commercial treating cycles (times and magnitude are for illustration only).

and Garratt 1953). The pits may be aspirated, encrusted with extractives, or blocked by air embolisms that make them impervious to liquid flow (Kelso 1962, MacLean 1952, Miller and Graham 1963, Thompson and Koch 1981). Gas-phase treatments have been used extensively for remedial treatment of wood in service (Morrell and Corden 1986, Morrell 1989). Efforts to modify wood using gaseous reagents have met with only moderate success (McMillin 1963, Barnes et al. 1969). Reaction with alkylene oxides has yielded some decay and termite resistance (Rowell and Gutzmer 1975, Rowell et al. 1979, Rowell 1991).

Cooperative research between Imperial College, London, and the Forest Research Institute, New Zealand has led to vapor-phase boron treatments applied as primary treatments for wood and wood-based materials (Turner and Murphy 1987, Burton et al. 1990, FRI 1990, Turner et al. 1990, Bergervoet et al. 1992, Hashim et al. 1992, Hashim et al. 1994, Turner and Murphy 1995, Turner and Murphy 1998). In this treatment, trimethyl borate (TMB) is heated and introduced into an evacuated cylinder containing dried wood or composite panels. Diffusion is rapid and penetration is complete. The main advantages of the process are the speed and cleanliness of treatment and the potential for drying, treating, and conditioning in a single vessel. TMB has been successfully used to treat a wide range of wood composites (Hashim et al. 1992, Hashim et al. 1994, Murphy et al. 2002, Barnes and Murphy 2005, Barnes and Murphy 2006) including OSB, LVL, plywood, and MDF. No commercial use of the process is in place at this time.



### 2.2.2.4 Supercritical fluid treatment

The potential for treating wood using supercritical carbon dioxide (SCCO<sub>2</sub>) as a carrier is promising (Morrell et al. 1993, Junsophonsri 1994, Morrell et al. 1994). In this case, there are no problems with the high surface tension associated with liquid treatment because treatments are done above the critical point so that there is no distinction among phases. Evans (2003) reported that a plant for SCCO<sub>2</sub> treatment is operational in Denmark. The use of SCCO<sub>2</sub> in composites is particularly appealing (Oberdorfer et al. 2000). Based on the pioneering treatment of composites with SCCO<sub>2</sub> tebuconazole by Acda et al. (1997a,b), Tsunoda and Muin (2003) successfully treated composites with a IPBC + silafluofen mixture. Of a wide range of composites treated with SCCO<sub>2</sub>, most showed minimal loss in mechanical properties (Muin et al. 2001). The notable exception was a large loss of bending strength in OSB. Previously, Kim et al. (1997) had shown some loss in bending strength when using SCCO<sub>2</sub> to treat southern pine with TCMTB. For above-ground exposure in Hilo, Hawaii, Morrell et al. (2005) showed excellent performance of plywood, MDF, particleboard, and OSB treated with tebuconazole by using SCCO<sub>2</sub> as long as retention was high enough. Kang et al. (2006) noted that the movement of cyproconazole in the SCCO<sub>2</sub> treatment of ponderosa pine was influenced more by diffusion than by bulk flow. The use of SCCO<sub>2</sub> was originally developed to extract flavors or decaffeinate coffee. Its use to improve treatability of Douglas-fir by extracting fatty acids has been investigated (Kumar and Morrell 1993). SCCO<sub>2</sub> extraction has been used to extract PAHs and organo-chlorine compounds from wood, demonstrating its potential in waste recycling (Legay et al. 1998, Schrive et al. 1998).

### 2.2.2.5 High pressure process

Refractory species such as spruce pose a challenge to the treater. One approach has been to use pressures of 4-7 MPa, a level up to five times that of conventional processes. The early work in this area was conducted at CSIRO Australia with oilborne systems (Dale 1960, Keating 1961). According to Wilkinson (1979), one plant in Tasmania used high pressures to treat pipe staves with CCA. More recently, Hösli and Ruddick (1988) modified the OPM process to treat spruce with CCA using a pulsation technique. Drawing from their experience with oilborne systems (Hösli 1980, Hösli and Filion 1983, Hösli and Osusky 1982), the authors rapidly pulsed pressure between initial air and pressures

as high as 2.1 MPa to greatly improve preservative uptake and penetration in spruce. Mechanical damage to the wood was considerable, however.

## 2.2.3 In-situ processes to minimize environmental release

This section discusses new processes developed in part to minimize the impact of preservatives and preservative migration on the environment. Modifications to existing processes to achieve this goal are discussed under post-treatment practices.

### 2.2.3.1 MSU process

W.C. Kelso, Jr. (1981) developed the "MSU Process" for the empty-cell treatment of wood with CCA. This process makes it possible to obtain full-cell CCA gradients using an empty-cell process. Empty-cell treatment yields cost savings due to weight reductions especially with treated timbers and roundstock. No problems with strength reduction, disproportionation, gradients, leaching, or effluents have been noted (Anonymous 1977, Weaver 1981, Wood 1980, Wood and Kelso 1977, Wood et al. 1980). The process has also been used to successfully treat lodgepole pine (Barnes 1988).

The key feature of the process is the removal of preservative while maintaining pressure high enough to prevent kickback of the preservative solution and the introduction of a heating medium. The preservative components are then fixed in the wood by heating, usually by steam or hot water, prior to releasing pressure and allowing "kickout" to occur.<sup>1</sup> The kickout can then be segregated, treated, and returned to the working tank, thus achieving the zero discharge requirements of the EPA. Extension of the basic process to other preservatives and preservative systems seems to offer the potential for further savings for the wood preserving industry (Anonymous 1977).

### 2.2.3.2 Multiphase pressure (MPP) process

The MPP process developed in New Zealand is a similar process in that the excess solution is removed while maintaining pressure above that of initial air (Hedley et al. 1999, Nasheri et al. 1997, 1998; Pearson et al. 1998, 2001;

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1. The term "kickout" is used to differentiate it from the normal kickback occurring in the conventional empty-cell treatment of wood with the Lowry or Rueping processes.

Pendlebury et al. 1997). However, in this process, hot CCA treating solution is used and provides the heat for fixation. The kickout and vacuum drip are segregated from the working solution.

### 2.2.3.3 MCI process

Another *in-situ* fixation process for use with copper naphthenate is the MCI (Mooney Chemical Inc.) process (Hein and Kelso 1987). In this process, wood is treated empty-cell with a conventional Rueping process. At the end of the cycle, the temperature is raised and a heating bath cycle is applied before removing the preservative and venting to atmospheric pressure.

Moldrup (1983) described a technique developed in Europe for treating wood with CCA followed by seasoning and staining of the wood in one cycle. The process is basically a modification of the Royal process whereby wood is impregnated with CCA, followed by heating in pigmented linseed oil under vacuum after removal of the CCA treating solution. The Royal process was developed in Sweden. It is a process in which a Boulton cycle is performed using pigmented oil to impart a natural finish to the wood after a full-cell treatment (Wilkinson 1979).

## 2.2.4 Other minor processes

This section discusses other treatment processes that were important historically or are used currently to produce small volumes of treated wood.

### 2.2.4.1 Solvent recovery systems

In the 1960s, two solvent recovery systems were developed. Bescher (1965) developed the Cellon® process for treating wood with pentachlorophenol (penta) in liquefied petroleum gas. The actual treating process was either a full- or empty-cell process, but the change of solvent systems from hydrocarbon oil to LPG left a clean, paintable, and gluable surface (Goodwin and Hug 1961, Henry 1963). Methylene chloride was another recoverable solvent used with penta and patented as the Dow process (Marouchoc 1972, Winn 1973). In the UK, Stalker (1974) patented the use of TBTO (Rentokil process) with the same solvent. These solvent recovery processes have been completely abandoned in the United States.

