Observed Relationships between Wood Density and Solution Uptake during Pressure Treatment

Steve Halverson
Stan Lebow
USDA Forest Service, Forest Products Laboratory
Madison, Wisconsin

ABSTRACT

A better understanding of the relationship between wood properties and solution uptake during pressure treatment could lead to improvements in treatment quality and more efficient use of preservatives. In this study several years of treatment data representing a range of wood species, charge conditions and preservative formulations were analyzed to evaluate the relationship between wood density and solution uptake. Density and solution uptake (weight gain per unit volume) were determined for individual specimens in each charge. The analysis revealed that in many cases there was little or no relationship between wood density and solution uptake. When a relationship was present it was negative (more dense specimens tended to have lower uptakes). The strongest relationship between wood density and solution uptake was generally found with southern pine, and the weakest relationship with the less easily treated softwood species. Smaller specimens exhibited a stronger relationship between uptake and density than larger specimens cut from dimension lumber. The relationship between wood density and solution uptake appeared to be slightly stronger for oil-type preservatives than water-based preservatives, but this effect was not as apparent as those of wood species and specimen dimensions. In general, the results of this analysis indicate that a consistent relationship between wood density and solution uptake should not be expected for lumber and timbers treated with current commercial schedules.

Keywords: Density, uptake, pressure treatment, wood species, specimen dimensions

INTRODUCTION

Wood density is widely recognized as having some relationship to both permeability and solution uptake during pressure treatment. It is logical that wood with lower density might have more void space and thus potential for greater uptake of solution. This type of negative relationship between density and solution absorption was taught as early as 1935 in MacLean's "Manual on Preservative Treatment of Wood by Pressure" (MacLean, 1935). MacLean summarized the relationship by stating that "*The preservative enters the air spaces in the wood and when a large part of the air space is occupied no more preservative can enter*." MacLean does not provide data or references for this statement, but the inverse relationship between density and solution absorption was subsequently clearly demonstrated by Duncan in her research to improve the soil-block test (Duncan, 1953). However, Duncan's research utilized small (19 by 19 mm) cubes, and the relationship between density and solution uptake becomes more nuanced with larger specimens and commodities where permeability becomes a greater factor. In contrast to uptake, permeability has been reported as positively correlated with density (Arsenault, 1988; Belford and Firth, 1966; Hunt and Garrett, 1953; MacLean, 1935, 1952; Usta and Hale, 2006). This positive correlation is thought to result from a larger proportion of more permeable latewood bands in denser material (MacLean, 1952). Thus it is possible that the positive relationship between density and penetration could obscure a negative relationship between absorption and density. To add to the uncertainty there is not universal consensus that penetration is greater in latewood bands for all softwood species (Baines and Saur, 1985; Belford and Firth, 1966; Flynn, 1995).

Despite their computation in many aspects of preservative research, relatively few reports discuss the relationship between wood density and solution uptake. Perhaps the most comprehensive of these are reports by Arsenault (1988) and Schultz, et al, 2004. Arsenault (1988) reported density and retention data for several dimensions of treated specimens or commodities (Arsenault, 1988). Although the relationship between wood density and absorption was not the focus of the paper, Arsenault does mention that a negative relationship was observed. Data included in the paper indicates regression coefficients of determination between wood density and solution uptake as high as R^2 = 0.49 for 19 by 19 by 457 mm southern pine stakes, with somewhat lower coefficients for southern pine posts. In their more recent study evaluating biocide retention in 19 by 19 by 1016 mm southern pine stakes, Schultz et al (2004) report a relatively strong negative relationship (R^2 = 0.77) between uptake and specific gravity following CCA treatment. Fewer reports are available for woods other than southern pine, although an evaluation of specimens cut from a single Caucasian fir tree (Usta and Hale, 2006) indicated that density had a significant relationship with absorption. The results of that study may have been influenced by the small specimen dimensions (10 mm along the grain) which may have been easily penetrated during treatment. Researchers have also reported either positive (Usta and Hale, 2006) or negative (Laks, et al, 1996) relationships between density and uptake between tree species, although it is likely that other wood characteristics also played a role in the relationships observed in those studies. Both Arsenault (1988) and MacLean (1935) have noted that the correlation between density and absorption may vary between treatment solutions (Arsenault, 1988). MacLean (1935) specifically noted that the relationship between density and absorption may differ for water and solvent-based preservatives. This hypothesis was based on the assumption that, unlike water-based preservatives, oil-based preservatives would not penetrate into the cell wall. In this paper we report on the relationships observed between density and uptake over several years of pressure treatment of specimens at the USDA, Forest Products Laboratory (FPL) in Madison, Wisconsin.

