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.

A number of researchers have studied wood moisture content (MC), focusing on its impact on preservative treatability and its relationship to the practical aspects of commercial pressure treatment. According to Choong et al. (4) a lower MC should increase ceil wall permeability, possibly resulting in improved preservative treatment. Kumar and Morrell (5) theorized that western hemlock wood near the fiber saturation point (FSP) should be most treatable, with no free water present, the ceil 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 MC levels evaluated (9%, 18%, 28%, and 40%) 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 (5) 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 improved penetration with CCA. Lebow et al. (4) 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 MCs 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 (EMCs): 12 and 17.5 percent.

MATERIALS AND METHODS

Nominal 2 by 4's were produced from yellow-poplar sapwood and heartwood (*Liriodenaron tulipifera* L.), red maple sapwood and heartwood (*Acer rubrum* L.), red oak heartwood (*Quercus rubra*). hickory sapwood and heartwood (*Carya*

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spp.), and beech sapwood and heartwood (*Fagus grandifolia* Ehrh.) as described in Slahor et al. (8). Straight-grained, as defect-free as possible, 6-inch long samples were cut and placed in conditioning rooms set at 70°F (21°C)/65 percent relative humidity (RH) or 80°F (27°C)/85 percent RH to equilibrate at 12 percent or 17.5 percent MC. The 17.5 percent MC was dictated by the limitations of the conditioning unit available at the time. All samples at the higher MC had first dried to the 12 percent MC under the previously 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 percent MC treated with ambient and heated ACQ-B solutions. Wood for these treatments was conditioned to 17.5 percent MC without drying to 12 percent MC first. Ovendry MCs were determined using excess samples in the same conditioning unit. After several weeks, when the ovendry MC leveled off at 12 or 17.5 percent, it was assumed the remaining samples were at like MCs 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.

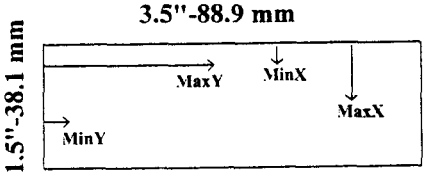

Figure 1. – Penetration measurements.

End-matching of samples was not done. However, as just desribed, 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 MC 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 differences (density, within and between board, within and between tree, storage, and preservative solution) should have been minimized with the likelihood that any/all of these sources of variability could be found in the 12 percent MC group just as likely as their being found in the 17.5 percent group.

Preservative solution concentrations were 1 and 2 percent active ingredient, respectively, for ACQ-B and CCA-C. The ACQ-B solutions were heated to either 180°F (82°C) or 80°F (27°C) henceforth referred to as a heated or ambient solution, respectively. The CCA solutions used complied with AWPA (1) Standard P5-93 section 6. 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-minute periods.

Of the ACQ-B solutions, all were in compliance with AWPA Standard P5 section 13, except for the following instances; red maple and yellow-poplar heartwood, and hickory heartwood and sapwood samples at 12 percent 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 percent active ingredient solution, and beech heartwood and sapwood samples at 12 percent 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. (8), retentions were determined using x-my fluorescence spectroscopy (ASOMA). The densities used for retention determination, based on 0 percent MC, were as follows: yellow-poplar, 26.2 pcf; red maple, 33.7 pcf; beech, 39.9, pcf, red oak, 39.3 pcf; and hickory, 44.9 pcf (7). Penetration measurements were made as shown in **Figure 1;** Min(imum)X, Max(imum)X, Min(imum)Y. Max (imum)Y, as well as a rating of percentage of cross section penetrated Maximum measurements were limited to one-

TABLE 1. — Sample sizes by species, preservatives, MC, and pressure time period.

	CCA						Ambient ACQ-B						Heated ACQ-B					
	12% MC			17.5% MC			12% MC			17.5% MC			12% MC			17.5% MC		
Time (min.)	60	90	120	60	90	120	60	90	120	60	90	120	60	90	120	60	90	120
Beech sapwood	10	10	10	10[a]	10[a]	10[a]	10	10	10	6	6	7	10	10	10	10	10	10
Beech heartwood	10	10	10	10[a]	10[a]	10[a]	10	10	10	6[a]	5[a]	12[a]	10	10	10	10	10	10
Hickory sapwood	10	10	10	10	10	5	10	10	10	6	6	6	10	10	10	8	8	10
Hickory heartwood	10	10	10	10	10	5	10	10	10	6	6	6	10	10	10	8	10	10
Red oak heartwood	10	10	10	10[a]	10[a]	5[a]	10	10	10	7[a]	10[a]	10[a]	10	10	10	10	10	10
Yellow-poplar sapwood	10	10	10	8	--	--	10	10	10	--	--	--	10	10	10	--	--	--
Yellow-poplar heartwood	10	10	10	10	10	5	10	10	10	6	6	6	10	10	10	7	8	10
Red maple sapwood	10	10	10	10	--	--	10	10	10	--	--	--	10	10	10	--	--	--
Red maple heartwood	10	10	10	10	10	5	10	10	10	6	6	6	10	10	10	8	9	10

