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Preservative treatment evaluation of five Appalachian wood species with four preservatives

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Dedication

I dedicate this work first to my parents without whom I would not be here, especially my Mother whom I could never repay in an infinite number of lifetimes. Secondly to my children who often gave me reason to continue when I could find no other. Thirdly to my teachers, co-workers, and friends for all their help and assistance. And finally to myself-never stop trying.

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Abstract

Preservative Treatment Evaluation of Five Appalachian Wood Species With Four Preservatives

Jeffrey J. Slahor

Hardwoods have been used extensively throughout the years for many uses. In the last century, wood railway tie and bridge material has been treated almost exclusively with the preservative creosote in order to improve durability. This has led to the knowledge that hardwoods treated with creosote are extremely durable. However, there have been few well documented studies of what has been termed “treatability”. This work investigated and documented the treatability of five common and abundant Appalachian hardwoods vacuum/pressure treated with the four wood preservatives creosote, chromated copper arsenate (CCA), ammoniacal copper quaternary compound Type-B (ACQ-B), and a borate preservative (Tmbor®). These preservatives were chosen because the first two are the most commonly used wood preservatives in the US. The latter two were included as possible alternative treatments for the former two.

Heartwood and sapwood samples were produced from rough-cut lumber for all hardwood species except red oak. Some southern pine samples were produced as well and included in some, but not all, of the treatments for comparison to this standard softwood species. Sample size for all treatments was a six-inches long nominal two-by-four (1.5" by 3.5"). Samples were conditioned to two distinct moisture contents to allow for comparison of the effect (if any) of moisture content on the various treatments. Three pressure periods of 60, 90, and 120 minutes in duration were used. The ACQ-B solution was applied either as a heated or ambient solution (180^{O}F, 80^{O}F). Creosote heated to 120^{O}F, while the CCA and borate solutions were applied at ambient temperatures (approximately 80^{O}F). The borate treated samples were either wrapped in plastic immediately following treatment in order to determine if there was any difference in the penetration via diffusion of the preservative. All results were analyzed statistically using a General Linear Model analysis of variance as well as having results compared to the American Wood Preservers Association (AWPA) Book of Standards.

Statistical analysis carried out on the results using preservative, moisture content, pressure period, species, wrapping of samples in plastic vs not wrapping, and heartwood/sapwood as factors produced less than conclusive results. Some of the more clear-cut results were that sapwood treats better than heartwood, a lower moisture content yielded better penetration results for samples treated with creosote, and borate treated samples wrapped in plastic immediately following treatment had better penetration results than the samples not wrapped in plastic. Also, the hardwoods were generally as treatable as southern pine, where applicable. When judged by AWPA standards, most treatments fell short of specified requirements except for the creosote treatments. The hardwood results were so variable that no generalized statement can be made as to their treatability can be made.

Chapter 1
Literature Review/Introduction

SIGNIFICANCE and RATIONALE

In 1989, legislation known as the Timber Bridge Initiative was passed by the U.S. Congress. The legislation established a national program which emphasized wood as a structural material for highway bridges. The heart of the program was to establish the overall feasibility (cost effectiveness and engineering) of using wood in the replacement of deteriorating highway bridges across the nation. A central theme throughout the program was that local species of wood could be used in the replacement of small to medium sized bridges, especially in rural areas, spurring the local economy by providing increased job potential, reduced cost to local transportation authorities, and an improved transportation network. A potential offshoot of this work would be that any successfully demonstrated preservative treatment of under-utilized hardwood species for use in timber transportation structures could be applied for other high biodeterioration hazard end-uses as well. With the added value of a protective treatment, species of wood not normally cut, or utilized at the lowest possible level could improve the economic outlook of small, rural businesses.

Wood is susceptible to biological degradation by insect and/or decay fungi attack and preservative treatment is imperative for any load bearing structure made from wood. An effective preservative solution and compatibility with the wood is a critical requirement for the success of the preservative process. A third critical aspect, and the one dealt with in the following papers, is that the preservative be introduced into the wood substrate to sufficient depth (penetration) and in sufficient quantity (retention) to protect the wood from biodeterioration during the planned service-life of the structure.

The aforementioned introduction of preservative into the wood substrate is primarily done using a combination of applied vacuum and pressure. Teesdale and MacLean (35) did some of the earliest work on hardwoods. The primarily heartwood samples of hardwoods were pressure treated with creosote and analyzed for penetration and retention. Based on these results, the authors grouped them into three treatability classes (**Table 1.1**).

Table 1.1— Tested Species Grouped According to Difficulty of Impregnation With Creosote (35).

Basis for Grouping	Group I	Group II	Group III
Depth of Penetration (inches) at 100 psi[1]			
Lateral	Complete	Variable	************
Longitudinal	>8	4—8	2.5—
Retention, pcf[2]	12+	7—10	6—
Tyloses	Absent	Present, closure incomplete	Vessels occluded by tyloses
	Ash, green Ash, white Basswood Beech Birch, river Birch, sweet Birch, yellow Cherry Elm, American Elm, slippery Hackberry[4] Maple, silver[4] Oak, chestnut Oak, red Sweetgum[4] Tupelo gum[4 5]	Aspen, biggtooth Chestnut Elm, rock Hackberry Hickory[3] Maple, silver Maple, sugar Sycamore Willow, black	Beech Oak, bur Oak, white Sweetgum

[1]Psi—pounds per square inch [2]Pcf—Pounds per cubic foot [3]Vessels closed by tyloses, but creosote penetrated through fibers and trachieds [4]Samples were sapwood; all others were heartwood [5]Probably *Nyssa sylvatica* Marsh.

It is of note that this grouping has stood the test of time as a general classification of treatability with creosote and, more generally, oil borne preservatives.

Other authors took a slightly different approach to the classification of woods than that taken by Teesdale and MacLean(35). By determining longitudinal penetration into samples treated with a solution of 0.5% keystone oil red dye in mineral spirits, Sribahiono *et al* (34). determined an easier way to classify woods into groups as per Teesdale and MacLean (35). Siau *et al* (27). developed his own classification of southern hardwoods based on samples impregnated with methyl methacrylate monomer using a vacuum process. Grouping, as presented in **Table 1.2**, was determined based on the fractional void volume filled with monomer.

Table 1.2— Southern Hardwoods Grouped by Difficulty of Impregnation With Methyl Methacrylate Monomer by Vacuum Process (27).

Easy (0.8 + of Voids Filled)	Moderate (0.4 - 0.8 of Voids Filled)	Difficult (Less Than 0.4 of Voids Filled)
Maple, red	Ash, green	Hackberry
Sweetbay	Elm, American	Oak, black
Sweetgum	Elm, winged	Oak, blackjack
Tupelo, black	Hickory	Oak, post
Yellow-poplar	Oak, cherrybark	Oak, white
	Oak, laurel	
	Oak, northern red	
	Oak, scarlet	
	Oak, Shumard	
	Oak, southern red	
	Oak, water	

A common shortcoming of research work into preservative treatment of wood, especially hardwoods, is highlighted by comparing **Table 1.1** and **1.2**. **Table 1.1** has green ash in Group I (most easily treated) while **Table 1.2** places it in the moderate category. Sweetgum is listed as easy to impregnate in **Table 1.2** while it is listed in Group I (easiest) and Group III (hardest) in **Table 1.1** with the caveat that the former were sapwood samples while the later were heartwood samples. A similar instance occurs with hackberry. This type of confusion is not uncommon in this type of research.

Many researchers have approached the same problem from a different perspective. While the previously discussed works on treatability focused on the empirically determined data of penetration measurement following treatment, other work has looked at the relationship between the permeability of wood and the treatability of same. Permeability is the most important physical property of a porous medium in much the same way as the porosity is its most important geometrical property. Permeability quantitatively measures the ability of a porous medium to conduct fluid flow. A fairly extensive body of work exists on gas permeability of wood. This method of investigation avoids the complications of cell wall interactions. However, most wood preservatives are applied using a liquid carrier. Some work has been done to determine if a relationship between gas permeability and treatability exists.

In a study using end-matched samples, Tesoro *et al* (36). sought to determine if a relationship existed between transverse air permeability of wood and its treatability with creosote. Using one sample to determine the volume flow rate of air through the sample and the matched specimen pressure treated with creosote, the preservative retention and depth of penetration were compared to the permeability. The authors found evidence of a direct relationship between the log of the lateral permeability and both retention and penetration of creosote. Choong and Fogg (5) found significant correlations for both retention and penetration of creosote in shortleaf pine for longitudinal and transverse permeability. The correlation was true for the measures of permeability taken separately and together. For yellow-poplar, there was no correlation found for either longitudinal or transverse permeability (taken separately) and the measures of treatability. However, when the former were taken together, the correlation coefficients for retention and penetration were both significant and high. Overall the authors found slightly better correlation of permeability with retention than with penetration. The reason for this was stated as being the result of difficulty in evaluating penetration because of variations in anatomical structure.

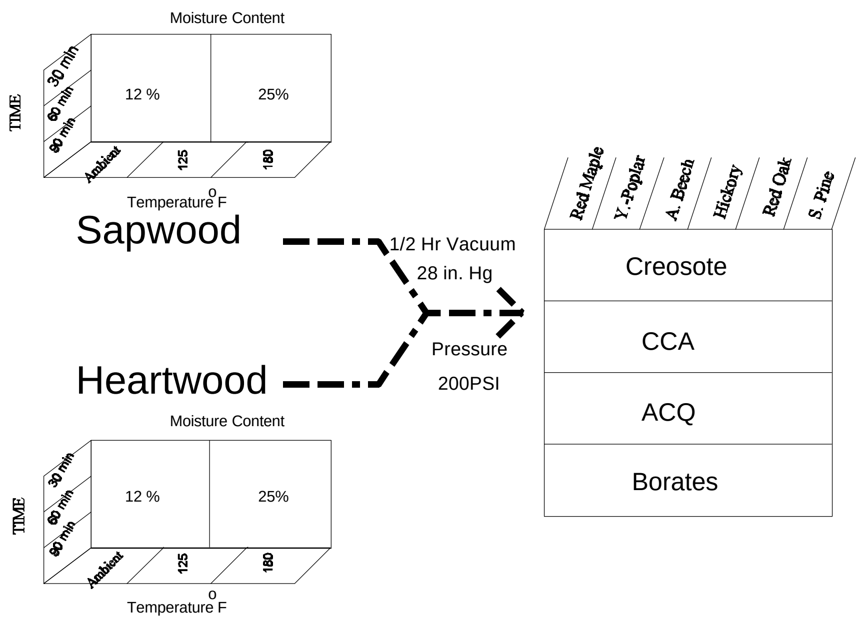

Figure 1.1 Experimental Design

INTRODUCTION

The work described in the following papers involved four preservative chemicals applied to the heartwood and/or sapwood of the species being investigated. Several conditions were also used such as heating of solution, varied pressure periods, and different moisture content of samples prior to treatment. **Figure 1.1** illustrates the proposed matrix for investigating the treatability of Appalachian hardwoods. The total number of treated samples was planned to be 4,080 based on ten samples per treatment. However, because of equipment problems and constraints as well as raw material procurement problems, the actual number of treated samples was just under 2,500.

Treatment Variables

Wood Preservative Chemicals

Wood preservative chemicals fall into three major groups:

1) tar oil preservatives
2) water-borne preservatives
3) organic solvent-based preservatives.

Organic solvent-based preservatives are composed of insecticides and/or fungicides dissolved in a volatile or non-volatile, non-polar solvent. Pentachlorophenol is the most widely used preservative of this type. This type of preservative was not used in the work described here, and is mentioned as reference only.

Generally speaking, the greatest difference between creosote (tar-oil) and the waterborne preservatives used in this study is that no swelling of the wood substrate occurs with creosote treatment. Rather the wood is coated or "encased" in the preservative. Waterborne preservatives cause swelling by way of the hygroscopic nature of wood. Water molecules are taken up within and between the various wood fibres. The biocide dissolved in the water carrier thus has intimate access to the wood substrate. The biocide can then bond to the wood substrate. These bonds may or may not be permanent.

Tar-oil preservatives were originally derived from wood tar but today are mainly produced from high-temperature coke-oven tar (9). Wood tar creosote was was patented in the USA in 1716 by Dr. William Cook for treatment of ship's timbers while coal tar creosote was patented in 1836 by German chemist Franz Moll. In 1838 John Bethell patented a process - the full-cell or Bethell process - for treating timber with tar oils. This process is still used today, essentially unchanged.

Creosote, one of the preservatives used in this study, is a brownish-black, oily liquid derived fron the tar produced during the carbonisation of bituminous coal. The portion of the tar boiling from 200 to 400^{O}C forms the creosote oil used in wood preservation (40). Creosote has a complex and variable make-up comprised of about two hundred or more compounds. The fact that there is such a wide range of compounds in creosote undoubtedly is a key factor in the effectiveness of creosote against decay, insect, and marine borer attack (37). In addition to its effectiveness as a biocide, creosote has other desirable qualities. Being extremely insoluble in water, it is resistant to leaching. Hand in hand with the aforementioned aspect is that it imparts a high degree of resistance to water imbibition which minimizes the shrinking and swelling of the treated wood. It also imparts a high degree of electrical resistance. Creosote is the most commonly used preservative for hardwood species primarily as railway ties. As such it can be considered standard reference preservative for hardwoods, and thus its inclusion in this work.

Water-borne preservatives are aqueous solutions of toxic salts (9). While the modern waterborne preservatives have not been around as long as creosote, "Kyanizing" was patented in 1832 using mercuric chloride as the active ingredient. The active ingredient(s) found in waterborne preservatives can generally be grouped as follows (9):

1) Zinc-Based Compounds
2) Copper Salts
3) Flour Chrome Arsenate Phenol (FCAP) Mixtures
4) Boron Compounds
5) Alkyl Ammonium Compounds (AAC)

The three waterborne preservatives used in this work fall into the second (chromated copper arsenate or CCA and ammoniacal copper quaternary compound or ACQ) and fourth (Timbor® or disodium octaborate tetrahydrate) categories. As such they are discussed in further detail.

Many early waterborne preservative formulations were effective but suffered from the major drawback of leaching out of the wood when placed in wet conditions. In the early 1900's a German scientist, Heinrich Brüning, discovered that large amounts of chromium added to metal-salt formulations resulted in their becoming insoluble or fixed in the wood. In 1933 an Indian research worker, Sonti Kamesan, used chromium to fix both arsenic and copper in treated wood. This general formulation has become known as chromated copper arsenate (CCA) and is the most widely used wood preservative today. Since the 1930's various formulations of CCA, based on percentage of copper, chromium, and arsenic have been tried. Currently the most widely used formulation in the USA is CCA-C, which consists of hexavalent chromium as chromium trioxide (CrO_3 - 47.5%), copper as copper oxide (CuO - 18.5%), and arsenic as arsenic pentoxide (As_2O_5 - 34.0%). Aside from the high degree of leach resistance of CCA, some of the other positive attributes of this preservative are its relative low cost, no odor, and a clean paintable surface of the treated wood.

While CCA is the most widely used preservative in the USA, the vast majority of the CCA treated wood is southern pine and western softwoods. The dominance of the softwood species in this area is two-fold; proven effectiveness and, at least for southern pine, ease of treatability. Neither of these claims can flatly be made for the hardwood species. Premature failure of CCA treated hardwoods, as compared to similarly treated softwoods, led Henshaw (16) to investigate possible fixation mechanism differences between hardwoods and softwoods. His conclusion that there was no systematic difference in fixation levels between hardwoods and softwoods did not shed any light on possible reasons for the premature failure of CCA treated hardwoods in service. Other researchers investigated possible differences in the microdistribution of the elements of CCA preservatives in hardwoods versus softwoods. Greaves (11) found the distribution of CCA to be relatively even in softwoods but found large pockets of untreated cells in the hardwoods. He also concluded different fixation mechanisms exist between soft and hardwoods and found that the ratios of the preservative components differ between the two as well as varying between different anatomical structures.

While this and much other work are less than conclusive relative to appropriateness of treating hardwoods with CCA (i.e. effectiveness), it was carried out for the most part using hardwood species not commonly treated in the USA (such as eucalyptus). There is a substantial volume of hardwoods treated with CCA in West Virginia (29). As such, inclusion of CCA in this work in order to determine treatability of some of the common Appalachian hardwood species was warranted.

Ammoniacal copper quaternary (ACQ) compound is a preservative that has been marketed recently as an alternative to CCA. From a marketing stand-point, the key selling point is its ‘environmental friendliness’ in that it does not use the heavy metal chromium or the arsenic as insecticide. The formulation used in this work was ACQ-B which has a formulation of copper as CuO (minimum 62%/maximum 71%) and Quat as didecyldimethylammonium (DDAC-minimum 29%/maximum 38%) (2). Further, the ammoniacal component theoretically has the potential to improve penetration into refractory woods, as the ammoniacal component enhances preservative penetration into refractory woods. This was a key consideration when deciding to include the preservative in the study or not as many hardwood species are refractory in nature. While much work has been carried out on ACQ-B relative to its effectiveness, virtually all of the work has used southern pine. As a possible alternative to CCA treated hardwood products, both from a marketing view-point and an improved penetration stance, it was included for investigation.

Research into and commercial use of borate compounds as wood preservatives has been extensive in the United Kingdom, Australia, and New Zealand. Their use in the USA is still fairly limited and ‘new’ in spite of the fact that some of the earliest work was done in the USA (23).

The greatest attractions for the borate wood preservatives is their low mammalian toxicity and the fact they can be applied as a diffusible preservative. The latter can be very attractive, as a treating system can be set-up at very low cost, consisting of little more than a dip-tank (1). Another plus is that diffusion can accomplish complete penetration of unseasoned or otherwise refractory wood (41). The efficacy of the treatment (boron within the wood converts to boric acid) is well established relative to many insects and decay fungi (23). The biggest hindrance to the wider use of the borates is that it is not 'fixed' to the wood and readily leaches out of wood in wet conditions. However, for wood that is only indirectly exposed to exterior conditions, such a siding under an overhang or patio furniture under roof, a borate treatment would be appropriate.

While much work has been carried out on various aspects of the use of borate based preservatives as they apply to hardwoods, much of that work used tropical hardwoods. To further widen the base of knowledge on the treatability of Appalachian hardwoods, Timbor® was included in the study.

Hardwoods versus Softwoods

The one constant in virtually all of the work carried out on hardwoods is the criticality of anatomical structure. In their 'Preservative Treatment of Hardwoods: A Review', Thompson and Koch (38) note that lack of agreement among investigators on the importance of different cell and tissue types to wood permeability may be due to natural among and within species variations. Tremendous variation is possible within species, as well. Greaves (12) reviewed the influence of the various tissue types of hardwood on liquid penetration into same. His conclusions are similar to those of Thompson and Koch (38), mentioned above. The diversity of hardwood anatomical features creates far more variable results in terms of penetration and distribution as compared to softwoods. The key primary factor for penetration into hardwoods is the vessels. He adds that the pits are the all important interconnecting factors, and that the extent of extractives and other extraneous material which may block them is critical in affecting subsequent preservative distribution. The primary factor which Teesdale and MacLean (35) proffered for differences in treatability was anatomical structure. They concluded that in species with scattered tyloses the effect on preservative treatment is proportional to their frequency. When hardwood vessels are blocked by tyloses or other extraneous materials, penetration may proceed through other anatomical tissues. It was also concluded that hardwood rays are not important in transverse penetration of preservatives. It is worth noting that the assertion, made by Teesdale and MacLean (35) in 1918 that anatomical structure is the key factor in preservative treatment of hardwoods has also stood the test of time, although specific interpretations have varied greatly.