A solvent recovery process patented by the Kanematsu-NNK Corp. in 1990 is currently being used by 22 companies in Japan, the Philippines, and New Zealand (Kanematsu-NNK Corporation n.d.; personal communication, Koichi Yamamoto, 2006). Known as the Dry process-KNN Nissan

Clean Treatment, the process uses a non-combustible organic solvent to carry copper naphthenate, zinc naphthenate, or cyproconazole + imidacloprid. The wood is treated full-cell and then undergoes a solvent recovery phase that uses high frequency heating while the wood is still in the treating cylinder.

### 2.2.4.2 Sap displacement systems

Hudson developed two sap displacement pressure processes in the late 1960s: the *Slurry-Seal process* (Hudson 1968, 1969a) and the *Prescap process* (Hudson 1969b, Hudson and Shelton 1969). These processes are modifications of the old Boucherie process. Neither process is being used commercially. Treatment of green wood has been accomplished by sap displacement using modifications of the *Boucherie process*. In the *Gewecke* modification (Wilkinson 1979), poles are fitted with suction caps driven into the end of each pole in a treating charge. The caps are attached via flexible tubes to a vacuum manifold inside the pressure cylinder. The manifold is piped through the vessel wall to the vacuum system and the wood is treated by filling the cylinder with preservative under pressure while simultaneously applying a vacuum to the manifold. This process is used extensively in Denmark to treat refractory spruce (*Picea* spp.) and was used in the UK without vacuum to treat green spruce and Scots pine (*Pinus sylvestris*) poles. In the UK operation, the pressure differential between the applied and atmospheric pressures was sufficient to drive the preservative into the sapwood while pushing the sap out of the poles. The poles were called "green giants" by the utilities and disliked because of their high weight even though excellent treatment was achieved. Methods for suction cap displacement have been reviewed by Stalker and McClymont (1976a). Another modification is the pressure band method suitable for treatment of green poles in developing countries (Stalker and McClymont 1976b).

### 2.2.4.3 Specialized vacuum/pressure processes

The *oscillating pressure method* (OPM), developed in Sweden in 1946 (Hudson and Henriksson 1956, Walchii 1970, Wilkinson 1979), alternates cycles of vacuum and pressure after an initial pressure period. The alternating periods of pressure gradually increase in length throughout the cycle while the periods of vacuum decrease. A final vacuum similar to the full-cell cycle completes the method. This method has been used commercially in Germany and Switzerland to treat spruce and fir (Peek 1987).

Improvements to the OPM cycle have been suggested (Goetsch and Peek 1991). Initial work in New Zealand with steam-conditioned radiata pine (*P. radiata*) using the OPM cycle (McQuire 1962, Rudman et al. 1963) led to the commercial use of the *alternating pressure method* [APM]. This modified Lowry process has been used to treat partially seasoned pine with CCA preservatives. Typically, the wood is steamed and allowed to cool before treatment. After introduction of the preservative, pressure is cycled quickly between maximum pressure and atmospheric pressure with the hold period at atmospheric pressure increasing at each cycle. On the last cycle, maximum pressure is maintained until refusal is reached. This process has the advantage of being less energy intensive because the need for initial kiln-drying is eliminated. Fifteen cycles are adequate for treating steam-conditioned radiata pine (Bergervoet 1981, 1982, 1984, Vinden and McQuire 1978). Steam-conditioned southern pine at moisture contents as high as 60% has been successfully treated using this cycle (Barnes 1987). The most serious drawback to the APM process is possible sludge formation from working solutions contaminated with wood acids and sugars. Sludge formation is not normally a major problem because of rapid solution turnover and can be further minimized if a full-cell charge is treated at the end of a production shift.

The *double vacuum process* is used almost exclusively for millwork/joinery. It consists of two vacuum periods in which the treating fluid, usually AWPA P9 Type C or LOSP (light organic solvent preservative), can penetrate the small dimension pieces, like window stock or joinery, usually used in the process. After the application of an initial vacuum, the treating vessel is vented, solution drained, and a second vacuum applied to remove excess fluid and clean the surface.

## 2.3 NON-PRESSURE PROCESSES<sup>2</sup>

### 2.3.1 Cold soak method

This method is sometimes used for treatment of fence posts with oil-type preservatives such as copper naphthenate. It is also being used commercially for millwork/joinery treatment and for sapstain/mold control treatments. In this process, the joinery is submerged in a wood preserva-

tive fluid and treatment of the end grain is achieved with minimal penetration of the other surfaces. The method is widely used for sapstain and mold control applications in hardwood and softwood sawmills and re-manufacturing plants. Depending on solution active ingredient content, active ingredient surface levels surface retention rates of  $> 1.5 \times 10^{-3} \text{ kg/m}^2$  are commonly achieved.

The use of anti-sapstain dip tanks is probably the oldest method for the application of chemicals in a water-based bath to retard the growth of sapstain organisms and molds on fresh cut wooden items (lumber, flitches, planks, etc.). The process is very simple. The anti-sapstain chemicals, mostly water-soluble or water-dispersible, are mixed with large volumes of water and placed into a large tank. Freshly cut unseasoned wood is placed into the bulk dip tank with the use of cranes, forklifts, or hoists. The wood is usually submerged for 1-3 min, depending on if it is dead-stacked or stickered, then the wood bundle is raised above the tank and allowed to drain (or alternately, placed on a drip pad, which will collect the drainage from the bundle, and then pump the liquid back into the tank). Once the wood has been treated with an effective "prophylactic" surface treatment, the wood is allowed to air-dry, temporarily stored before it goes into the pre-dryer or dry kiln, or shipped from the sawmill location. The chemicals currently used make this operation a sound investment as wood can be degraded by hundreds of dollars per MBF if it is stained or moldy. Good preventative maintenance on these systems includes overflow protection and a contained self-enclosed foundation to control drippage and chemical spills.

Other delivery systems are being or have been used for delivering sapstain chemicals to wood. Flood coaters, foaming coaters, lateral spray boxes, and in-line spray boxes are also used in the application of anti-sapstain chemicals. These devices basically flood an aqueous solution or dispersion of mixtures of anti-sapstain chemicals over the individual boards in a manufacturing line, either linearly or horizontally. Electrostatic spray systems allow users to uniformly coat all the surfaces of a board with the same amount of an anti-stain system and also allow the use of non-aqueous systems. Widely used in the furniture finishing industry, this technology has only been successful in small-scale sawmill trials.

### 2.3.2 Diffusion treatments

Diffusion systems have been widely investigated over the last 200 years. Today, only a few small treaters use diffus-

2. The author is indebted to M. H. Freeman, Independent Wood Scientist, Memphis, TN, for most of the information and discussion in this section. Much of the information can be found in Baileys and Freeman (2002).



ible borate systems without subsequent employment of a pressure/vacuum system (Figures 2.13 and 2.14). Recent studies (Amburgey and Sanders 2007, Amburgey et al. 2003) have proven that pre-treatment of hardwood cross-ties with borates can successfully extend the service life of the tie when followed by a second, water resistant system. It is estimated that 150,000 tonnes of diffusible borates are used in wood preservation annually. This does not include the amount being used by the pest control industry for home spraying and termite abatement. In most diffusible treatments, wood is pressure treated to deliver a high concentration of borates in the shell, and then allowed to diffuse under cover/tarps before sampling and retention/assay takes place. Diffusion rates follow Fick's laws, and are directly proportional to concentration, heat, and moisture content.

Double diffusion treatment involves treatment of wood with a waterborne system incorporating a diffusion period followed by treatment with a second water soluble compound. In theory, the second compound reacts with the first with the product being less soluble than either of the starting compounds. These treatments are being investigated again in Colorado and Alaska using locally grown species to produce fence posts by first treating with copper sulfate followed by sodium fluoride. Neither of these two chemicals is currently registered for this use by the USEPA, and no work has been done on the toxicity of the leachate from these systems.

