Trends in the wood-treating industry: state-of-the-art report

H.M. Barnes

Abstract

This state-of-the-art report discusses recent trends in the production and use of treated products as well as constraints faced by the industry. Particularly timely are the discussions of new preservative systems and environmental concerns. In addition to new waterborne penta systems, new biocides and stabilizing chemicals are discussed. The section on processing includes a discussion of environmental quality standards and their impact on the industry. New treating processes and methods of conditioning stock for treatment are detailed, along with the major in-plant changes occurring over the last 15 years. Commodity production is discussed and estimates of future production are given. Research needs in each area of discussion are included.

A look at current trends and technology in the wood-treating industry requires a historical perspective. Graham (45), in his excellent monograph, traces the history of wood preservation from 2000 B.C. to 1971 A.D. Richardson's (107) book on wood preservation also has an excellent history, as does the classic text of Hunt and Garratt (68). Thompson and Barnes (126) described more recent advances in the industry. The last state-of-the-art report on wood treating published by FPRS was in 1961 (130). A comprehensive report on wood preservation in the U.S. has been issued recently (97). That report is one of a continuing series detailing the preservation industry in several countries (1, 26, 27, 69, 83, 106, 119).

The modern wood preservation era in the United States began in 1875 with the construction of a plant in Pascagoula, Miss. by the L & N Railroad. This plant used the Bethell process, patented in 1838, to treat ties and other stock with creosote. Most of the early growth in the industry was in response to the growth of the railroad and utilities.

Until recently, commercial treatment technology has remained unchanged since the development of the Rueping (114) and Lowry (84) empty-cell processes in 1902 and 1906, respectively. These processes were modifications of the full-cell processes (21, 23).

Similarly, the major wood preservatives were all patented prior to 1940. Creosote, the oldest preservative, was in use in the early 1800s. Pentachlorophenol (penta), patented in 1931, was followed by the patent for chromated copper arsenate (CCA) in 1938 (78). Ammoniacal copper arsenate (ACA) was patented in 1939 (42), while acid copper chromate (ACC) was patented in 1928 (49). These broad spectrum preservatives are used to treat most of the wood products used in the United States, whereas Europe uses any of several preservatives depending on end-use requirements.

The changes in preservative usage and treatment technology now underway in the United States 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 effect of treated wood on man and other non-target organisms.

This paper will examine the current status of the industry with respect to preservative usage, treatment process, and commodity production. Constraints and needs of the industry will be addressed along with the current status of preservation research.

Trends in preservative use

Detailed discussions of the chemical and physical properties of wood preservatives can be found in the literature (50, 95, 99). Comprehensive bibliographies are also available (14, 15, 89). In 1981, Nicholas (96)

The author is an Associate Professor, Mississippi Forest Products Lab., Mississippi State Univ., P.O. Drawer FP, Mississippi State, MS 39762. This paper was presented at the annual meeting of the Mid-South Section of the FPRS in Alexandria, La., on March 15, 1984, and was received for publication in April 1984.

Forest Prod. J. 35(1):13-22.

presented data to the American Institute of Chemical Engineers detailing current trends in preservative usage. The consumption of major preservatives (38) for the period 1970-81 is given in Figures 1 and 2.

The emerging picture is one of static consumption of creosote formulations, decreasing penta consumption, and rising use of arsenicals, most notably CCA. The increasing consumption of treated wood, shown in Figure 3, can be attributed in part to the increasing use of CCA for such things as the All Weather Wood Foundation (AWWF).

Development of waterborne penta systems. — The increased cost of petroleum has led to the development of waterborne penta systems. At least three of these appear to have commercial application.

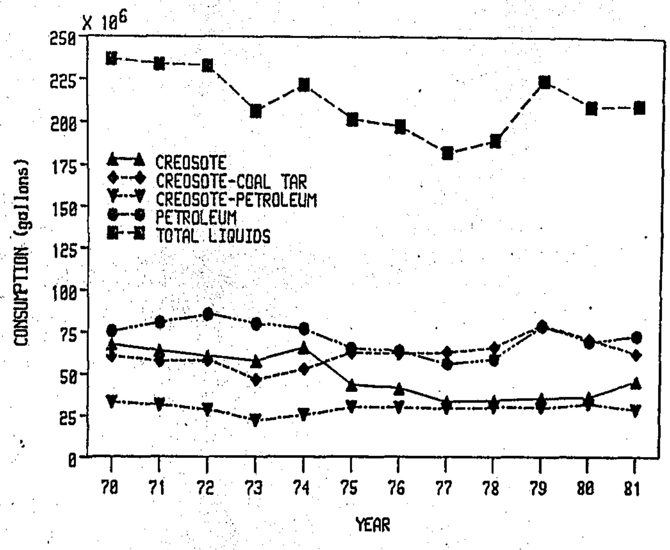

Figure 1. — Trends in the consumption of liquid preservatives, 1970-81 (38).

The first type, based on dispersion technology (51, 52, 80), is currently being produced by five formulators. Formulations vary, but all utilize penta dissolved in a mixture of hydrocarbon solvents and co-solvents to form a concentrated solution. Surfactants and dispersing agents allow for dispersion of the concentrate in water to form a 1 to 7 percent treating solution. These systems have been commercialized, and treatability trials have proven successful (10). These systems effectively reduce petroleum usage by 75 to 85 percent.

Amundsen et al. (2) have developed a water miscible penta by using a combination of butyl alcohol and ammonia to dissolve the penta. Known as PAS, this system has preliminary committee approval from AWPA (59, 120) for aboveground use. Similarly, other ammoniacal systems for chlorinated phenols are being developed, the ACT system (acronym for ammoniacal copper tetrachlorophenol) being one example (58). Both the ACT and PAS systems have the advantage of requiring no oil since they are based on organic solvent/water penta solutions.

The attempt to develop water soluble/miscible penta systems is not new. Sodium pentachlorophenate (NaPCP) has been used for years as a stain and mold preventative in lumber dipping operations. Unfortunately, current penta salts are readily leachable from the wood. One successful approach has been to dissolve penta in a basic medium and then mix with a water soluble activator such as an organic ester (53).

Another approach may be to produce a penta complex which would have a fixation mechanism required to prevent excessive depletion of the preservative from wood during exposure. Developmental work at this laboratory has been successful with an adduct formed by reacting penta with various compounds to form salts which are non-leachable and have low vapor pressures. Several combinations appear feasible and exploratory work is continuing. Changing the solvent system may also provide water-miscible systems for penta.

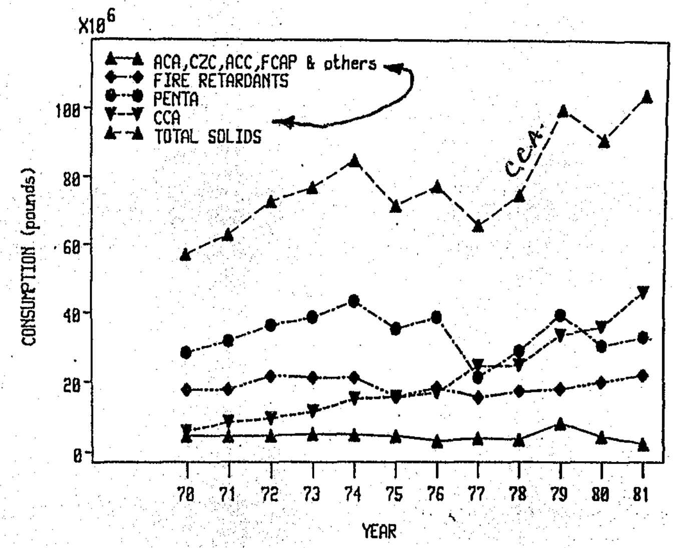

Figure 2. — Trends in the consumption of preservative solids, 1970-81 (38).