MATERIALS AND METHODS

The USDA FPL conducts pressure treatments for a variety of purposes, including treatability studies, preparation of exposure specimens, and mechanical properties evaluations. These studies involve a range of wood species and preservative formulations as well as specimen dimensions. For the majority of these charges each specimen is weighed before and after treatment, allowing calculation of pre-treatment wood density and solution uptake. In this paper, solution uptake refers to specimen weight gain divided by specimen volume. To conduct this analysis, consolidated specimens from over 100 applicable charges were collected over a period of several years. Only those charges with at least 20 replicate specimens were included in the data set. The charges included softwoods and hardwoods treated with either water-based or oil-type preservatives (Table 1). The majority of the charges were conventional full cell, but a few used reduced vacuum and/or pressure. In most cases when multiple concentrations of the same formulation were being applied as part of a study, the data from those charges were combined and treated as a single charge. However, in a few situations it appeared that solution concentration (usually higher concentrations) was affecting uptake. In those cases the charge data was either not used or was evaluated separately. All of the preservatives evaluated were solutions, with the biocide dissolved in the carrier. The final data set utilized 69 charges or charge combinations comprised of slightly over 8,000 specimens. The coefficient of determination (R^2) between wood density and solution uptake was calculated, and then evaluated to determine how it was affected by factors such as wood species, formulation type and specimen dimensions.

RESULTS AND DISCUSSION

In many charges little relationship was observed between wood density and solution uptake, and the resulting average R^2 for all charges combined was only 0.26. However, the relationship between wood density and solution uptake clearly differed with wood species and to some extent with specimen size. In some wood species/specimen size combinations a much stronger relationship was observed.

Table 1. Wood species, preservatives and specimen dimensions included in charges evaluated.

Wood Species		Preservative Types	Dimensions (mm)		
Softwoods	**Hardwoods**	Amine copper	**Width**	**Height**	**Length**
Balsam fir	Cottonwood	Amoniacal copper	19	19	457
Douglas-fir	Hard maple heartwood[a]	CCA Type C	25	48	178
Eastern hemlock	Hard maple sapwood[a]	Copper Naph - diesel	38	89	305
Engelmann hpruce	Keruing	Copper Naph – Water	38	89	914
Lodgepole pine	Red maple	Diesel + toluene	38	89	1176
Red spruce	Red oak	Fire retardant	38	89	1524
Sitka spruce	Silver maple	Oxine copper - Diesel	38	140	254
Southern pine sap	Yellow birch	Sodium borate	38	140	305
Western hemlock			38	140	576
White spruce					

[a] Primarily sugar maple but may have included black maple

Wood Species and Specimen Size

The relationship between wood density and solution uptake appeared to vary most greatly with wood species. The relationship was generally weak for the fir, hemlock, lodgepole pine and spruce wood species and was strongest for southern pine sapwood (Figure 1). Relationships noted for the hardwood species were intermediate. It would seem logical that wood species that are less treatable and have greater variability in treatability might have a weaker relationship between wood density and solution uptake, and that this might explain the species affects observed. To further investigate this possibility, the wood density vs. solution uptake R^2 value for each charge or charge combination was regressed against the associated coefficient of variation of solution uptake. This regression yielded an R^2 of only 0.22, indicating that factors other than variability in uptake were contributing to the weak relationship between wood density and solution uptake. One of these factors appears to be specimen size. Most of the charges involving balsam fir, spruces, hemlocks and lodgepole pine were part of treatability studies and utilized relatively large specimens cut from dimension lumber. It is likely that in these specimens the depth of penetration had a large influence on amount of solution absorbed. In contrast, the hardwood species were treated for stake durability tests and were cut to the smaller 19 by 19 by 457 mm dimension. Southern pine specimens included the 19 by 19 mm stakes as well as specimens cut from dimension lumber. A comparison of the relationship between wood density and solution uptake in southern pine by specimen dimension revealed that the R^2 value for the 19 by 19 mm stakes was much greater (R^2 = 0.57) than that for the larger specimens cut from dimension lumber (R^2 = 0.23). This large difference is somewhat surprising given the treatability of southern pine sapwood and it indicates that much of the weak relationship between wood density and solution uptake observed for balsam-fir, the spruces, the hemlocks and lodgepole pine may be attributable to specimen size. Or, viewed in another way, it indicates that the stronger relationships observed for the 19 by 19 mm hardwood and southern pine specimens could be misleading.