[a]These samples were conditioned from green to 17.5 percent MC without going below 17.5 percent MC.

half the total possible distance in each dimension (i.e., 0.75 in. = 19.5 mm in the X dimension, 1.75 in. = 44.4 mm in the Y dimension). Percentage of cross section penetrated was given a rating of 0, 1, 2, or 3 where 0 = 0 to 25 precent, 1 = 25 to 50 percent, 2 = 50 to 75 percent, and 3 = 75 to 100 percent penetration. An entire cross section of the sample was ground and used for the retention determination. Therefore, the values discussed here are likely to be very conservative as compared to values determined from the assay zone of 0 to 0.6 inch, as referred to in AWPA Standard C2.

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 (6) analysis, which adjusts for unequal sample sizes, showed no trend as a result of pressure time period (60, 90, and 120 min.), except for one instance, which is discussed in the appropriate results section. Given this result from the two-way analysis of variance (ANOVA) with interaction, the three pressure periods were combined (eliminating time period as a factor) and a one-way ANOVA of MC was used to describe the results for simplicity sake. The two-way GLM is specified as follows:

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

where:

Y_{ijk} = measure of treatability, as either retention or penetration, for the jth sample of the ith MC

m = overall mean penetration or retention

MC_i = effect of the ith MC (1 = 12%; 2 = 17.5%)

T_j = effect of the jth pressure time period (60, 90, or 120 min.)

$\in_{ijk}$ = experimental error associated with Y_{ijk}; all tests of significance were conducted at a significance level of 0.05

The model just described is given for the sake of clarity. As was mentioned previously, only the results of a one-way ANOVA, with MC 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, MC, and time period are presented in **Table 1.** Time period is noted for clarification purposes only, and is not reported in subsequent tables.

BEECH

In all measures of treatability for beech sapwood treated with CCA, except for the MaxX measurement, the 12 percent MC level was statistically better than the 17.5 percent MC **(Table 2).** For the ACQ-B solutions, only 5 of 12 treatability parameters were statistically significant **(Table** 2). Both retention results were significant and favored the 17.5 percent MC, as did the MaxX mean for

TABLE 2. — Means of percentage rating of cross section penetrated, retention (pcf, total oxide basis), and penetration (in.) for beech sapwood at two MCs treated with CCA and ambient and heated ACQ-B solutions.

	Rating[a]		Retention		MinX		MaxX		MinY		MaxY	
	12% MC	17.5% MC	12% MC	17.5% MC	12% MC	17.5% MC	12% MC	17.5% MC	12% MC	17.5% MC	12% MC	17.5% MC
	----- (%) -----		----- (pcf) -----		----- (in.) -----							
CCA	2.50*[b]	1.70	0.481*	0.414	0.13*	0.04	0.70	0.67	0.36*	0.04	1.59*	1.10
			(7.70)[c]	(6.63)	(3.3)[c]	(1.0)	(17.8)	(17.0)	(9.1)	(1.0)	(40.4)	(27.9)
ACQ-B, A[d]	2.67	2.74	0.188	0.208*	0.33	0.36	0.65	0.74*	0.55	0.54	1.18	1.12
			(3.01)	(3.33)	(8.4)	(9.1)	(16.5)	(18.8)	(14.0)	(13.7)	(30.0)	(28.4)
ACQ-B, H[d]	2.97*	2.73	0.197	0.237*	0.41	0.39	0.73	0.72	0.65	0.56	1.64*	1.02
			(3.16)	(3.80)	(10.4)	(9.9)	(18.5)	(18.3)	(16.5)	(14.2)	(41.6)	(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] Values with an asterisk are significantly better than the values at the other MC level.
[c] Values in parentheses for retention are kg/m^3; values in parentheses for penetrations are mm.
[d] A = ambient temperature; H = heated.

TABLE 3. — Means of percentage rating of cross section penetrated, retention (pcf, total oxide basis), and penetration (in.) for beech heartwood at two MCs treated with CCA and ambient and heated ACQ-B solutions.