Behr *et al* (3). found that longitudinal parenchyma did not serve as a preservative reservoir in most species while ray parenchyma was a key pathway for penetration in some species. The latewood vessels of both diffuse and ring porous hardwood species were found to contain more preservative than the earlywood vessels in transverse section. In other views of the same samples, large earlywood vessels were found to be full of oil. Berh's (3) work confirms an earlier work by Bossard (4). Ray tissue of several CCA-treated hardwoods was also found to have high concentrations of CCA (Tanalith) formulation by Greaves and Levy (13).

While Teesdale and MacLean (35) found fibers to be poor to nonexistent pathways for preservative penetration unless the vessels were completely blocked, and Liese (20) found pits incapable of transmitting preservative because they contain no pores, other researchers have found differently. Côte´ (8) found no visible openings in basswood pits, yet they had been penetrated by preservative. Behr (3) observed fiber to fiber movement of creosote via pits. However, there is virtually no disagreement to be found with Teesdale and MacLean's (35) assertion that the key to preservative penetration into most hardwoods is their vessels.

Softwoods, by great contrast, can be viewed as consisting overwhelmingly of one cell type, the trachied. While variation within and among softwood species is still evident, it is relatively non-existent compared to the hardwoods. A permeability model specific to softwoods was proposed by Comstock (7) (the Comstock Model for softwoods) in which the number and condition of the pit openings determine the permeability. The pit openings are small compared to the lumens, and are assumed to be the source of all flow resistance, while the lumen size of the trachieds is assumed to be constant. It was found to be in good agreement with experimental results, in contrast to the models proposed for the more complicated hardwoods.

Heartwood versus Sapwood

According to MacLean (21) the most universal cause of difference in the penetration of preservatives into both hardwoods and softwoods is the difference between heartwood and sapwood. Siau (25) confirmed this for both softwoods and hardwoods. In softwoods, this is thought to be largely the result of pit aspiration and occlusion by extraneous material. In hardwoods, the heartwood vessels may become blocked by pith-like growths called tyloses or with gum.

The work done for this thesis included an initial evaluation on the sapwood of all species treated with CCA. If treatment was found to approach 100% penetration, it was assumed that treatment with the other preservatives would be at least as good. Based on this assumption, the sapwood of any species with CCA penetration approaching 100% was not treated with the other preservatives used in this study.

Preservative Solution Temperature

For some preservative solutions, the temperature at which they may be applied may be fixed. This is true for CCA-C which is applied at approximately standard room temperature (60-80^{O}F) in order to prevent unwanted precipitation of the active ingredients out of solution. While creosote does not have to be heated for application to prevent some unwanted chemical reaction, heating ($\approx$ 180^{O}F) is done for the purely physical reason of reducing viscosity and thereby improving penetration. For Timbor® solutions, heating is required in order to keep the active ingredient in solution when a high solution strength (20%) is used (39). At low solution strength (2%), as was used in this work, a solution temperature of approximately room temperature (as with CCA) is adequate. Because there was only one temperature at which these preservatives were applied in this work, there was no statistical comparison possible. With the ACQ-B solution, heating or not heating of solution is an option.

The heating of preservative solution has been well documented as improving both penetration and retention for creosote, creosote solutions, and preservative oils, primarily by reducing viscosity (21). While the viscosity of water based preservatives is much lower than creosote/creosote solutions, and changes less with given changes in temperature, experiments with zinc-chloride solution showed that small changes in viscosity which take place with increase of solution temperature have a considerable positive effect on the penetration into wood (21). In the case of refractory heartwoods, any possibility of improving treatment was deemed worth investigating.

Diffusion

Diffusion was discussed briefly in the preservative solution section under borate compounds. Simply put, diffusion treatment of wood, works by creating an area of high concentration of the diffusible preservative in or on the wood from which the preservative will migrate to the areas of low concentration While much of the work carried out on diffusion treatment of hardwoods has been done on green lumber above fiber saturation point, this project treated the samples at below fiber saturation. After pressure treatment, samples which are refractory will have a shell or envelope of treatment. This area will be at very high moisture content, higher than the untreated interior of the sample. The moisture movement in these samples, if simply stacked to dry, will be from this wet shell area to the surrounding atmosphere, away from the untreated interior. This would essentially negate the desired effect of the diffusible preservative (penetration throughout the sample). Slowing or temporarily stopping the drying process might allow the desired diffusion process to take place. Borate treatment consisted of vacuum/pressure treatment after which samples were either immediately spaced on wire grills to air dry and stop diffusion or were dead-stacked and wrapped tightly in plastic to promote diffusion. The plastic wrapped samples remained so for six weeks, at which time they were spaced on wire grills to air dry.

Moisture Content

General wisdom relative to wood moisture content and pressure treating wood is that the best treatment will be obtained with the wood below fiber saturation point. This is logical for the simple reason that below fiber saturation, all free water is gone leaving cell lumens empty and therefore able to hold more preservative solution. However, seasoning or drying too long or too quickly can result in "surface hardening" (21) and increased resistance to penetration at the surface. Drying refractory woods too far below the fiber saturation point may also result in reduced penetration. Other work, discussed in more detail in the second paper presented here, suggests that a moisture content closer to the fiber saturation point than the standard 12% for kiln dried lumber or the 15-25% for air dried lumber actually yields better treatment results. Whether this might be true for the hardwoods species in this work was investigated. All treatments were done at two moisture contents. The original design called for 12% and 25% moisture contents. Because of equipment problems, wood at 12% and 17.5% moisture contents were used in parts of this study.

Pressure Periods

The length of pressure period required to obtain a given absorption of preservative is largely determined by the refractory nature or lack thereof of the wood being treated (21). Easily treated southern pine will be well treated with CCA in 20 to 30 minutes at a standard pressure of 150 pounds per square inch. Refractory western softwoods may be kept under pressure for eight hours or more to obtain an adequate treatment. Pressure treatment of Appalachian hardwoods with CCA is commonly done to refusal, when gauges indicate no more preservative is being taken up by the wood (2-3 hours). Three pressure periods, 60, 90, and 120 minutes, were selected.

Wood Species

Five of the most common, readily available, and abundant species found in the Appalachian region, yellow-poplar (*Liriodendron tulipifera* L.), red maple (*Acer rubrum* L.), hickory (*Carya* spp.), beech (*Fagus grandifolia* Ehrh.), and northern red oak (*Quercus rubra*) were chosen for study. Southern yellow pine obtained from western Virginia (most likely *Pinus echinata* Mill.) was simultaneously evaluated for comparison purposes.

Physical sample size was a major consideration. Much of the work in the literature cited used small clear, defect free samples which yielded results which were not readily transferable to full-size commercial operations (26). It was decided that a nominal two-by-four (1.5" by 3.5") by six inches in length would be used. While samples showing major defect and obvious decay were not used, this larger sample sample size included greater grain deviation and some small red knots. This, along with the fact that the sample represented a true to life size of lumber, was reason for using the nominal two-by-four sample size. In order to have an adequate number of samples per treatment (*n*) for subsequent statistical analysis, ten samples per treatment was used for most situations. All samples were end-sealed with an appropriate material (so as not to dissolve in the preservative) to minimize end-grain penetration. In this way, the limiting factor of transverse or lateral penetration would be measured and analyzed. These papers detail the results of the available comparisons. Five papers were produced from the work done in this project, and are presented in the following order.

The first paper describes the treatment of yellow-poplar and red maple with ACQ-B solution at an ambient temperature or one heated to 180^{O}F. The second paper widened the perspective, looking at all five hardwood species, at a 12% moisture content, treated with CCA, an ambient ACQ-B solution, or one heated to 180^{O}F. The third paper describes the results of treatment of all five hardwood species, at two moisture contents, with CCA and ACQ-B. The fourth paper covered all variables in reference to the five hardwoods treated with creosote and Timbor®. The final paper tied up the loose-ends by making comparison, statistical and otherwise, between southern pine and the hardwoods, where applicable. The second, third, fourth, and sixth chapters have been published in the Forest Products Journal. The fifth paper is in print in the American Wood Preservers Association Proceedings-1998.

OBJECTIVES

While much work has been done on preservative treatability (3, 4, 5, 7, 13, 14, 15, 21, 27, 30, 31, 32, 33, 34, 35, 36) of various species of hardwoods, most of the conclusions drawn in and from these works have not been readily or easily applicable from a commercial treaters stand-point or from a potential end-users point of view. Many of the species of wood investigated such as river birch, slippery elm, hackberry, black willow, bur oak, and sweetbay just to name a few, are not readily available because they are not commercial species beyond a regional base,.

The objective of this work was to evaluate the preservative treatability of five common and abundant Appalachian wood species for possible use in timber bridge structures, as well southern pine. The evaluation was based on 2-by-4 inch specimens, there-by more closely enabling direct comparison to real-life situations. These measurements were compiled and statistically analyzed allowing for direct species to species comparison as well as preservative/species comparisons. Because wood in such applications must be treated to American Wood Preservers Association (2) standards for the specified end-use, these standards were used as another criteria for evaluation. From these two perspectives, it was hoped that clearer and more applicable conclusions could be drawn as to which species could be successfully treated with which preservative chemical. This, in turn, could set the stage for the next step of efficacy testing.

Chapter 2

Preservative Treatment Evaluation of Red Maple and Yellow-Poplar with ACQ-B

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Abstract

This project sought to determine if an ammoniacal preservative solution would improve treatment of chosen refractory hardwood species. Six inch long nominal two-by-four samples of red maple and yellow-poplar heartwood were end-sealed and vacuum/pressure treated with a 1% active ingredient solution of ACQ-B. Duration of pressure time period was varied as well as temperature of solution. Measurements were taken of minimum and maximum penetration, percentage of cross-sectional area penetrated, and retention of preservative as determined by X-ray fluorescence spectroscopy (ASOMA). Statistical analysis indicated improved penetration into yellow-poplar heartwood when preservative solution was heated. Red maple results were an indication of difficulty in either obtaining true heartwood or confirming the refractory nature of the species.

INTRODUCTION

Refractory softwoods have been investigated for ways of improving preservative treatment as characterized by penetration and retention. Improvement in these criteria has been demonstrated when an ammoniacal preservative solution was used in comparison to chromated copper arsenate (CCA) (10,18). These studies primarily focused on the effect of incising refractory softwoods respectively treated in commercial treating facilities or on a laboratory scale. Both studies compared CCA to an ammoniacal preservative solution (ACZA and ACA, respectively). When the effect of preservative was singled out, generally better and statistically significant (respectively) penetration was observed for the ammoniacal solutions.

While Appalachian hardwoods have been and are extensively used for railroad ties (treated with creosote) many species fall into the refractory category when treated with waterborne preservatives. Two of these refractory species, yellow-poplar and red maple, are found in abundance in the Appalachian forest and until relatively recent times were fairly underutilized. In the past 10-15 years, both of these species have seen increased use in the furniture, composite, and export markets. If the wood of these species could be satisfactorily and consistently treated with an effective preservative, use, marketability, and value would further be enhanced for applications in adverse conditions.

From previous work done with the sapwood of these two species, vacuum/pressure - treated with CCA, it was determined that sapwood was 100 percent treatable and the decision was made to focus on the heartwood of both species for this work, treated with ammoniacal copper quaternary compound-Type B (ACQ-B) at three different pressure periods and two different solution temperatures. The treatability of red maple sapwood is further corroborated by Smith *et al* (33).

MATERIALS AND METHODS

Green yellow-poplar and red maple logs were roughcut into full two-inch random width/length boards. Opening cuts were made so as to leave as much wane as possible (to help identify sapwood) and still most of the board two inches thick. This left a boxed-heart cant which was cut a full two-inches thick. The green, rough-cut lumber was then dried to below fiber saturation point (FSP) by air drying or in a dehumidification dry-kiln. Once below FSP, oversized two-inch by four-inch blanks were ripped from the boards, making every effort to produce all sapwood or all heartwood blanks. While wane on the opening cut boards helped to identify sapwood, both proximity to the pith, and ring orientation combined with discoloration were used as indicators of heartwood. The blanks were then processed through a moulder/planer to produce random length nominal two-by-fours. Straight grained, defect free six-inch long samples were then cut and placed in a conditioning room (70^{O}F at 65%RH) to equilibrate at 12% moisture content. Prior to vacuum/pressure treatment samples were end-sealed with an elastomeric sealant.

A four percent active ingredient solution of ACQ-B was supplied by Chemical Specialties Inc. from which a one percent active ingredient solution was prepared by dilution for use in vacuum/pressure treatment of the heartwood samples. Treatment constants were pressure (200 psi) and an initial vacuum (28 in.Hg) period of thirty minutes. Variables were pressure period duration (60, 90, and 120 minutes) and solution temperature (80^{O}F, or 180^{O}F) to give a simple matrix as in **Table 2.1** for a total of 120 treated samples.

Table 2.1—Experimental Design for Yellow-Poplar and Red Maple Treated With ACQ-B.

	60 Min.		90 Min.		120 Min.	
Ambient	YP* n=10	RM* n=10	YP n=10	RM n=10	YP n=10	RM n=10
180^{O}F	YP n=10	RM n=10	YP n=10	RM n=10	YP n=10	RM n=10

* YP--Yellow-Poplar RM--Red Maple

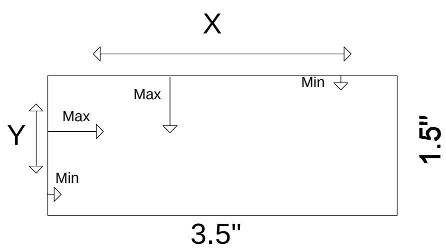

Figure 2.1— Penetration Measurements.

An entire cross-section, taken from the center of each sample, was ground for copper retention analysis using X-Ray Fluorescence-ASOMA, while one of the freshly sawn faces was sprayed with chrome azurol for subsequent penetration measurements. The penetration measurements were made according to the **Figure 2.1**, so that a total of four depth of penetration measurements (in inches) per sample were recorded; MinX, MaxX, MinY, MaxY, as well as a rating of percentage of cross-section penetrated. Maximum measurements were limited to one-half the total possible distance in each dimension, i.e., 0.75" in the X dimension, 1.75" in the Y dimension. Percentage of cross-section penetrated was given a rating of 0, 1, 2, or 3 where 0 = 0-25%, 1 = 25-50%, 2 = 50-75%, and 3 = 75-100% penetration. The penetration measurement data and ASOMA retention data were analyzed using an unweighted means analysis of variance where the model used was;

$$y_{ijk} = \mu + Time_i + Temp_j + (Time * Temp)_{ij} + \varepsilon_{ijk} \qquad 2.1$$

where:

- y_{ijk} = actual penetration measurement
- μ = overall mean penetration (in.) or retention (pcf)
- $Time_i$ = effect of the i^{th} pressure period (min.) (i = 1,2,3 or 60,90,120 min.)
- $Temp_j$ = effect of the j^{th} temperature (^{O}F) (j = 80^{O}F or 180^{O}F)
- $(Time\ x\ Temp)_{ij}$= interaction effect between the i^{th} pressure period and the j^{th} temperature
- ε_{ijk} = experimental error associated with y_{ijk}; $k = k^{th}$ observation of the ij^{th} treatment

All tests of significance are conducted at an alpha level of 0.05.

RESULTS AND DISCUSSION

Tables 2.2 and **2.3** give the mean penetration and retention results for yellow-poplar and red maple treated with ACQ-B, respectively.

Table 2.2 — Penetration(in.), Percentage Rating of Cross-Section Penetrated, and Retention (Pcf CuO) Means, StDevs., and Ranges for Yellow-Poplar.

Time/Temp.	MinX	MaxX	% Rating	MinY	MaxY	PCF***
60/80	0.17(.18)* *.03-.59***	0.56(.19) *.25-.75*	1.1(1.2) *0-3*	0.22(.21) *.04-.71*	0.74(.55) *.28-1.75*	0.123(.056) *.063-.201*
90/80	0.08(.04) *.05-.17*	0.39(.24) *.14-.75*	0.8(.8) *0-2*	0.08(.06) *.04-.23*	0.38(.25) *.14-.89*	0.110(.035) *.068-.181*
120/80	0.19(.21) *.06-.75*	0.49(.21) *.28-.75*	1.4(1.2) *0-3*	0.28(.52) *.05-1.75*	0.76(.57) *.27-1.75*	0.102(.04) *.040-.195*
60/180	0.20(.21) *.01-.75*	0.66(.13) *.54-.75*	1.9(1.3) *0-3*	0.48(.59) *.10-1.75*	0.90(.61) *.37-1.75*	0.118(.049) *.062-.204*
90/180	0.27(.18) *.14-.75*	0.68(.12) *.38-.75*	2.4(.8) *1-3*	0.38(.50) *.12-1.75*	1.04(.58) *.38-1.75*	0.114(.034) *.071-.173*
120/180	0.22(.10) *.11-.40*	0.62(.18) *.30-.75*	2.3(.9) *1-3*	0.25(.12) *.09-.47*	1.06(.60) *.28-1.75*	0.121(.041) *.080-.183*

* - One Standard Deviation ** - Range *** - Pounds per Cubic Foot CuO as Determined by ASOMA.

Table 2.3— Penetration(in.), Percentage Rating of Cross-Section Penetrated, and Retention(Pcf CuO) Means, StDevs. and Ranges for Red Maple.

Time/Temp.	MinX	MaxX	% Rating	MinY	MaxY	PCF***
60/80	0.33(.16)* *.05-.58*****	0.66(.16) *.29-.75*	2.5(.7) *1-3*	0.66(.22) *.27-.91*	1.21(.50) *.58-1.75*	0.171(.027) *.121-.209*
90/80	0.24(.31) *.03-.75*	0.72(.07) *.56-.75*	2.3(.8) *1-3*	0.45(.70) *.03-1.75*	1.38(.48) *.74-1.75*	0.142(.031) *.089-.181*
120/80	0.09(.13) *.00-.34*	0.62(.18) *.32-.75*	1.5(1.0) *0-3*	0.21(.36) *.00-1.08*	1.25(.49) *.19-1.75*	0.094(.030) *.033-.142*
60/180	0.03(.02) *.00-.07*	0.56(.20) *.34-.75*	0.8(.9) *0-2*	0.03(.04) *.00-.12*	0.86(.66) *.16-1.75*	0.088(.032) *.047-.137*
90/180	0.06(.02) *.03-.08*	0.63(.16) *.31-.75*	0.7(1.2) *0-3*	0.08(.08) *.0-.27*	0.64(.68) *.00-1.75*	0.091(.038) *.053-.169*
120/180	0.04(.02) *.02-.07*	0.44(.27) *.11-.75*	0.6(1.1) *0-3*	0.10(.02) *.08-.14*	.63(.62) *.13-1.75*	0.078(.040) *.037-.155*

* - One Standard Deviation ** - Range *** - Pounds per Cubic Foot CuO as Determined by ASOMA.