### 2.3.3 Thermal treatment process (TTP)

The TTP was originally patented by C.A. Seely (1867), is also known as the open-tank treatment, the boiling-and-cooling method, and more recently the thermal process. It involves immersion of seasoned wood, for many hours, in successive baths of hot and relatively cool preservative (Hunt and Garratt 1953). The function of the hot bath is to expand the surface of the wood; the duration of the bath and temperature of the preservative will largely determine the extent to which air and water vapor leave the wood. The cold bath, in turn, causes the air and vapor remaining in the outer shell of the wood to contract, thus forming a partial vacuum. To satisfy this vacuum, atmospheric pressure tends to force the surrounding preservative into the wood. Some penetration takes place during the hot bath in unusually absorptive wood, but most of the absorption and penetration occurs during the cold bath. The change in baths may be accomplished in several ways; by transferring the heated wood to a separate tank



Figure 2.13 Dipping lumber bundles for diffusion treatment.



Figure 2.14 Pole stock subjected to a final steam/vacuum cycle.

of relatively cool preservative; by withdrawing the hot liquid from the tank and replacing it with unwarmed preservative, without moving the timber; or by merely discontinuing the heating and allowing the wood and preservative to cool together. In the first two cases, it is imperative that the change be made without delay; otherwise, the benefits of heating for the subsequent cold bath will be impaired. The timber to be treated should be rather thoroughly air dried, not only to facilitate penetration but also to eliminate subsequent extension of seasoning checks through the impregnated shell of wood.

Both preservative oils and water-soluble salts may be applied by the hot- and cold-bath process, but the great bulk of treatment is done with coal-tar creosote and other oils. Preservative oils have a definite advantage in that they afford more permanent protection to poles, posts, and other forms of timber that are to be exposed to the weather and also because they can be heated to the desired temperatures in open tanks with less evaporative loss.

When water solutions are employed in the hot bath, temperatures must be kept low enough to maintain proper solution strength. Water-borne preservatives that cannot be heated to high temperatures without danger of precipitating part of the salts out of solution are not suitable.

When coal-tar creosote is used, hot-bath temperatures of 99° to 104°C are usually adequate for general purposes. However, Standard T-1 of the American Wood Protection Association (AWPA 2008), covering treatment of cedar poles by the thermal process, stipulates a temperature range of 88° to 113°C. Higher temperatures tend to improve penetration but also cause somewhat greater evaporation of oil from the treating tank; this loss may be considerable with creosotes of relatively low boiling range. The cold bath should be as cool as is consistent with keeping the preservative thoroughly liquid; temperatures of around 38°C are suitable for coal-tar creosote. Standard T-1 requires that the cold bath shall be “between 66°C and the temperature at which solids form in preservative.” In practice, both maximum and minimum temperatures vary widely, sometimes more than the specification limits allow. When water solutions are used, the cold bath can be maintained at ambient temperatures, as long as they remain above freezing. Treating time may vary considerably depending upon such factors as the species of wood, type of product, extent to which the timber has been seasoned, weather conditions, and often the opinion of the person in charge of the operation. Baths may last 1 to 12 h or even longer. AWPA Standard T-1 provides for a hot bath of not less than 6 h and cold bath of at least 2 h.

In another variation (Boardman 1941), the wood is placed in an open tank, the tank covered with a tarpaulin or other suitable material, and steam at atmospheric or slightly higher pressure is admitted for several hours. When the wood has been heated sufficiently, steaming is discontinued and a cold solution of water-borne preservative admitted to the tank. This method has found commercial use on a small scale. Heating in steam can also be accomplished in a closed cylinder either at or above atmospheric pressure; this procedure is also in limited commercial use, mainly for treatment of mine timbers with a water-borne preservative.

Still another modification of the hot and cold bath (Hammond 1945) provides for heating wood in water at temperatures of 49°C to 100°C and then replacing the water with a waterborne solution of a diffusible wood-preserving or fire-retarding chemical. The stated purpose

of the water treatment is to increase the moisture content of the wood so that diffusion of the chemical will occur more rapidly in the second bath.

## 2.4 POST-TREATMENT PROCESSES

### 2.4.1 Post-treatment processing

The effect of conditioning on the properties of treated wood was studied extensively in the 1980s and 1990s (Barnes 1985b, Barnes and Mitchell 1984, Bendtsen et al. 1983, Winandy et al. 1983, 1992), particularly wood treated with waterborne preservatives. Reductions in modulus of rupture have been found for full-sized material kiln-dried after CCA treatment and have resulted in a redrying temperature limitation of 71°C. Similar results were found for ACQ-treated wood (Barnes et al. 1993). Research on post-treatment accelerated fixation methods and drying effects has shown the need to dry the wood slowly in order to prevent excessive depletion of preservative in use. The use of high humidity during the early drying phase has been recommended (Anderson 1990, Avramidis and Ruddick 1989). Data for redrying wood treated with new generation systems such as waterborne copper naphthate, copper xylogen, copper azole, and copper betaine have yet to be developed.

With oil-type systems, the use of a post-treatment steam/vacuum cycle is perhaps the most successful way of reducing preservative bleeding and removing excess preservative from the wood surface. After removal of the preservative to the work tank, the cylinder charge is steamed for a period of time followed by a vacuum to remove excess preservative and entrapped air. Some plants employ two such steam flash/vacuum cycles. As shown in Figure 2.14, the resultant stock is dry and free of excess oil.

### 2.4.2 Best Management Practices

Perhaps the most important aspect of post-treatment handling is adherence to Best Management Practices (BMPs). A consortium of organizations including Wood Preservation Canada, the Western Wood Preservers Institute, Southern Pressure Treaters' Association, and the Timber Piling Council has promulgated a series of practices aimed at minimizing the environmental impact of treated wood (WWPI 2006). Included in the BMPs are a guide to selection, specification, and quality assurance, BMPs for the production of treated wood and for specific preservatives, installation and maintenance guidelines, and quality





Figure 2.15 Typical barrier wraps for round and rectangular sections. From (a) <http://www.postprotector.com>; (b) <http://www.pplfieldliners.com/users.htm>; (c) <http://www.pplfieldliners.com/users.htm>; (d) Barnes et al. (2009).

assurance inspection procedures. The reader is referred to Chapter 11 of this volume for a discussion of BMPs by Hayward, Lebow, and Brooks.

## 2.5 THE ROLE OF BARRIERS IN PERFORMANCE

Bandage wraps, such as that reported by Amburgey and Freeman (1993), have long been used for the remedial treatment of poles. Barrier wraps (also known as field liners) represent a different approach for a similar product (Figure 2.15). The history and data for barrier wraps were covered in papers given at AWPA in 2005 and 2006 (Freeman et al. 2005, 2006). Included in these reviews were papers and data from the British Research Establishment (Carey and Lea 1998, Dearling 2004), Oregon State University (Scheffer and Morrell 1997), Mississippi State University (Amburgey and Parikh 2000), and research from South Africa by Baecker (1993) and his colleagues (Baecker and Behr 1995, 1998; Behr and Baecker 1994; Behr et al. 1996, 1997).

Morris and Ingram reported on the performance of wrapped posts in an accelerated soilbed test (2005a) and after 9 y in ground contact (2005b). In the soilbed exposure, the authors found post wrapping reduced the decay rate in untreated lodgepole pine posts and delayed the onset of decay in CCA-treated posts. Time to failure for unwrapped, untreated posts was 30 mo compared to 90 mo for untreated material wrapped before installation. After 8 y of the soil bed exposure, posts treated to an above-ground retention of  $4 \text{ kg/m}^3$  were performing as well as or better than unwrapped posts treated to  $10 \text{ kg/m}^3$  (Morris and Ingram 2005a). The matched samples placed in ground contact exposure yielded a different result (Morris and Ingram 2005b). In this case there was no observable bio-deterioration in the CCA posts treated to an above ground



Table 2.1 Service conditions for use category designations (AWPA 2008).