Preservative Type

With two possible exceptions, preservative formulation did not appear to have a consistent effect on the relationship between wood density and solution uptake (Figure 2). The first exception is that higher solution concentrations of some preservatives appeared to have weaker relationships between wood density and solution uptake. Typically this was accompanied by much lower absorptions and in some cases (as in high concentrations of copper naphthenate in oil) the data was not used in this evaluation. Another possible trend is the stronger relationship between wood density and solution uptake noted for the solvent-based preservatives. This was particularly notable for the diesel/toluene solution used as a solvent control in some of the durability evaluations. The diesel/toluene solutions appeared to have consistently greater correlations between wood density and solution uptake than the other preservatives. The reason for this is unclear, although it is possible that the toluene increased the uniformity of penetration, or was less affected by hydrophobic areas within the wood substrate. Differences were observed between water-based formulations, but were no greater than those observed between different charges with the same formulation.

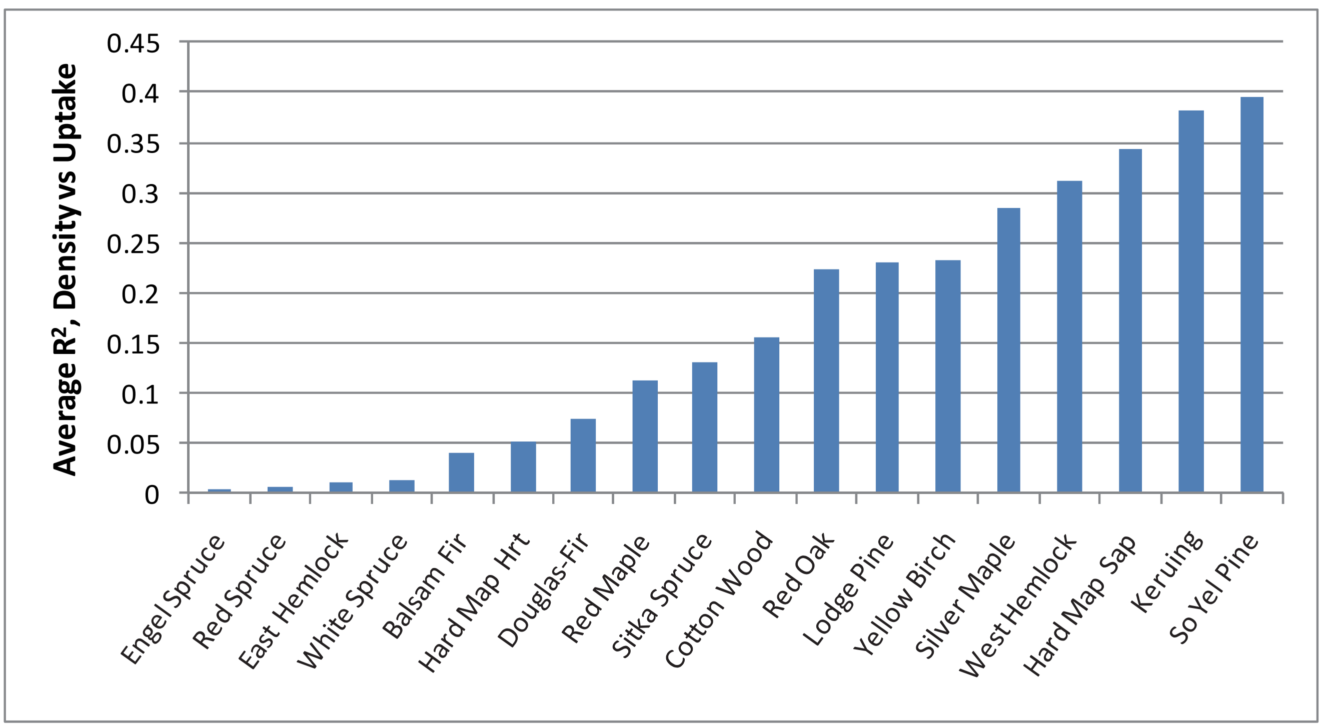

Figure 1. Regression relationship between wood density and solution uptake by wood species. Includes all preservatives and specimen sizes.