	Rating[a]		Retention		MinX		MaxX		MinY		MaxY	
	12% MC	17.5% MC	12% MC	17.5% MC	12% MC	17.5% MC	12% MC	17.5% MC	12% MC	17.5% MC	12% MC	17.5% MC
	----- (%) -----		----- (pcf) -----		----- (in.) -----							
CCA	1.47*[b]	0.37	0.321*	0.221	0.04	0.02	0.63	0.54	0.10	0.02	1.07*	0.58
			(5.14)[c]	(3.54)	(1.0)[c]	(0.5)	(16.0)	(13.7)	(2.5)	(0.5)	(27.2)	(14.7)
ACQ-B, A[d]	2.37*	0.09	0.167*	0.047	0.24*	0.02	0.64*	0.38	0.41*	0.03	1.04*	0.33
			(2.68)	(0.75)	(6.1)	(0.5)	(16.2)	(9.6)	(10.4)	(0.8)	(26.4)	(8.4)
ACQ-B, H[d]	0.77*	0.07	0.093*	0.050	0.07*	0.06	0.46	0.37	0.11	0.07	0.64*	0.38
			(1.49)	(0.80)	(1.8)	(1.5)	(11.7)	(9.4)	(2.8)	(1.8)	(16.2)	(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] Values with an asterisk are significantly better than the values at the other MC level.
[c] Values in parentheses for retention are kg/m^3; values in parentheses for penetrations are mm.
[d] A = ambient temperature; H = heated.

TABLE 4. — Means of percentage rating of cross section penetrated, retention (pcf, total oxide basis), and penetration (in.) for hickory sapwood at two MCs treated with CCA and ambient and heated ACQ-B solutions.

	Rating[a]		Retention		MinX		MaxX		MinY		MaxY	
	12% MC	17.5% MC	12% MC	17.5% MC	12% MC	17.5% MC	12% MC	17.5% MC	12% MC	17.5% MC	12% MC	17.5% MC
	(%)		(pcf)		(in.)							
CCA	0.83	1.36*[b]	0.174	0.200*	0.13	0.23*	0.35	0.55*	0.11	0.20	0.37	0.42
			(2.78)[c]	(3.20)	(3.3)[c]	(5.8)	(8.9)	(13.7)	(2.8)	(5.1)	(9.4)	(10.7)
ACQ-B, A[d]	0.57	1.28*	0.090*	0.073	0.11	0.19*	0.34	0.53*	0.08	0.21	0.29	0.41
			(1.44)	(1.17)	(2.8)	(4.8)	(8.6)	(13.5)	(2.0)	(5.3)	(7.4)	(10.4)
ACQ-B, H[d]	2.97*	1.35	0.197*	0.093	0.41*	0.18	0.73*	0.54	0.65*	0.22	1.64*	0.50
			(3.16)	(1.49)	(10.4)	(4.6)	(18.5)	(13.7)	(16.5)	(5.6)	(41.6)	(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] Values with an asterisk are significantly better than the values at the other MC level.
[c] Values in parentheses for retention are kg/m^3; values in parentheses for penetrations are mm.
[d] A = ambient temperature; H = heated.

TABLE 5. — Means of percentage rating of cross section penetrated, retention (pcf, total oxide basis), and penetration (in.) for hickory heartwood at two MCs treated with CCA and ambient and heated ACQ-B solutions.

	Rating[a]		Retention		MinX		MaxX		MinY		MaxY	
	12% MC	17.5% MC	12% MC	17.5% MC	12% MC	17.5% MC	12% MC	17.5% MC	12% MC	17.5% MC	12% MC	17.5% MC
	(%)		(pcf)		(in.)							
CCA	0	0.76*[b]	0.140	0.142	0.02	0.12*	0.13	0.45*	0.01	0.12*	0.16	0.38*
			(2.24)[c]	(2.27)	(0.1)[c]	(3.0)	(3.3)	(13.7)	(0.1)	(3.0)	(4.1)	(9.6)
ACQ-B, A[d]	0.03	0.33*	0.055	0.035	0.01	0.07*	0.25	0.42*	0.01	0.07*	0.30	0.30
			(0.88)	(0.56)	(0.2)	(1.7)	(6.4)	(10.7)	(0.2)	(1.8)	(7.6)	(7.6)
ACQ-B, H[d]	0.77	1.00	0.093*	0.068	0.07	0.13	0.46	0.54	0.11	0.18	0.64	0.50
			(1.49)	(1.09)	(1.7)	(3.3)	(11.7)	(13.7)	(2.8)	(4.6)	(16.2)	(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] Values with an asterisk are significantly better than the values at the other MC level.
[c] Values in parentheses for retention are kg/m^3; values in parentheses for penetrations are mm.
[d] A = ambient temperature; H = heated.

