EXPERIMENTS ON THE EFFECT OF ULTRASONIC ENERGY ON THE ABSORPTION OF PRESERVATIVES BY WOOD[1]

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ABSTRACT

The effect of ultrasonic energy on the absorption of CCA by spruce, Douglas-fir, and ponderosa pine, as well as the absorption of pentachlorophenol and creosote by the latter species was investigated at atmospheric pressure and 20 C temperature. The results showed an increase in the percentage uptake due to the effect of the ultrasound for all species and preservatives, with the only exception being creosote at immersion times below 30 minutes. The effect of ultrasound was more pronounced in more permeable species.

Keywords: Preservatives, ultrasonic energy, CCA pentachlorophenol, creosote.

INTRODUCTION

Many times, wood and wood products have to be used in environments where deterioration risks are very high. In that case it is customary to treat wood with various liquid chemicals in order to improve its resistance to the degrading agents. Pressure and non-pressure methods of impregnation have been developed over the years; the former involves bulk flow through the interconnected voids of the wood structure under the influence of a static or capillary pressure gradient, whereas the latter involves mainly penetration due to diffusion. Pressure impregnation is by far the most effective method of protecting wood because deeper and more uniform penetration can be obtained, and the retention of the liquid chemical can be more closely controlled.

The depth of penetration and level of liquid chemical retention depend on many factors such as wood anatomy, properties of the fluid, and conditions of application. Although much research has been carried out in all of them, conditions have been the easiest to manipulate in industrial applications. The use of ultrasonic energy is one of the methods that has been partially investigated in the past and has shown promising results. Ultrasonic energy can be generated by different methods like air jets and sirens, piezoelectricity, electrostatic and electrodynamic devices, and magnetostriction. One of the most important properties of ultrasound is the cavitation phenomenon, namely formation of bubbles that grow and collapse very fast. Because of the rapidity of the collapse, large instantaneous pressures and temperatures are developed at the center of the bubble and consequently shock waves are generated. These shock waves are thought to cause vibration of

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the wood structure and in particular of the pit membranes, and as a result, increased fluid penetration and retention (Burdell and Barnett 1969).

Kitazawa (1949), was the first to investigate the effect of shock waves of frequency range of 20–21 kHz on the penetration of water into wood under atmospheric pressure. The results showed an increased free water flow in the sapwood but no appreciable increase in the heartwood. Bystrov et al. (1960) showed that ultrasonic waves at 20 kHz frequency and atmospheric pressure increased depth of penetration, evenness, and intensity of coloring of an aqueous solution of an acidic stain. The combination of mechanically generated shock waves and pressure was also investigated in a pilot plant by Burdell and Barnett (1969). Pressure cycles were reduced by $^1/_6$ to $^1/_{20}$ of the time used in commercial practice.

Borgin and Corbett (1970) found that, in general, capillary penetration of nonpolar liquids into wood chips could not be improved by the use of ultrasound. However, upon introducing one or more hydrophilic groups into straight-chain hydrocarbons, positive responses were obtained with ultrasonic treatment, but were reduced by the dilution with nonpolar solvents. Capillary penetration of water into the chips increased when the surface tension was diminished by adding surfactants. Walters (1977), by steeping ponderosa pine specimens that were presoaked in cold or warm water for an hour, in a CCA solution and in a laboratory-type cleaning tank operating at a frequency of 50–55 kHz, concluded that neither ultrasonic energy, nor its interaction with presoaking time had any significant effect on the absorption of the chemical by the wood.

The purpose of this project was to investigate further the effects of ultrasonic energy on the absorption of different kinds of liquid preservatives by wood under ambient pressure and temperature.

MATERIALS AND METHODS

All tests were done with end- and side-matched *sapwood* specimens of air-dried coast-type Douglas-fir [*Pseudotsuga menziesii* (Mirb.) Franco], kiln-dried Sitka spruce [*Picea sitchensis* (Bong.) Carr], and ponderosa pine (*Pinus ponderosa* Laws), $2 \times 2 \times 5$ cm with the long dimension in the fiber direction. In preparing the specimens, effort was made to have the four absorbing surfaces of each specimen as near as possible to a perfect tangential or radial one, and the percentage of earlywood and latewood in the tangential surfaces approximately the same. Two layers of epoxy resin were applied to seal the ends of each specimen in order to limit the penetration to the transverse direction. Specimens were oven-dried twice, before and after epoxy application, in order to determine the oven-dry weights (ODW) and the weights of the epoxy coatings. All specimens were equilibrated before the experimental runs in a conditioning room at 20 C and 65% relative humidity, resulting in an average moisture content of 10.62% for the ponderosa pine and 12.14% and 11.42% for the spruce, and Douglas-fir specimens, respectively. The coefficients of variation (CV) for the above moisture contents were 2.83%, 4.58% and 2.05%, respectively.