Use category	Service conditions	Use environment	Common agents of deterioration	Typical applications
UC1	Interior construction Above ground Dry	Continuously protected from weather or other sources of moisture	Insects only	Interior construction & furnishings
UC2	Interior construction Above ground Damp	Protected from weather, but may be subject to sources of moisture	Decay fungi & insects	Interior construction
UC3A	Exterior construction Above ground Coated & rapid water runoff	Exposed to all weather cycles, not exposed to prolonged wetting	Decay fungi & insects	Coated millwork, siding & trim
UC3B	Exterior construction Above ground Uncoated or poor water run-off	Exposed to all weather cycles including prolonged wetting	Decay fungi & insects	Decking, deck joists, railings, fence pickets, uncoated millwork
UC4A	Ground contact or fresh water Non-critical components	Exposed to all weather cycles, normal exposure conditions	Decay fungi & insects	Fence, deck, & guardrail posts, crossties & utility poles (low decay areas)
UC4B	Ground contact or fresh water Critical components or difficult replacement	Exposed to all weather cycles, high decay potential includes salt water splash	Decay fungi & insects with increased potential for biodeterioration	Permanent wood foundations, building poles, horticultural posts, crossties & utility poles (high decay areas)
UC4C	Ground contact or fresh water Critical structural components	Exposed to all weather cycles, severe environments extreme decay potential	Decay fungi & insects with extreme potential for biodeterioration	Land & freshwater piling, foundation piling, crossties & utility poles (severe decay areas)
UC5A	Salt or brackish water & adjacent mud zone Northern waters	Continuous marine exposure (salt water)	Salt water organisms	Piling, bulkheads, bracing
UC5B	Salt or brackish water & adjacent mud zone NJ to GA, south of San Francisco	Continuous marine exposure (salt water)	Salt water organisms Including creosote tolerant <i>Limnoria tripunctata</i>	Piling, bulkheads, bracing
UC5C	Salt or brackish water & adjacent mud zone South of GA, Gulf Coast, Hawaii, & Puerto Rico	Continuous marine exposure (salt water)	Salt water organisms Including <i>Martesia</i> , <i>Sphaeroma</i>	Piling, bulkheads, bracing
UCFA	Fire protection as required by codes Above ground Interior construction	Continuously protected from weather or other sources of moisture	Fire	Roof sheathing, roof trusses, studs, joists, paneling
UCFB	Fire protection as required by codes Above ground Exterior construction	Subject to wetting	Fire	Vertical exterior walls, inclined roof surfaces or other construction which allows water to quickly drain

retention after 9 y in service. This compared well to the soilbed data, which showed some measurable decay after 8 y. The major difference was in the comparison between wrapped and unwrapped, untreated posts for both studies. In the ground contact study, no retardation in decay rate was noted, but the authors attribute this to deterioration of the barrier wrap used in this study. Based on their excellent results with eucalypts, Australian researchers suggested that lower pole retentions could be used when barriers were employed (Howgrave-Graham et al. 2008). Barnes et al. (2009) describe good performance of barrier wrap systems on a variety of species of timbers and roundstock exposed in AWPAs hazard zone 4. After 27 mo of exposure in covered and uncovered ground contact exposure, no decay or termite attack was found for any of the booted timbers or roundstock.

Since 2006, an AWPAs standard for barrier wraps (P20-08) has been promulgated (AWPA 2008) and one system has been listed (BP1). A new commodity specification (Commodity Specification K: Barrier Protection Systems) is listed in Standard U1-08. An evaluation report has been issued by the ICC for the same system (BP1), thus clearing the way for its use in the building codes (ICC 2008). Barrier wraps allow users to prescribe above-ground retentions for ground contact use. They may also help to minimize migration of preservative into the environment, although this potential benefit needs further evaluation.

Barriers have been applied to marine piling in the Los Angeles harbor (Horeczko 1987). Gambetta (1989) reports excellent performance for marine piles with plastic wraps exposed in Denmark, India, Italy, Tahiti, Syria, Spain, and the UK. Several commercial applications of barrier wraps can be found. The Protective Packaging Ltd. (2009) website lists several companies using a barrier wrap system. Included are Eskom, eThekweni Electricity, Buffalo City, and Benoni Town Council in South Africa, Kenya Power and Lighting Company, and Seattle City Light, Puget Sound Energy, and Snohomish PUD in the United States.

## 2.6 WOOD TREATMENT STANDARDS

The primary organization setting standards for preservatives and treated wood commodities in the U.S. is the American Wood Protection Association (AWPA). Beginning as the Wood-Preservers' Association, the AWPA has been setting standards since its inception in 1904. It publishes an annual Book of Standards (BOS) which is available at <http://www.awpa.com/>. The major section is the Use Category System Standard, composed of two sections: U1

User Specification for Treated Wood and T1 Processing and Treatment Standard. Section U1 places treated wood into six use categories as shown in Table 2.1. This system was instituted, and the old commodity specification standards eliminated in order to make specifying treated wood easier for the end user.

Section T1 includes items of particular interest to companies producing treated wood. This section includes general treatment requirements, treatment, results of treatment requirements, retreatment, and processing of wood after treatment. Special requirements by commodity are given, including penetration and retention requirements by species.

Also included in the BOS are standards for non-pressure treatment (N standards), standardized preservative systems (P standards), standards for analyzing preservatives and wood containing preservatives (A standards), evaluation (E) standards for evaluating preservative systems under various service conditions, and miscellaneous (M) standards related to the purchase of treated wood, inspection and quality control, and care of preservative treated wood including mitigation of potential environmental impacts of preservative-treated wood. An excellent discussion of the new AWPAs standards can be found in McCown (2007).

Standards and specifications are requisites for producing commodities with increased service life while protecting the interest of the consumer. The combination of specifications and the use of BMPs allow for the production of a quality product that is environmentally sound and minimizes the impact of preservatives on the environment. Good stewardship requires such an approach.

## 2.7 SUMMARY

This paper reviewed the treatment of wood using pressure non-pressure processes, and the preparation of material for treatment. Conventional commercial processes were covered as were sap-displacement, solvent recovery, and in situ fixation cycles along with methods aimed at treating green or refractory wood. Post-treatment handling of treated wood was discussed. In this regard, the most important operations are related to best management practices. A section on novel treatments discussed liquid jet treatment, sonic wave treatment, vapor phase treatments, and supercritical fluid treatments.

## LITERATURE CITED

- Acda, M.N., J.J. Morrell, and K.L. Levien. 1997a. Effects of supercritical fluid treatments on physical properties of wood-based composites. *Wood Fiber Sci.* 29(2):121–130.