American Wood Preservers' Association Standards 1993 (2) do not specify use of ACQ-B with either of the species investigated in this study. However, as a point of reference, the specified retention of ACQ-B in southern pine (C2—Lumber, Timber, and Ties-Preservative Treatment by Pressure Processes) is 0.25 (above ground) or 0.40 (soil and fresh water use) pcf (2). The following penetration of creosote, creosote solutions, and oil-borne preservatives is specified for maple: 80 percent of 20 borings (from 20 pieces per charge) must meet the penetration requirement of 1.50 inches or 75 percent of the sapwood, whichever is less and the maximum penetration required in any piece of sawn material will be no greater than half the width or depth of said pieces, depending on the orientation of the measurement (C1—All Timber Products-Preservative Treatment by Pressure Processes) (2). Based upon theses criteria and assuming that the samples were 100 percent heartwood, it is conceivable that an aboveground retention level of 0.25 pcf and minimum penetration reqirements can be consistently achieved.

For yellow-poplar heartwood, a solution temperature of 180^{O}F showed statistical significance over 80^{O}F in improving all measures of penetration (MinX, MinY, MaxX, MaxY, % Rating). However, there was no significant difference in retention due to temperature. Also, there were no statistical differences among the three pressure periods, nor were any of the interactions significant.

Treatability results for red maple indicated a difficulty on differentiating between sapwood and heartwood. The effect of temperature was statistically significant for all six dependent variables (0.05 alpha). Penetration was greater at 80^{O}F than at 180^{O}F. Whether there are chemical reactions between copper and maple extractives that limited penetration at the higher temperature is a matter of supposition. Pressure time, as with yellow-poplar, showed no statistical significance, although penetration for MinX and MaxX were both nearly statistically significant , i.e., 0.056 and 0.054, respectively (0.05 alpha). In both cases, the 120-minute pressure periods exhibited poorer penetration. The Time x Temperature interaction was not statistically significant, although MinX and MinY were both marginally so (i.e., 0.051 and 0.058, respectively, 0.05 alpha). In both cases, penetration was better at the lower temperature and shorter time period. Retention showed statistical significance in all factors. The lower temperature and shorter pressure period showing improved retention in red maple. A close visual examination of the red maple specimens indicated a tendency for the lower temperature/shorter pressure period samples to have been located further from the pith than samples in the other treatment combinations and may have contained greater amounts of the more treatable sapwood or some sort of transition wood. This result indicates the difficulty in accurately distinguishing between heartwood and sapwood in red maple. It may also be an indication that red maple has relatively little heartwood, as has been indicated in the previously mentioned study done by Smith *et al* (33).

The most poorly treated red maple samples all had the pith within the cross-section. Twenty-eight out of 120 red maple specimen minimum measurements (X and Y dimensions) exhibited less than 0.05 inch of penetration. In fact, seven specimens showed no penetration in at least one dimension. Of the 60 yellow-poplar samples, only 5 specimens showed penetration of 0.05 inch or less. Unlike the red maple, all of the specimens had at least 0.01 inch of penetration.

CONCLUSIONS

While some question as to whether the red maple samples were, in fact, all heartwood is bound to cloud any interpretation of the red maple results, it appears that red maple heartwood tends to be refractory in nature. Of the 10 samples where pith was apparent in the sample, 6 treated very poorly, while 3 treated very well. This may indicate that the refractory nature of red maple heartwood may not be as pronounced as in the heartwood of other species. Further, some sort of incising, as suggested in the Smith *et al* study (33), may produce a consistently and adequately treated composite, or possibly a solid wood product, durability studies not withstanding. Otherwise, this study further confirms the difficulty in treating refractory heartwood of hardwood species.

Chapter 3
Preservative Treatment Evaluation With CCA and ACQ-B of Four Appalachian Wood Species for Use in Timber Transportation Structures

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Abstract

This work investigated the treatability of four Appalachian hardwoods with the waterborne preservatives CCA-C and ACQ-B. Heartwood and sapwood of the species were investigated, at least initially, for all species. Six-inches-long nominal 2-by-4 samples of red maple, yellow-poplar, hickory, and beech were end-sealed and vacuum/pressure treated with a 1% active ingredient solution of ACQ-B or a 2% solution of CCA-C. Duration of pressure was varied as well as temperature of solution(for ACQ-B). Measurements were taken of minimum and maximum penetration, percentage of cross-sectional area penetrated, and retention of preservative as determined by X-ray fluorescence spectroscopy (ASOMA). The sapwood of yellow-poplar and red maple was found to be 100% treatable. Hickory sapwood was consistent in treatablility, although limited, while beech sapwood fell somewhere in between hickory and the other species. Statistical analysis indicated that the duration of pressure periods used in this study had no consistent positive effect on treatment. Preservative solution was a significant factor in improved measures of treatability in some instances.

MATERIALS AND METHODS

The materials and methods used for the section of the project described in the following chapter is essentially identical to that described in the materials and methods section of Chapter 2, except for the following. Green logs were cut into full 2-inch random width/length boards of yellow-poplar (*Liriodendron tulipifera* L.), red maple (*Acer rubrum* L.), as well as hickory (*Carya spp.*), and beech (*Fagus grandifolia* Ehrh.). A 50% concentrate solution of CCA-C was supplied by Osmose Wood Preserving Inc. from which a two percent active ingredient solution was prepared by dilution with water. Actual solution strengths for CCA-C ranged from 1.946 to 2.185 percent with the individual components falling within the ranges set forth in AWPA Standard P5-93 section 6 (2). Of the seven vacuum/pressure treatment cycles using ACQ-B solutions, all were in compliance with AWPA Standard P5 section 13, except for the first solution (r. maple and y.-poplar heartwood, and hickory heartwood and sapwood samples treated for 60 min. with an ambient solution temperature). This treatment cycle had somewhat elevated amounts of CuO and DDAC, and the last solution (beech heartwood and sapwood treated for 120 min. with a heated solution) had a low NH_3:CuO ratio (0.88), the latter being the result of heating. The reader is referred to the previous chapter for the description of penetration measurements made as per Figure 2.1.

All species, both sapwood and heartwood, were treated initially with CCA. The sapwood and heartwood results were compared, and if sapwood was found to be extremely well treated with CCA, it was judged to be very treatable in general and was dropped from further investigation with ACQ-B. This was found to be the situation for yellow-poplar and red maple. The heartwood of these species was treated with the ACQ-B to determine if results might be improved in what appeared to be refractory heartwood. Hickory sapwood showed only fair treatment results with CCA at best, and was treated with ACQ-B. Beech sapwood, which treated somewhere between hickory sapwood and the readily treatable sapwood of yellow-poplar, was also treated with ACQ-B. For red maple and yellow-poplar where sapwood was found to be 100% treatable with CCA, heartwood penetration measurement data were analyzed using an unweighted means analysis of variance where the model used was;

$$y_{ijk} = \mu + T_i + P_j + (T*P)_{ij} + \epsilon_{ijk} \tag{3.1}$$

where,

y_{ijk}= actual penetration measurement

μ = the overall mean penetration (in.);

T_i = the effect of the i^th pressure period (min.)(I=1,2,3 or 60,90,120 minutes, respectively);

P_j= the effect of the j^th Preservative Solution (j = 1, 2, 0r 3-CCA, Ambient ACQ-B, or Heated ACQ-B respectively);

$(T*P)_{ij}$ = the interaction effect between the i^th pressure period and the j^th Preservative Solution;

ϵ_{ijk} = the experimental error associated with y_{ijk} ;

For beech and hickory where sapwood was also a factor in the analysis, the model was;

$$y_{ijkl} = \mu + T_i + P_j + W_k + (T*P)_{ij} + (T*W)_{ik} + (P*W)_{jk} + (T*P*W)_{ijk} + \epsilon_{ijkl} \tag{3.2}$$

where,

μ = the overall mean penetration (in.);

T_i = the effect of the i^th pressure period (min.)(I=1,2,3 or 60,90,120 minutes, respectively);

P_j= the effect of the j^th Preservative Solution (j = 1, 2, 0r 3-CCA, Ambient ACQ-B, or Heated ACQ-B respectively);

W_k = the effect of the k_{th} Wood Type (k = 1 or 2, heartwood or sapwood);

$(T * P)_{ij}$ = the interaction effect between the i^th Pressure Period and the j^th Preservative Solution;

$(T * W)_{ik}$ = the interaction effect between the i^th pressure period and the k^th Wood Type;

$(P * W)_{jk}$ = the interaction effect between the j^th Preservative Solution and the k^th Wood Type;

$(T * P * W)_{ijk}$ = the interaction effect between the i^th Pressure Period the j^th Preservative Solution and the k^th Wood Type;

ϵ_{ijkl} = the experimental error associated with y_{ijkl};

all tests of significance are conducted at an alpha-level of 0.05.

Multiple comparisons were done using Fisher’s Least Significant Difference test.

RESULTS AND DISCUSSION

For the sake of discussion, reference is made here to the AWPA Book 0f Standards 1993 (2). Standard C14-93—Wood for Highway Construction-Preservative Treatment by Preservative Processes, specifies penetration requirements as well as preservatives for this end-use. The two preservatives investigated in this work are not included in this standard for hardwoods, however as a point of reference, specified retention of CCA in southern pine (C14-93) is 0.60 or 0.40 pcf depending on usage, while the specified retention of ACQ-B in southern pine (C2—Lumber, Timber and Ties-Preservative Treatment by Pressure Processes) is 0.25 (above ground) or 0.40 (soil and fresh water use) pcf, depending on usage. According to standard C2, penetration of creosote, creosote solutions, and oil-borne preservatives is specified for maple as follows; eighty percent of 20 cores per charge must equal or exceed 1.50" or 75% of sapwood, whichever is less (C1). Standard C1 (All Timber Products-Preservative Treatment by Pressure Processes) further states that maximum penetration required in any piece of sawn material shall be no greater than half the width or depth of said piece, depending on the orientation of the measurement.

Assuming samples treated in this work were either all sapwood or all heartwood, the minimum penetration requirements can be stated hypothetically as follows: Sapwood - 0.56 inch of thickness (75% of ½ of 1.5 in.) or 1.31inches of width (75% of ½ of 3.5 in.), Heartwood - 0.75 inch of thickness or 1.50 inches of width. Given that the randomness of borings taken from a commercial charge of treated lumber would yield average penetration values between the lowest mean minimum and the highest mean maximum penetration values obtained in this work, the likelihood that these hypothesized penetration criteria could be met, as it applies to all preservative solutions used in this work, are good for yellow-poplar and red maple, fair to poor for beech and poor for hickory. Yellow-poplar and red maple sapwood were found to be extremely treatable with CCA and would easily exceed the aforementioned criteria. The heartwood of these species along with the sapwood of beech was not as clear-cut, yet the results approach the minimum requirements, as can be seen in **Table 3.1**.

Table 3.1—Frequency Table of Best Penetration Measurements for "Best" Species.[a]

	CCA						Ambient ACQ-B						Heated ACQ-B					
	MinX			MaxX			MinX			MaxX			MinX			Max		
Range (in.)	AB	YP	RM	AB	YP	RM	AB	YP	RM	AB	YP	RM	AB	YP	RM	AB	YP	RM
0 - .25	83.3	90.0	66.7	0	6.7	26.7	46.7	86.7	60.0	0	20.0	0	13.3	76.7	100	0	0	16.7
.26 -.55	16.7	10.0	13.3	10.0	26.7	16.7	43.3	6.7	30.0	26.7	33.3	20.0	73.3	16.7	0	6.7	20.0	26.7
.56 - .75	0	0	20.0	90.0	66.6	56.6	10.0	6.6	10.0	73.3	46.7	80.0	13.3	6.6	0	93.4	80.0	56.6
Total	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
	MinX			MaxX			MinX			MaxX			MinX			Max		
0 - .75	83.3	100	70.0	0	53.3	43.0	83.3	96.7	80.0	26.7	76.7	66.7	83.3	90.0	100	6.7	53.3	66.7
.76 -1.30	16.7	0	10.0	23.3	16.7	0	6.7	0	13.3	33.3	10.0	10.0	6.7	0	0	3.3	6.7	10.0
1.30 - 1.75	0	0	20.0	76.7	30.0	56.7	10.0	3.3	6.7	40.0	13.3	23.3	10.0	10.0	0	90.0	40.0	23.3
Total	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

[a] Data based on 30 samples. AB = American Beech; YP = Yellow-Poplar; RM = red Maple

The assay zone for determination of preservative retention in maple is 0 - 0.6" from the surface. Because an entire cross-section was used for determination of retention in this work, the analytical procedure used yielded very conservative estimates of retentions that might be achieved in the outer 0.6 inch of the wood member. Desired retention levels of CCA are apparently achievable for yellow-poplar, red maple, and beech although some adjustment of solution strength may be necessary. Retention of CCA for hickory was so low that increasing solution strength to increase retention might not be feasible. Along the same line of reasoning, desired retention levels of ACQ-B would be achievable for yellow-poplar and red maple sapwood, possible for yellow-poplar and red maple heartwood and beech heartwood and sapwood, but questionable for hickory sapwood or heartwood.

Another way of evaluating the data summarized in the following sections would be to look for evidence of a viable "shell" treatment. By looking at the two minimum measurements, along with the respective standard deviation and range, it can be determined whether there is a "good" or, at least, a consistent shell of treatment. From this point of view yellow-poplar and red maple might be successfully treated with any of the preservatives used in this work while the sapwood or heartwood of beech might be successfully treated with one of the ACQ-B solutions . Conversely, large maximum penetration values with an average percentage cross-section penetrated of 0 (0-25%) or 1 (25-50%) would be an indication of erratic treatment results.

Tables summarizing penetration and retention results will be found in the following sections specific to species. The tables show the mean results by treatment with standard deviation and range of measurement for each respective treatment. Cells with a 0 in parentheses, such as (1.75(0)), indicate that all measurements were the same and, therefore, there is no standard deviation or range. Statistical analysis of preservative retention was not carried out because of the different natures of the two preservatives.

BEECH

Tables 3.2, **3.3**, and **3.4** give the penetration and retention summary results for all treatments of beech. The results of treatment with CCA (**Table 3.2**) indicate that sapwood is more treatable than heartwood, but overall treatment of both heartwood and sapwood was somewhat erratic. The minimum penetration measurements are predominately low with relatively high standard deviations and ranges that include zero penetration occur in all cases but one (MinY at a 90 minute pressure period for sapwood). Retention of 0.40 PCF of CCA in beech sapwood is clearly achievable while solution strength might have to be increased to achieve the same in heartwood. The solution strength of the ACQ-B might need to be increased in order to consistently treat to 0.25 pounds per cubic foot.

Table 3.2— Percentage Rating of Cross-Section Penetrated, Retention (PCF Total Oxide Basis) and Penetration (in.), Means, StDevs., and Ranges for Beech Treated with CCA.

Time (Min.)/ Sap-Heart.	% Rating†	PCF	MinX	MaxX	MinY	MaxY
60/Sap	2.2(.8)* *1-3***	0.536(.080) *.388-.651*	0.09(.08) *.00-.23*	0.63(.20) *.30-.75*	0.25(.32) *.00-.82*	1.52(.33) *1.00-1.75*
90/Sap	2.7(.5) *2-3*	0.425(.066) *.360-.550*	0.23(.13) *.00-.39*	0.73(.05) *.59-.75*	0.73(.24) *.31-1.05*	1.55(.28) *1.10-1.75*
120/Sap	2.6(.5) *2-3*	0.481(.066) *.352-.552*	0.07(.11) *.00-.37*	0.74(.03) *.66-.75*	0.11(.24) *.00-.78*	1.69(.19) *1.15-1.75*
60/Heart	1.0(.8) *0-3*	0.267(.113) *.157-.565*	0.03(.01) *.00-.04*	0.61(.19) *.25-.75*	0.03(.02) *.00-.06*	0.80(.38) *.31-1.75*
90/Heart	1.7(.8) *0-3*	0.332(.079) *.193-.455*	0.02(.02) *.00-.05*	0.67(.13) *.40-.75*	0.02(.03) *.00-.08*	1.17(.52) *.20-1.75*
120/Heart	1.7(1.1) *0-3*	0.364(.161) *.091-.644*	0.09(.23) *.00-.75*	0.61(.21) *.15-.75*	0.26(.54) *.00-.51*	1.24(.59) *.35-1.75*

† - Rating of percent cross-section penetrated where 0=0-25%, 1=25-50%, 2=50-75%, 3=75-100%   * - One Standard Deviation   ** - Range

Penetration results for beech sapwood treated with either solution of ACQ-B (**Table 3.3**) approach the previously discussed minimum penetration requirements, while the heartwood, treated with an ambient solution of ACQ-B (**Table 3.4**), shows evidence for a possible shell treatment. The mean minimum penetration measurements of heartwood treated with an ambient ACQ-B solution in all three time periods are consistently higher in comparison to the CCA or heated ACQ-B/heartwood groups with smaller standard deviations and fewer instances of ranges that include zero penetration.

Table 3.3— Percentage Rating of Cross-Section Penetrated, Retention (PCF CuO), and Penetration (in.), Means, StDevs., and Ranges for Beech Sapwood Treated with ACQ-B.

Time (Min.)/ Temp. (^{O}F)	% Rating†	PCF	MinX	MaxX	MinY	MaxY
60/80	2.4(0.97)* *0-3***	0.165(.020) *.134-.196*	0.28(.20) *.00-.69*	0.61(.17) *.26-.75*	0.39(.51) *.00-1.75*	0.98(.47) *.36-1.75*
90/80	2.6(.52) *2-3*	0.188(.028) *.128-.219*	0.33(.17) *.22-.75*	0.64(.14) *.44-.75*	0.60(.45) *.17-1.75*	1.22(.57) *.36-1.75*
120/80	3.0(0) ---	0.212(.016) *.179-.225*	0.36(.18) *.10-.75*	0.71(.09) *.52-.75*	0.65(.42) *.34-1.75*	1.35(.44) *.78-1.75*
60/180	2.9(.32) *2-3*	0.197(.032) *.135-.236*	0.36(.16) *.19-.75*	0.73(.07) *.54-.75*	0.62(.43) *.29-1.75*	1.43(.53) *.51-1.75*
90/180	3.0(0) ---	0.195(.025) *.139-.213*	0.46(.15) *.20-.75*	0.71(.09) *.62-.75*	0.68(.39) *.40-1.75*	1.75(0) ---
120/180	3.0(0) ---	0.200(.015) *.170-.221*	0.41(.13) *.25-.75*	0.75(0) ---	0.65(.40) *.30-1.75*	1.75(0) ---

† - Rating of percent cross-section penetrated where; 0=0-25%, 1=25-50%, 2=50-75%, 3=75-100% *- One Standard Deviation ** - Range

Table 3.4— Percentage Rating of Cross-Section Penetrated, Retention (PCF CuO) and Penetration (in.), Means, StDevs. and Ranges for Beech Heartwood Treated with ACQ- B.