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 MC produced consistently improved treatability with CCA. the results for both ACQ-B treatments were inconclusive with regard to a preferred MC.

Beech heartwood results showed that three of the six treatability measures with CCA were statistically significant (percent rating, retention, and MaxY) and favored the 12 percent MC **(Table 3).** For the remaining three parameters, although not statistically significant. 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** 3). In most cases, the mean differences are several times larger at the 12 percent MC (all but MaxX are at least three times greater at the 12% MC). The heated ACQ-B solution produced significantly higher mean results for the 12 percent MC in four of six treatability parameters (percent rating, retention. MinX, and MaxY). In the two cases of nonsignificant 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.

HICKORY

Hickory sapwood and heartwood treatability results at the two MCs were significantly different, 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** and **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; only the retention parameter at 12 percent MC was significant.

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.

RED OAK

As noted previously. because of the difficulty in obtaining sufficient volumes of sapwood to produce a nominal 2- by 4-inch (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 MC was evident **(Table 6).** The two instances of significantly improved treatability at 12 percent MC were retention of both ACQ-B solutions.

TABLE 6. — Means of percentage rating of cross section penetrated, retention (pcf, total oxide basis), and penetration (in.) for red oak heartwood at two MCs treated with CCA and ambient and heated ACQ-B solutions.

	Rating[a]		Retention		MinX		MaxX		MinY		MaxY	
	12% MC	17.5% MC	12% MC	17.5% MC	12% MC	17.5% MC	12% MC	17.5% MC	12% MC	17.5% MC	12% MC	17.5%MC
	(%)		(pcf)		(in.)							
CCA	0.03	0.08	0.175	0.168	0	0.003*[b]	0.20	0.27	0	0.003*	0.20	0.16
			(2.80)[c]	(2.69)	(0)[c]	(.1)	(5.1)	(6.8)	(0)	(0.1)	(5.1)	(4.1)
ACQ-B, A[d]	0.07	0.59*	0.095*	0.076	0.001	0.09*	0.38	0.50*	0.02	0.11*	0.47	0.42
			(1.59)	(1.22)	(0.1)	(2.3)	(9.6)	(12.7)	(0.5)	(2.8)	(11.9)	(10.7)
ACQ-B, H[d]	0.33	0.27	0.196*	0.095	0	0.01*	0.30	0.32	0	0.09	0.34	0.28
			(3.13)	(1.52)	(0)	(0.2)	(7.6)	(8.1)	(0)	(2.3)	(8.6)	(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] Values with an asterisk are significantly better than the values at the other MC level.
[c] Values in parentheses for retention are kg/m^3; values in parentheses for penetrations are mm.
[d] A = ambient temperature; H = heated.

TABLE 7. — Means of percentage rating of cross section penetrated, retention (pcf, total oxide basis), and penetration (in.) for yellow-poplar heartwood at two MCs treated with CCA and ambient and heated ACQ-B solutions and sapwood at two MCs treated with CCA.

	Rating[a]		Retention		MinX		MaxX		MinY		MaxY	
	12% MC	17.5% MC	12% MC	17.5% MC	12% MC	17.5% MC	12% MC	17.5% MC	12% MC	17.5% MC	12% MC	17.5% MC
	(%)		(pcf)		(in.)							
CCA	1.57*[b]	0.60	0.445*	0.236	0.12*	0.06	0.60	0.49	0.13*	0.06	0.92*	0.53
Heartwood			(7.13)[c]	(3.78)	(3.0)[c]	(1.5)	(15.2)	(12.4)	(3.3)	(1.5)	(23.4)	(13.5)
CCA	3.00*	2.25	0.626*	0.455	0.70*	0.15	0.75	0.75	1.60*	0.28	1.75*	1.48
Sapwood			(10.03)	(7.29)	(17.8)	(3.8)	(19.0)	(19.0)	(40.6)	(7.1)	(44.4)	(37.6)
ACQ-B, A[d]	1.10	1.00	0.112	0.112	0.14*	0.07	0.48	0.64*	0.20	0.08	0.63	0.63
Heartwood			(1.79)	(1.79)	(3.6)	(1.8)	(12.2)	(16.2)	(5.1)	(2.0)	(16.0)	(16.0)
ACQ-B, H[d]	2.20	1.72	0.136	0.165	0.23	0.23	0.66	0.66	0.37	0.40	1.00	0.73
Heartwood			(2.18)	(2.64)	(5.8)	(5.8)	(16.8)	(16.8)	(9.4)	(10.2)	(25.4)	(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] Values with an asterisk are significantly better than the values at the other MC level.
[c] Values in parentheses for retention are kg/m^3; values in parentheses for penetrations are mm.
[d] A = ambient temperature; H = heated.