- Acda, M.N., J.J. Morrell, and K.L. Levien. 1997b. Effects of process variables on supercritical fluid impregnation of composites with tebuconazole. *Wood Fiber Sci.* 29(3):282–290.
- Amburgey, T.L., H.M. Barnes, and M.G. Sanders. 2007. US Patent 6,142,198.
- Amburgey, T.L., and M.H. Freeman. 1993. Ten year field test with a copper-borate ground line treatment for poles. *Int. Res. Grp. on Wood Pres.*, doc. no. IRG/WP 93-30017.
- Amburgey, T.L., and M.G. Sanders. 2007. Borate pre-treated crossties, a 20 year field test. *Proc. Am. Wood Protect. Assoc.*, pp. 109–111.
- Amburgey, T.L., and S.V. Parikh. 2000. Laboratory test to determine the resistance of plastic coated wood to subterranean termites, Mississippi Forest Products Laboratory, Forest and Wildlife Research Center, Mississippi State Univ., Mississippi State, MS.
- Amburgey, T.L., J.L. Watt, and M.G. Sanders. 2003. Extending the preservative life of wooden crossties by using pre-and supplemental preservative treatments, 125 year exposure report. *Crossties*, May/June, pp. 10, 12, 14–16.
- American Wood Protection Association. 2008. *Book of Standards*. AWPA, Birmingham, AL.
- Anderson, D.G. 1990. The accelerated fixation of chromated copper preservative treated wood. *Proc. Am. Wood-Preservers' Assoc.* 86:129–151.
- Anonymous. 1977. Announcement of a new wood preserving process. Forest Products Utilization Laboratory, Mississippi State Univ., Mississippi State, MS.
- Anonymous. 1991. Verfahren zur Behandlung von Holz mit Holzschimmitteln. Merkblatt, Teil 1: Druckverfahren. Deutsche Gesellschaft für Holzforschung e. V., Munchen (in German).
- Avramidis, S., and J.N.R. Ruddick. 1989. Effect of temperature and moisture on CCA fixation. *Holz als Roh und Werkstoff* 47(8):328.
- Baecker, A.A.W. 1993. A non-pressure method of protection based on hurdle theory to control the spectrum of internal environmental factors which affect the decay of poles in soil contact. *Int. Res. Grp. Wood Pres.*, doc. no. IRG/WP/93-20005.
- Baecker, A.A.W., and M.R. Behr. 1998. Field liners eliminate maintenance and replacement budgets by securing pole performance and protecting the environment. *In: Proceedings, International Conference on Utility Line Structures*, Fort Collins, Colorado, USA, March 23–25, 1998, ed. L.S. Nelson, Engineering Data Management, pp. 45–54.
- Baecker, A.A.W., and M.R. Behr. 1995. Biostatic film as a primary treatment against pole failure in soil. *Int. Res. Grp. Wood Pres.*, doc. no. IRG/WP/95-40053.
- Baileys, R.T., and Freeman, M.H. 2002. Thermal treatment of western red cedar with copper naphthenate. *In: Proceedings, International Conference on Utility Line Structures*, Engineering Data Management, Ft. Collins, CO.
- Barnes, H.M. 1985a. Trends in the wood-treating industry: state-of-the-art report. *Forest Prod. J.* 35(11):13–22.
- Barnes, H.M. 1985b. Effect of steaming temperature and CCA retention on mechanical properties of southern pine. *Forest Prod. J.* 35(6):31–32.
- Barnes, H.M. 1987. Treatment of partially seasoned southern pine with CCA. *Proc. Am. Wood-Preservers' Assoc.* 83:51–70.
- Barnes, H.M. 1988. Treatment of lodgepole pine poles using the MSU Process. *Proc. Am. Wood-Preservers' Assoc.* 84:201–210.
- Barnes, H.M., E.T. Choong, and R.C. McIlhenny. 1969. Several vapor phase chemical treatments for dimensional stabilization of wood. *Forest Prod. J.* 19(3):35–39
- Barnes, H.M., G.B. Lindsey, T.E. Johnson, J.M. Hill, and C.R. McIntyre. 2009. Barrier wrap performance in hazard zone 4. *Proc. Am. Wood Protect. Assoc.* 105:59–65.
- Barnes, H.M., D.E. Lyon, A. Zahora, and F. Muisu. 1993. Strength properties of ACQ-treated southern pine lumber. *Proc. Am. Wood-Preservers' Assoc.* 89:51–60.
- Barnes, H.M., and P.H. Mitchell. 1984. Effects of post-treatment drying schedule on the strength of CCA-treated southern pine dimension lumber. *Forest Prod. J.* 34(6):29–33.
- Barnes, H.M., and R.J. Murphy. 1995. Wood preservation: the classics and the new age. *Forest Prod. J.* 45(9):16–26.
- Barnes, H.M., and R.J. Murphy. 2005. Bending and tensile properties of vapor boron-treated composites. *Wood Fiber Sci.* 37(3):379–383.
- Barnes, H.M., and R.J. Murphy. 2006. Effect of vapor boron treatment on properties of wood strand and fiber composites. *Compos. Part A-Appl. Sci.* 37(9):1402–1405.
- Behr, M.R., and A.A.W. Baecker. 1994. Quantification of creosote migration down wooden poles and the prevention of its depletion during flood irrigation. *Int. Res. Grp. Wood Pres.*, doc. no. IRG/WP/94-50032.
- Behr, M.R., G.D. Shelver, and A.A.W. Baecker. 1996. Field liners prevent creosote migration from transmission poles to soil during service. *Int. Res. Grp. Wood Pres.*, doc. no. IRG/WP/96-40067.
- Behr, M.R., G.D. Shelver, and A.A.W. Baecker. 1997. Transmission poles with sub-standard creosote retentions protected by field liners outperform standard poles in service. *Int. Res. Grp. Wood Pres.*, doc. no. IRG/WP/96-40095.
- Bendtsen, B.A., L.R. Gjovik, and S. Verrill. 1983. The mechanical properties of salt-treated longleaf pine. USDA Forest Service, Forest Prod. Lab., Res. Pap. FPL-434, Madison, WI.
- Bescher, R.H. 1965. U.S. Patent 3,200,003.
- Bergervoet, A.J. 1981. Commercial trials with the steam-vacuum-APM system of preservative treatment. New Zealand Forest Service, Forest Res. Inst., Forest Prod. Div. Rept. No. FH WP65 (unpublished).
- Bergervoet, A.J. 1982. Partial seasoning and preservative treatment systems for pine roundwood. *Int. Res. Grp. Wood Pres.* doc. no. IRG/WP/3187.
- Bergervoet, A.J. 1984. A method for treating partially seasoned pine with CCA preservatives. *Proc. Am. Wood-Preservers' Assoc.* 80:90–96.
- Bergervoet, T., R. Burton, K. Naseri, D. Page, and P. Vinden. 1992. Gaseous boron treatments of wood and wood products. *Int. Res. Grp. on Wood Pres.*, doc. no. IRG/WP/92-3691.
- Bethell, J. 1838. British Patent 7731.
- Boardman, A.D. 1941. U.S. pat. 2,235,822.
- Boulton, S.B. 1884. On the antiseptic treatment of timber. *Minutes of the Proceedings of the Institution of Civil Engineers*, 1883–1884 (London), vol. 78.
- Bryan, E.L. 1963. High energy jet as a new concept of wood machining. *Forest Prod. J.* 13(8):305–312.
- Burnett, W. 1838. British Patent 7747.
- Burton, R., T. Bergervoet, K. Naseri, P. Vinden, and D. Page. 1990. Gaseous preservative treatment of wood. *Int. Res. Grp. on Wood Pres.*, doc. no. IRG/WP/3631.
- Carey, J.K., and R.G. Lea. 1998. Evaluation of a Pole Wrapping System for the Prevention of Decay-Laboratory Test Based on ENV 807:1993, Test 2, BRE Report No: TCR 22/98.
- Cech, M.Y., and D.R. Huffman. 1970. Dynamic transverse compression treatment of spruce to improve intake of preservative. *Forest*