60/80	2.4(.84)* *1-3***	0.153(.024) *.122-.194*	0.21(.21) *.02-.64*	0.64(.13) *.47-.75*	0.34(.24) *.00-.85*	1.10(.56) *.44-1.75*
90/80	2.2(.92) *1-3*	0.169(.037) *.119-.218*	0.29(.17) *.14-.75*	0.59(.15) *.38-.75*	0.49(.47) *.11-1.75*	1.01(.59) *.28-1.75*
120/80	2.5(.85) *1-3*	0.180(.040) *.106-.220*	0.20(.14) *.02-.42*	0.68(.16) *.31-.75*	0.39(.27) *.00-1.75*	1.03(.49) *.52-1.75*
60/180	0.5(.85) *0-2*	0.080(.040) *.041-.160*	0.05(.02) *.02-.09*	0.46(.19) *.24-.75*	0.09(.14) *.03-.48*	0.57(.63) *.17-1.75*
90/180	1.6(1.4) *0-3*	0.123(.058) *.041-.181*	0.09(.05) *.04-.19*	0.53(.22) *.24-.75*	0.17(.16) *.03-.49*	0.85(.64) *.19-1.75*
120/180	0.2(.42) *0-1*	0.077(.023) *.036-.110*	0.08(.02) *.06-.12*	0.41(.19) *.21-.75*	0.07(.03) *.03-.12*	.49(.23) *.16-.87*

† - Rating of percent cross-section penetrated where; 0=0-25%, 1=25-50%, 2=50-75%, 3=75-100%   *- One Standard Deviation   ** - Range

Table 3.5 summarizes the statistical analysis for treatments of beech in relation to heartwood/sapwood, preservative solution and the respective interaction. The statistical results (**Table 3.5**) for beech clearly indicate sapwood is more treatable than heartwood. When

Table 3.5— ANOVA Probability Level of Significance for Beech Penetration Categories and "Best" Treatment(s).

		MinX	MaxX	% Rating	MinY	MaxY
A*	Probability**	0.000	0.000	0.000	0.000	0.000
	Significantly Best Mean	2	2	2	2	2
B***	Probability	0.000	0.038	0.000	0.000	0.021
	Significantly Best Mean	2=3	1=2	2	2=3	1
AB****	Probability	0.000	0.000	0.000	0.004	0.000
	Significantly Best Mean	(2,3)	(2,3)=(2,1)	(2,3)=(2,2)	(2,3)=(2,2)	(2,3)=(2,1)
C*****	Probability	0.036	0.320	0.013	0.034	0.031
	Significantly Best Mean	2=3	NS******	2=3	2=3	2=3

*1-Heartwood, 2- Sapwood ** Of Larger F-Ratio ***1-CCA, 2-Ambient ACQ-B, 3-Heated ACQ-B
****Interaction (Heartwood/Sapwood×Preservative) ***** 1-60 min., 2-90 min., 3-120 min.   ****** Not Statistically Significancant

preservative solution is singled out a "best" preservative is not readily apparent. One or both of the ACQ-B solutions was best or equally best in 4 of 5 categories while CCA was best or equally best in 2 categories. The reason CCA shows up as statististically "best" in the maximum penetration categories and not in the other categories of penetration can be explained as long tangential "spikes" of penetration within one or two annual rings running perpendicular to the side of the sample, accounting for little of the total penetration. The interaction of heartwood/sapwood and preservative solution showed similar results with a heated solution of ACQ-B being significantly better than one or both of the other solutions in combination with sapwood for all categories. Statistically significant differences were found in relation to heartwood/sapwood, preservative solution, and the respective interaction between the two ($\alpha = 0.05$). Statistical significance ($\alpha = 0.05$) in relation to time, for all categories, except MaxX, was also indicated as can be seen in **Table 3.5**, although no clear-cut interpretation is apparent. In the MinX, MinY and percent cross-section penetrated categories, a 90 minute pressure period was equally "best" with a 120 minute pressure period. However there was no statistically significant differences in the treatment mans of the 60 minute and 120 minute pressure periods according to Fisher's LSD. In the MaxY category the 90 and 120 minute pressure periods were statistically different from the 60 minute pressure period ($\alpha = 0.05$). All remaining 2-way and 3-way interactions were not significant, except for an ACQ-B ambient solution interacting with a 120 minute pressure period was significant in percent cross-section penetrated, while the interaction of sapwood, CCA, and a 90 minute pressure period was significant for the MinY category. The statistically significant differences in these areas was most likely the result of random chance, were simply anomalous, or the result of difficulty in heartwood/sapwood differentiation.

YELLOW-POPLAR

Tables 3.6 and **3.7** give the penetration and retention summary results for all treatments of yellow-poplar. Yellow-poplar sapwood was found to be 100% treatable with CCA and would meet any criteria for treatment. As such, it was decided that sapwood would treat the same with ACQ-B and therefore was not included in the analysis of variance. Only the heartwood was investigated further.

Evidence for a shell treatment of heartwood, ranging from marginal to very good can be seen in the summary tables. The minimum penetration results for heartwood treated with CCA (**Table 3.6**) are all greater than zero, and assuming the penetration values of randomly sampled boards similarly treated would fall between the minimum and maximum penetration means, a shell of treatment of at least 0.3 inches could be reasonably expected. Treatment with the ambient solution of ACQ-B produced results (**Table 3.7**) similar to those from treatment with CCA. The heated solution of ACQ-B yielded the best penetration results (**Table 3.7**) and significantly best mean (α 0.05) in all penetration categories (**Table 3.8**). **Table 3.1** shows the frequency distribution of penetration results for heartwood (ignoring time). Desired retention levels of CCA in sapwood or heartwood would be easily achieved with a 2% solution. An ACQ-B solution strength of 2% or greater would probably be needed to reach 0.25 PCF in heartwood.

Table 3.6— Percentage Rating of Cross-Section Penetrated, Retention (PCF Total Oxide Basis) and Penetration (in.), Means, StDevs. and Ranges for Yellow-Poplar Treated with CCA.

Time (min.)/ Sap-Heart	% Rating†	PCF	MinX	MaxX	MinY	MaxY
60/Sap	3.0(0)* ---**	0.614(.042) *.569-.708*	0.74(.03) *.64-.75*	0.75(0) ---	1.67(.24) *.99-1.75*	1.75(0) ---
90/Sap	3.0(0) ---	0.622(.042) *.564-.699*	0.67(.17) *.34-.75*	0.75(0) ---	1.56(.45) *.37-1.75*	1.75(0) ---
120/Sap	3.0(0) ---	0.641(.039) *.560-.692*	0.69(.20) *.11-.75*	0.75(0) ---	1.58(.55) *.00-1.75*	1.75(0) ---
60/Heart	0.7(1.2) *0-3*	0.322(.161) *.144-.620*	0.13(.11) *.03-.44*	0.49(.20) *.22-.75*	0.08(.06) *.03-.23*	0.58(.62) *.11-1.75*
90/Heart	2.3(.7) *1-3*	0.571(.104) *.382-.707*	0.11(.06) *.05-.26*	0.72(.05) *.62-.75*	0.12(.05) *.05-.23*	1.39(.48) *.27-1.75*
120/Heart	1.7(1.2) *0-3*	0.443(.158) *.209-.673*	0.12(.08) *.04-.28*	0.58(.19) *.16-.75*	0.19(.17) *.06-.51*	0.78(.53) *.36-1.75*

† - Rating of percent cross-section penetrated where; 0=0-25%, 1=25-50%, 2=50-75%, 3=75-100%   *- One Standard Deviation   ** - Range

Table 3.7— Percentage Rating of Cross-Section Penetrated, Retention (PCF CuO) and Penetration (in.), Means, StDevs, and Ranges for Yellow-Poplar Heartwood Treated with ACQ-B.

Time (min.)/ Temp. (^{O}F)	% Rating†	PCF	MinX	MaxX	MinY	MaxY
60/80	1.1(1.2)* *0-3***	0.123(.056) *.063-.201*	0.17(.18) *.03-.59*	0.56(.19) *.25-.75*	0.22(.21) *.04-.71*	0.74(.55) *.28-1.75*
90/80	0.8(.8) *0-2*	0.110(.035) *.068-.181*	0.08(.04) *.05-.17*	0.39(.24) *.14-.75*	0.08(.06) *.04-.23*	0.38(.25) *.14-.89*
120/80	1.4(1.2) *0-3*	0.102(.04) *.040-.195*	0.19(.21) *.06-.75*	0.49(.21) *.28-.75*	0.28(.52) *.05-1.75*	0.76(.57) *.27-1.75*
60/180	1.9(1.3) *0-3*	0.118(.049) *.062-.204*	0.20(.21) *.01-.75*	0.66(.13) *.54-.75*	0.48(.59) *.10-1.75*	0.90(.61) *.37-1.75*
90/180	2.4(.8) *1-3*	0.114(.034) *.071-.173*	0.27(.18) *.14-.75*	0.68(.12) *.38-.75*	0.38(.50) *.12-1.75*	1.04(.58) *.38-1.75*
120/180	2.3(.9) *1-3*	0.121(.041) *.080-.183*	0.22(.10) *.11-.40*	0.62(.18) *.30-.75*	0.25(.12) *.09-.47*	1.06(.60) *.28-1.75*

† - Rating of percent cross-section penetrated where; 0=0-25%, 1=25-50%, 2=50-75%, 3=75-100% *- One Standard Deviation ** - Range

Table 3.8— ANOVA Probability Level of Significance for Yellow-Poplar Heartwood Penetration Categories and "Best" Treatment(s).

		MinX	MaxX	% Rating	MinY	MaxY
A*	Probability**	0.012	0.001	0.001	0.016	0.016
	Significantly Best Mean	3	3=1	3	3	3=1
B***	Probability	0.843	0.630	0.053	0.732	0.732
	Significantly Best Mean	NS****	NS	NS	NS	NS
AB*****	Probability	0.364	0.012	0.087	0.380	0.012
	Significantly Best Mean	NS	(1,2)† (3,2) (3,1) (3,3) (1,3)	NS	NS	(1,2)† (3,3) (3,2)

* 1-CCA, 2-Ambient ACQ-B, 3-Heated ACQ-B **Of Larger F-Ratio ***1-60 Minutes, 2-90 Minutes, 3-120 Minutes
****No Statistically Significant difference *****Statistically Significant Interaction (Preservative x Time)
† All Equally "Best."

Statistically significant differences in the maximum penetration categories were found for CCA. As with beech, this can be explained as long tangential "spikes" of penetration within one to several annual rings running perpendicular to the side of the sample which accounted for relatively little of the total penetration. Time, when singled out, showed no statistically significant effect. The two categories where interactions between the preservative and time were significant include a heated solution of ACQ-B, CCA and all three time periods. The statistically significant effect of the heated solution of ACQ-B is self explanatory, while the inclusion of CCA in the two maximum penetration categories can be explained by the previously mentioned tangential spikes.

RED MAPLE

Tables 3.9 and **3.10** give the penetration and retention summary results for all treatments of red maple. Red maple, as with yellow-poplar, had easily treated sapwood (**Table 3.9**) with the same assumptions being made. As such, sapwood was not included in the analysis of variance.

Table 3.9— Percentage Rating of Cross-Section Penetrated, Retention (PCF Total Oxide Basis) and Penetration (in.), Means, StDevs. and Ranges for Red Maple Treated with CCA.

Time (min.)/ Sap-Heart.	% Rating†	PCF	MinX	MaxX	MinY	MaxY
60/Sap	3.0(0)* ---**	0.707(.077) *.594-.820*	0.54(.24) *.28-.75*	0.75(.02) *.70-.75*	1.11(.61) *.40-1.75*	1.68(.22) *1.06-1.75*
90/Sap	2.6(.7) *1-3*	0.619(.133) *.357-.776*	0.36(.37) *.00-.75*	0.75(0) ---	0.85(.86) *.00-1.75*	1.69(.19) *1.18-1.75*
120/Sap	3.0(0) ---	0.756(.071) *.644-.842*	0.64(.24) *.07-.75*	0.75(0) ---	1.55(.52) *.12-1.75*	1.75(0) ---
60/Heart	0.0(0) ---	0.189(.056) *.113-.265*	0.04(.02) *.00-.06*	0.27(.11) *.17-.53*	0.03(.02) *.00-.05*	0.18(.10) *.05-.31*
90/Heart	3.0(0) ---	0.670(.075) *.515-.760*	0.38(.27) *.05-.75*	0.75(0) ---	0.94(.65) *.09-1.75*	1.75(0) ---
120/Heart	2.0(1.4) *0-3*	0.539(.262) *.147-.790*	0.32(.34) *.00-.75*	0.59(.26) *.13-.75*	0.60(.80) *.00-1.75*	1.30(.75) *.00-1.75*

† - Rating of percent cross-section penetrated where; 0=0-25%, 1=25-50%, 2=50-75%, 3=75-100% *- One Standard Deviation ** - Range

Table 3.10— Percentage Rating of Cross-Section Penetrated, Retention (PCF CuO) Penetration (in.), Means, StDevs. and Ranges for Red Maple Heartwood Treated With ACQ-B.

Time (min.)/ Temp. (^{O}F)	% Rating†	PCF	MinX	MaxX	MinY	MaxY
60/80	2.5(.7)* *1-3***	0.171(.027) *.121-.209*	0.33(.16) *.05-.58*	0.66(.16) *.29-.75*	0.66(.22) *.27-.91*	1.21(.50) *.58-1.75*
90/80	2.3(.8) *1-3*	0.142(.031) *.089-.181*	0.24(.31) *.03-.75*	0.72(.07) *.56-.75*	0.45(.70) *.03-1.75*	1.38(.48) *.74-1.75*
120/80	1.5(1.0) *0-3*	0.094(.030) *.033-.142*	0.09(.13) *.00-.34*	0.62(.18) *.32-.75*	0.21(.36) *.00-1.08*	1.25(.49) *.19-1.75*
60/180	0.8(.9) *0-2*	0.088(.032) *.047-.137*	0.03(.02) *.00-.07*	0.56(.20) *.34-.75*	0.03(.04) *.00-.12*	0.86(.66) *.16-1.75*
90/180	0.7(1.2) *0-3*	0.091(.038) *.053-.169*	0.06(.02) *.03-.08*	0.63(.16) *.31-.75*	0.08(.08) *.0-.27*	0.64(.68) *.00-1.75*
120/180	0.6(1.1) *0-3*	0.078(.040) *.037-.155*	0.04(.02) *.02-.07*	0.44(.27) *.11-.75*	0.10(.02) *.08-.14*	.63(.62) *.13-1.75*

† - Rating of percent cross-section penetrated where 0=0-25%, 1=25-50%, 2=50-75%, 3=75-100%   *- One Standard Deviation   ** - Range

While the percent of minimum penetration measurements that meet or exceed the hypothesized minimum penetration requirement was lower than that found for yellow-poplar, they still range from 58.6 to 62.1 percent while the lowest percentage for the maximum penetration values meeting or exceeding minimum requirements was 86.7 percent (MaxY). As such, sapwood was not included in the analysis of variance. **Table 3.1** shows the frequency distribution (ignoring time) of penetration results for the treatment of red maple heartwood.

Evidence of a shell treatment of red maple heartwood is similar to, yet less pronounced than, that found for yellow-poplar heartwood. While the mean minimum penetration values for CCA and Ambient ACQ-B were generally greater than those of a heated solution of ACQ-B, all three solutions had instances of zero penetration in these categories. A close visual examination of the red maple specimens indicated a tendency for the lower temperature/shorter pressure period samples to have been located further from the pith than samples in other treatment combinations and may have contained greater amounts of the more treatable sapwood or some sort of transition wood. This result indicates the difficulty in accurately distinguishing between heartwood and sapwood in red maple. It may also be an indication that red maple has relatively little heartwood, as has been indicated in the previously mentioned study done by Smith *et al* (33). Whether there are chemical reactions between copper and maple extractives which limited penetration at the higher temperature is a matter of supposition.

Statistical results (**Table 3.11**) for heartwood penetration show an ambient solution of ACQ-B was significantly (α = 0.05) best in the MaxX category, and, along with CCA, best in the other four penetration categories when compared to a heated solution of ACQ-B.

Table 3.11— ANOVA Probability Level of Significance for Red Maple Heartwood Penetration Categories and "Best" Treatment(s).

		MinX	MaxX	% Rating	MinY	MaxY
A*	Probability**	0.000	0.010	0.000	0.000	0.000
	Significantly Best Mean	1=2	2	2=1	1=2	2=1
B***	Probability	0.147	0.000	0.001	0.086	0.002
	Significantly Best Mean	NS****	2	2	NS	2=3
AB*****	Probability	0.001	0.000	0.000	0.001	0.000
	Significantly Best Mean	(1,2)† (2,1) (1,3) (2,2)	(1,2)† (2,2) (2,1) (3,2) (2,3) (1,3) (3,1)	(1,2)† (2,1) (2,2) (1,3)	(1,2)† (2,1) (1,3) (2,2)	(1,2)† (2,2) (1,3) (2,3) (2,1)

* 1-CCA, 2-Ambient ACQ-B, 3-Heated ACQ-B **Of Larger F-Ratio ***1-60 Minutes, 2-90 Minutes, 3-120 Minutes
****No Statistical Significance *****Statistically Significant Interaction(Preservative xTime) †All Equally "Best"

Time and the interaction between time and preservative had statistical significance in some categories but the interpretation of these results is not readily apparent. A 90 minute pressure period was best for MaxX and percent cross-section penetrated, and equally best, along with a 120 minute period, in the MaxY category. All categories for the interaction between preservative solution and time period were statistically significant (α = 0.05) but the interpretation of this is less than clear and may be affiliated with the previously mentioned proximity to pith observation.

HICKORY

Table 3.12 gives the penetration and retention summary results for the statistically best treatment of hickory, a heated ACQ-B solution. The remaining treatments are not summarized here, since they were so poor as to not warrant discussion, as the reader can judge from **Table 3.12** (being the best results). The probability that hickory would meet or exceed minimum penetration requirements for solid wood products is low based on these results. Hickory also had the lowest retentions of any of the species. Solution strengths of CCA might have to be doubled in order to consistently reach 0.40 PCF while ACQ-B retentions were consistently below 0.10 PCF.

Table 3.12— Percentage Rating of Cross-Section Penetrated, Retention (PCF CuO) and Penetration (in.), Means, StDevs. and Ranges for Hickory Sapwood Treated with ACQ-B.