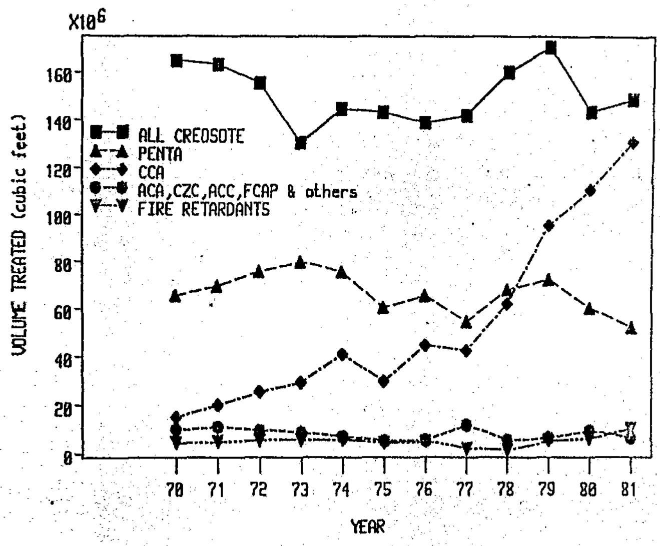

Figure 3. — Volume of wood treated by preservative type, 1970-81 (38).

New waterborne systems. — There has been considerable activity in developing new formulations using biocides which already have EPA approval for other uses, particularly those in use as agricultural fungicides. This approval eliminates the need for extensive toxicity testing. Development of new preservative systems with low mammalian toxicity appears to be a fertile area for research.

Several long-standing preservatives have been subjected to further evaluation. Copper-8-quinolinolate, introduced in 1962, has been formulated into water-based systems. Acceptable results in dipping operations and aboveground uses have been found with this system alone or in combination with other compounds (104).

Copper naphthenate, first entering the marketplace in 1948 (92), has also been formulated into a water-based system which has given adequate protection in aboveground exposures. Dyes and pigments have been added in an attempt to mask the vivid green color obtained with this chemical.

Other salts of the naphthenic acids have been developed into water-dispersible formulations. The zinc salt has DOD approval for ammunition boxes. Zinc naphthenate has the advantage of being colorless. Tributyltin oxide (TBTO), long a standard in the millwork industry, can be formulated into a waterborne system by solubilizing TBTO with alkylammonium compounds (108).

Several attempts have been made to modify arsenical preservatives. Ammoniacal copper arsenate (ACA) (44) was approved by the AWPA Preservative Committees in 1949 (8) and is a standard preservative used today to treat western species, particularly Douglas-fir. Acid copper chromate (ACC) (49) was approved in 1950 (9) and is used primarily in Florida. Attempts to entirely replace arsenic with other compounds have not proven successful (74, 75), except for chromated copper borate (CCB) used in Europe (107). Reduction of the arsenic content in ACA by replacing it in part with zinc has led to a new preservative, ammoniacal copper zinc arsenate (ACZA), which has AWPA Committee approval (94, 102, 120).

Perhaps the most promising of the new biocides are the alkylammonium compounds (AAC). Extensive investigation of these compounds has shown didecyldimethylammonium chloride to be particularly effective (105). AACs have reached commercialization in New Zealand, and their effectiveness in ground-contact applications is being studied (99). Other compounds with potential efficacy include 3-iodo-2-propynyl butyl carbamate, isothiazolinones, benzothiasoles, salicylanilide derivatives, sulfonamides, ammoniacal copper-fatty acids, and tetrachloroisophthalonitrile (96).

Combining fungicides with more environmentally safe insecticides may also have potential. Several insecticides, chlorpyrifos among them (109), seem to have potential in low concentrations. The potential for combining these insecticides with creosote could possibly lead to a single preservative system for use in warm marine waters, thus alleviating the problem of having to dual treat with CCA and creosote in order to obtain protection against *Limnoria sp.* These insecticides may also have potential as additives to some of the new fungicides to provide the necessary insecticidal properties for a wood preservative.

Fire retardants. — Goldstein (41, 42) and others (56, 77) have reviewed the major fire retardants and their effects on properties. These surveys, plus earlier reviews (22, 85), are recommended for those readers requiring more detailed information.

Commercial fire retardants are generally made from monoammonium and diammonium phosphates, ammonium sulfate, borax, boric acid, and zinc chloride (28). In recent years, proprietary formulations utilizing organo-phosphates and resin systems have been commercialized. The resultant fire retardant is leach resistant and suitable for exterior use (56, 77, 116). Another significant development has been the production of proprietary interior systems which exhibit reduced hygroscopicity.

Remedial treatments. — Protection of structural wooden members in ground contact is essential. Replacement is often a difficult, expensive task. Therefore, remedial maintenance treatments to prolong life, especially in poles, have increased in recent years. Taylor (123) and other researchers (81) have discussed the need for groundline treatment and efficient application methods. An excellent handbook on pole maintenance is available (48).

Starting in 1920, groundline treatments have progressed to today's systems through trial and error. Groundline treatments for surface decay are generally either greases or grease-bandage systems employing creosote, chlorinated phenols, salts such as potassium dichromate and sodium fluoride, and insecticides in various combinations.

Extensive work by Graham (46, 47) has led to the development of several fumigants for controlling internal decay in structural members, especially poles. Vapam (sodium-N-methyldithio carbamate), Vorlex (methylisothiocyanate and dichloropropenes), and chloropicrin (trichloronitromethane) have proven effective for at least 12 years after treatment (46). Data suggest that retreating cycles of 15 years are obtainable with the latter two compounds. Research with fumigants is continuing and includes investigations on encapsulated delivery systems and the extension of uses to include marine pilings and timbers.

Aboveground remedial treatments are also available. A discussion of these treatments is beyond the scope of this paper. An excellent paper by Feist (37) reviews this area. Work in Europe with fused boron rods is a new technology with potential (29).

Wood stabilization. — Treatments to stabilize wood have long been sought and the importance of such treatments should not be overlooked. Excellent summaries on dimensional stabilization can be found in the literature (117, 118) and will not be repeated here.

For commercial applications, stabilization agents should be cost effective, should require simple equipment to apply, should penetrate the cell wall, and should be effective in low concentrations. Dimensionally stable wood would greatly increase service life by reducing leachability, volatility, and checking and thus prevent subsequent invasion by agencies of deterioration into exposed, untreated wood.

Water-reducible alkyds are a recent development which may have promise (131). Preliminary results with these compounds have been excellent and a patent has been issued (132). Continuing work at this and other laboratories indicates that other compounds may also be effective at low weight gains.

Considerable work has been done at the U.S. Forest Products Laboratory on dimensional stabilization and chemical modification. An excellent summary of this work is available (112) and includes discussions of reactions and reaction requirements, proofs of bonding, and the distribution of several bonded chemicals used for chemical modification.

Trends in processing

As indicated earlier, pressure treating processes have changed very little since the early 1900s. Most of the changes in wood treating plants have arisen because of environmental considerations. In a series of articles, Thompson and others (31, 32, 124, 125, 127, 128) have thoroughly discussed pollution control methods for wood-treating industry effluents.