- Prod. J. 20(3):47–52.
- Cech, M.Y., and D.R. Huffman. 1972. Dynamic compression results in greatly increased creosote retention in spruce heartwood. *Forest Prod. J.* 22(4):21–25.
- Dale, F.A. 1960. First commercial high-pressure plant starts production. *C.S.I.R.O. Forest Products Newsletter*, July (265):1–3.
- Dearling, T. 2004. Fenson and Co. Ltd EN252 Testing Year 4 Report, BRE Report No: 215–394.
- Evans, P. 2003. Emerging technologies in wood protection. *Forest Prod. J.* 53(1):14–22.
- Forest Research Institute. 1990. Vapour boron treatment. What's New in Forest Research No. 200, Forest Research Institute, Rotorua, New Zealand.
- Freeman, H.H., C.R. McIntyre, and J. Makuvek. 2005. The use of barrier wraps to increase service life of treated and untreated wood in ground contact. *Proc. Am. Wood-Preservers' Assoc.* 101:85–88.
- Freeman, H.H., C.R. McIntyre, and J. Makuvek. 2006. The use of Postsaver® barrier wraps to increase service life of wood in ground contact. *Proc. Am. Wood-Preservers' Assoc.* 102:112–115.
- Freeman, M.H., T.F. Shupe, R.P. Vlosky, and H.M. Barnes. 2003. Past, present, and future of the wood preservation industry. *Forest Prod. J.* 53(10):8–15.
- Fry, H.J. 1976. US Patent 3950577.
- Gambetta, A. 1989. Information from the DOIPM wood group. *Int. Res. Grp. on Wood Pres.*, doc. no. IRG/WP 4256.
- Goodell, B., F.A. Kamke, and J. Liu, J. 1991. Laser incising of spruce lumber for improved preservative penetration. *Int. Res. Grp. on Wood Pres.*, Doc. no. IRG/WP/3646.
- Goetsch, S., and R.-D. Peek. 1991. Possibilities of improving the oscillating pressure method. *Int. Res. Grp. on Wood Pres.*, doc. no. IRG/WP/3668.
- Goodwin, D.R., and R.E. Hug. 1961. A new wood preserving process. *Forest Prod. J.* 11(11):504–507.
- Graham, R.D. 1973. History of wood preservation. *In: Wood Deterioration and Its Prevention by Preservative Treatments. Vol. I. Degradation and Protection of Wood*, D.D. Nicholas, ed. Syracuse Univ. Press, Syracuse, NY, pp. 1–30.
- Hammond, R.N. 1945. U.S. pat. 2,381,049.
- Hashim, R., D.J. Dickinson, R.J. Murphy, and J. Dinwoodie. 1992. Effect of vapour boron treatment on mechanical properties of wood based board materials. *Int. Res. Grp. on Wood Pres.*, doc. no. IRGIWP/92-3727.
- Hashim, R., D.J. Dickinson, R.J. Murphy, and J. Dinwoodie. 1994. The mechanical properties of boards treated with vapor boron. *Forest Prod. J.* 44(10):73–79.
- Hedley, M.E., K. Nasheri, and G. Durbin. 1999. Multiple-Phase Pressure (MPP) Process: One-stage CCA treatment and accelerated fixation process. 5. Treatment of Sitka spruce and Scots pine. *Int. Res. Grp. on Wood Pres.*, doc. no. IRG/WP 99-40136.
- Hein, R.W., and W.C. Kelso, Jr. 1987. U.S. Patent 4,649,065.
- Henry, W.T. 1963. A new method for impregnating wood with preservatives. *Proc. Am. Wood-Preservers' Assoc.* 59:68–74.
- Henry, W.T. 1973. Treating processes and equipment. *In: Wood Deterioration and Its Prevention by Preservative Treatments. Vol. II. Preservatives and Preservative Systems*, D.D. Nicholas, ed. Syracuse Univ. Press, Syracuse, NY, pp. 279–298.
- Horeczko, G. 1987. Summary of development of pile wrapping in Los Angeles harbor. *Int. Res. Grp. on Wood Pres.*, doc. no. IRG/WP 4141.
- Hösli, J.P. 1980. Untersuchung über die Imprägnierbarkeit von Buchenholz mit Steinkohlenteerdl 3. Mitteilung: Verbesserung der Trankung von Eisenbahnschwellen. *Holz als Roh- und Werkstoff* 38:89–94.
- Hösli, J.P., and M. Filion. 1983. Suitability of the pulsation process for the impregnation of white spruce roundwood by creosote. *Int. J. Wood Pres.* 3(1):23–30.
- Hösli, J.P., and A.R. Osusky. 1982. Teerolimprägnierung von Buchenholz mittels Pulsationsverfahren. *Die Holzschwelle* 77/93:36–40.
- Hösli, J.P., and J.N.R. Ruddick. 1988. Suitability of the pulsation process to pressure treat white spruce lumber with CCA. *Forest Prod. J.* 38(6):47–50.
- Howgrave-Graham, A.R., L.J. Cookson, and T. Hale. 2008. Field liners as physical barriers to prevent wooden utility pole decay in soil: an accelerated field simulation trial. *Int. Res. Grp. on Wood Protect.*, doc. no. IRG/WP 08-20384.
- Hudson, M.S. 1942. U.S. Patent 2,373,039.
- Hudson, M.S. 1968. New process for longitudinal treatment of wood. *Forest Prod. J.* 18(3):31–35.
- Hudson, M.S. 1969a. U.S. Patent 3,427,186.
- Hudson, M.S. 1969b. U.S. Patent 3,443,881.
- Hudson, M.S., Henriksson, S.T. 1956. The oscillating pressure method of wood impregnation. *Forest Prod. J.* 6(101):381–386.
- Hudson, M.S., and S.V. Shelton. 1969. Longitudinal flow of liquid in southern pine poles. *Forest Prod. J.* 19(5):25–32.
- Hunt, G.M., and G.A. Garratt. 1953. *Wood Preservation*. McGraw-Hill (New York).
- ICC Evaluation Service. 2008. Report to Postsaver® USA, ESR 1834, ICC Evaluation Service, Inc., Whittier, CA.
- Inoue, M., and K. Adachi. 2003. A new impregnation technology using roll press system in preservative solution. *APAST* 13(2):11–15 (in Japanese, translation by K. Yamamoto).
- Inoue, M., K. Adachi, K. Tsunoda, Y. Imamura, and S. Kawai. 2001. Application of roller-pressing method to the novel liquid impregnation treatment of green timber. *Int. Res. Grp. on Wood Pres.*, doc. no. IRG/WP 01-40198.
- Jewell, R.A., W.T. Nearn, J.A. Roze, and L.E. Perdelwitz. 1985. Performance of high pressure jet treated 2 x 4 stakes. *Proc. Am. Wood-Preservers' Assoc.* 81:127–134.
- Junsophonsri, S. 1994. Solubility of biocides in pure and modified supercritical carbon dioxide. Master's thesis, Oregon State Univ., Corvallis, OR.
- Kanematsu-NKK Corporation. nd. Dry process-KNN Nissan clean treatment. Information Sheet, Kanematsu-NKK Corporation, Tokyo.
- Kang, S., K. Levien, and J.J. Morrell. 2006. Effect of process variations during supercritical fluid impregnation on cyproconazole retention and distribution in ponderosa pine sapwood. *Wood Fiber Sci.* 38(1):64–73.
- Keating, W.G. 1961. Preservative treatment of eucalypt pole and cross-arm timbers in Australia. *Record, 1961 Annual Conv. of the Brit. Wood Pres. Assoc.*, pp. 69–101.
- Kelso, W.C., Jr. 1962. The effect of air blockage upon the permeability of wood to liquids. Ph.D. dissertation, Univ. of Minnesota, St. Paul, MN.
- Kelso, W.C., Jr. 1981. U.S. patent 4,303,705.
- Kim, G., -H, S. Kumar, E.S. Demessie, K.L. Levien, and J.J. Morrell. 1997. Bending properties of TCMTB-treated southern pine sapwood using supercritical carbon dioxide impregnation process. *Int.*