Time (min.)/ Temp. (^{O}F)	% Rating†	PCF	MinX	MaxX	MinY	MaxY
60/180	0.8(.4) *0-1*	0.092(.015) *.072-.124*	0.11(.07) *.00-.22*	0.32(.05) *.24-.40*	0.10(.07) *.00-.23*	0.33(.16) *.19-.65*
90/180	0.2(.4) *0-1*	0.090(.020) *.066-.118*	0.10(.06) *.02-.20*	0.33(.04) *.31-.42*	0.07(.05) *.00-.13*	0.27(.11) *.16-.49*
120/180	0.7(.5) *0-1*	0.080(.010) *.064-.091*	0.11(.07) *.00-.21*	0.36(.05) *.30-.47*	0.08(.06) *.00-.17*	.27(.06) *.21-.37*

†- Rating of percent cross-section penetrated where; 0=0-25%, 1=25-50%, 2=50-75%, 3=75-100%   *- One Standard Deviation   ** - Range

Hickory was the most consistent of the species as to the factors which were statistically significant (**Table 3.13**) in improved penetration. While sapwood, a heated solution of ACQ-B, and the interaction between the two were statistically significant ($\alpha = 0.05$) in improving penetration in comparison to the other treatments, this “best” treatment had penetration values well below the theoretical minimums discussed in this work. Percent cross-section penetrated category for the interaction between sapwood and the 60 and 120 minute pressure periods was also statistically significant ($\alpha = 0.05$), as well as the interaction between a heated ACQ-B solution and the 90 minute pressure period. The latter interaction was also statistically significant ($\alpha = 0.05$) in the MaxY category. As with beech, these statistical significances appear to be the result of random chance or were simply anomalous occurrences.

Table 3.13— ANOVA Probability Level of Significance for Hickory Penetration Categories and "Best" Treatment(s).

		MinX	MaxX	% Rating	MinY	MaxY
A*	Probability**	0.000	0.000	0.000	0.000	0.000
	Significantly Best Mean	2	2	2	2	2
B***	Probability	0.000	0.000	0.000	0.000	0.000
	Significantly Best Mean	3	3	3	3	3
AB****	Probability	0.000	0.000	0.000	0.000	0.000
	Significantly Best Mean	(2,3)	(2,3)	(2,3)	(2,3)	(2,3)
C*****	Probability	0.077	0.221	0.749	0.884	0.392
	Significantly Best Mean	NS******	NS	NS	NS	NS

* 1-Heartwood, 2- Sapwood ** Of Larger F-Ratio ***1-CCA, 2-Ambient ACQ-B, 3-Heated ACQ-B ****Interaction (Heartwood/Sapwood×Preservative) ***** 1-60 min., 2-90 min., 3-120 min. ******No Statistical Significance

CONCLUSIONS

The treatability of hardwoods cannot be generalized, and in particular, this study further supports the difficulty in treating refractory heartwood of hardwood species. Each species must be investigated and evaluated on an individual basis. Generally sapwood is more treatable than heartwood in the species investigated here, ranging from very good (yellow-poplar) to poor (hickory). Durability studies not withstanding, based on these results, sawn stock of yellow-poplar and red maple could meet or exceed the referenced AWPA minimum penetration requirements for solid wood products, although incising might be required to consistently treat the heartwood. Where a shell treatment of preservative is deemed adequate, beech and the heartwood of yellow-poplar and red maple might be acceptable alternatives to the more commonly treated wood species, especially in light of improved penetration using an ammoniacal preservative. This work may be another example of why hickory, and beech, is one of the least utilized of the Appalachian hardwoods. However, with the potential for modest improvement of penetration of preservative into the refractory wood of these species arises the possibility of a preservative treatment system for composite wood products, adhesion studies not withstanding. Whether there are reactions occurring with extractives which might explain why an ambient solution ACQ-B showed improved penetration results in red maple and beech, while the heated ACQ-B solution showed improved results for yellow-poplar and hickory, and further why CCA was as good or better in some instances can not be definitively answered here.

Chapter 4

Preservative Treatment Evaluation of Five Appalachian Hardwoods at Two Moisture Contents

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Abstract

Better documentation of the treatability of Appalachian hardwoods may lead to improved utilization of species such as beech and hickory and the lower grades of other more widely used species. Samples of yellow-poplar, red maple, red oak, hickory, and beech were pressure treated with the preservatives chromated copper arsenate Type-C (CCA-C) and ammoniacal copper quat Type-B (ACQ-B) at two moisture contents: 12 percent and 17.5 percent. Mixed results indicated that treatability is affected by moisture content differently, depending on species. Practical application of this moisture content effect is questionable.

INTRODUCTION

A number of researchers have studied wood moisture content, focusing on its impact on preservative treatability and its relationship to the practical aspects of commercial pressure treatment. According to Choong *et al* (6) a lower moisture content should increase cell wall permeability, possibly resulting in improved preservative treatment. Kumar and Morrell (17) theorized that western hemlock wood near the fiber saturation point (FSP) should be most treatable, with no free water present, the cell wall fully swollen and, therefore, no mechanical stress present. The results from treating hemlock wood at FSP with chromated copper arsenate Type-C (CCA-C) did not show improved treatment. Of the four moisture content (MC) levels evaluated (9, 18, 28, and 40 percent), the combination of treatability and practical application of the results indicated that the 18 percent MC level was the most effective for treating western hemlock. Morris (22) investigated pretreatment procedures and pressure processes for spruce-pine-fir and found that incising and drying to 30 percent (MC), as opposed to drying to 16 percent MC and then incising, produced statistically significant ($\alpha = 0.05$) improved penetration with CCA. Lebow *et al* (19) sought to determine if an optimum MC for preservative treatment of several western softwoods with CCA was possible. Generally, the research indicated that the range of moisture contents investigated had little influence on treatment. However, for Douglas-fir the least treatable species tested, a slight improvement in retention occurred between 17 and 19 percent MC. There was also some indication of improved penetration for Douglas-fir and Pacific silver fir between 17 and 25 percent MC and substantial improvement at 25 percent MC for western hemlock and mountain hemlock.

Preservative treatment variability among and within species is common and was apparent in the aforementioned studies of softwood species. Treatment variability among hardwoods, while generally accepted as an inherent trait, is not well documented. As part of a series of papers, this work endeavors to further study the treatability of Appalachian hardwoods, by analyzing the treatability of five Appalachian hardwood species treated with the preservatives CCA-C and ammoniacal copper quat Type-B (ACQ-B) at two equilibrium moisture contents (EMC): 12 and 17.5 percent.

MATERIALS AND METHODS

Nominal two-by-fours were produced from yellow-poplar sapwood and heartwood (*Liriodendron tulipifera* L.), red maple sapwood and heartwood (*Acer rubrum* L.), red oak heartwood (*Quercus rubra)*, hickory sapwood and heartwood (*Carya spp.*), and beech sapwood and heartwood (*Fagus grandifolia* Ehrh.) as described in Slahor *et al* (30). Straight grained, as defect free as possible, six-inch long samples were cut and placed in conditioning rooms set at 70^{O}F (21^{O}C)/65 percent relative humidity (RH) or 80^{O}F (27^{O}C)/85 percent RH to equilibrate at 12 percent or 17.5 percent (MC). The 17.5% moisture content was dictated by the limitations of the conditioning unit available at the time. All samples at the higher moisture content had first dried to the 12% MC under the above mentioned conditions, except for beech and oak heartwood and beech sapwood samples at 17.5 percent MC treated with CCA, and beech and oak heartwood samples at 17.5% MC treated with ambient and heated ACQ-B solutions. Wood for these treatments was conditioned to 17.5% MC without drying to 12% MC first. Oven dry moisture contents were determined using excess samples in the same conditioning unit. After several weeks, when the OD moisture content leveled off at 12 or 17.5%, it was assumed the remaining samples were at like moisture contents and were left undisturbed until treatment. Before vacuum/pressure treatment, samples were end-sealed with an elastomeric sealant so that penetration and retention values would be the result of only radial and/or tangential pathways.

End-matching of samples was not done. However, as described above, samples with major grain deviation and defect were eliminated from inclusion in the study. Samples were randomly distributed in the conditioning units and randomly chosen for the various treatments. While some of the moisture content groups (e.g. beech heartwood at 12 and 17.5% MC) were not treated simultaneously, when the time period between treatments exceeded several days, a fresh preservative solution was mixed for subsequent treatments. Thus, any density, within and between board, within and between tree, storage, and preservative solution differences should have been minimized with the likelihood of any/all of these sources of variability being found in the 12% moisture content group as likely as their being found in the 17.5% group.

Preservative solution concentrations were 1 percent and 2 percent active ingredient, respectively for ACQ-B and CCA-C. The ACQ-B solutions were heated to either 180^{O} F (82^{O}C) or 80^{O}F (27^{O}C), henceforth referred to as a heated or ambient solution, respectively. The CCA solutions used complied with AWPA Standard P5-93 section 6 (2). Treatment constants were pressure (200 psi) and an initial vacuum (28 in. Hg) period of 30 minutes. Pressure period duration was variable and included 60, 90, and 120 minutes periods.

Of the ACQ-B solutions, all were in compliance with AWPA Standard P5 section 13 (2), except for the following instances; red maple and yellow-poplar heartwood, and hickory heartwood and sapwood samples at 12% EMC treated for 60 minutes with an ambient solution, which had somewhat elevated amounts of CuO (0.773%) and DDAC (0.397%-didecyldimethyl ammonium chloride) in a 1.170% active ingredient solution, and beech heartwood and sapwood samples at 12% EMC treated for 120 minutes with a heated solution which had a low NH_3:CuO ratio (0.88), the latter being the result of heating. As described in Slahor *et al* (30), retentions were determined using X-Ray Fluorescence spectroscopy-ASOMA. The densities used for retention determination, based on 0% MC, were as follows (28): yellow-poplar-26.2 lb/ft^3, red maple-33.7 lb/ft^3, beech-39.9 lb/ft^3, red oak-39.3 lb/ft^3, and hickory-44.9 lb/ft^3.

Penetration measurements were made as per **Figure 2.1** and the reader is referred to the materials and methods section of Chapter 2 for a detailed description of the penetration measurements.

The sapwood of yellow-poplar and red maple were not included in any treatments other than CCA because the thorough treatability of the sapwood of these species was assumed to be applicable to all preservatives used in this study. In the case of red oak sapwood, the amount of sapwood was insufficient to produce the 2-by-4 inch sample size, and so it was not included in any detailed analysis. Furthermore, GLM SAS (24) analysis, which adjusts for unequal sample sizes, showed no trend as a result of pressure time period (60, 90, and 120 minutes), except for one instance which is discussed in the appropriate results section. Given this result from the two-way analysis of variance with interaction, the three pressure periods were combined (eliminating time period as a factor) and a one-way analysis of variance of moisture content was used to describe the results for simplicity sake.

The two-way General Linear Model is specified as follows:

$$Y_{ijk} = \mu + MC_i + T_j + (MC*T)_{ij} + \epsilon_{ijk} \quad (4.1)$$

where,

Y_{ijk} = the measure of treatability, as either retention or penetration, for the *j*th sample of the *i*th moisture content,

μ = the overall mean penetration or retention,

MC_i = the effect of the *i*th moisture content (1 = 12 percent, 2 = 17.5 percent),

T_j = the effect of the *j*th pressure time period (60,90, or 120 minutes)

ϵ_{ijk} = the experimental error associated with Y_{ijk};

all tests of significance were conducted at a significance level of 0.05.

The model described above is given for the sake of clarity. As was mentioned previously, only the results of a one-way ANOVA, with moisture content as the sole factor, are reported.

Results and Discussion

Results are presented on a species-by-species basis in the following sections. Original sample sizes, by species, preservative, moisture content, and time period are presented in **Table 4.1**. Time period is noted for clarification purposes only, and as noted above, is not reported in subsequent tables.

Table 4.1—Sample Sizes by Species, Preservatives, Moisture Content, and Pressure Time Period.

	CCA						Ambient ACQ-B						Heated ACQ-B					
Moisture Content	12%			17.5%			12%			17.5%			12%			17.5%		
Time (min)	60	90	120	60	90	120	60	90	120	60	90	120	60	90	120	60	90	120
Beech Sap	10	10	10	10[1]	10[1]	10[1]	10	10	10	6	6	7	10	10	10	10	10	10
Beech Heart	10	10	10	10[1]	10[1]	10[1]	10	10	10	6[1]	5[1]	12[1]	10	10	10	10	10	10
Hickory Sap	10	10	10	10	10	5	10	10	10	6	6	6	10	10	10	8	8	10
Hickory Heart	10	10	10	10	10	5	10	10	10	6	6	6	10	10	10	8	10	10
Red Oak Heart	10	10	10	10[1]	10[1]	5[1]	10	10	10	7[1]	10[1]	10[1]	10	10	10	10	10	10
Yellow-Poplar Sap	10	10	10	8	-	-	10	10	10	-	-	-	10	10	10	-	-	-
Yellow-Poplar Heart	10	10	10	10	10	5	10	10	10	6	6	6	10	10	10	7	8	10
Red Maple Sap	10	10	10	10	-	-	10	10	10	-	-	-	10	10	10	-	-	-
Red Maple Heart	10	10	10	10	10	5	10	10	10	6	6	6	10	10	10	8	9	10

1 - These samples were conditioned from green to 17.5% MC without going below 17.5% MC.

BEECH

In all measures of treatability for beech sapwood treated with CCA, except for the MaxX measurement, the 12 percent MC level was statistically higher ($\alpha = 0.05$) than the 17.5 percent MC (**Table 4.2**). For the ACQ-B solutions, only 5 of 12 treatability parameters were statistically significant ($\alpha = 0.05$) (**Table 4.2**). Both retention results were significant and favored the 17.5 percent MC, as did the MaxX mean for the ambient solution. Alternatively, the percent rating and MaxY parameters of the heated ACQ-B solution favored the 12 percent MC. While a 12 percent produced consistently improved treatability with CCA, the results for both ACQ-B treatments were inconclusive with regard to a preferred moisture content.

Beech heartwood results showed that three of the six treatability measures with CCA were statistically significant ($\alpha = 0.05$) (percent rating, MaxY, and retention, $\alpha = 0.05$) and favored the 12 percent MC (**Table 4.3**). For the remaining three parameters, although not statistically significant ($\alpha = 0.05$), the 12 percent MC means were higher than the 17.5 percent means. The ambient ACQ-B treatment showed significantly greater treatability at 12 percent for all parameters (**Table 4.3**). In most cases, the mean differences are several times larger at the 12 percent MC (all but MaxX were at least three times greater at the 12 percent MC). The heated ACQ-B solution produced significantly higher mean results in four of six treatability parameters (percent rating, retention, MinX, and MaxY). In the two cases of non-significant statistical results, the 12 percent MC means were somewhat higher than the 17.5 percent MC (MaxX and MinY). Unlike beech sapwood, heartwood results strongly indicate that the 12 percent MC level had a greater positive impact on treatability than the higher MC for all three preservative treatments.

Table 4.2— Means of Percentage Rating of Cross-Section Penetrated, Retention (Pounds per Cubic Foot (PCF) Total Oxide Basis) and Penetration (Inches) for Beech Sapwood at Two Moisture Contents Treated with CCA and Ambient and Heated ACQ-B Solutions.

	% Rating[a]		PCF		MinX		MaxX		MinY		MaxY	
Moisture Content	12	17.5	12	17.5	12	17.5	12	17.5	12	17.5	12	17.5
CCA	2.50*	1.70	0.481* (7.70)[c]	0.414 (6.63)	0.13* (3.3)[d]	0.04 (1.0)	0.70 (17.8)	0.67 (17.0)	0.36* (9.1)	0.04 (1.0)	1.59* (40.4)	1.10 (27.9)
A[b]-ACQ-B	2.67	2.74	0.188 (3.01)	0.208* (3.33)	0.33 (8.4)	0.36 (9.1)	0.65 (16.5)	0.74* (18.8)	0.55 (14.0)	0.54 (13.7)	1.18 (30.0)	1.12 (28.4)
H[b]-ACQ-B	2.97*	2.73	0.197 (3.16)	0.237* (3.80)	0.41 (10.4)	0.39 (9.9)	0.73 (18.5)	0.72 (18.3)	0.65 (16.5)	0.56 (14.2)	1.64* (41.6)	1.02 (25.9)

[a] Rating is the percent of cross-section penetrated where 0=0 to 25 percent; 1=25 to 50 percent; 2=50 to 75 percent; and 3=75 to 100 percent [b] A-Ambient Temperature; H-Heated
[c] kg/m^3 [d] Millimeters * Statistically Significant $\alpha = 0.05$.

Table 4.3— Means of Percentage Rating of Cross-Section Penetrated, Retention (Pounds per Cubic Foot (PCF) Total Oxide Basis) and Penetration (Inches) for Beech Heartwood at Two Moisture Contents Treated with CCA and Ambient and Heated ACQ-B Solutions.

	% Rating[a]		PCF		MinX		MaxX		MinY		MaxY	
Moisture Content	12	17.5	12	17.5	12	17.5	12	17.5	12	17.5	12	17.5
CCA	1.47*	0.37	0.321* (5.14)[c]	0.221 (3.54)	0.04 (1.0)[d]	0.02 (0.5)	0.63 (16.0)	0.54 (13.7)	0.10 (2.5)	0.02 (0.5)	1.07* (27.2)	0.58 (14.7)
A[b]-ACQ-B	2.37*	0.09	0.167* (2.68)	0.047 (0.75)	0.24* (6.1)	0.02 (0.5)	0.64* (16.2)	0.38 (9.6)	0.41* (10.4)	0.03 (0.8)	1.04* (26.4)	0.33 (8.4)
H[b]-ACQ-B	0.77*	0.07	0.093* (1.49)	0.050 (0.80)	0.07* (1.8)	0.06 (1.5)	0.46 (11.7)	0.37 (9.4)	0.11 (2.8)	0.07 (1.8)	0.64* (16.2)	0.38 (9.6)

[a] Rating is the percent of cross-section penetrated where 0=0 to 25 percent; 1=25 to 50 percent; 2=50 to 75 percent; and 3=75 to 100 percent.[b] A-Ambient Temperature; H-Heated
[c] kg/m^3 [d] Millimeters * Statistically Significant $\alpha = 0.05$.

HICKORY

Hickory sapwood and heartwood treatability results at the two moisture contents were significantly different ($\alpha = 0.05$), but with different results for the different preservative solutions. Both CCA and ambient ACQ-B showed better treatment at 17.5 percent MC, for both sapwood and heartwood (**Tables 4.4** and **4.5**). In the case of CCA, four of six treatability parameters for sapwood, and five of six for heartwood were significantly higher at 17.5 percent MC. Treatments with ACQ-B at ambient conditions resulted in four of six treatability parameters for sapwood and four of six for heartwood being significantly greater at 17.5 percent MC. Conversely, the heated ACQ-B treatment produced significantly better results at the 12 percent MC for hickory sapwood, with all treatability parameters statistically greater than the ambient treatment. The heated ACQ-B solution for hickory heartwood was much less conclusive, with only the retention parameter being statistically significantly higher (0.05 alpha)for samples at 12% moisture content.

For practical purposes, the treatability of hickory in all cases was so poor, with regard to solid wood products, that the results are of little value for increasing the commercial treatment of hickory.

Table 4.4— Means of Percentage Rating of Cross-Section Penetrated, Retention (Pounds per Cubic Foot (PCF) Total Oxide Basis) and Penetration (Inches) for Hickory Sapwood at Two Moisture Contents Treated with CCA and Ambient and Heated ACQ-B Solutions.