A major concern of the industry today is hazardous waste disposal and the clean-up of old treating plant sites, lagoons, etc., under the Superfund (Comprehensive Environmental Response, Liability, and Compensation Act) legislation and the monitoring of ground water under the Resource Conservation and Recovery Act (RCRA). Economics of disposal of contaminated soil are such that a producer literally cannot afford to close a plant because of the costs involved. For organic preservatives, a soil farming biodeterioration scheme may be a feasible solution. However, a considerable amount of research will be required before this type of system can be commercialized.

Considerable research has been aimed at the effect of wood preservatives on non-target organisms, primarily airborne components of penta and creosote (70-73). Several coating systems have been found which will reduce airborne vaporization (72, 73). Arsenic residues have also been studied (115), and currently AWPA is considering a commodity standard for wood used for playground equipment similar to the current California standard (90). Airborne and waterborne emissions monitored during kiln-drying of CCA-treated wood indicate some concern over waterborne components (141). The airborne hazard appears to be nil.

The proliferation of new laws, rules, and regulations has the entire industry playing the "letters" game — EPA, FIFRA, RPAR, RCRA, and other alphabet soup acronyms. In the early 1970s, the AWPI organized a Government Affairs Committee in response to the congressional amendments (designated the Federal Pesticide Control Act) to the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA). In 1977, this committee, in cooperation with the AWPA's EPA Liaison Committee, presented a symposium on environmental action at the AWPA Annual Meeting (5, 39, 76, 82, 136). This committee's work led to the submission of a series of "white papers" to EPA by AWPI on behalf of the industry.

In 1978 EPA initiated its formal Rebuttable Presumption Against Reregistration (RPAR) review of the major wood preservatives under FIFRA. A biological and economic impact study has been completed (40). The initial position of EPA with regard to the RPAR'd preservatives is currently being challenged in the courts by environmentalists. Effluent discharge standards were issued in 1979 and finalized in 1981 (87). These standards are given in Table 1. Summaries of the various laws and their impact on the industry can be found in the literature (6, 13, 91, 103, 121, 137-140).

Comprehensive position documents (PD 1, PD 2/3, PD 4) on wood preservatives have been issued by the EPA (33-35), the most recent in July 1984. Several industry rebuttals and updates have been published to PD 1 and PD 2/3 (6, 88, 103, 121, 138, 139). An excellent summary on environmental considerations was presented at the 1984 Annual Meeting of FPRS by Talarek (122). The interested reader can obtain copies of this presentation from the author.

For brevity, the highlights of the USEPA final position as elucidated in PD 4 (35) will be given here. First, with the exception of brush-on treatments of inorganic arsenicals, all three major wood preservatives are classified as restricted-use pesticides requiring application by certified applicators. Commercial treaters will be required to participate in a consumer awareness and labeling program extending throughout the chain of commerce.

A Consumer Information Sheet (CIS) will be required for each shipment of all pressure-treated wood under the authority of the Toxic Substances Control Act

TABLE 1. — *Water quality regulations for wood preserving wastewater effluent streams.*

1. Waterborne preservatives — zero discharge in all cases.
2. New plants — zero discharge limit in all cases.
3. Organic preservatives — existing sources.

a. Direct discharge steaming subcategory

Parameter	Daily maximum (lb./1,000 ft.^{3})	30-day average (lb./1,000 ft.^{3})
COD	68.5	34.5
Phenol	0.14	0.4
Oil & grease	1.5	0.75
pH	6-9	6-9

Boultonizing subcategory

Zero discharge limitation

b. Pretreatment (city sewer discharge) steaming and boultonizing subcategories

	Limit (max.) (ppm)
Oil & grease	100
Copper	5
Chromium	4
Arsenic	4

(TSCA). The CIS will cover such areas as 1) disposal and handling of treated products; 2) recommendations against the use of treated wood in contact with food, feed, public drinking water (all three preservatives), and drinking water for animals (penta and creosote); 3) requirements that wood treated with penta and creosote not be used for interior applications, with some exceptions requiring coating the treated wood; and 4) the requirement that penta and creosote treated wood not be used in barns where domestic animals could lick the wood.

Provisions for the use of protective clothing, gloves, and respirators by pressure applicators are given along with the prohibition on eating, drinking, and smoking during application. Closed mixing systems are required for powdered formulations of the arsenicals immediately and will be required for penta preservatives after a 3-year "phase-in" period. Pressure treaters are also required to reduce surface residue of arsenic. Similar guidelines for non-pressure applicators (groundline pole treatment, sapstain control, and millwork and board products) were given along with the requirement that home and farm uses of penta and creosote be restricted to use by certified applicators.

Penta and its salts will be heavily regulated under PD 4. A teratogenicity/fetotoxicity label warning will be required for all uses of penta. The most severe restriction will be on the dioxin content of technical penta. An upper limit of 15 ppm hexachlorodibenzo-p-dioxin (HxCDD) is effective immediately. Within 18 months this level will be reduced to 1 ppm. This decision is tantamount to cancellation since the technology does not currently exist to produce penta with the HxCDD levels mandated. In addition, the method used to reduce HxCDD must not increase the hexachlorobenzene or chlorinated dibenzofuran content in penta above the current levels found in technical penta. Also, levels for 2, 3, 7, 8-tetrachlorodibenzo-p-dioxin must be below detectable limits using the gas chromatography-mass spectrometry method. Objections to the final position of EPA in PD 4 have already been filed (4).

In addition to those items listed above, PD 4 requires that registrants submit additional data on chemical alternatives to the three wood preservatives, exposure data on spray applications of penta for farm and home use, teratogenicity/fetotoxicity data on inorganic arsenic, epidemiology, air monitoring, and dermal exposure data for workers in creosote plants, and data on the effectiveness of protective clothing for creosote and the inorganic arsenicals.

Conditioning of stock for treatment. — Green wood must be seasoned prior to treatment in order to get adequate penetration and retention of preservative. Mechanical preparation may be used with refractory species in order to improve seasoning and treatability. Incising is a typical commercial practice with hardwood ties and thin sapwood western species, such as Douglas-fir poles and timbers. Deep incising, boring, and kerfing techniques are also used (48). Transverse compression has been used experimentally to improve the treatability of refractory wood and heartwood (24, 25), but has not been used commercially.

Henry (55) has detailed the various seasoning techniques used prior to preservative treatment. These include air seasoning, kiln-drying, Boultonizing, steam conditioning, and vapor drying. Vapor drying of green ties is the newest seasoning technique to reach commercialization (60-63). Boulton drying of green pine ties began in 1978 and has grown rapidly. Many plants are now Boultonizing green hardwood ties, and Boulton drying is used extensively for Douglas-fir poles treated with oilborne preservatives. The major advance in steam conditioning has been a move toward closed steaming (126) in order to reduce process wastewater. Kiln-drying is the fastest growing method of conditioning, primarily because of the increased use of CCA-type preservatives, the reduction of wastewater volumes generated, and the rapid turnover of inventory.

A recent seasoning technology, pressure steam drying (PSD), seems readily adaptable to existing treating facilities (110, 111). PSD has the potential for rapid seasoning of stock with minimal degrade. Other techniques (11), discussed later, may allow for the treatment of green wood with CCA-type preservatives.