As with hickory, the treatability results are so poor as to make any practical application unlikely.

YELLOW-POPLAR

CCA was the only sapwood treatment evaluated. All 12 percent MC treatability parameters, except MaxXm, showed improved results over the higher MC **(Table 7).** It is important to note that both MC levels for CCA could potentially meet theoretical AWPA 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 MC.

CCA treatment of yellow-poplar heartwood showed significantly better treatability in all categories (except MaxX) at 12 percent MC **(Table 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.

RED MAPLE

Red maple sapwood treated with CCA was affected little by MC, with only two parameters showing significantly better treatment (MaxY and retention) at 12 percent MC **(Table** 8). MC 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. (8) 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 10 heartwood samples at the 12 percent MC treated with CCA for the 60-minute pressure period had pith apparent within the cross section. Of the 20 remaining samples (ten 90-min. samples and ten 120-min. samples) only 4 contained the pith.

Results indicate that red maple sapwood treated with CCA has the potential to meet theoretical AWPA 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 the potential for meeting these minimum retention and penetration requirements as well.

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,

TABLE 8. — Means of percentage rating of cross section penetrated, retention (pcf, total oxide basis), and penetration (in.) for red maple heartwood at two MCs treated with CCA and ambient and heated ACQ-B solutions and sapwood at two MCs treated with CCA.

	Rating[a]		Retention		MinX		MaxX		MinY		MaxY	
	12% MC	17.5% MC	12% MC	17.5% MC	12% MC	17.5% MC	12% MC	17.5% MC	12% MC	17.5% MC	12% MC	17.5% MC
	(%)		(pcf)		(in.)							
CCA	1.67*[b]	0.48	0.466*	0.257	0.25*	0.05	0.54	0.60	0.52*	0.10	1.07*	0.79
Heartwood			(7.46)[c]	(4.12)	(6.4)[c]	(1.3)	(13.7)	(15.2)	(13.2)	(2.5)	(27.2)	(20.1)
CCA	2.86	2.80	0.697*	0.536	0.52	0.40	0.75	0.75	1.18	1.16	1.71*	1.33
Sapwood			(11.16)	(8.59)	(13.2)	(10.2)	(19.0)	(19.0)	(30.0)	(29.5)	(43.4)	(33.8)
ACQ-B, A[d]	2.10*	0.22	0.132*	0.058	0.22*	0.02	0.66*	0.41	0.44*	0.03	1.28*	0.43
Heartwood			(2.11)	(0.93)	(5.6)	(0.5)	(16.8)	(10.4)	(11.2)	(0.8)	(32.5)	(10.9)
ACQ-B, H[d]	0.70	0.44	0.086*	0.082	0.04	0.05	0.54	0.53	0.07	0.05	0.71	0.57
Heartwood			(1.38)	(1.31)	(1.0)	(1.3)	(13.7)	(13.5)	(1.8)	(1.3)	(18.0)	(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] Values with an asterisk are significantly better than the values at the other MC level.
[c] Values in parentheses for retention are kg/m^3; values in parentheses for penetrations are mm.
[d] A = ambient temperature; H = heated.

TABLE 9. — Overall effect of MC on treatability of five Appalachian hardwoods.[a]

	CCA		Ambient ACQ-B		Heated ACQ-B	
	12% MC	17.5% MC	12% MC	17.5% MC	12% MC	17.5% MC
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

[a] + = generally improved treatability over other moisture content; I = inconclusive results; N/A = not analyzed in this study.

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 study. The treatment trends for the diffuse-porous yellow-poplar, red maple, and beech woods were similar, and these woods showed clearly better treatability compared to the ring-porous red oak and hickory woods.

The end-sealing of samples in this study resulted in penetration dependent on tangential and radial movement of preservative solution into the wood, extremely limiting the role played by vessels. An overall explanation of the generally poor results for heatwood might be based on this minimized vessel penetration if, as concluded by Greaves (3), 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. (2) 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 MC resulted in improved treatability results. However, red oak and hickory showed some proclivity toward improved treatability at the 17.5 percent MC. **Table 9** summarizes the results of the effect of MC on the hardwood species evaluated here.

It is important to note that while statistical significance was evident in many cases, the actual level of treatment implies a note of caution in applying the use of the results for improving commercial treatment application. In many cases, the effective level of treatability was essentially negligible, even though the differences between MCs were statistically significant. However, in the case of certain sapwood treatments, the differences in MC may mean the difference in meeting minimum treatment requirements.

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