	% Rating[a]		PCF		MinX		MaxX		MinY		MaxY	
Moisture Content	12	17.5	12	17.5	12	17.5	12	17.5	12	17.5	12	17.5
CCA	0.83	1.36*	0.174 (2.78)[c]	0.200* (3.20)	0.13 (3.3)[d]	0.23* (5.8)	0.35 (8.9)	0.55* (13.7)	0.11 (2.8)	0.20 (5.1)	0.37 (9.4)	0.42 (10.7)
A[b]-ACQ-B	0.57	1.28*	0.090* (1.44)	0.073 (1.17)	0.11 (2.8)	0.19* (4.8)	0.34 (8.6)	0.53* (13.5)	0.08 (2.0)	0.21 (5.3)	0.29 (7.4)	0.41 (10.4)
H[b]-ACQ-B	2.97*	1.35	0.197* (3.16)	0.093 (1.49)	0.41* (10.4)	0.18 (4.6)	0.73* (18.5)	0.54 (13.7)	0.65* (16.5)	0.22 (5.6)	1.64* (41.6)	0.50 (12.7)

[a] Rating is the percent of cross-section penetrated where 0=0 to 25 percent; 1=25 to 50 percent; 2=50 to 75 percent; and 3=75 to 100 percent [b] A-Ambient Temperature; H-Heated
[c] kg/m^3 [d] Millimeters * Statistically Significant $\alpha = 0.05$.

Table 4.5— Means of Percentage Rating of Cross-Section Penetrated, Retention (Pounds per Cubic Foot (PCF) Total Oxide Basis) and Penetration (Inches) for Hickory Heartwood at Two Moisture Contents Treated with CCA and Ambient and Heated ACQ-B Solutions.

	% Rating[a]		PCF		MinX		MaxX		MinY		MaxY	
Moisture Content	12	17.5	12	17.5	12	17.5	12	17.5	12	17.5	12	17.5
CCA	0	0.76*	0.140 (2.24)[c]	0.142 (2.27)	0.02 (0.1)[d]	0.12* (3.0)	0.13 (3.3)	0.45* (13.7)	0.01 (0.1)	0.12* (3.0)	0.16 (4.1)	0.38* (9.6)
A[b]-ACQ-B	0.03	0.33*	0.055 (0.88)	0.035 (0.56)	0.01 (0.2)	0.07* (1.7)	0.25 (6.4)	0.42* (10.7)	0.01 (0.2)	0.07* (1.8)	0.30 (7.6)	0.30 (7.6)
H[b]-ACQ-B	0.77	1.00	0.093* (1.49)	0.068 (1.09)	0.07 (1.7)	0.13 (3.3)	0.46 (11.7)	0.54 (13.7)	0.11 (2.8)	0.18 (4.6)	0.64 (16.2)	0.50 (12.7)

[a] Rating is the percent of cross-section penetrated where 0=0 to 25 percent; 1=25 to 50 percent; 2=50 to 75 percent; and 3=75 to 100 percent. [b] A-Ambient Temperature; H-Heated
[c] kg/m^3 [d] Millimeters * Statistically Significant $\alpha = 0.05$.

RED OAK

As noted previously, because of the difficulty in obtaining sufficient volumes of sapwood to produce a nominal 2-by-4 (50.8-by 101.6 mm) sample, only heartwood of red oak was evaluated. Although, not as pronounced in hickory, some indication of improved treatability at the higher moisture content was evident (**Table 4.6**). The two instances of significantly improved treatability at 12 percent MC were retention of both ACQ-B solutions. As with hickory, the treatability results are so poor as to make any practical application unlikely.

Table 4.6— Means of Percentage Rating of Cross-Section Penetrated, Retention (Pounds per Cubic Foot (PCF) Total Oxide Basis) and Penetration (Inches) for Red oak Heartwood at Two Moisture Contents Treated with CCA and Ambient and Heated ACQ-B Solutions.

	% Rating[a]		PCF		MinX		MaxX		MinY		MaxY	
Moisture Content	12	17.5	12	17.5	12	17.5	12	17.5	12	17.5	12	17.5
CCA	0.03	0.08	0.175 (2.80)[c]	0.168 (2.69)	0 (0)[d]	0.003* (.1)	0.20 (5.1)	0.27 (6.8)	0 (0)	0.003* (0.1)	0.20 (5.1)	0.16 (4.1)
A[b]-ACQ-B	0.07	0.59*	0.095* (1.59)	0.076 (1.22)	0.001 (0.1)	0.09* (2.3)	0.38 (9.6)	0.50* (12.7)	0.02 (0.5)	0.11* (2.8)	0.47 (11.9)	0.42 (10.7)
H[b]-ACQ-B	0.33	0.27	0.196* (3.13)	0.095 (1.52)	0 (0)	0.01* (0.2)	0.30 (7.6)	0.32 (8.1)	0 (0)	0.09 (2.3)	0.34 (8.6)	0.28 (7.1)

[a] Rating is the percent of cross-section penetrated where 0=0 to 25 percent; 1=25 to 50 percent; 2=50 to 75 percent; and 3=75 to 100 percent. [b] A-Ambient Temperature; H-Heated
[c] kg/m^3 [d] Millimeters * Statistically Significant $\alpha = 0.05$.

YELLOW-POPLAR

CCA was the only sapwood treatment evaluated. All 12 percent MC treatability parameters, except MaxX, showed improved results over the higher moisture content (**Table 4.7**). It is important to note that both MC levels for CCA could potentially meet theoretical AWPA (2) minimum penetration and retention requirements (for the sample size used in this work) for yellow-poplar sapwood, as well as heartwood treated at the lower moisture content.

CCA treatment of yellow-poplar heartwood showed significantly better treatability in all categories (except MaxX) at 12 percent MC (**Table 4.7**). Better treatment for the ACQ-B solutions was limited to the 12 percent MC for MinX and the 17.5 percent MC for MaxX of the ambient solution.

Table 4.7— Means of Percentage Rating of Cross-Section Penetrated, Retention (Pounds per Cubic Foot (PCF) Total Oxide Basis) and Penetration (Inches) for Yellow-Poplar Heartwood at Two Moisture Contents Treated with CCA and Ambient and Heated ACQ-B Solutions and Sapwood at Two moisture Contents Treated with CCA.

	% Rating[a]		PCF		MinX		MaxX		MinY		MaxY	
Moisture Content	12	17.5	12	17.5	12	17.5	12	17.5	12	17.5	12	17.5
CCA Heartwood	1.57*	0.60	0.445* (7.13)[c]	0.236 (3.78)	0.12* (3.0)[d]	0.06 (1.5)	0.60 (15.2)	0.49 (12.4)	0.13* (3.3)	0.06 (1.5)	0.92* (23.4)	0.53 (13.5)
CCA Sapwood	3.00*	2.25	0.626* (10.03)	0.455 (7.29)	0.70* (17.8)	0.15 (3.8)	0.75 (19.0)	0.75 (19.0)	1.60* (40.6)	0.28 (7.1)	1.75* (44.4)	1.48 (37.6)
A[b]-ACQ-B Heartwood	1.10	1.00	0.112 (1.79)	0.112 (1.79)	0.14* (3.6)	0.07 (1.8)	0.48 (12.2)	0.64* (16.2)	0.20 (5.1)	0.08 (2.0)	0.63 (16.0)	0.63 (16.0)
H[b]-ACQ-B Heartwood	2.20	1.72	0.136 (2.18)	0.165 (2.64)	0.23 (5.8)	0.23 (5.8)	0.66 (16.8)	0.66 (16.8)	0.37 (9.4)	0.40 (10.2)	1.00 (25.4)	0.73 (18.5)

[a] Rating is the percent of cross-section penetrated where 0=0 to 25 percent; 1=25 to 50 percent; 2=50 to 75 percent; and 3=75 to 100 percent. [b] A-Ambient Temperature; H-Heated
[c] kg/m^3 [d] Millimeters * Statistically Significant $\alpha = 0.05$.

RED MAPLE

Red maple sapwood treated with CCA was little affected by moisture content, with only two parameters showing significantly better treatment (MaxY and retention) at 12 percent moisture content. Moisture content affected treatability of red maple heartwood with decreasing effect by preservative, starting with ambient ACQ-B, CCA, and finally heated ACQ-B. In the case of ambient ACQ-B, all heartwood treatability parameters were significantly greater at the 12 percent MC level. The 12 percent MC was also significantly greater in four of six heartwood treatability parameters in CCA and one of six for heated ACQ-B. Some question may arise here in referring to the previous work by Slahor *et al* (30) where there was some indication that the 90 and 120 minute pressure periods were statistically better than the 60 minute period for the CCA treatment of heartwood. The caveat in that paper explained this occurrence as the result of difficulty in differentiating heartwood and sapwood in this species. Six of the ten heartwood samples at the 12% moisture content treated with CCA for the 60 minute pressure period had pith apparent within the cross-section. Of the twenty remaining samples (10-90 minute, 10-120 minute) only four contained the pith.

Results (**Table 4.8**) indicate that red maple sapwood treated with CCA has the potential to meet theoretical AWPA (2) minimum penetration and retention requirements (for the sample size used in this work). Red maple heartwood treated with CCA at 12 percent MC also has potential for meeting these minimum retention and penetration requirements as well.

Table 4.8— Means of Percentage Rating of Cross-Section Penetrated, Retention (Pounds per Cubic Foot (PCF) Total Oxide Basis) and Penetration (Inches) for Red Maple Heartwood at Two Moisture Contents Treated with CCA and Ambient and Heated ACQ-B Solutions and Sapwood at Two Moisture Contents Treated with CCA.

	% Rating[a]		PCF		MinX		MaxX		MinY		MaxY	
Moisture Content	12	17.5	12	17.5	12	17.5	12	17.5	12	17.5	12	17.5
CCA Heartwood	1.67*	0.48	0.466* (7.46)[c]	0.257 (4.12)	0.25* (6.4)[d]	0.05 (1.3)	0.54 (13.7)	0.60 (15.2)	0.52* (13.2)	0.10 (2.5)	1.07* (27.2)	0.79 (20.1)
CCA Sapwood	2.86	2.80	0.697* (11.16)	0.536 (8.59)	0.52 (13.2)	0.40 (10.2)	0.75 (19.0)	0.75 (19.0)	1.18 (30.0)	1.16 (29.5)	1.71* (43.4)	1.33 (33.8)
A[b]-ACQ-B Heartwood	2.10*	0.22	0.132* (2.11)	0.058 (0.93)	0.22* (5.6)	0.02 (0.5)	0.66* (16.8)	0.41 (10.4)	0.44* (11.2)	0.03 (0.8)	1.28* (32.5)	0.43 (10.9)
H[b]-ACQ-B Heartwood	0.70	0.44	0.086* (1.38)	0.082 (1.31)	0.04 (1.0)	0.05 (1.3)	0.54 (13.7)	0.53 (13.5)	0.07 (1.8)	0.05 (1.3)	0.71 (18.0)	0.57 (14.5)

[a] Rating is the percent of cross-section penetrated where 0=0 to 25 percent; 1=25 to 50 percent; 2=50 to 75 percent; and 3=75 to 100 percent. [b] A-Ambient Temperature; H-Heated
[c] kg/m^3 [d] Millimeters * Statistically Significant $\alpha = 0.05$.

CONCLUSIONS

Several conclusions can be drawn from this evaluation. First, the results further indicate that hardwood species exhibit a range of treatability attributes, at least with regard to CCA and ACQ-B. This is similar to the mixed results of studies conducted on softwood species, as cited earlier. Additionally, as reported in previous work, the difficulty associated with treating heartwood was further validated.

An “anatomical generalization” might be drawn from the work conducted on hardwoods treated with the preservatives used in this work. The diffuse-porous wood of yellow-poplar, red maple, and beech followed a similar treatment trend as compared to the treatment trend of the ring-porous wood of red oak and hickory. The former had clearly greater (better) treatability compared to the latter.

The end-sealing of samples in this study resulted in penetration dependent on tangential and radial movement of preservative solution into the wood, limiting to the extreme the role played by vessels. An overall explanation of the generally poor results for heartwood might be based on this minimized vessel penetration if, as concluded by Greaves (12), the primary preservative flow in hardwoods is through the vessels then, via the pits, to adjacent cell types. With flow through the vessels limited, it could be assumed that rays might play a key role in preservative transport. This could be a factor in explaining the generally better penetration results found in yellow-poplar and red maple heartwood as compared to the other heartwoods. For instance, Behr *et al* (3). noted a lack of oil or creosote in the wide rays of pressure-treated beech, red oak, and hickory.

In most cases, this study indicated that a lower moisture content resulted in improved treatability results. However, red oak and hickory showed some proclivity toward improved treatability at the 17.5 percent MC. **Table 4.9** summarizes the results of the effect of moisture content on the hardwood species evaluated here.

Table 4.9— Overall Effect of Moisture Content on Treatability of Five Appalachian Hardwoods.

	CCA		Ambient ACQ-B		Heated ACQ-B	
	12%	17.5%	12%	17.5%	12%	17.5%
Beech Sapwood	+		I	I	I	I
Beech Heartwood	+		+		+	
Hickory Sapwood		+		+	+	
Hickory Heartwood		+		+	I	I
Red Oak Heartwood		+		+		+
Yellow-Poplar Sapwood	+		N/A	N/A	N/A	N/A
Yellow-Poplar Heartwood	+		I	I	I	I
Red Maple Sapwood	I	I	N/A	N/A	N/A	N/A
Red Maple Heartwood	+		+		I	I

+ **-** Generally Improved Treatability Over Other Moisture Content   I **-** Inconclusive Results
N/A **-** Not Analyzed In This Study

It is important to note that while statistically significant differences ($\alpha = 0.05$) in the treatment means were found in many cases, the actual level of treatment implies a note of caution in applying the use of the statistical results relative to improving commercial treatment application. In many cases the actual level of treatability was essentially negligible, even though the differences between moisture contents was statistically significant ($\alpha = 0.05$). However, in the case of certain sapwood treatments, the differences in moisture content may mean the difference in meeting minimum treatment requirements.

Chapter 5

Treatability Of Five Appalachian Wood Species With Creosote And Timbor®

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Abstract

The work described in this paper culminates an investigation into the treatability of five Appalachian hardwood species. Previous papers have described work using the waterborne preservatives CCA-C and ACQ-B. This paper details the results of pressure treatment with creosote and Timbor®. Six-inch long nominal two-by-four samples of red maple, yellow-poplar, red oak, hickory, and beech were end-sealed and vacuum/pressure treated. Two borate treatments were tested: wrapped in plastic or not wrapped. Measurements were taken of minimum and maximum penetration, percentage of cross-sectional area penetrated, and retention of preservative as determined by gross uptake of solution. Statistical analysis indicated that the duration of pressure periods employed in this and previously described work had no consistent positive effect on treatment. Sample moisture content significantly impacted creosote treatment. While a lower moisture content resulted in greater retentions of the borate preservative, it had no effect on the other treatability parameters. Rather, the samples wrapped in plastic for six weeks, at either moisture content, had greater treatability results compared to the unwrapped samples indicating that while a higher moisture content limits the uptake of the preservative, the wrapping in plastic enhances the diffusion of the borate at either moisture content.

INTRODUCTION

Historically, hardwoods have been successfully treated with creosote, providing excellent service in railway applications, among others. More recently, borates have been receiving attention as a possible alternative treatment for hardwoods. This paper presents treatability results for five hardwood species treated with creosote and borate (Timbor®). It is a companion study to Slahor *et al.* (30) and Hassler *et al* (14) which evaluated the treatability of the same five hardwood species with CCA and ACQ-B.

MATERIALS AND METHODS

Nominal two-by-fours were produced from yellow-poplar heartwood (*Liriodendron tulipifera* L.), red maple heartwood(*Acer rubrum* L.), red oak heartwood (*Quercus rubra),* hickory heartwood and sapwood (*Carya spp.*), and beech heartwood and sapwood (*Fagus grandifolia* Ehrh.) as described in Slahor *et al* (30). Straight grained, as defect free as possible, six-inch long samples were cut and placed in conditioning rooms set at 70^{O}F (21^{O}C) and 65%RH or 80^{O}F (27^{O}C) and 85%RH to equilibrate at 12% or 17.5-17.9% moisture content (MC) respectively for subsequent treatment with coal tar creosote. Like samples were placed in 70^{O}F (21^{O}C) and 65%RH or 60^{O}F (15.5^{O}C) and 95%RH to equilibrate at 12% or 24% moisture content for subsequent treatment with borates. Before vacuum/pressure treatment, samples were end-sealed with an elastomeric sealant (borate) or epoxy (creosote). Borate solution strength was 2% active ingredient by weight/volume with 7.4 ml of industrial moldicide added to the 50 gallons (189.3 L) of solution used to treat samples. Treatment conditions were a thirty minute vacuum of 28 mm Hg followed by pressure periods of 60, 90, or 120 minutes at 150 psi (105.4 kg/cm^2). The borate solution temperature was ambient (80 degrees F/26.7 degrees C) and the creosote temperature was 120 degrees F (48.8 degrees C).

Following treatment, the borate treated samples were randomly divided into two groups. With one group, samples were placed on wire grills and air dried immediately after treatment while the second group was immediately dead stacked, wrapped in plastic, and stored at room temperature for six weeks. Following the six weeks, the samples were unwrapped, open stacked, and allowed to dry.

Preservative retentions were determined by gross uptake of solution determined by weighing samples immediately before and immediately after treatment. As such, the retention values discussed in the following sections are likely to be very conservative compared to results that would be obtained from chemical analysis of an assay of 0 - 0.6" (0 -15.24 mm) from the surface of the samples. That assay zone is specified for softwood lumber 2" or less in thickness (AWPA Standard C2) (2). Penetration measurements were made according to the diagram contained in **Figure 2.1** and the reader is referred to the materials and methods section of chapter 2 for a detailed description of the measurement method.

Penetration and retention results were analyzed statistically using analysis of variance (ANOVA). Creosote results were analyzed as a 2-way ANOVA with interaction, where moisture content (12 percent and 17.5 percent) and pressure period (60, 90, or 120 minutes) were the treatment factors. Borate results were analyzed as a 3-way ANOVA with interaction, where preservative sub-group (wrapped and unwrapped), moisture content (12 percent and 24 percent), and pressure period (60, 90, or 120 minutes) were the treatment factors. All tests of significance were performed ($\alpha = 0.05$). Sample size, by species, for the borate treated samples wrapped in plastic was 15, while the other treatments (creosote and unwrapped borate), sample size was 30.

Results were also compared to the minimum treatability requirements as specified in the AWPA Book of Standards 1993 (2). Standard C2 and standard C14-93 specify penetration and retention requirements for oak and maple treated with creosote. Standard C2 specifies a minimum of 10 pcf (pounds per cubic foot) /160 kg/m^3 (kilograms per cubic meter) for creosote retention in maple (both above ground and soil/fresh water contact use). Standard C14-93 further specifies 7 and 6 pcf (112 and 96 kg/m^3) for red oak pieces under 5 inches (127 mm) thick in soil/fresh water contact and above ground applications, respectively.