For the past several years, considerable research effort has been directed toward the effect of conditioning on the properties of treated wood (11, 12, 16, 142), particularly wood treated with CCA. Significant reductions in modulus of rupture have been found for full-sized material dried after treatment. Additional data are needed in order to specify proper design values for CCA-treated wood. The need for strength values for wood treated with fire retardants is particularly acute. Accurate strength reduction factors for design do not exist for fire retardant-treated wood.

Treatment mechanics. — Basic treating technology for wood remained unchanged until the 1960s. In the early 1960s, Bescher (20, 43, 54) developed the Cellon process for treating wood with penta in LPG. The actual treating process is either a full- or empty-cell process, but the change of solvent systems from hydrocarbon oil to LPG leaves a clean, paintable, and gluable surface.

Disadvantages include the requirement that the poles be dry prior to treatment, whereas oil/penta treatment does not. Plant costs and the environmental costs of handling penta sludge are also higher than with oil/penta systems. Quality and process control is also more difficult. In 1975, 6 of 394 treating plants in the United States used this process (98). Today only one or two U.S. plants use the process. Another change in the solvent system for penta led to the Dow, or methylene chloride, process (86, 143). One or two U.S. plants use this process.

Hudson developed two sap displacement pressure processes in the late 1960s: the Slurry-Seal process (64, 65) and the Prescap process (66, 67). The latter is a modification of the old Boucherie process. Neither process is being used commercially. Commercialization of a process employing the application of sonic waves has yet to be implemented although it has been studied by several researchers (100).

In 1983, Moldrup (93) 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.

Research at the Forest Research Institute in New Zealand has led to the commercialization of a process used to treat partially seasoned wood with CCA preservatives (17-19, 113, 133). Designated the alternating pressure method (APM), the process cycles between atmospheric and maximum pressure and is essentially a multi-Lowry process.

APM is based on the early work with oscillating pressure (113). Fifteen cycles have been found to give adequate treatment of pine roundwood which has been steamed and removed from the cylinder for at least 1 day before treating. Heartwood penetration is also possible (18, 19, 113).

The nature of this process could lead to sludge deposits on the surface of the treated wood, although no practical problems of this type have been reported in New Zealand. Preliminary trials at this laboratory using this process with steam-conditioned southern pine posts from peeler cores yielded complete sapwood penetration. This indicates that APM may have potential for treating partially-seasoned stock with CCA in this country.

The newest process developed for treating wood is the MSU process developed by W.C. Kelso, Jr. (79). In this process, it is possible to obtain full-cell CCA gradients using an empty-cell process. Empty-cell treatment yields cost savings due to weight reductions (145). No problems with strength reduction, disproportionation, gradients, leaching, or effluents have been noticed (3, 135, 144, 146). The process is illustrated in Figure 4.

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 prior to releasing pressure and allowing "kickout"[1] to occur. 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 (3).

Plant changes. — Most in-plant changes have arisen in response to pollution control requirements. Basic equipment changes have been evolutionary as new pumps, measuring systems, etc. have entered the marketplace. For the most part, the industry has remained unchanged since the turn of the century, especially those plants treating with oils. In fact, the commercial trials for the MSU process were done in the original Lowry cylinder in Brunswick, Ga.

[1]The kickback in this process is designated "kickout" to differentiate it from the kickback occurring in traditional empty-cell treatments.

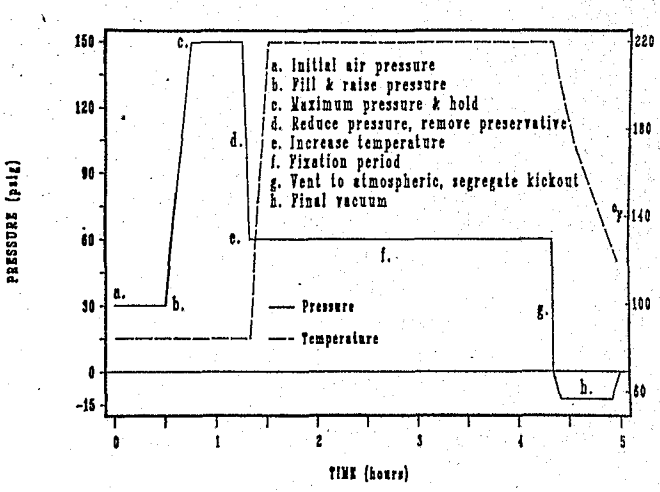

Figure 4. — Typical MSU process treating cycle.

Over the last 20 years, the major in-plant change for penta treaters has been the change to still bottom/diesel types of P9-A oil. The current practice at many plants is to use higher penta-in-oil concentrations in the 10 to 12 percent range. The effect of this change on performance is not known, but there is strong evidence that concentrations in excess of 8 percent are not as effective as lower concentrations (7).

The move to CCA-type preservatives in the past 15 years has led to modern, well-designed plants. A typical modern-day CCA plant is completely automated (57). Computerization will be the future, with computers controlling all aspects of the treating process and inventory control. Several U.S. plants have been integrated into the computer age.

With the advent of high volume pumps, many CCA treaters are using very short treating cycles. Modified full-cell cycles utilizing low initial vacuums (15 in. Hg) are also commonplace. Some treaters are using an empty-cell process. Sludging is minimized by rapid turnover of working solution and by using refrigerated working tanks to reduce the reaction rate of the components. CCA treaters have changed to the type C formulation and today generally use oxide liquid concentrates. The use of liquid concentrate eliminates the need to mix dry chemicals. Oxide formulations remove the often expressed concern over conductivity and corrosion.

Trends in commodity production

Commodity production is increasing, as is clear from Figure 5. The picture is one of expanding markets for lumber and timbers treated with arsenicals. The data in Figure 5, taken from AWPA statistics (38), should be considered conservative, with trends outweighing actual values. The total volume of treated products over the period 1970-81 was almost 3.5 billion cubic feet (Fig. 6). Over that period, tie stock represented the largest commodity volume (34%) followed by lumber/timber and poles/pilings.

The growth in volume of treated lumber and timbers may be much larger than indicated. Recent data suggest that the industry was 35 percent larger than that reported by AWPA and that 8.7 percent of the total lumber and timber production in 1982 was treated (134). This production represented over 2.4 billion board feet of lumber.

In 1982, 40 percent of the total volume of southern pine lumber was treated, representing 80 percent of the total market. In 1983, total production was 2.86 billion board feet, an increase of 31 percent over 1982 (28).

The growth of this market can be attributed to two major factors: 1) the development of the All Weather Wood Foundation (AWWF) (28, 30, 101) and Plen-Wood Systems (28, 36); and 2) an increased awareness on the part of the consumer of the need for using treated wood.

In the period 1978-82, industry volume increased 40 percent, while the total U.S. lumber demand declined 30 percent over the same period. Residential repairs and alterations represented the largest end-use over this period (134). Farm use was second.

In the United States the AWWF has grown from nothing in 1970 to 10,000 units in 1978 (28, 134). In 1983 almost 23 million BF of lumber were treated for foundations (28) — enough to build over 14,000 homes. A wood foundation home averages an additional 1,500 square feet of treated plywood and 2,500 BF of treated lumber. The forecast growth in treated lumber and timbers ranges from 90 to 125 percent for the period from 1982 to 1990. A 120 percent growth in the AWWF is anticipated over the same time period.

New products, such as Radius Edge Decking, and new concepts, such as Wood Slab, are expected to add to increased demand (28). Radius Edge Decking is treated decking, 1 inch in thickness, which has a 0.25-inch radius rounded edge on all four sides. The Wood Slab concept utilizes treated plywood over treated joists. The joist/subfloor assembly forms a wooden slab which is placed directly on a gravel-filled bed.