- Res. Grp. on Wood Pres., doc. no. IRG/WP 97-40080.
- Kumar, S., and J.J. Morrell. 1993. Effect of fatty acid removal on treatability of Douglas-fir. *Int. Res. Grp. on Wood Pres.*, doc. no. IRG/WP 93-40008.
- Legay, S., P. Marchal, and G. Labat. 1998. Alternative technologies for wood wastes recycling-Part B: biotreatment of PCP- and creosote-treated wood. *Int. Res. Grp. on Wood Pres.*, doc. no. IRG/WP 98-50101-18b.
- Lowry, C.B. 1906. U.S. Patent 831,450.
- MacLean, J.D. 1952. Preservative treatment of wood by pressure processes. *Agriculture Handbook No. 40*, USDA Forest Service, Washington, DC.
- Marouchoc, S.R. 1972. A new process for the clean treatment of wood. *Proc. Am. Wood-Preservers' Assoc.* 68:148-151.
- McMillin, C.W. 1963. Dimensional stabilization of wood with polymerizable vapor of ethylene oxide. *Forest Prod. J.* 13(2):56-61.
- McCown, C. 2007. AWPAs Use Category System: A newfangled approach to utility pole and crossarm specifications. *In: Proceedings, 2007 Southeastern Utility Pole Conference*, Feb. 11-13, 2007, Tunica, MS, ed. H.M. Barnes. Forest Products Society, Madison, WI, pp. 139-145.
- McIntyre, C.R., and D. Eakin. 1984. U.S. Patent 4,466,998.
- McQuire, A.J. 1962. A pilot-plant investigation into the pressure treatment of green radiata pine with boron. *Interim Res. Rel. No. 17*, Res. Note 29, New Zealand Forest Serv., Forest Res. Inst.
- Miller, D.B., and R.D. Graham. 1963. Treatability of Douglas-fir from the western United States. *Proc. Am. Wood-Preservers' Assoc.* 59:218-222.
- Moldrup, B. 1983. All-in-one treatment processes and plant. *Proc. Am. Wood-Preservers' Assoc.* 79:58-62.
- Morrell, J.J. 1989. The use of fumigants for controlling decay of wood: a review of their efficacy and safety. *Int. Res. Grp. on Wood Pres.*, doc. no. IRG/WP/3525.
- Morrell, J.J. 1996. Wood pole maintenance manual (1996 edition). Research Contribution 15. Forest Research Laboratory, Oregon State Univ., Corvallis, Oregon.
- Morrell, J.J., M.N. Acda, and A. Zahora. 2005. Performance of oriented strandboard, medium density fiberboard, plywood, and particleboard treated with tebuconazole in supercritical carbon dioxide. *Int. Res. Grp. on Wood Protect.*, doc. no. IRG/WP 05-30364.
- Morrell, J.J., and M.E. Corden. 1986. Controlling wood deterioration with fumigants: a review. *Forest Prod. J.* 36(10):26-34.
- Morrell, J.J., K.L. Levien, E.S. Demessie, and H.M. Barnes. 1994. Impregnation of wood poles using supercritical fluid treatment processes. *In: Proc., Inter. Conf. on Wood Poles and Piles*, Colorado State Univ., Ft. Collins, CO, pp. 325-337.
- Morrell, J.J., K.L. Levien, E.S. Demessie, S. Kumar, S. Smith, and H.M. Barnes. 1993. Treatment of wood using supercritical fluid processes. *In: Proceedings, 14th Annual Meeting of the Canadian Wood Preservation Association*, November 1-3, 1993, Vancouver, B.C., pp. 6-25.
- Morrell, J.J., and J.E. Winandy. 1987. Incising practices used to improve preservative treatment in western species: a preliminary report. Appendix A, Report of Committee T-7. *Proc. Am. Wood-Preservers' Assoc.* 83:400-404.
- Morris, P.I. 1991a. Effect of treating schedule on double-density incised spruce-pine-fir. *Forest Prod. J.* 41(6):43-46.
- Morris, P.I. 1991b. Improved preservative treatment of spruce-pine-fir at higher moisture contents. *Forest Prod. J.* 41(11/12):29-32.
- Morris, P.I. 1991c. "Refractory" is a relative term. Incised alpine fir is treatable. *Int. Res. Grp. on Wood Pres.*, doc. no. IRG/WP/3670.
- Morris, P.I., and J.K. Ingram. 2005a. An accelerated ground-contact test of wrapped posts. Project No. 4931, Forintek Canada Corp., Western Division, Vancouver, BC, April 2005.
- Morris, P.I., and J.K. Ingram. 2005b. A nine year field test of wrapped and unwrapped fence posts. Project No. 4931, Forintek Canada Corp., Western Division, Vancouver, BC, August 2005.
- Morris, P.I., J.N.R. Ruddick, and R. Silcox. 1991. Development, design, and construction of a double-density incisor. *Forest Prod. J.* 41(2):15-20.
- Muin, M., A. Adachi, and K. Tsunoda. 2001. Applicability of supercritical carbon dioxide to the preservative treatment of wood-based composites. *Int. Res. Grp. on Wood Pres.*, doc. no. IRG/WP 01-40199.
- Murphy, R.J., H.M. Barnes, and D.J. Dickinson. 2002. Vapor boron technology. *In: Proceedings, Enhancing the Durability of Lumber and Engineered Wood Products*, Publication No. 7249, Forest Products Society, Madison, WI, pp. 251-255.
- Nair, H.U., and J. Simonsen. 1994. Sonic wood treatment: results at low frequency. *Proc. Am. Wood-Preservers' Assoc.* 90:292-299.
- Nair, H.U., and J. Simonsen. 1995. The pressure treatment of wood with sonic waves. *Forest Prod. J.* 45(9):59-64.
- Nasheri, K., A.J. Pendlebury, J.A. Drysdale, H. Pearson, and M.E. Hedley. 1997. The multi-phase pressure (MPP) process. One-stage CCA treatment and accelerated fixation process - The process as a new concept in preservative treatment. *Int. Res. Grp. on Wood Pres.*, doc. no. IRG/WP 97-40078.
- Nasheri, K., J.A. Drysdale, G. Durbin, and M.E. Hedley. 1998. Multiple-Phase Pressure (MPP) Process: One-stage CCA treatment and accelerated fixation process. 4. MPP compared with other processes for achieving acceptable treatment of radiata pine heartwood. *Int. Res. Grp. on Wood Pres.*, doc. no. IRG/WP 98-40115.
- Nearn, W.T., and R.A. Megraw. 1972. Discontinuous treatment for flame-spread control. *Forest Prod. J.* 22(7):47-52.
- Nicholas, D.D., and R. Cockcroft. 1982. Wood preservation in the USA. *Styrelsen for Teknisk Utvekkling Informationssektionen*, Info. No. 288.
- Oberdorfer, G., P.E. Humphrey, R.J. Leichti, and J.J. Morrell. 2000. Internal pressure development within oriented strand board during supercritical fluid impregnation. *Int. Res. Grp. on Wood Pres.*, doc. no. IRG/WP 00-40175.
- Page, R.F., and B.E. Reed, Jr. 1969. U.S. Patent 3,467,546.
- Pearson, H., K. Nasheri, J.A. Drysdale, G. Durbin, and M.E. Hedley. 1998. Multiple-Phase Pressure (MPP) Process: One-stage CCA treatment and accelerated fixation process. 3. Effect of process variables on sapwood treatment and CCA fixation. *Int. Res. Grp. on Wood Pres.*, doc. no. IRG/WP 98-40114.
- Pearson, H., Durbin, G., Hedley, M.E. 2001. Multiple-Phase Pressure (MPP) Process: Pilot plant trials for disposal of kickback using reverse osmosis membrane filtration. *Int. Res. Grp. on Wood Pres.*, doc. no. IRG/WP 01-40202.
- Peek, R.-D. 1987. Application of oscillating pressure to improve treatability of refractory species. *Int. Res. Grp. on Wood Pres.*, doc. no. IRG/WP/3449.
- Pendlebury, A.J., J.A. Drysdale, K. Nasheri, H. Pearson, and M.E. Hedley. 1997. The multi-phase pressure (MPP) process. One stage CCA treatment and accelerated fixation process - Concepts proved by repetitive pilot plant treatments. *Int. Res. Grp. on Wood Pres.*, doc. no. IRG/WP 97-40079.

