Treatability Of Five Appalachian Wood Species With Creosote And Timbor®[1]

Jeffrey J. Slahor
Curt C. Hassler
Appalachian Hardwood Center
West Virginia University
Morgantown West Virginia

Rodney C. DeGroot
Forest Products Laboratory
USDA Forest Service
Madison, Wisconsin

Douglas J. Gardner
Institute of Wood Research
Michigan Technological University
Houghton Michigan

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.* [7] and Hassler *et al.* [8] 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 sap-

[1]Acknowledgment and appreciation to AlliedSignal Corporation for supplying coal-tar creosote and to US Borax for supply of Timbor® and analysis of preservative solutions.

wood (*Fagus grandifolia* Ehrh.) as described in Slahor et al[8]. Straight grained, as defect free as possible, six-inch long samples were cut and placed in conditioning rooms set at 70°F (21°C) and 65%RH or 80°F (27°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°F (21°C) and 65%RH or 60°F (15.5°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 mmHg 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[1]).

Penetration measurements were made according to the diagram contained in Figure 1: Min(imum)X, Max(imum)X, Min(imum)Y, Max(imum)Y, and a rating of percentage of cross-section penetrated (where ratings were 0 = 0-25 percent, 1 = 25-50 percent, 2 = 50-75 percent, and 3 = 75-100 percent penetrated). Maximum measurements were limited to one-half of the total possible distance in each dimension (i.e., 0.75 inches/ 19.05 mm in the X dimension and 1.75 inches/44.45 mm in the Y dimension).

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 at an alpha level of 0.05. Sample size, by species, for the borate treated samples wrapped in plastic was 15, while the other treatments (creosote and unwrapped borate) were 30.

Results were also compared to the minimum treatability requirements as specified in the AWPA Book of Standards 1995[1]. Standard C2-Lumber, Timber, and Ties-Preservative Treatment by Pressure Processes and Standard C14-93- Wood for Highway Construction-Preservative Treatment by Pressure Processes, 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.

Creosote penetration in Standard C2 for red oak requires that in a sample of 3-inch-long cores from 20 pieces in a charge, an average of at least 65% of annual rings should be penetrated. 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 Cl (All Timber Products-Preservative Treatment by Pressure Processes) 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, since the requirement is that 65 percent of annual rings must be penetrated.

Standard C31-95-Lumber Used Out of Contact With the Ground and Continuously Protected From Liquid Water-Treatment by Pressure Processes specifies penetration and retention requirements for southern pine and hem-fir, 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 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 effect on penetration across all species, except in beech heartwood (Table 1).

In many instances, statistical significance was not present 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 1. It is further evident in Table 1 that the 12 percent MC level was statistically superior in improving penetration. 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 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. As such, percent of growth ring penetration was not determined. 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 2 contains the creosote retention results for both moisture contents. Statistical significance occurred for yellow-poplar, red oak, and hickory heartwood, and hickory sapwood, all favoring the 12 percent MC. 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/l54.8 kg/m^3) 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°F (49°C) the heavier fractions of creosote did not become viscous enough for extensive radial and tangential penetration.

Borates

The most consistent statistical result, across all species. was the difference between wrapped and unwrapped samples for the five penetration parameters. The only non-significant results between these two treatments was MaxX for beech heartwood and sapwood and MaxY for beech sapwood. Table 3 illustrates the means for the wrapped and unwrapped treatments. It is important to note that statistical significance 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).

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 4). In the case of hickory sapwood, the 12 percent MC was statistically significant in all 5 parameters. Of the remaining statistical differences, four of six were better at the higher moisture content.

Description of the results for the hardwoods pressure treated with borates in terms of AWPA standards is decidedly problematic because Standard C31-95, Lumber Used Out of Contact With the Ground and Continuously Protected From Liquid Water -Treatment by Pressure Processes, 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 between the retentions for the wrapped and unwrapped treatments. However, moisture content was statistically significant for all species. Table 5 summarizes the mean borate 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.

Conclusions

Treatability of the hardwoods with creosote was significantly affected by wood moisture content. This generally follows the theory of Choong *et al.* [2] 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[6] 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-9, or borates[3,8]

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 was significant in affecting borate retention, in all cases, with the lower MC providing for greater retention.