The trend with other commodities is nebulous at best. The treated tie market offers perhaps the greatest potential for increases in treated wood volume, depending on the commitment to rebuild the nation's railway infrastructure.

Poles and pilings and crossarms (included in "others") have shown a downward trend (Fig. 5) reflective of the changing communications and utility industries, the demand for esthetics, and the competition from other materials. Increased production of poles over current levels can be expected in the future. With the completion of many nuclear power plants and the shelving of future plans, utilities are expected to upgrade their existing systems. Fence post production is in an analogous position due to increasing competition from steel posts.

Trends in treated plywood show an increase in use, but the future is difficult to forecast. Plywood markets are coming under severe pressure from higher costs for raw materials. New composite materials, such as structural exterior flakeboard and oriented strandboard, are the wave of the future and will replace plywood in many applications. While it is doubtful that these materials will replace plywood in the AWWF and ground contact markets, treating techniques and chemicals should be developed for this new class of composites.

Current plywood production incorporates refractory species such as spruce, intermountain Douglas-fir, aspen, and mixed southern hardwoods as veneers in plywood panels. The treatment, and subsequent durability, of these materials requires investigation and is the topic of a current subcommittee in AWPA.

In order to better utilize our forest resource, underutilized species, especially hardwoods, will be used to a greater extent in the future. Preservation of hardwood species will require new chemicals and approaches to wood treatment if a durable commodity is to be produced. Thompson and Koch (129) have summarized treatments used with hardwoods.

With respect to regions, the South and Midwest continue to lead the United States in total production of treated wood. This trend is consistent across all commodity categories (Fig. 7), with the South accounting for 65.7 percent of the total production and the West, Midwest, and Northeast accounting for 12.7 percent, 16.5

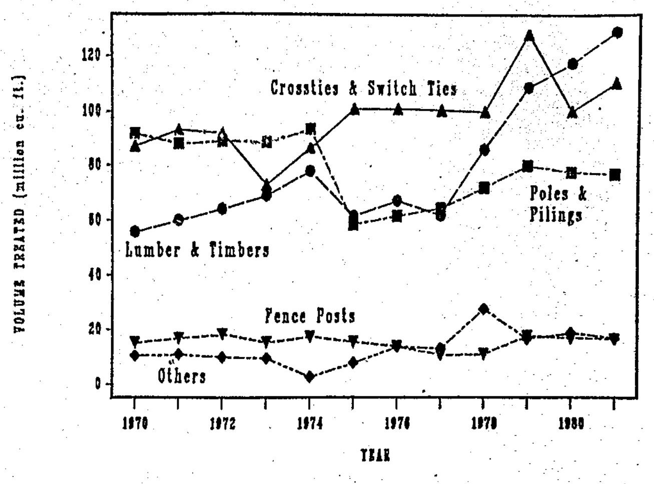

Figure 5. — Volume of treated wood by commodity group for the years 1970-81 (38).

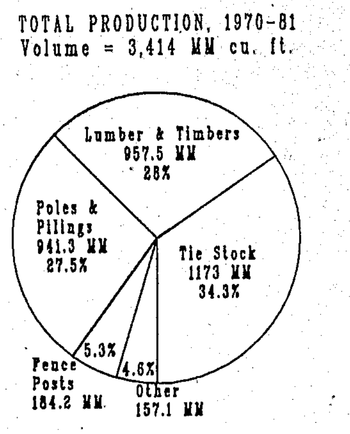

Figure 6. — Total production of treated wood by category from 1970-81 (38).

percent, and 6.71 percent, respectively. Except for tie stock and crossarms, southern pine represents the major species treated across commodity groups. Hardwoods dominate the tie market, while Douglas-fir is the primary species used for crossarms.

A breakdown by preservative for each commodity group shows the arsenicals dominating the lumber and timber and plywood markets. Creosote is used almost exclusively on ties, and penta is the leading preservative used for poles and pilings with creosote a close second. About one-half of the fence posts are treated with arsenicals with the remaining one-half equally split between creosote and penta.

The above discussion has centered entirely on pressure-treated wood. By comparison, the amount of non-pressure-treated wood is insignificant. Poles represent the largest volume of non-pressure-treated wood, an additional 3.7 percent increase in pole volume. These poles are mostly western redcedar given a butt treatment.

Summary and conclusions

This report has covered the development of the wood-treating industry over the past several years. Much of the developmental work over the past two decades has been in response to environmental and energy concerns. New preservative systems which will greatly reduce the need for oil carriers are entering the marketplace. Research on the efficacy of and synergism in new formulations needs to be conducted, as does basic work on the mechanism of wood decay and interaction of preservatives with wood.

Computerization of treating plants will be the wave of the future. New processes need to be developed and current technologies, such as the MSU process and APM, will need to be evaluated. Basic work in treatment mechanics will put the industry on a firm scientific foundation.

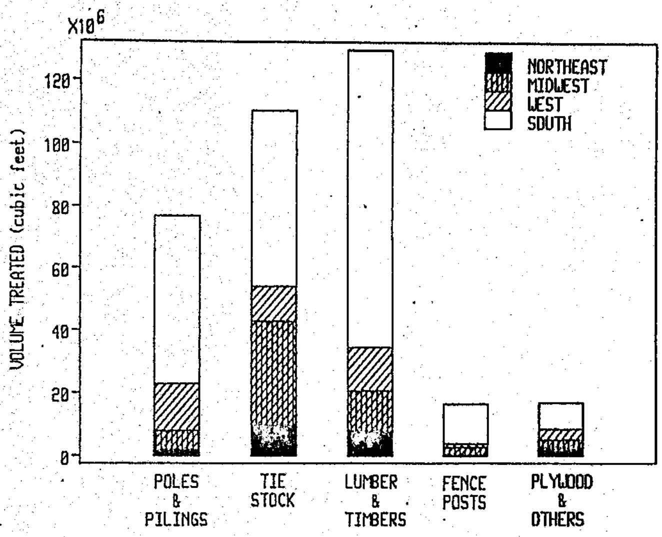

Figure 7. — Volume of treated wood by product class and region, 1981 (38).

New trends in commodity production will emphasize the need for protecting composite materials. Hardwood production will increase and these species require new approaches to increasing the service life. Production of traditional commodities is likely to remain static or decrease, except for lumber and timbers and tie stock.