Twenty-four 5-specimen groups of the three species were treated by two methods in an aqueous solution of chromated copper arsenate (CCA) at atmospheric pressure. Half of them were immersed in the solution for a period of time under the effect of continuous ultrasonic energy, whereas the other half were immersed without ultrasonic energy, the solution being at the same temperature in both

TABLE 1. *Results obtained for the three species treated in CCA with (+) and without (−) the effect of ultrasound.*

Time (min)	Spruce					Douglas-fir					Ponderosa pine				
	(+)		(−)		Gain	(+)		(−)		Gain	(+)		(−)		Gain
	x	CV	x	CV	%	x	CV	x	CV	%	x	CV	x	CV	%
5	2.45	4.07	2.07	6.59	18.4	2.19	17.67	1.48	14.03	47.9	2.83	19.00	2.10	6.35	34.8
10	2.85	7.44	2.53	7.25	12.6	2.08	13.05	1.66	8.38	25.3	3.24	17.12	2.89	7.09	12.1
20	3.52	5.02	3.24	5.17	8.6	2.42	6.51	1.92	7.04	26.0	4.04	11.33	3.77	5.70	7.2
60	5.95	6.10	5.86	9.03	1.5	4.37	5.93	2.99	8.83	46.2	7.37	11.83	6.56	6.09	12.3

x = Mean preservative uptake per specimen, %; CV = coefficient of variation, %; GAIN = percent increase in uptake of the treated specimens compared with the untreated control.

TABLE 2. *Results obtained for the ponderosa pine treated in three preservatives with (+) and without (−) the effect of ultrasound.*

Time (min)	Creosote					Penta					CCA				
	(+)		(−)		Gain	(+)		(−)		Gain	(+)		(−)		Gain
	x	CV	x	CV	%	x	CV	x	CV	%	x	CV	x	CV	%
5	2.25	5.14	2.70	7.37	−16.6	4.07	2.61	3.85	5.60	5.7	2.83	19.00	2.10	6.35	34.8
10	2.68	4.26	2.91	3.43	−7.9	4.59	2.09	4.35	1.98	5.5	3.24	17.12	2.89	7.09	12.1
20	2.36	8.98	2.81	13.55	−16.0	4.62	5.87	4.43	5.14	3.1	4.04	11.33	3.77	5.70	7.2
60	4.75	20.12	3.68	14.55	+29.1	5.35	4.41	4.93	6.49	7.9	7.37	11.83	6.56	6.09	12.3

x = Mean preservative uptake per specimen, %; CV = coefficient of variation, %; GAIN = percent increase in uptake of the treated specimens compared with the untreated control.

TABLE 3. *F-values and levels of significance (in parenthesis) obtained from ANOVA of the uptakes between treated specimens and controls.*

Time (min)	5	10	20	60
Spruce[1]	24.936 (0.01)	6.902 (0.05)	5.481 (0.05)	0.089 (0.95)
D-Fir[1]	13.083 (0.01)	9.611 (0.05)	29.833 (0.01)	69.266 (0.01)
Pine[1]	8.489 (0.05)	5.755 (0.05)	6.593 (0.05)	7.727 (0.05)
Pine[2]	7.357 (0.05)	16.460 (0.01)	6.297 (0.05)	5.830 (0.05)
Pine[3]	19.985 (0.01)	11.041 (0.05)	5.348 (0.05)	4.785 (0.10)

[1] Treated with CCA.
[2] Treated with pentachlorophenol.
[3] Treated with creosote.

cases. For each half, the first group of five replicates was removed from the solution after 5 minutes, the second after 10 minutes, the third after 20 minutes, and the last after 60 minutes. Each specimen's weight was recorded before and after treatment with a high speed electronic balance to four places of decimals, in order to calculate the total absorption per specimen. The total amount of liquid absorbed was expressed as a percentage of the oven-dry weight, and uptake; and for each group the mean, the standard deviation, and the coefficient of variation were calculated. No depth of penetration was measured in this study.

Sixteen 5-specimen groups of ponderosa pine were treated in the same way with a 2% solution of pentachlorophenol in mineral spirit and with pure creosote in order to evaluate any effects of ultrasound between and within different types of preservatives.

Ultrasonic energy was provided by a laboratory-type cleaner operating at a frequency of 50–55 kHz. Since preliminary experiments showed that the temperature of the water bath in the cleaner increased from 20 to 60 C after three hours of operation, aluminum coils connected to a water circulator were used to keep the temperature of the preservatives at 20 $\pm$ 1 C during the experimental runs.