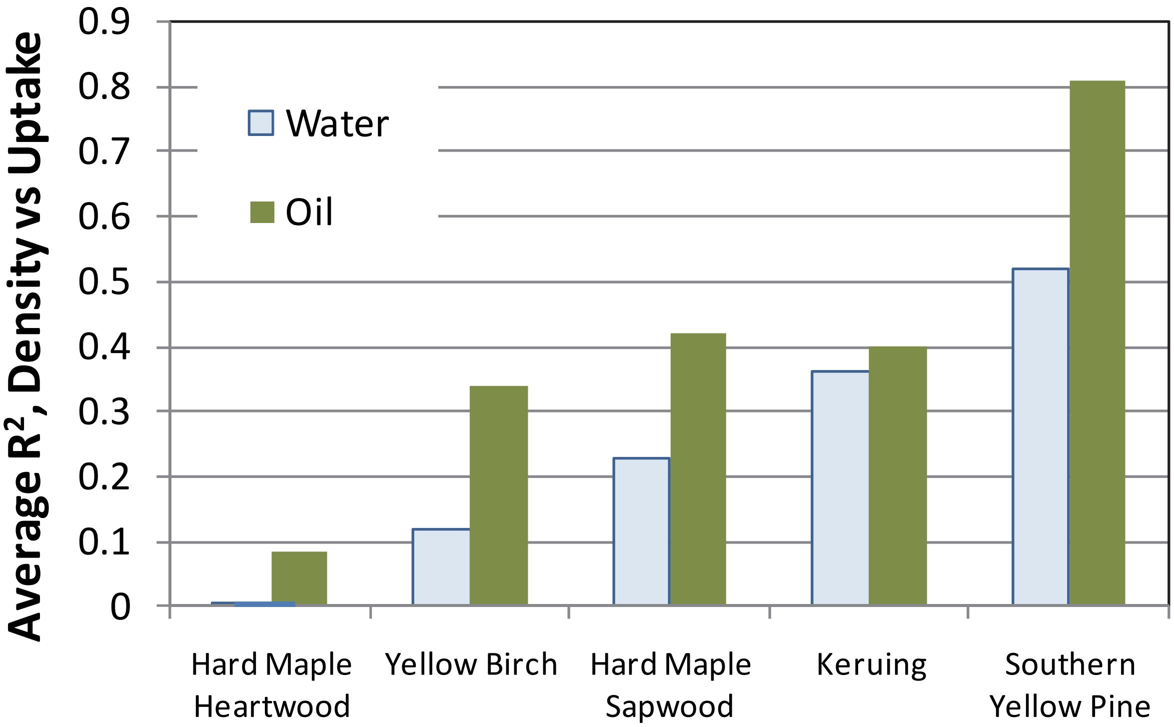

Figure 2. Regression relationship between wood density and solution uptake, oil versus water. Data limited to charges of 19 by 19 by 457 mm stakes.

Charge Parameters

All but a few charges evaluated were full cell and utilized an initial vacuum of 24 in. Hg (gauge) followed by pressure of at least 150 psi (gauge) for a minimum of 60 minutes. These are relatively rigorous conditions that are intended to yield uniform preservative distribution in exposure specimens, and should have helped to maximize penetration. The effect of charge parameters on the density-uptake relationship was difficult to assess in this data set because charge parameters tended be associated with specific wood species-preservative combinations. Some comparisons were possible for southern pine, however. A comparison of the relationship between wood density and solution uptake for 60 and 120 minute pressure periods indicated that the longer pressure period had little effect in 19 by 19 by 457 mm stakes. A similar lack of effect was noted when the pressure was increased from 150 to 200 psi (gauge). In contrast the relationship between wood density and solution uptake did appear to suffer when much less rigorous treatment schedules were used in a few charges of southern pine lumber specimens (Figure 3). Although this data is limited, it supports the assumption that charges with less rigorous schedules, which should result in less uniform uptake, will have a weaker relationship between wood density and solution uptake. If so, the relationship between wood density and solution uptake observed in the modified full cell schedules used commercially would be expected to be weaker than those observed with the full cell schedules used in this study.