Literature cited

1. Amemiya, S. and R. Cockcroft. 1982. Wood preservation in Japan. Styrelsen for Teknisk Utveckling Informationssektionen, Info. No. 272, 88 pp.
2. Amundsen, J., R.J. Goodwin, and W.H. Wetzel. 1978. Republic of South Africa Patent 857,035.
3. Anonymous. 1977. Announcement of a new wood preserving process. Mississippi Forest Prod. Utiliza. Lab., Mississippi State Univ., 16 pp.
4. ________. 1984. Seven companies file objections to wood preservatives final decision. Pestic. & Toxic Chem. News 12(37):11-12.
5. Arsenault, R.D. 1977. Summary of arsenical wood preservatives memorandum. Proc., Am. Wood-Preservers' Assoc. 73:72.
6. ________. 1979. RPAR update — preservatives, overview and arsenicals. Proc., Am. Wood-Preservers' Assoc. 75:80-84.
7. ________, J. Ochrymowych, and J. Kressbach. 1984. Solvent and solution properties affecting pentachlorophenol performance as a wood preservative. Proc., Am. Wood-Preservers' Assoc. 80:(in press).
8. Baechler, R.H. 1949. Reports of preservatives committee. Proc., Am. Wood-Preservers' Assoc. 45: 14-61.
9. ________. 1950. Reports of preservatives committee. Proc., Am. Wood-Preservers' Assoc. 46: 15-61.
10. Barnes, H.M. 1983. Influence of processing variables on the treatment of wood with a water-dispersible penta formulation. Proc., Am. Wood-Preservers' Assoc. 79: 213-221.
11. ________. 1984. The effect of steaming temperature on mechanical properties of CCA-treated southern pine. Forest Prod. J. (in press).
12. ________ 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.
13. Baxter, A.X. 1978. Report on environmental matters: FIFRA, TOSCA, and the rest of the alphabet. Proc., Am. Wood-Preservers' Assoc. 74:16-19.
14. Behr, E.A. 1979. New information on water-borne preservatives. Appendix A, Report of Committee P-4 Water-Borne Systems. Proc., Am. Wood-Preservers' Assoc. 75:46-48.
15. ________. 1981. New information on water-borne preservatives II. Appendix A, Report of Committee P-4 Water-Borne Systems. Proc., Am. Wood-Preservers' Assoc. 77:65-68.
16. Bendtsen, B.A., L.R. Gjovik, and S. Verrill. 1983. The mechanical properties of salt-treated longleaf pine. USDA Forest Serv., Forest Prod. Lab., Res. Pap. FPL-434, Madison, Wis.
17. Bergervoet, A.J. 1981. Commercial trials with the steam-vacuum-APM system of preservative treatment. New Zealand Forest Serv., Forest Res. Inst., Forest Prod. Div. Rept. No. FP/WP65 (unpublished), 16 pp.
18. ________. 1982. Partial seasoning and preservative treatment systems for pine roundwood. Int. Res. Group on Wood Preserv. Document No. IRG/WP/3187.
19. ________. 1984. A method for treating partially seasoned pine with CCA preservatives. Proc., Am. Wood-Preservers' Assoc. 80:(in press).
20. Bescher, R.H. 1965. U.S. Patent 3,200,003.
21. Bethell, J. 1838. British Patent 7731.
22. Browne, F.L. 1958. Theory of the combustion of wood and its control. USDA Forest Service, Forest Prod. Lab. Rept. No. 2136. Madison, Wis., 59 pp.
23. Burnett, W. 1838. British Patent 7747.
24. 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.
25. ________ and ________. 1972. Dynamic compression results in greatly increased creosote retention in spruce heartwood. Forest Prod. J. 22(4):21-25.
26. Cockcroft, R. 1979. Wood preservation in the United Kingdom. Styrelsen for Teknisk Utveckling Informationssektionen, Info. No. 153, 56 pp.