Standard C2 requires that creosote penetration for red oak, based on 3-inch-long cores from 20 pieces in a charge, be an average of at least 65% of the annual rings. For maple, penetration requirements are that 80% of borings from 20 pieces in a charge must equal or exceed 1.50 inches (38.1 mm) or 75% of the sapwood, whichever is less. Standard C1 further states that the maximum penetration required in any piece of sawn material shall be no greater than one-half the width or depth of said piece, depending on the orientation of the measurement.

Assuming samples treated here were either all sapwood or all heartwood, minimum penetration requirements can be established hypothetically for maple sapwood - 0.56 inches (15 mm) of thickness (75 percent of ½ of 1.5 inches) or 1.31 inches (33.3 mm) of width (75 percent of ½ of 3.5 inches); heartwood - 0.75 inches (19 mm) of thickness and 1.50 inches (38.1 mm) of width. Red oak penetration standards are somewhat more difficult to quantify because of the methods used in this work. If the percentage of ring penetration is determined in one direction, it can not be determined in the other direction.

Standard C31-93 specifies penetration and retention requirements for southern pine and hem-fir treated with borates, but not for any hardwood species. However, as a point of reference, extending these specifications to hardwoods would require 0.17 pcf (2.7 kg/m^3) retention of borate as B_2O_3. Penetration is specified as 90 percent of 20 borings per charge equaling or exceeding 2.5 inches (64 mm) or 85 percent of sapwood, whichever is less. Also, Standard C1 regarding minimum required penetration applies here. Assuming samples treated here were either all sapwood or all heartwood, minimum penetration requirements can be stated hypothetically as follows: sapwood - 0.64 inches (16 mm) of thickness (85 percent of ½ of 1.5 inches) or 1.49 inches (38 mm) of width (85 percent of ½ of 3.50 inches); heartwood - 0.75 inches (19 mm) of thickness or 1.75 inches (44 mm) of width.

RESULTS AND DISCUSSION

Creosote

There was no consistent statistically significant effect ($\alpha = 0.05$) on penetration (MinX, MaxX, % Rating, MinY, and MaxY) due to pressure period (60, 90, or 120 minutes) or due to the interaction between moisture content and pressure period, across all species evaluated. However, moisture content (12 and 17.5 percent) had a statistically significant ($\alpha = 0.05$) effect on penetration across all species, except in beech heartwood or sapwood (**Table 5.1**).

Table 5.1—Mean Penetration Results by Species and Moisture Content for Creosote Treated Samples.

	MinX[a]		MaxX[a]		%[b]		MinY[a]		MaxY[a]	
Moisture Content	12%	17.5%	12%	17.5%	12%	17.5%	12%	17.5%	12%	17.5%
Yellow-Poplar Heartwood	0.72* (18.3)†	0.58 (14.7)	**0.75 (19.0)**	0.74 (18.8)	2.97	2.93	1.67* (42.4)	1.10 (27.9)	1.70* (43.2)	1.37 (34.8)
Red Maple Heartwood	0.69* (17.5)	0.39 (9.9)	**0.75* (19.0)**	0.71 (18.0)	**3.00***	2.43	1.59* (40.4)	0.73 (18.5)	1.71* (43.4)	1.06 (26.9)
Red Oak Heartwood	0.72* (18.3)	0.63 (16.0)	**0.75 (19.0)**	**0.75 (19.0)**	**3.00**	2.93	1.66* (42.2)	1.29 (32.8)	1.71 (43.4)	1.61 (40.9)
Beech Sapwood	**0.75 (19.0)**	**0.75 (19.0)**	**0.75 (19.0)**	**0.75 (19.0)**	**3.00**	**3.00**	**1.75 (44.4)**	**1.75 (44.4)**	**1.75 (44.4)**	**1.75 (44.4)**
Beech Heartwood	0.31 (7.9)	0.32 (8.1)	0.73 (18.5)	0.73 (18.5)	2.47	2.23	0.73 (18.5)	0.59 (15.0)	1.21 (30.7)	1.10 (27.9)
Hickory Sapwood	0.72* (18.3)	0.30 (7.6)	**0.75* (19.0)**	0.58 (14.7)	**3.00***	1.87	1.65* (41.9)	0.37 (9.4)	1.71* (43.4)	0.66 (16.8)
Hickory Heartwood	0.38* (9.6)	0.29 (7.4)	0.68 (17.3)	0.66 (16.8)	2.30*	1.80	0.46 (11.7)	0.38 (9.6)	0.78* (19.8)	0.61 (15.5)

a - Inches   b - 0 = 0 to 25%, 1 = 25 - 50%, 2 = 50 -75%, 3 = 75 - 100%

* Denotes Statistically Greater Value † Millimeters Entries in Bold Face Indicate 100% Penetration

In many instances, no statistical significant differences were observed because the parameter means were at their physical maximums (0.75 inches in the X-dimension and 1.75 inches in the Y-dimension), indicating complete (through and through) penetration. This was the case in all penetration measures of beech sapwood. Other cases are noted in bold face type in **Table 5.1**. It is further evident in **Table 5.1** that the 12 percent MC level had statistically significant($\alpha = 0.05$) effect on penetration, especially for red maple heartwood and hickory sapwood. In all cases, except beech heartwood and hickory heartwood, penetration met or approached the physical maximums at the lower moisture content.

Describing the results in terms referring to AWPA Standard C-2 (2) is somewhat problematic as the number of 2-by-4 inch samples was ten rather than twenty. Further, the method of penetration measurement used could determine percentage of growth ring penetration for red oak in only one of the directions measured on the cross-sections (either the X or the Y direction), resulting from ring orientation due to flat-sawn or quarter-sawn samples. However, at 12% moisture content, the percentage of minimum penetration measurements for yellow-poplar and red maple heartwood, beech and hickory sapwood exceeded the AWPA requirement (specific to maple)of 80 percent of measurements equaling 0.75"(19 mm) in the X direction and equal to or exceeding 1.50" (38 mm) in the Y direction. The red oak samples at 12% moisture content had at least 93% of minimum measurements equal to equal to or in excess of the aforementioned depths of penetration. At the higher moisture content only beech sapwood had minimum measurements which exceeded the 80% requirement. Yellow-poplar, red maple, and red oak heartwood, and hickory sapwood at the higher moisture content all had considerably less than 80% of the minimum measurements at least equal to the requirements.

Table 5.2 contains the creosote retention results for both moisture contents. Effect of moisture content on creosote penetration in yellow-poplar, red oak, and hickory heartwood, and hickory sapwood was statistically significant ($\alpha = 0.05$) with the highest retention in the 12% moisture content samples. However, beech sapwood was the only treatment to exceed the 10 pcf (160.2 kg/m^3) minimum requirement for retention, at both moisture contents. Yellow-poplar heartwood (9.66 pcf/154.8 kg/m3)) and hickory sapwood (9.78 pcf/156.7 kg/m^3) at the 12 percent MC level, were very close to meeting the minimum penetration requirement. Red oak heartwood did not meet the minimum requirements for either above or below ground applications, although the above ground standard of 6 pcf (96 kg/m^3) was nearly attained at the 12 percent MC level (5.81 pcf/93.1 kg/m^3). A possible explanation for this result is that because of the end-sealing of samples, virtually no end-grain penetration occurred, and with a treatment temperature of only 120^{O}F (49^{O}C) the heavier fractions of creosote did not become viscous enough for extensive radial and tangential penetration.

Table 5.2— Mean Retention (PCF) Results for Creosote Treatment,by Species and Moisture Content.

Moisture Content	12%	17.5%
Yellow-Poplar Heartwood	9.66[*](154.8)[a]	6.82 (100.6)[a]
Red Maple Heartwood	7.58(121.4)	6.29(100.8)
Red Oak Heartwood	5.81[*](93.1)	4.38 (70.2)
Beech Sapwood	13.48 (215.9)	13.16 (210.8)
Beech Heartwood	5.73(91.8)	4.70 (75.3)
Hickory Sapwood	9.78[*](156.7)	3.90 (62.5)
Hickory Heartwood	6.79[*](108.8)	3.55 (56.9)

* - Denotes Statistically Greater Value. a - kg/m^3.

Borates

Mean retention across all species for wrapped and unwrapped samples were statistically significant ($\alpha = 0.05$) with mean retention of wrapped samples being higher. However, for MaxX for beech heartwood and MaxY for beech sapwood, no statistically significant effect ($\alpha = 0.05$) of the two treatments were observed. **Table 5.3** illustrates the means for the wrapped and unwrapped treatments. It is important to note that statistically significant ($\alpha = 0.05$) differences also indicated significant practical differences between wrapped and unwrapped samples. Good examples of this are MinY results for red maple heartwood (1.27 inches versus 0.24 inches for wrapped and unwrapped treatments, respectively) and MinX for beech heartwood (0.31 inches versus 0.08 inches for wrapped and unwrapped treatments, respectively).

Table 5.3— Mean Penetration Results by Species and Type of Treatment (Wrapped vs. Unwrapped) for Borate Treated Samples.

	MinX[a]		MaxX		%[b]		MinY		MaxY	
Treatment	W[c]	U	W	U	W	U	W	U	W	U
Yellow-Poplar Heartwood	0.60* (15.2)†	0.26 (6.6)	0.73* (18.5)	0.62 (15.7)	2.73*	1.50	1.21* (30.7)	0.50 (12.7)	1.41* (35.8)	0.96 (24.4)
Red Maple Heartwood	0.59* (15.0)	0.15 (3.8)	0.74* (18.8)	0.68 (17.3)	2.73*	1.37	1.27* (32.2)	0.24 (6.1)	1.40* (35.6)	0.91 (23.1)
Red Oak Heartwood	0.37* (9.4)	0.18 (4.6)	0.65* (13.5)	0.57 (14.5)	2.20*	1.32	0.46* (11.7)	0.16 (4.1)	0.83* (21.1)	0.47 (11.9)
Beech Sapwood	0.71* (18.0)	0.52 (13.2)	0.75 (19.0)	0.73 (18.5)	3.00*	2.75	1.65* (41.9)	1.21 (30.7)	1.73 (43.9)	1.58 (40.1)
Beech Heartwood	0.31* (7.9)	0.08 (2.0)	0.70 (17.8)	0.66 (16.8)	2.23*	1.10	0.63* (16.0)	0.12 (3.0)	1.03* (26.2)	0.82 (20.8)
Hickory Sapwood	0.52* (13.2)	0.18 (4.6)	0.71* (18.0)	0.59 (15.0)	2.60*	1.42	0.94* (23.9)	0.15 (3.8)	1.20* (30.5)	0.43 (10.9)
Hickory Heartwood	0.38* (9.6)	0.28 (7.1)	0.67 (17.0)	0.58 (14.7)	2.07*	1.27	0.55* (14.0)	0.16 (4.1)	0.94* (23.9)	0.50 (12.7)

a - Inches b - 0 = 0 to 25%, 1 = 25 - 50%, 2 = 50 -75%, 3 = 75 - 100%

* Denotes Statistically Greater Value † Millimeters c - Wrapped/Unwrapped

In general, results showed that penetration at the 12 percent MC was reasonably good, approaching maximum possible values (0.75 inches in the X-dimension and 1.75 inches in the Y-dimension, and 3.0 for percent rating) in a number of instances. Red oak heartwood, hickory heartwood, and beech heartwood generally exhibited the poorest penetration.

Moisture content played a minor role in explaining penetration (**Table 5.4**). In the case of hickory sapwood, the 12 percent MC was statistically significant ($\alpha = 0.05$) in all 5 parameters. Of the remaining statistical differences, four of six were better at the higher moisture content.

Table 5.4— Mean Penetration Results by Species and Moisture Content for Borate Treated Samples.

	MinX[a]		MaxX		%[b]		MinY		MaxY	
Moisture Content	12%	24%	12%	24%	12%	24%	12%	24%	12%	24%
Yellow-Poplar Heartwood	0.40 (10.2)†	0.36 (9.1)	0.68 (17.3)	0.64 (16.2)	2.13	1.69	0.80 (20.3)	0.68 (17.3)	1.26* (32.0)	0.97 (24.6)
Red Maple Heartwood	0.29 (7.4)	0.30 (7.6)	0.70 (17.8)	0.71 (18.0)	1.76	1.89	0.58 (14.7)	0.59 (15.0)	1.09 (27.7)	1.05 (26.7)
Red Oak Heartwood	0.23 (5.8)	0.26* (6.6)	0.60 (15.2)	0.59 (15.0)	1.60	1.62	0.20 (5.1)	0.32* (8.1)	0.55 (14.0)	0.63 (16.0)
Beech Sapwood	0.64 (16.2)	0.52 (13.2)	0.72 (18.3)	0.75 (19.0)	2.93	2.73	1.53* (38.9)	1.18 (30.0)	1.70 (43.2)	1.56 (39.6)
Beech Heartwood	0.16 (4.1)	0.15 (3.8)	0.70 (17.8)	0.65 (16.5)	1.56	1.40	0.32 (8.1)	0.26 (6.6)	0.88 (22.4)	0.89 (22.6)
Hickory Sapwood	0.36* (9.1)	0.23 (5.8)	0.66* (16.8)	0.61 (15.5)	2.20*	1.42	0.53* (13.5)	0.29 (7.4)	0.75* (19.0)	0.62 (15.7)
Hickory Heartwood	0.19 (4.8)	0.28* (7.1)	0.62 (15.7)	0.60 (15.2)	1.29	1.78*	0.23 (5.8)	0.35 (8.9)	0.59 (15.0)	0.71 (18.0)

a - Inches b - 0 = 0 to 25%, 1 = 25 - 50%, 2 = 50 -75%, 3 = 75 - 100%
* Denotes Statistically Greater Value † Millimeters

Description of the results for the hardwoods pressure treated with borates in terms of AWPA (2) standards is decidedly problematic because Standard C31-93 (borate treatments), stipulates southern pine and hem-fir as the only species groups to be used. However, using the penetration and retention specifications stated in this standard as references, the following inferences can be made about the hardwood treatments carried out in this work. Only wrapped beech sapwood samples (at either moisture content) matched the requirement (for southern pine, hem-fir) that 90% of penetration measurements meet or exceed 2.5" (64 mm) or 85% of the sapwood. Yellow-poplar and red maple heartwood samples (at either moisture content) were closest, of the remaining groups, to meeting the same penetration requirements (47 to 73 percent of the minimum X and Y measurements).

There was no statistically significant difference ($\alpha = 0.05$) between the retention means for the wrapped and unwrapped treatments. However, moisture content was statistically significant ($\alpha = 0.05$) for all species. **Table 5.5** summarizes the mean retention values for all species. All of the mean retentions met the 0.17 pcf requirement for southern pine/hem-fir, except for red oak heartwood and hickory heartwood, both at the higher moisture content.

Table 5.5— Mean Retention[a] Results for Borate Treatment, by Species and Moisture Content.

Moisture Content	12%	17.5%
Yellow-Poplar Heartwood	0.56*(8.97)[b]	0.41(6.57)
Red Maple Heartwood	0.35*(5.61)	0.28(4.48)
Red Oak Heartwood	0.17*(2.72)	0.13 (2.08)
Beech Sapwood	0.70* (11.2)	0.49(7.85)
Beech Heartwood	0.31*(4.97)	0.21(3.36)
Hickory Sapwood	0.33*(5.29)	0.19(3.04)
Hickory Heartwood	0.17*(2.72)	0.14(2.24)

* Denotes Statistically Greater Value. a-PCF As B_2O_3 b-kg/m^3

CONCLUSIONS

Treatability of the hardwoods with creosote was significantly affected by wood moisture content. This generally follows the theory of Choong *et al* (6) that a lower moisture content should increase cell wall permeability, possibly resulting in improved preservative treatment. At the 12 percent MC level, all species except beech and hickory heartwood, had in excess of 80% of all penetration measurements made equaling 0.75" (19 mm) in the X direction and equaling or exceeding 1.5" (38.1 mm) in the Y direction. At the higher MC level, only beech sapwood met the same criteria. Creosote retention was also influenced by MC but to a lesser extent than penetration. Retention results also fell short of 10 pcf (160 kg/m^3), except for beech sapwood, which exceeded this by over 3 pcf at each MC. For several species, the application of incising should increase penetration and retention to acceptable potential AWPA standard levels.

In his work on preservative treatment methods, MacLean (21) noted better relative penetrations and absorbtions of the waterborne preservative solution zinc chloride versus coal-tar creosote. This is the opposite of any findings in this and previous work with hardwoods. Creosote clearly had the best treatability results compared to CCA, ACQ-B, or borates (30, 14).

Borate treatment was most affected by whether the samples were wrapped in plastic or unwrapped following treatment. As the wrapped treatment significantly outperformed the unwrapped case, the common practice of shipping lumber wrapped (particularly softwoods), this alternative should be easily incorporated into commercial practice with hardwoods. Moisture content played only a minor role in improving penetration, with the greatest impact occurring for hickory sapwood. Conversely, MC had statistically significant ($\alpha = 0.05$) effect on borate retention, in all cases, with the lower MC providing for greater retention.

Borate penetration favored the wrapped treatment and moisture content in retention. However, only beech sapwood matched the minimum AWPA (2) penetration requirements specified for southern pine and hem-fir. Similarly, all but red oak heartwood and hickory heartwood, both at 24 percent MC, matched the AWPA retention standard for southern pine and hem-fir.

As the culmination of a work investigating the treatability of selected Appalachian hardwoods with the preservative CCA, ACQ-B, creosote, and borates, creosote was clearly the most effective from the treatability perspective, particularly with the refractory heartwood of hardwoods. That there is no swelling of the wood when treated with creosote as opposed to any of the waterborne solutions is likely a factor in these results. While an optimum moisture content higher than 12% may be the case for some softwoods as postulated by Kumar (17), Morris (22), and Lebow *et al* (19), it was evident that moisture content plays a key role in treatability of both creosote and borates, with a lower moisture content generally providing a greater degree of treatability.

Chapter 6

A Comparison of the Treatability of Southern Yellow Pine to Five Appalachian Hardwoods

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Abstract

The variability of many hardwood species treatability with preservative solutions is one of the key stumbling blocks to their wider use in high biodeterioration situations, except for railway ties treated with creosote. The home-use or Do-It-Yourself market is dominated by southern yellow pine treated with CCA. Recent work performed to determine the treatability of Appalachian hardwoods with CCA, ACQ-B, creosote and borates allowed for some direct comparison of the hardwoods (red oak, beech, hickory, yellow-poplar, and red maple) to southern yellow pine. Southern yellow pine sapwood was as good or better, in relation to treatability with CCA, when compared to yellow-poplar and red maple sapwood. Southern yellow pine heartwood was consistently in the middle range of treatability when compared to the five hardwoods heartwood. Given this and several economic facts related to the marketing of hardwoods, it is unlikely hardwoods will go beyond niche marketing status in the preservative treated wood market.