Strong statistical differences in borate penetration favored the wrapped treatment and the lower moisture content in retention. However, only beech sapwood matched the minimum AWPA 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 (1989)[4], Morris (1991)[7], and Lebow et al (1996)[5], 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.

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DISCUSSION

SESSION CHAIRMAN PRESTON: Thank you, Jeff. Does anyone have any questions for Jeff? Scott Conklin.

SCOTT W. CONKLIN, UNIVERSAL FOREST PRODUCTS: Thank you for the paper. That was very interesting. My basic question is on the borate treatment. Did you have any particular end use in mind? I just get a little nervous when I hear the Timber Bridge Initiative associated with borate treatment.

MR. SLAHOR: Well, that was one of the things discussed, perhaps not in depth, at the beginning of the project. If you were to have outdoor patio furniture that was either protected from the rain, maybe not continuously, but a fair amount, or the type of thing that would be brought in that would be outside, but not necessarily in the weather all the time, that might be an application. Perhaps some construction applications like treatment for sill plates for softwoods. If you were going to build an oak log cabin, this might be an appropriate treatment.

JEFFREY J. MORRELL, OREGON STATE UNIVERSITY: There's a lot of data on conifers that suggest that wood at 27% moisture content treats much better than wood at 12% moisture content. I'm curious as to what you think are the differences between your results and those and why?

MR. SLAHOR: I think in the anatomy of the differences in the woods is where the key to the answer to that question is, but not being an anatomist, the best I could do is guess.

DR. MORRELL: Then the follow-up question was have you looked at the woods to see what the distribution of the creosote is in those particular species?

MR. SLAHOR: No, that's one thing we haven't done.

WILLIAM SMITH; COLLEGE OF ENVIRONMENTAL SCIENCE AND FORESTRY, SYRACUSE: When you determined retention how did you determine volume and when?

MR. SLAHOR: Volume was assumed to be the 1½ by 3½ by 6 inches that the samples were made to be by the molder-planer process. Now I know there would be some variations after that fact with change in moisture content, but for better or worse they were ignored.

DR. SMITH: Okay, so because at 12% moisture a smaller volume, if you measured it at 12, could give you a higher retention for a same piece. If you're measuring the volume at 12 versus the volume at MR. SLAHOR: Right.

DR. SMITH: How did you determine heartwood?

MR. SLAHOR: In some instances like beech and hickory, it's fairly easy to do. Although there is no clear cut test like there is for Southern pine, there is a fair to great difference in coloration. We also used ring orientation. Certainly if pith were present, or from the way the rings were arranged obviously close to the sample. Most of the trees that we had cut were sizeable - 2 to 3 feet in diameter.

DR. SMITH: The reason I asked is one of your slides which showed heartwood penetration, I saw what I would consider a characteristic curved shape that would show me the sapwood-heartwood distinction line on one corner, which looked like heartwood.

MR. SLAHOR: Right, the yellow poplar heartwood sample treated with CCA and that is a problem. The accurate and consistent distinction between heartwood and sapwood is a problem. There is one paper published by the Forest Products Journal and another one that is in process right now that discusses this problem in this type of work.

DR. SMITH: May I make a suggestion on experience we've had. When you visit saw mills when you don't have a clear distinction by color, as in red oak or Douglas-fir or Southern pine, you can often tell by moisture content in that the sapwood and heartwood has a distinctly different moisture content. The fibers tear differently on the crosscut saw. If you see it in log form, you can typically tell moisture content differences. Then obtain some end sealing paint - Anchor seal, the Chapman product, what-have-you - two different colors and just paint it. When the lumber comes off, you typically have a board, which you can much more easily track, when it's wet as opposed to when it's dry. That helps you follow up the studies with pure heartwood, or pure sapwood. In the paper with did with Rod DeGroot a couple of year's ago, we saw very clear distinctions in treatability of red maple heartwood and sapwood when we were truly confident we had different material.

Just one other thing. Did you in your x-y direction, did you keep a distinction on tangential versus radial, as opposed to simply x-y in the 2x4?

MR. SLAHOR: No, that was something that was discussed again at the outset, but with the volume that we were talking about for the total project, we have just under 2,500 samples that were treated and measured, it was concluded that it would be too difficult and too time consuming to produce that volume of samples paying attention to such.