27. ________ and H. WILLEITNER. 1981. Wood preservation in the Federal Republic of Germany. Styrelsen for Teknisk Utveckling Informationssektionen; Info. No. 214, 53 pp.
28. CRAIG, J.E. 1984. Market changes related to solid wood products. Presented at Annual Meeting, Mid-South Section, Forest Prod. Res. Soc., March 15, 1984, Alexandria, La.
29. DICKER, P.E., D.J. DICKINSON, M.L. EDLUND, and B. HENNINGSSON. 1983. Borate diffusion techniques for the in-situ treatment of joinery. Record, 1983 British Wood-Preservers' Assoc. Annual Convention, pp. 73-81.
30. DOST, W.A. 1977. All weather wood foundation — a truly new market for wood. Forest Prod. J. 27(11):17-18.
31. DUST, J.V., and W.S. THOMPSON. 1972. Pollution control in the wood preserving industry. Part III. Chemical and physical methods of treating wastewater. Forest Prod. J. 22(12):25-30.
32. ________ and ________. 1973. Pollution control in the wood preserving industry. Part IV. Biological methods of treating wastewater. Forest Prod. J. 23(9):59-66.
33. ENVIRONMENTAL PROTECTION AGENCY. 1978. Creosote, Inorganic Arsenicals, Pentachlorophenol. Position Document No. 1, Office of Pesticides and Toxic Substances, U.S. Environmental Protection Agency, Washington, D.C.
34. ________. 1981. Creosote, Inorganic Arsenicals, Pentachlorophenol. Position Document No. 2/3, Office of Pesticides and Toxic Substances, U.S. Environmental Protection Agency, Washington, D.C.
35. ________. 1984. Creosote, Inorganic Arsenicals, Pentachlorophenol. Position Document No. 4, Office of Pesticides and Toxic Substances, U.S. Environmental Protection Agency, Washington, D.C.
36. FASICK, C.A., and H.E. DICKERHOOF. 1970. Underfloor plenum system for heating and cooling. Forest Prod. J. 20(1):10-15.
37. FEIST, W.C. 1983. Weathering and protection of wood. Proc., Am. Wood-Preservers' Assoc. 79:195-205.
38. FERRY, J.D., ASSOCIATES. 1982. Wood preservation statistics — 1981. Proc., Am. Wood-Preservers' Assoc. 78:209-228.
39. GASKIN, P.C. 1977. Discharge to publicly owned treatment works. Proc., Am. Wood-Preservers' Assoc. 73:77-82.
40. GJOVIK, L.R., et al. 1981. The biologic and economic assessment of pentachlorophenol, inorganic arsenicals, creosote. Vol. I: Wood preservatives. U.S. Dept. of Agric. Tech. Bull. No. 1658-1, 435 pp.
41. GOLDSTEIN, I.S. 1973. Degradation and protection of wood from thermal attack. In: Wood Deterioration and Its Prevention by Preservative Treatments. Vol. I. Degradation and Protection of Wood, D.D. Nicholas, ed. Syracuse Univ. Press (Syracuse, N.Y.).
42. ________ and W. E. LOOS. 1973. Special treatments. In: Wood Deterioration and Its Prevention by Preservative Treatments. Vol. I. Degradation and Protection of Wood, D.D. Nicholas, ed. Syracuse Univ. Press (Syracuse, N.Y.), pp. 341-371.
43. GOODWIN, D.R., and R.E. HUG. 1961. A new wood preserving process. Forest Prod. J. 11(11):504-507.
44. GORDON, A. 1939. U.S. Patent 2,149,284.
45. 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, N.Y.), pp. 1-30.
46. ________. 1983. Improving the performance of wooden poles. Proc., Am. Wood-Preservers' Assoc. 79: 222-229.
47. ________ and M. E. GORDEN. 1980. Controlling biological deterioration of wood with volatile chemicals. Electric Power Res. Inst. EL-1480, Proj. [illegible] Final Rept., 57 pp.
48. ________ and G.G. [illegible]. 1979. Wood pole maintenance manual: inspection and supplemental treatment of Douglas-fir and western redcedar poles. Res. Bull. 24, Forest Res. Lab., Oregon State Univ., 62 pp.
49. GUNN, G. 1928. U.S. Patent 1,684,222.
50. HARTFORD, W.H. 1973. Chemical and physical properties of wood preservatives and wood-preservative systems. In: Wood Deterioration and Its Prevention by Preservative Treatments. Vol. II. Preservatives and Preservative Systems, D.D. Nicholas, ed. Syracuse Univ. Press (Syracuse, N.Y.), pp. 1-120.
51. HATCHER, D.B. 1980. Dura-Treet II, a water dispersible pentachlorophenol. Proc., Am. Wood-Preservers' Assoc. 76:308-320.
52. ________. 1981. Dura-Treet II, a water dispersible pentachlorophenol, update. Proc., Am. Wood-Preservers' Assoc. 77:50-57.
53. ________. 1981a. Dura-Treet I — A new completely water-borne pentachlorophenol process. Proc., Am. Wood-Preservers' Assoc. 77:89-98.
54. HENRY, W.T. 1963. A new method for impregnating wood with preservatives. Proc., Am. Wood-Preservers' Assoc. 59:68-74.
55. ________. 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, N.Y.), pp. 279-298.
56. HOLMES, C.A. 1977. Effect of fire-retardant treatment on performance properties of wood. In: Wood Technology: Chemical Aspects, I.S. Goldstein, ed. ACS Symp. Series 43, Amer. Chem. Soc. (Washington), pp. 82-106.
57. HUGHES, F.A., JR. 1984. Report of ITD Committee on Plant Operations and Environmental Control. Proc., Am. Wood-Preservers' Assoc. 80:(in press).
58. HUDSON, C.D. 1983. Report of Committee P-3, Organic and Organometallic Preservative Systems. Proc., Am. Wood-Preservers' Assoc. 79:144-159.
59. ________. 1984. Report of Committee P-3, Organic and Organometallic Preservative Systems. Proc., Am. Wood-Preservers' Assoc. 80:(in press).
60. HUDSON, M.S. 1942. U.S. Patent 2,273,039.
61. ________. 1947. Vapor drying: the artificial seasoning of wood in vapor of organic chemicals. Proc., Forest Prod. Res. Soc. 1:124-146.
62. ________. 1948. U.S. Patent 2,435,218.
63. ________. 1948a. U.S. Patent 2,435,219.
64. ________. 1968. New process for longitudinal treatment of wood. Forest Prod. J. 18(3):31-35.
65. ________. 1969. U.S. Patent 3,427,186.
66. ________. 1969a. U.S. Patent 3,443,881.
67. ________ and S.V. SHELTON. 1969. Longitudinal flow of liquid in southern pine poles. Forest Prod. J. 19(5):25-32.
68. HUNT, G.M., and G.A. GARRATT. 1953. Wood Preservation. McGraw-Hill (New York), 417 pp.
69. ILHAN, R., and R. COCKCROFT. 1982. Wood preservation in Turkey. Styrelsen for Teknisk Utveckling Informationssektionen, Info. No. 294, 44 pp.
70. INGRAM, L.L., JR., G.D. MCGINNIS, and L.R. GJOVIK. 1981. The relative amount of pentachlorophenol volatilization from treated wood. Proc., Am. Wood-Preservers' Assoc. 77:102-108.
71. ________, ________, G. JASPERSE and L.R. GJOVIK. 1981. The effect of solvent systems on the volatilization of pentachlorophenol from treated wood. Proc., Am. Wood-Preservers' Assoc. 77:109-117.
72. ________, ________, P.M. POPE, and W.C. FEIST. 1983. Effect of coating systems on the vaporization of pentachlorophenol from treated wood. Proc., Am. Wood-Preservers' Assoc. 79:32-41.
73. ________, ________, S.E. PRINCE, L.R. GJOVIK, and D.A. WEBB. 1984. The effects of temperature, air flow rates, and coating systems on the vaporization of creosote components from treated wood. Proc., Am. Wood-Preservers' Assoc. 80:(in press).
74. JOHNSON, B.R. 1983. Field trials with ammoniacal copper borate wood preservatives. Forest Prod. J. 33(9):59-63.
75. ________ and D.I. GUTZMER. 1978. Ammoniacal copper borate: a new treatment for wood preservation. Forest Prod. J. 28(2):33-36.
76. JOSEPHSON, H.R. 1977. Economic, social, and environmental benefits from use of wood preservatives. Proc., Am. Wood-Preservers' Assoc. 73:67-71.
77. JUNEJA, S.C. 1975. Combustion of cellulosic materials and its retardance-status and trends. Part I. Ignition, combustion processes, and synergism. Wood Sci. 7(3):201-208.
78. KAMESAM, S. 1938. U.S. Patent 2,106,978.
79. KELSO, W.C., JR. 1981. U.S. Patent 4,303,705.
80. KIRCHNER, R.P., and J.M. TAYLOR. 1983. A water dispersible oil-borne preservative for treatment of timber. Record, 1983 B.W.P.A. Annual Convention, pp. 26-37.
81. LEUTRITZ, J., and G.Q. LUMSDEN. 1962. The groundline treatment of standing southern pine poles. Proc., Am. Wood-Preservers' Assoc. 58:79-87.
82. LINDSAY, D.R. 1977. Penta. Proc., Am. Wood-Preservers' Assoc. 73:74-76.
83. LOPEZ DE ROMA, A., and R. COCKCROFT. 1983. Wood preservation in Spain. Styrelsen for Teknisk Utveckling Informationssektionen, Info. No. 373, 56 pp.
84. LOWRY, C.B. 1906. U.S. Patent 831,450.
85. LYONS, J.W. 1970. The Chemistry and Uses of Fire Retardants. Wiley-Interscі. Div., John Wiley and Sons (New York).
86. MAROUCHOC, S.R. 1972. A new process for the clean treatment of wood. Proc., Am. Wood-Preservers' Assoc. 68:148-151.
87. MARR, T.A. 1981. Wood preserving wastewater regulations. proc., Am. Wood-Preservers' Assoc. 77:23-26.
88. ________. 1982. Report of special committee for Environmental Protection Agency liaison. Proc., Am. Wood-Preservers' Assoc. 78:38-40.