INTRODUCTION

Work done by Slahor *et al* (30) and Hassler *et al* (14) investigated the treatability of yellow-poplar (*Liriodendron tulipifera* L.), red maple (*Acer rubrum* L.), hickory (*Carya* spp.), beech (*Fagus grandifolia* Ehrh.), and northern red oak (*Quercus rubra*). These studies included six preservative treatments, including: CCA (chromated copper arsenate), ambient ACQ-B (ammoniacal copper quaternary compound-Type B), heated ACQ-B, creosote, unwrapped borate, and wrapped borate. In addition, the treatments were conducted at two moisture contents (12 percent and either 17.5 or 25 percent), with sapwood and heartwood, and at three different pressure periods (60, 90, and 120 minutes). Southern yellow pine obtained from western Virginia (most likely *Pinus echinata* Mill.) was simultaneously evaluated for comparison purposes. However, the pine was subjected to only a subset of the total hardwood treatment combinations investigated. This paper details the results of those available comparisons.

MATERIALS AND METHODS

Nominal two-by-four inch samples, six inches in length were produced from rough-cut material of all sapwood or all heartwood, as described in previous work (30, 14). The southern yellow pine logs obtained for this work were primarily sapwood with heartwood/sapwood being differentiated according to AWPA Standard M2-91, Section 5.3.1 (2). The limited number of heartwood samples restricted the ability for direct comparison to the hardwoods in all treatments. The following comparisons were made: yellow-poplar, red maple, and pine sapwood at 12 and 17.5 percent moisture content (MC) treated with CCA; the heartwood of all of the hardwoods and pine heartwood at 12 percent MC with CCA and both treatments of ACQ-B; and the heartwood of all the hardwoods and pine heartwood at either 17.5 or 24 percent moisture content treated with creosote and borates, respectively. Samples were vacuum/pressure treated in an identical manner (i.e. at the same time). Treatment cycles consisted of a 30 minute vacuum of 28 mm Hg followed by 60, 90, or 120 minute pressure periods. Pressure for the CCA and ACQ-B treatments was 200 psi (0.141 kg/mm^2) and 150 psi (0.105 kg/mm^2) for creosote and borate treatments. Creosote was heated to 120 degrees F (48.9 degrees C) and ACQ-B treatment solutions (1% active ingredient) were heated (180 degrees F/82.2 degrees C) or ambient (80 degrees F/26.7 degrees C). The CCA solution (2% active ingredient) and the borate solution (2% active ingredient) were at ambient (80 degrees F/26.7 degrees C) temperature. Samples were end-sealed before treatment. Borate treated samples consisted of two subgroups: the first group being spaced on wire grills to allow air-drying immediately after treatment, while the second group was immediately dead stacked and wrapped in plastic and stored at room temperature for six weeks. Following the six week period, the samples were unwrapped, open stacked, and allowed to dry.

Preservative penetration measurements were taken according to **Figure 2.1** and the reader is referred to the materials and methods section of chapter 2 for a detailed description of the measurement method. Retention of CCA and ACQ-B was determined by X-ray fluorescence (ASOMA). Retention of creosote and borate was calculated by gross uptake of solution.

Treatability results were tested statistically using analysis of variance (ANOVA). For sapwood comparisons a 2-way ANOVA with interaction was used and the experimental factors were species and moisture content. In all heartwood comparisons, a one-way ANOVA was used, with species as the treatment factor.

RESULTS AND DISCUSSION

<u>Sapwood</u>

Table 6.1 shows the sapwood treatment results. The overall treatment of all three species was excellent, with the pine achieving statistically higher (0.05 alpha) mean penetration on a fairly consistent basis. MaxX means were not statistically significant ($\alpha = 0.05$) since all three species were at their physical maximums (i.e., 0.75 inches). Retention was also significantly higher in pine (0.83 lbs/ft^3), well above the 0.60 pcf (pound per cubic foot) specified in AWPA Standard C2 (2).

Table 6.1— Mean Treatment Results for Southern Yellow Pine, Red Maple, and Yellow-Poplar Sapwood Treated with CCA

Species	# Samples	MinX (in./mm)	MaxX (in./mm)	% Rating[a]	MinY (in./mm)	MaxY (in./mm)	Retention (PCF)
Yellow-Poplar	38	0.58 (15)	0.75 (19)	2.84[b]	1.32 (34)	1.69 (43)	0.59[b] (9.4)[c]
Red Maple	39	0.49[b] (12)	0.75 (19)	2.85 [b]	1.18 (30)	1.61[b] (41)	0.66[b] (10.6)
Southern Yellow Pine	50	0.65 (17)	0.75 (19)	3.00	1.75 (44)	1.75 (44)	0.83 (13.3)

a - 0 = 0-25%, 1 = 25-50%, 2=50-75%, and 3=75-100%
b -Statistically less than pine at $\alpha = 0.05$ c - kg/m^3

The interaction between species and moisture content was also statistically significant ($\alpha = 0.05$) in treatability parameters (except MaxX, where all means were at their physical maximum of 0.75 inches). The 17.5 percent MC for pine was statistically greater for MinX, MinY, and retention (MaxX, MaxY, and % rating were not statistically different since the maximum possible values were obtained for both moisture contents). The interactions further indicated that the 17.5 percent MC for pine consistently outperformed all species at either moisture content.

Heartwood

It is generally well documented that the heartwood of southern yellow pine is refractory. Slahor *et al* (30) and Hassler *et al* (14) also found the heartwood of hardwoods was generally difficult to treat. **Tables 6.2** through **6.7** contain the treatability results for all hardwood species compared to pine. These results support the refractory nature of heartwood, regardless of species studied here. The best penetration and retention occurred with creosote at 17.5 percent MC and borate wrapped in plastic at 25 percent MC.

Comparing the pine treatability results to the various hardwood species indicated a mix of results (**Table 6.2**), hardwood results (depending on species) being statistically (0.05 alpha) better, worse, or the same. In the case of CCA at 12 percent MC, yellow-poplar and red maple showed significantly higher penetration and retention. Beech also showed improved penetration in the MaxX, MaxY, and % Rating. In all cases, the results would be well below AWPA standards.

Table 6.2— Mean Treatment Results for Heartwood of Southern Yellow Pine and Five Hardwood Species Treated with CCA at 12 Percent Moisture Content.

Species	# Samples	MinX (in./mm)	MaxX (in./mm)	% Rating[a]	MinY (in./mm)	MaxY (in./mm)	Retention (PCF)
Yellow-Poplar	30	0.12[b] (3)	0.60[b] (15)	1.57 [b]	0.13 (3)	0.92[b] (23)	0.44[b] (7.0)[c]
Red Maple	30	0.25 [b] (6)	0.54[b] (14)	1.67 [b]	0.52[b] (13)	1.07 [b] (27)	0.47 [b] (7.5)
Red Oak	30	0 (0)	0.20[d] (5)	0.03	0 (0)	0.20 (5)	0.18[d] (2.9)
Beech	30	0.04 (1)	0.63[b] (16)	1.47[b]	0.10 (3)	1.07[b] (27)	0.32 (5.1)
Hickory	30	0 (0)	0.13[d] (3)	0	0 (0)	0.10 (3)	0.14[d] (2.2)
Southern Yellow Pine	30	0.04 (1)	0.32 (8)	0.17	0.03 (1)	0.36 (9)	0.31 (5.0)

a - 0 = 0-25%, 1 = 25-50%, 2=50-75%, and 3=75-100% b - Statistically greater than pine at α = 0.05
c - kg/m^3 d -Statistically less than pine at α = 0.05

Depending on the type of ACQ-B treatment, different results were evident. For the ambient solution (**Table 6.3**), both red maple and beech showed improved results over pine, in all treatability parameters. Both red oak and hickory showed a trend toward poorer treatability than pine in 3 of 6 treatability categories. Yellow-poplar showed no differences compared to southern pine. The heated ACQ-B solution showed yellow-poplar with better treatability results in 4 of 6 treatability parameters (**Table 6.4**). No significant trend was evident in the other species.

Table 6.3— Mean Treatment Results for Heartwood of Southern Yellow Pine and Five Hardwood Species Treated with Ambient ACQ-B at 12 Percent Moisture Content.

Species	# Samples	MinX (in./mm)	MaxX (in./mm)	% Rating[a]	MinY (in./mm)	MaxY (in./mm)	Retention (PCF)
Yellow-Poplar	30	0.14 (4)	0.48 (12)	1.10	0.20 (5)	0.63 (16)	0.11 (1.8) [b]
Red Maple	30	0.22[c] (6)	0.66[c] (17)	2.10[c]	0.44[c] (11)	1.28[c] (33)	0.13[c] (2.1)
Red Oak	30	0[d] (0)	0.38[d] (10)	0.67[d]	0.02 (1)	0.47 (12)	0.10 (1.6)
Beech	30	0.24[c] (6)	0.64[c] (16)	2.37[c]	0.41[c] (10)	1.04[c] (26)	0.17[c] (2.7)
Hickory	30	0.01 (0)	0.25[d] (6)	0.33	0.01 (0)	0.30[d] (8)	0.06[d] (1.0)
Southern Yellow Pine	30	0.08 (2)	0.49 (12)	1.20	0.01 (0)	0.30 (8)	0.10 (1.6)

a - 0 = 0-25%, 1 = 25-50%, 2=50-75%, and 3=75-100% b - kg/m^3
c - Statistically greater than pine at $\alpha = 0.05$ d -Statistically less than pine at $\alpha = 0.05$

Table 6.4— Mean Treatment Results for Heartwood of Southern Yellow Pine and Five Hardwood Species Treated with Heated ACQ-B at 12 Percent Moisture Content.

Species	# Samples	MinX (in./mm)	MaxX (in./mm)	% Rating[a]	MinY (in./mm)	MaxY (in./mm)	Retention (PCF)
Yellow-Poplar	30	0.23 (8)	0.66[b] (17)	2.20[b]	0.37[b] (9)	1.00[b] (25)	0.14 (2.2)[c]
Red Maple	30	0.04[d] (1)	0.54[b] (14)	0.70	0.07 (2)	0.71 (18)	0.09[d] (1.4)
Red Oak	30	0[d] (0)	0.30 (5)	0.33[d]	0 (0)	0.34 (5)	0.20[d] (2.9)
Beech	30	0.07[d] (2)	0.46 (12)	0.77	0.11[b] (3)	0.64 (16)	0.09[d] (1.4)
Hickory	30	0.04[d] (1)	0.41 (10)	0.83	0.04 (1)	0.45 (11)	0.08[d] (1.3)
Southern Yellow Pine	30	0.39 (10)	0.38 (10)	0.97	0.01 (0)	0.48 (12)	0.12 (1.9)

a - 0 = 0-25%, 1 = 25-50%, 2=50-75%, and 3=75-100% b - Statistically greater than pine at $\alpha = 0.05$
c - kg/m^3 h -Statistically less than pine at $\alpha = 0.05$

Creosote results were also mixed (**Table 6.5**). Southern pine had generally better treatability than beech and hickory. No statistically significant ($\alpha = 0.05$) differences were found between red maple and southern pine, while yellow-poplar was somewhat better. Red oak was also better in MinX, MinY, and MaxY, but poorer in retention.

Table 6.5— Mean Treatment Results for Heartwood of Southern Yellow Pine and Five Hardwood Species Treated with Creosote at 17.5 Percent Moisture Content.

Species	# Samples	MinX (in./mm)	MaxX (in./mm)	% Rating[a]	MinY (in./mm)	MaxY (in./mm)	Retention (PCF)
Yellow-Poplar	30	0.58[b] (15)	0.74 (19)	2.93[b]	1.10[b] (28)	1.37 (35)	6.82 (109.2)[c]
Red Maple	30	0.39 (10)	0.71 (18)	2.43	0.73 (19)	1.06 (27)	6.29 (100.8)
Red Oak	30	0.63[b] (16)	0.75 (19)	2.93[b]	1.29[b] (33)	1.61[b] (41)	4.38[d] (70.2)
Beech	30	0.32[d] (8)	0.73 (19)	2.23[d]	0.59 (15)	1.10 (28)	4.70[d] (75.3)
Hickory	30	0.23[d] (6)	0.66[d] (17)	1.80[d]	0.38 (10)	0.61[d] (15)	3.55[d] (56.9)
Southern Yellow Pine	30	0.45 (11)	0.74 (19)	2.63	0.80 (20)	1.22 (31)	8.29 (132.8)

a - 0 = 0-25%, 1 = 25-50%, 2=50-75%, and 3=75-100% b - Statistically greater than pine at $\alpha = 0.05$
c - kg/m^3 d -Statistically less than pine at $\alpha = 0.05$

The unwrapped borate treatment showed very few differences between pine and the hardwoods (**Table 6.6**). Yellow-poplar had the most definitive results, having better penetration in MinX, MinY and retention.

The wrapped borate treatment also showed little evidence of any differences between species (**Table 6.7**). Red maple showed improved results in MinX, MinY, and MaxY. Yellow-poplar also had better retention than southern pine, while red oak and hickory had statistically significant ($\alpha = 0.05$) lower retention.

Table 6.6— Mean Treatment Results for Heartwood of Southern Yellow Pine and Five Hardwood Species Treated With Borate (Unwrapped) at 25 Percent Moisture Content.

Species	# Samples	MinX (in./mm)	MaxX (in./mm)	% Rating[a]	MinY (in./mm)	MaxY (in./mm)	Retention (PCF)[b]
Yellow-Poplar	30	0.25[c] (6)	0.60 (15)	1.23	0.48[c] (12)	0.84 (21)	0.40[c] (6.4) [d]
Red Maple	30	0.14 (4)	0.70 (18)	1.40	0.20 (5)	0.89[c] (23)	0.30 (4.8)
Red Oak	30	0.17 (4)	0.55 (14)	1.23	0.17 (4)	0.46 (12)	0.12[e] (1.9)
Beech	30	0.09 (2)	0.61 (15)	1.00	0.11 (3)	0.81 (21)	0.20 (3.2)
Hickory	30	0.21 (5)	0.55 (14)	1.57	0.22 (6)	0.54 (14)	0.17[e] (2.7)
Southern Yellow Pine	30	0.16 (4)	0.62 (16)	1.20	0.24 (6)	0.54 (14)	0.26 (4.2)

a - 0 = 0-25%, 1 = 25-50%, 2=50-75%, and 3=75-100% b - as B_2O_3
c - Statistically greater than pine at $\alpha = 0.05$ d - kg/m^3 e -Statistically less than pine at $\alpha = 0.05$

Table 6.7— Mean Treatment Results for Heartwood of Southern Yellow Pine and Five Hardwood Species Treated With Borate (Wrapped in Plastic) at 25 Percent Moisture Content.

Species	# Samples	MinX (in./mm)	MaxX (in./mm)	% Rating[a]	MinY (in./mm)	MaxY (in./mm)	Retention (PCF)[b]
Yellow-Poplar	15	0.56 (14)	0.72 (18)	2.60	1.06 (27)	1.21 (31)	0.43[c] (7.4)[d]
Red Maple	15	0.63[c] (16)	0.73 (19)	2.87[c]	1.37[c] (35)	1.37 (35)	0.25 (4.0)
Red Oak	15	0.43 (11)	0.68 (17)	2.40	0.61 (15)	0.95 (24)	0.15[e] (2.4)
Beech	15	0.28[e] (7)	0.73 (19)	2.20	0.55 (14)	1.06 (27)	0.23 (3.7)
Hickory	15	0.42 (11)	0.68 (17)	2.20	0.61 (15)	1.04 (26)	0.18[e] (2.9)
Southern Yellow Pine	15	0.46 (12)	0.70 (18)	2.40	0.82 (21)	1.11 (28)	0.28 (4.5)

a - 0 = 0-25%, 1 = 25-50%, 2=50-75%, and 3=75-100% b - as B_2O3
c - Statistically greater than pine at $\alpha = 0.05$ d - kg/m^3 e -Statistically less than pine at $\alpha = 0.05$

CONCLUSIONS

The treatability of southern yellow pine is well established, in relation to waterborne preservatives (especially CCA), as evidenced by its market dominance in spite of having a refractory heartwood. Results of this investigation indicate that southern pine does not similarly dominate hardwoods with respect to treatability. Although southern pine sapwood treatability was as good in all treatment parameters and better in several as compared to yellow-poplar and red maple sapwood, such was not the case for heartwood. For CCA and ACQ-B, depending on the preservative, yellow-poplar, red maple, and beech heartwood showed better treatability. Yellow-poplar and red oak showed improved treatability with creosote, while the borate treatments showed little improvement for hardwoods over southern pine.

Hardwoods, despite some potentially improved treatability in certain species, have not made many inroads into the southern pine treated product market for several reasons. Traditionally, hardwoods have been marketed and sold as appearance graded lumber in non-structural markets. There remains no incentive to convert the high quality outer portions of logs, where the very treatable sapwood exists, to less valuable structural applications. The lower quality log hearts of hardwoods have traditionally been marketed to industrial applications where strength is important. Railroad ties and pallet materials, among others, have provided readily available markets for hardwood hearts. The necessary effort to redirect this material to treated markets dominated by southern pine has not been thorougly investigated. The hardwood industry, in general, currently is not consolidated sufficiently to allow for surfacing, trimming, structural grading, drying, and treating in a single location. The increased handling costs to accomplish these processes in the hardwood industry would need to be determined.

In the final analysis, if hardwoods are to become competetive in the end-use markets currently dominated bt southern pine, development of efficient, cost-effective preservative sysyem(s) is essential. If successful treating of hardwoods can bring a sufficient premium to the lower grades (#1 & 2A common) or pallet stock of species such as beech and hickory, a segment of the hardwood industry might be augmented. If the additional costs of production can be justified, establishment of an agency similar to Southern Pine Treaters Association (SPTA) or Western Wood Preservers Institute (WWPI) could help market the new products.

EPILOGUE

The main objective to quantify the treatabilty of the hardwood species investigated in this work was accomplished. While the statistical analysis of the data, for the most part, yielded inconclusive results some findings stand out:

1. That a lower moisture content improved creosote penetration and retention.
2. That wrapping borate treated samples in plastic improves penetration.
3. That, overall, treatability of hardwoods is comparable to treatabilty of southern pine.
4. That creosote clearly was the most effective preservative used in this study as it relates to treatability.
5. That treatability of hardwoods is extremely variable, from species to species, as well as within species.

The final note on variability is exemplified by looking at the results for red oak, hickory, and beech. For the three water-borne preservatives results for red oak and hickory were, for the most part, extremely poor with beech results being moderately better. However, the results from treatment with creosote were essentially the opposite for red oak and beech, but not for hickory. While red oak can be separated out from the other two species as a ring porous hardwoods, it is a curiosity as to why the two anatomically similar species of beech and hickory, can have very similar results when treated with water-borne preservatives (at least the heartwood samples) and such different results when treated with the tat-oil preservative creosote (especially the sapwood samples).

It is on this final note that the direction of any future work into preservative treatment of hardwoods is indicated. If hardwoods are to be treated for an end-use other than the traditional railway tie and bridge material, a suitable preservative other than creosote (to allow for easier handling, fabrication, and human contact) will need to be developed. If this work is any indication, that preservative will have to an oil-borne preservative. Further, the driving force of when/whether this will occur is economic in nature. The markets that a preservative treated (other than creosote) hardwood product would be competing in are currently dominated by CCA treated southern pine. There will have to be an economic reason driving the overall development of such a hardwood product.

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