DR. SMITH: I guess I'd be concerned with that because of an anatomical stand point tangential and radial means a lot from a scientific study as opposed to simply 2x4. On your penetration slides, I was seeing a lot of numbers in x-y, but I think the middle column was showing 3%. I've seen numbers I thought were about 3, was I off on that?

MR. SLAHOR: No, there were some. That would indicate that over the average of all of the samples that they were all given approximately 3s which would be 75 to 100% penetration.

DR. SMITH: Oh, okay, I was thinking that was 3%.

MR. SLAHOR: No, and that's one of the points of confusion that has arisen in the papers that we've tried to generate.

DR. SMITH: Thank you.

DARRELL SMITH, CONRAD WOOD PRESERVING: I'd like to know something about your ACQ-B? What was your process? Was your wood conditioned beforehand? Did you condition it in the retort? Then was the chemical heated?

MR. SLAHOR: The chemical was both heated and ambient. We did some samples at an ambient temperature of approximately 80° and some samples with a cylinder that we had for that at 180°.

MR. SMITH: So the wood wasn't like in conifers, something prepared before treatment, you just were using the chemical and it was heated. So it wasn't a typical treatment such as we would use in a commercial treatment?

MR. SLAHOR: Right, I guess, I guess the assumption there was that the samples were small enough that even within the shortest time period, the wood would come to the same temperature as the solution. It really wasn't considered beforehand.

MR. SMITH: But then you compared it against CCA under a pressure treatment process as the same as a commercial product.

MR. SLAHOR: We did not try to make comparisons between species, or between preservatives, because we did not want to get into the apples and oranges thing. We knew that there were a lot of loose ends here. So in that case what we tried to compare was the ambient ACQ versus the heated ACQ-B.

That paper has been published. At least the one dealing with the 12% moisture content samples in the Forest Products Journal about a year ago and we have another one that takes that same data including, and now includes the higher moisture content data samples, which should be published here in the next couple of months.

MR. SMITH: I know it doesn't need any conditioning, the conditioning process is usually used to help get your moisture contents in your serviceability, but it also helps in the treating process. We've found that that's so in our commercial process.

MR. SLAHOR: Conditioning was not really thought about beforehand.

MR. SMITH: The other point was, when you were doing the borates, am I mistaken, actual penetration was better with the 12% than the 17%?

MR. SLAHOR: Not when that was singled out of the statistical analysis. They were the same samples with the three-way analysis of variance run and if you pulled out the 12% versus the 24% data, there was essentially no difference between the two. If you just looked at the wrapping versus the unwrapping, the wrapped samples clearly had better results, either at 12% or 24%.

MR. SMITH: It didn't matter because it was wrapped and so there wasn't the evaporation so the movement was there.

MR. SLAHOR: Right.

MR. SMITH: Thank you.

MR. SLAHOR Thank you.

SESSION CHAIRMAN PRESTON: I'd like to give Jeff a round of applause for his paper. [Applause]

The last presentation before the Nonpressure and Treatments Committee Reports is by Jim Saur. He will being us up to date on the Use category System. Jim has been with CSI for about twelve years. He is General Chairman of the Treatments Committees. I'd like you to welcome Jim Saur. [Applause]

Figure 1 – Penetration Measurements

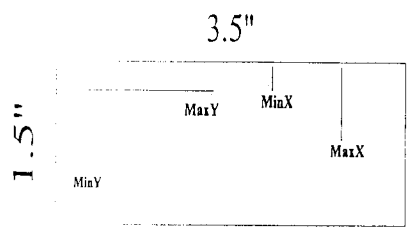

Table 1 Mean Penetration Results by Species and Moisture Content for Creosote Treated Samples.

	MinX[a]		MaxX[a]		%[b]		MinY[a]	
Moisture Content	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)	1.13 (27.9)
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)
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)
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)
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)
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)
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)

[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

Table 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)
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[a](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.

Table 3 Mean Penetration Results by Species and Type of Treatment (Wrapped vs. Unwrapped) for Borate Trea Samples.

	MinX[a]		MaxX		%[b]		MinY	
Treatment	W[c]	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)
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)
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)
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)
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)
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)
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)

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

Table 4 — Mean Penetration Results by Species and Moisture Content for Borate Treated Samples.

	MinX[a]		MaxX		%[b]		MinY	
Moisture Content	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)
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)
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)
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)
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)
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)
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)

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

Table 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

PROCEEDINGS

Ninety-Fourth Annual Meeting

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