89. Mathur, V.N.P. 1983. Report on new water-borne preservative formulations other than those used by present standards, or currently being used in treating plants or already in service. Appendix A, Report of Committee P-4 Water-Borne Systems. Proc., Am. Wood-Preservers' Assoc. 79:161-164.
90. McGill, T.P. 1984. Report on Committee T-2 Lumber and Timbers. Proc., Am. Wood-Preservers' Assoc. 80: (in press).
91. Micklewright, J.T., and L.R. Gjovik. 1981. Wood preservation statistics:update. Proc., Am. Wood-Preservers' Assoc. 77:143-147.
92. Minich, A., and M. Goll. 1948. The technical aspects of copper naphthenate as a wood-preserving chemical. Proc., Am. Wood-Preservers' Assoc. 44:72-80.
93. Moldrup, B. 1983. All-in-one treatment processes and plant. Proc., Am. Wood-Preservers' Assoc. 79:58-62.
94. Morgan, J., III. 1983. Report of Committee P-4 Inorganic Preservative Systems. Proc., Am. Wood-Preservers' Assoc. 79:160-161.
95. Nicholas, D.D. 1982. Preservative treated wood. In: Encyclopedia of Materials Science and Engineering. M.B. Bever, ed., Permagon Press (New York).
96. ________. 1983. Trends in the use of chemicals for preservative treatment of wood. Advances in Production of Forest Products, AICHE Symp. Series 79(233):75-78.
97. ________ and R. Cockcroft. 1982. Wood preservation in the USA. Styrelsen for Teknisk Utveckling Informationssektionen, Info. No. 288, 129 pp.
98. ________ and A. E. Lund. 1977. Modern trends of wood preservation in the United States. J. Timb. Dev. Assoc. (India) 13(3):1-7.
99. ________ and A.F. Preston. 1984. Interaction of preservatives with wood. In: The Chemistry of Solid Wood, R.M. Rowell, ed., ACS Symp. Series (in press).
100. Page, R.F., and B.E. Reed, Jr. 1969. U.S. Patent 3,467,546.
101. Percival, D.H. 1975. Experiences with a wood foundation. Forest Prod. J. 25(12):32-35.
102. Plackett, D.V. 1982. Ammoniacal copper zinc arsenate. Appendix A, Report of Committee P-4 Inorganic Preservative Systems. Proc., Am. Wood-Preservers' Assoc. 78:85-87.
103. Poletika, N.V. 1981. RCRA and superfund update. Proc., Am. Wood-Preservers' Assoc. 77:30-31.
104. Presnell, T.L. 1983. The evaluation of combinations of low hazard biocides for the control of mold and stain fungi on unseasoned southern yellow pine lumber. Unpublished Master's thesis, Mississippi State Univ., Mississippi State, Miss.
105. Preston, A.F., and D.D. Nicholas. 1981. Efficacy of a series of alkylammonium compounds against wood decay fungi and termites. Wood and Fiber 14(1):37-42.
106. Rananand, A., and R. Cockcroft. 1983. Wood preservation in Thailand. Styrelsen for Teknisk Utveckling Informationssektionen. Info. No. 372, 57 pp.
107. Richardson, B.A. 1978. Wood Preservation. The Construction Press (Lancaster, UK), 238 pp.
108. ________ and T.R.G. Cox. 1974. Aqueous organotin wood preservatives. Tin and Its Uses 102:6-10.
109. Rose, K., J. Kozuma, and P. Sparrow. 1984. Evaluation of chlorpyrifos as an insecticide component of a wood preservative. International Res. Grp. on Wood Preservation, Document No.: IRG/WP/3301, 10 pp.
110. 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.
111. ________. 1981. Drying of lumber in superheated steam above atmospheric pressure. Am. Inst. Chem. Eng. Symp. Ser. 77(207):32-37.
112. Rowell, R.M. 1984. Penetration and reactivity of cell wall components. In: The Chemistry of Solid Wood, R. Rowell, ed. Adv. in Chemistry Series No. 207, Am. Chem. Soc. (Washington):176-210.
113. 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.
114. Rueping, M. 1902. U.S. Patent 709,799.
115. Saur, J.M., P.J. Walcheski, and L.R. Gjovik. 1983. The level of respirable arsenic on the surface of treated wood. Proc., Am. Wood-Preservers' Assoc. 79:66-70.
116. Shunk, B.H. 1972. Development of an all-weather fire-retardant treatment. Forest Prod. J. 22(2):12-15.
117. Stamm, A.J. 1964. Wood and Cellulose Science. Ronald Press (New York), pp. 312-342.
118. ________. 1977. Dimensional changes of wood and their control. In: Wood Technology:Chemical Aspects, I.S. Goldstein, ed., ACS Symp. Series 43, Am. Chem. Soc. (Washington), pp. 115-140.
119. Stevens, M., and R. Cockcroft. 1981. Wood preservation in Belgium. Styrelsen for Teknisk Utveckling Informationssektionen, Info. No. 234, 38 pp.
120. Stoddard, C.L. 1984. Report of the Treatment Committees. Proc., Am. Wood-Preservers' Assoc. 80: (in press).
121. Talarek, W.G. 1982. Analysis of and update on EPA's RPAR review of the wood preservatives. Proc., Am. Wood-Preservers' Assoc. 78:41-45.
122. ________. 1984. Environmental considerations in the wood preserving industry. Presented at: Annual Meeting, Forest Prod. Res. Soc., Session 5 — Treated Wood Products, June 25, 1984, St. Louis, Mo.
123. Taylor, J.A. 1978. Pole maintenance — its need and effectiveness. Proc., Am. Wood-Preservers' Assoc. 74:129-141.
124. Thompson, W.S., ed. 1971. Proceedings of Conference on Pollution Abatement and Control in the Wood-Preserving Industry. Mississippi Forest Prod. Lab., Mississippi State, Miss.
125. ________. 1973. Pollution control. In: Wood Deterioration and Its Prevention by Preservative Treatments, Vol. II. Preservatives and Preservative Systems, D.D. Nicholas, ed., Syracuse Univ. Press (Syracuse, N.Y.), pp. 345-395.
126. ________ and H.M. Barnes. 1978. Advances in wood finishing and wood preserving technology for southern pine. In: Complete Tree Utilization of Southern Pine, C.W. McMillin, ed. Forest Prod. Res. Soc. (Madison), pp. 372-385.
127. ________ and J.V. Dust. 1971. Pollution control in the wood preserving industry, Part I. Nature and scope of the problem. Forest Prod. J. 21(9):70-75.
128. ________ and ________. 1972. Pollution control in the wood preserving industry, Part II. In-plant process changes and sanitation. Forest Prod. J. 22(7):42-47.
129. ________ and P. Koch. 1981. Preservative treatment of hardwoods: a review. USDA Forest Serv. Gen. Tech. Rept. 50-35, 47 pp.
130. Troxell, H.E. 1961. Progress in wood preservation, 1959-60. Forest Prod. J. 11(2):67-76.
131. Vasishth, R.C. 1983. Importance of depositing polymers in wood-cell walls for wood treatment. Proc., Am. Wood-Preservers' Assoc. 79:129-136.
132. ________ and D.P. De Silva. U.S. Patent 4,276,329.
133. Vinden, P., and A.J. McQuire. 1978. Improvements to APM schedules. Proc., New Zealand Wood-Preservers' Assoc. 18:21-31.
134. Walsh, M.R. 1983. The treated lumber industry, its markets, its outlook; quality sensitive areas. Marketing report, Data Resources, Inc.
135. Weaver, F.W. 1981. A modified empty-cell process for treatment of wood with chromated copper arsenate. Unpublished Master's thesis, Mississippi State Univ., Mississippi State, Miss.
136. Webb, D.A. 1977. Creosote — a wood preservative. Proc., Am. Wood-Preservers' Assoc. 73:73.
137. ________. 1979. A rebuttal to the EPA's presumption against the registration of creosote. Proc., Am. Wood-Preservers' Assoc. 75:89-95.
138. ________. 1981. Creosote, wood preservative, an update on the RPAR status. Proc., Am. Wood-Preservers' Assoc. 77:29.
139. Wilkinson, J.E. 1981. RPAR update wood preservative pentachlorophenol. Proc., Am. Wood-Preservers' Assoc. 77:27-28.
140. ________. 1979. Rebuttable presumption against registration update. Proc., Am. Wood-Preservers' Assoc. 75:85-88.
141. Williams, D.R., and J.F. Bridges. 1984. Characterization of airborne emissions and waterborne drainings associated with kiln-drying of CCA-treated wood. Proc., Am. Wood-Preservers' Assoc. 80: (in press).
142. Winandy, J.E., B.A. Bendtsen, and R.S. Boone. 1983. Effect of delay between treatment and drying on toughness of CCA-treated southern pine. Forest Prod. J. 33(6):53-58.
143. Winn, W.D. 1973. Results of commercial application of the Dow wood treating process. Proc., Am. Wood-Preservers' Assoc. 69:198-205.
144. Wood, M.W. 1980. Effects of the MSU process and high preservative retentions on southern pine treated with CCA-type C. Unpublished Master's thesis, Mississippi State Univ., Mississippi State, Miss.
145. ________ 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, Miss.
146. ________, ________, 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.