- Perrin, P.W. 1978. Review of incising and its effects on strength and preservative treatment of wood. *Forest Prod. J.* 28(9):27–33.
- Protective Packaging Ltd. 2009. Utility Company Field Liner Users. <http://www.pplfieldliners.com/users.htm> (as of 1/27/2009).
- Richardson, B.A. 1978. *Wood Preservation*. The Construction Press, Lancaster, UK.
- Rosen, H.N. 1980. Drying lumber above atmospheric pressure - development of a prototype dryer. *In: Proceedings of the Wood Drying Working Party, IUFRO Division V Conference, Oxford, England*, pp. 45–58.
- Rosen, H.N. 1981. Drying of lumber in superheated steam above atmospheric pressure. *Am. Inst. Chem. Eng. Symp. Ser.* 77(207):32–37.
- Rowell, R.M. 1991. Chemical modification of wood. *In: Handbook on Wood and Cellulosic Materials*, ed. D.N.-S. Hon and N. Shiraishi. Marcel Dekker, Inc., New York.
- Rowell, R.M., and D.I. Gutzmer. 1975. Chemical modification of wood: Reactions of alkylene oxides with southern yellow pine wood. *Wood Sci.* 7(3):240–246.
- Rowell, R.M., V. Hart, and G.R. Esenther. 1979. Resistance of alkylene oxide modified southern pine to attack by subterranean termites. *Wood Sci.* 11(4):271–274.
- Ruddick, J.N.R. 1985. A comparison of needle incising and conventional North American incising processes for improving preservative treatment. *Proc. Am. Wood-Preservers' Assoc.* 81:148–160.
- Ruddick, J.N.R. 1986. A comparison of needle and North American incising techniques for improving treatment of spruce and pine lumber. *Holz als Roh und Werkst.* 44:109–113.
- Ruddick, J.N.R. 1991. Laser incising of Canadian softwood to improve treatability. *Forest Prod. J.* 41(4):53–57.
- Rudman, P., L. Henderson, D.F. McCarthy, and E.A. Bowers. 1963. The impregnation of green *Pinus radiata* D. Don with an unfixed water-borne preservative by steam-vacuum drying and intermittent pressure treatment. *J. Inst. Wood Sci.* 11:45–56.
- Rueping, M. 1902. U.S. Patent 709,799.
- Saburo, I. 2001. Low pressure jet treatment using oilborne preservative for sill (Dodai). *Wood Protection* 27(6):269-275 (in Japanese).
- Scheffer, T.C., and J.J. Morrell. 1997. Ability of polyethylene boots to protect the belowground portion of small stakes against decay. *Forest Prod. J.* 47(5): 42–44.
- Scheurch, C. 1968. Treatment of wood with gaseous reagents. *Forest Prod. J.* 18(3):47–53.
- Schrive, L., C. Perre, and G. Labat. 1998. Alternative technologies for wood wastes recycling-Part A: Supercritical extraction of PAH compounds from wood wastes. *Int. Res. Grp. on Wood Pres.*, doc. no. IRG/WP 98-50101-18a.
- Seely, C.A. 1867. U.S. Patent 69,260.
- Skaar, C. 1972. *Water in wood*. Syracuse Univ. Press, Syracuse, NY.
- Stalker, I.N. 1974. British Patent 1,377,061.
- Stalker, I.N., and C.S. McClymont. 1976a. The effectiveness of the suction sap displacement method with some hardwoods and softwoods. *J. Instit. Wood Sci.* 7(3):5–9.
- Stalker, I.N., and C.S. McClymont. 1976b. Pressure band for sap displacement of freshly-felled trees using water-borne preservatives. *Forest Prod. J.* 26(3):55–57.
- Thompson, W.S., and H.M. Barnes. 1978. Advances in wood finishing and wood preserving technology for southern pine. *In: Complete Tree Utilization of Southern Pine*, ed. C.W. McMillin. Forest Prod. Res. Soc., Madison, WI, pp. 372–385.
- Thompson, W.S., and P. Koch. 1981. Preservative treatment of hardwoods: a review. USDA Forest Service, So. For. Exp. Sta., General Tech. Rpt. SO-35.
- Troxell, H.E. 1961. Progress in wood preservation, 1959-60. *Forest Prod. J.* 11(2):67–76.
- Tsunoda, K., and M. Muin. 2003. Preservative treatment of wood-based composites with a mixture formulation of IPBC-silafluofen using supercritical carbon dioxide as a carrier gas. *Int. Res. Grp. on Wood Pres.*, doc. no. IRG/WP 03-40251.
- Turner, P., and R.J. Murphy. 1987. A novel process for the treatment of manufactured wood based board materials. *Proceedings of the IUFRO Wood Protection Subject Group, IUFRO Division V-Forest Products, Subject Group S.5.03 "Wood Protection"*, Honey Harbour, Ontario, Canada.
- Turner, P., and R.J. Murphy. 1995. Treatment of timber products with gaseous borate esters .1. Factors influencing the treatment process, *Wood Sci. Technol.* 29:385–395.
- Turner, P., and R.J. Murphy. 1998. Treatment of timber products with gaseous borate esters Part 2. Process improvement, *Wood Sci. Technol.* 32:25–31.
- Turner, P., R.J. Murphy, and D.J. Dickinson. 1990. Treatment of wood based panel products with volatile borates. *Int. Res. Grp. on Wood Pres.*, doc. no. IRG/WP/3616.
- Vinden, P., and A.J. McQuire. 1978. Improvements to APM schedules. *Proc. New Zealand Wood Pres. Assoc.* 18:21–31.
- Walchii, O. (1970) Oscillating pressure method. *J. Inst. Wood Sci.* 5(21):42–43.
- Weaver, F.W. 1981. A modified empty-cell process for treatment of wood with chromated copper arsenate. Master's thesis, Mississippi State Univ., Mississippi State, MS.
- Wilkinson, J.G. 1979. *Industrial timber preservation*. Associated Business Press. London, UK.
- Winandy, J.E., H.M. Barnes, and P.H. Mitchell. 1992. Effect of CCA treatment and drying on tensile strength of lumber. *J. Materials in Civil Engineering* 4(3):240–251.
- Winandy, J.E., B.A., Bendtsen, and R.S. Boone, 1983. Effect delay between treatment and drying on toughness of CCA-southern pine. *Forest Prod. J.* 33(6):53–58.
- Winn, W.D. 1973. Results of commercial application of the Dow wood treating process. *Proc. Am. Wood-Preservers' Assoc.* 69:19–205.
- Wood, M.W. 1980. Effects of the MSU process and high preservative retentions on southern pine treated with CC A-type C. Master's thesis, Mississippi State Univ., Mississippi State, MS.
- Wood, M.W., and W.C. Kelso, Jr. 1977. Comparison of processing and shipping costs for wood treated with CCA preservatives using full-cell and empty-cell processes. Unpublished Rpt., Mississippi Forest Prod. Lab, Mississippi State Univ., Mississippi State, MS.
- Wood, M.W., W.C. Kelso, Jr., H.M. Barnes, and S. Parikh. 1980. Effects of the MSU process and high preservative retentions on southern pine treated with CCA-type C. *Proc. Am. Wood-Preservers' Assoc.* 76:22–37.
- Western Wood Preservers Institute. 2006. *Best Management Practices for the Use of Treated Wood in Aquatic and Other Sensitive Environments*. Western Wood Preservers Institute, Wood Preservation Canada, Southern Pressure Treaters' Association, Timber Piling Council.