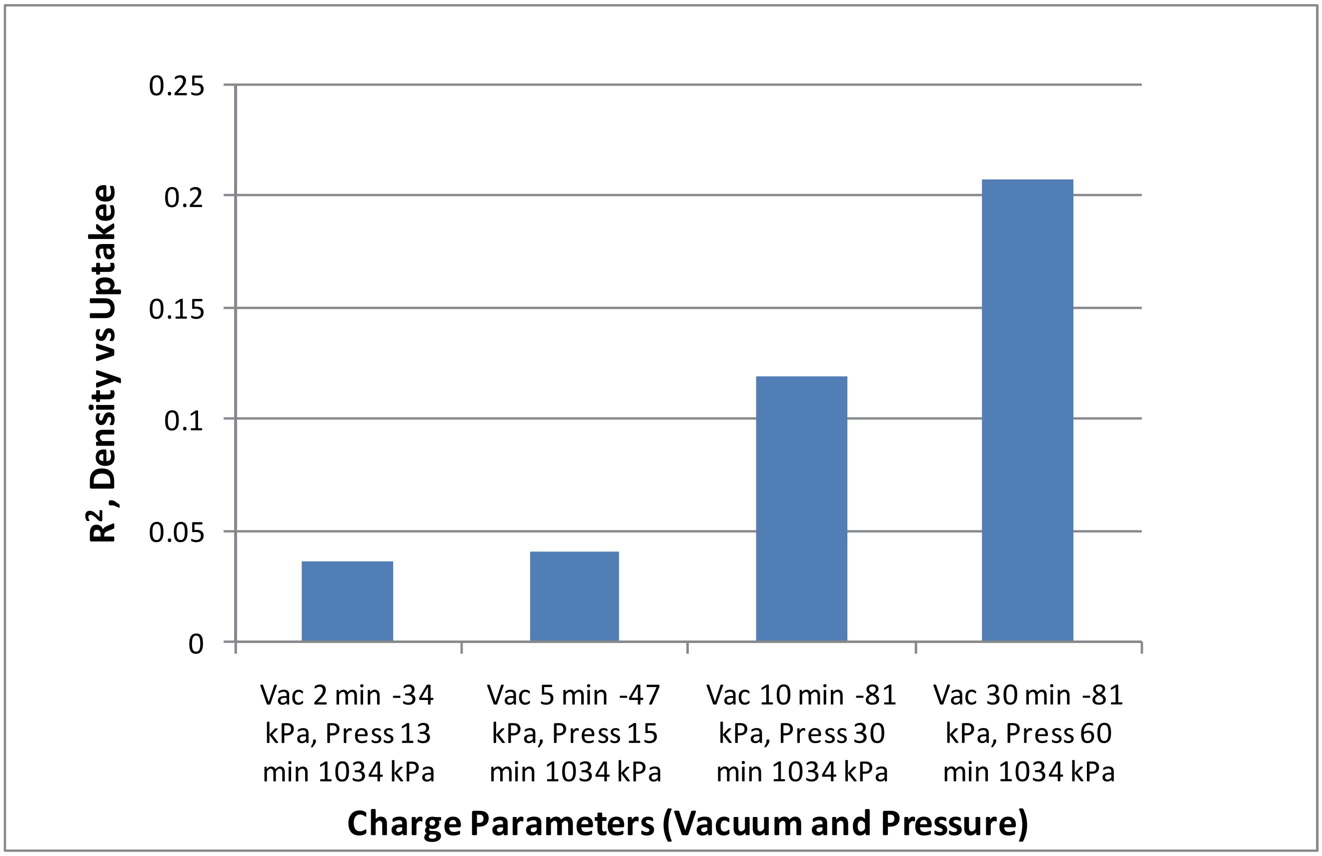

Figure 3. Effect of treatment parameters on the relationship between wood density and solution uptake. Charges shown were CCA-C treatment of specimens cut from southern yellow pine 38 by 140 mm (nominal 2 by 6) lumber.

CONCLUSIONS

This review of several years of charge data indicates that the negative relationship between wood density and solution uptake varies with wood species and specimen dimensions, and to a lesser extent with preservative formulation. In this data the strongest relationship between wood density and solution uptake was generally found with southern pine, and the weakest relationship with more refractory softwood species. Smaller southern pine specimens, such as 19 by 19 by 457 mm stakes, had a stronger relationship between wood density and solution uptake than larger specimens cut from dimension lumber. This indicates that uniformity of penetration is an important factor, even in relatively permeable southern pine sapwood. The relationship between wood density and solution uptake appeared to be slightly stronger for oil-type preservatives than water-based preservatives, but this effect was not as apparent as those of wood species and specimen dimensions. In general, the results of this analysis indicate that the relationship between wood density and solution uptake will not be particularly strong for dimension lumber and timbers treated with modified full cell schedules. However, the data analyzed in this paper was drawn from many unrelated studies, none of which were directly designed to assess the relationship between wood density and solution uptake.

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