RESULTS AND DISCUSSION

Table 1 contains the average values (x) and the coefficients of variation (CV) for the CCA absorption per specimen expressed as a percentage of the oven-dry weight for the three species used in this investigation. It can be seen that the absorption increased with the length of immersion time in both the ultrasound-treated specimens and the controls. It is obvious that, numerically, the specimens in the ultrasonic cleaner absorbed more CCA than the controls for the same length of time. The hypothesis that there is no difference in mean preservative uptake between ultrasound-treated specimens and controls was tested by using analysis of variance. It was found that the difference in CCA absorption between treatments

TABLE 4. *F-values and levels of significance (L.S.) from ANOVA between spruce and Douglas-fir mean gains.*

Time (min)	5	10	20	60
F	7.25	9.96	9.17	116.80
L.S.	0.05	0.05	0.05	0.01

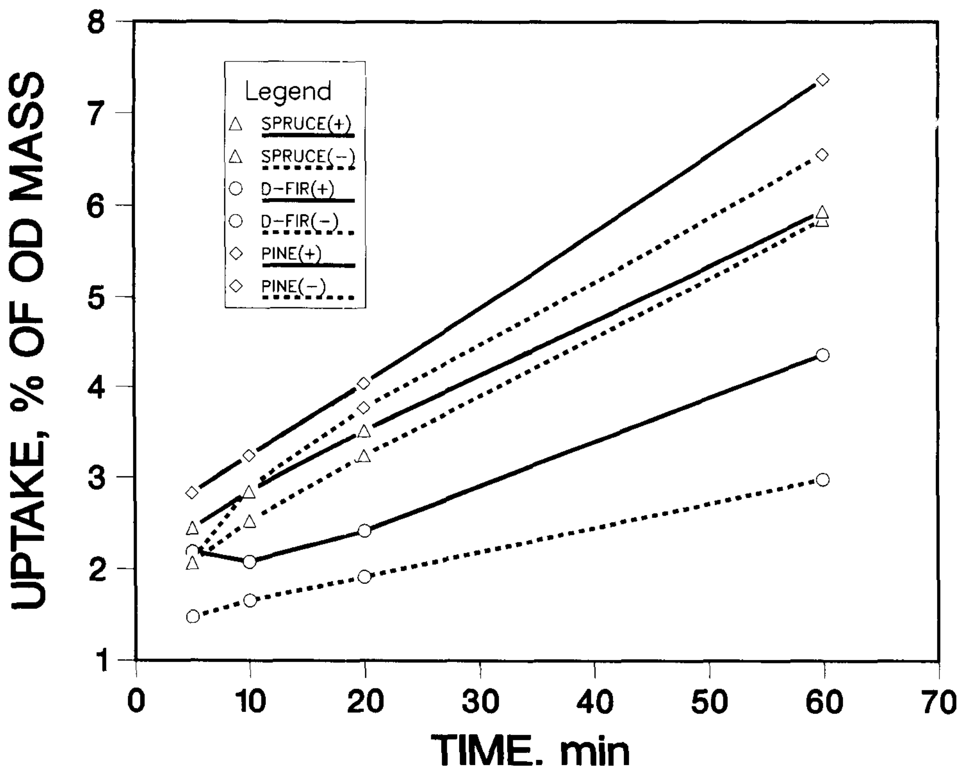

FIG. 1. Plot of the average CCA uptake by the three species against time. (+): with ultrasound; (−): without ultrasound.

within each species was significant at the 0.01 level for spruce at 5 min, and Douglas-fir at 5, 20, and 60 min of immersion. For spruce at 10 and 20 min, Douglas-fir at 10 min, and ponderosa pine at all times of immersion, the difference was significant at the 0.05 level. Only for spruce at 60 min, was there strong evidence of no statistical difference. The F-values and the levels of significance for all species and treatments are given in Table 3. Walters (1977) found no statistically significant difference in CCA absorption by presoaked sugar pine heartwood specimens with and without the effects of ultrasound at the same frequency range. Further analysis of his results showed that his coefficients of variation were very high, ranging from 12.96% up to 48.25%. In the present investigation, the CV's were very low, the maximum being only 19.0%. This shows that the experimental error was well contained.

The columns under the heading "gain" contain the percentage change of CCA absorption due to the effect of ultrasound. A positive number indicates that a greater amount of fluid was absorbed by the treated specimens under ultrasound compared to that of the controls for the same length of time. It can be seen that in all species and times of immersion, the gain was always positive. The average gain for sapwood Douglas-fir was 36.34%, and for sapwood ponderosa pine and spruce 16.59% and 10.29%, respectively. It is interesting to note that the use of ultrasound resulted in greater gains with Douglas-fir (permeable) specimens com-

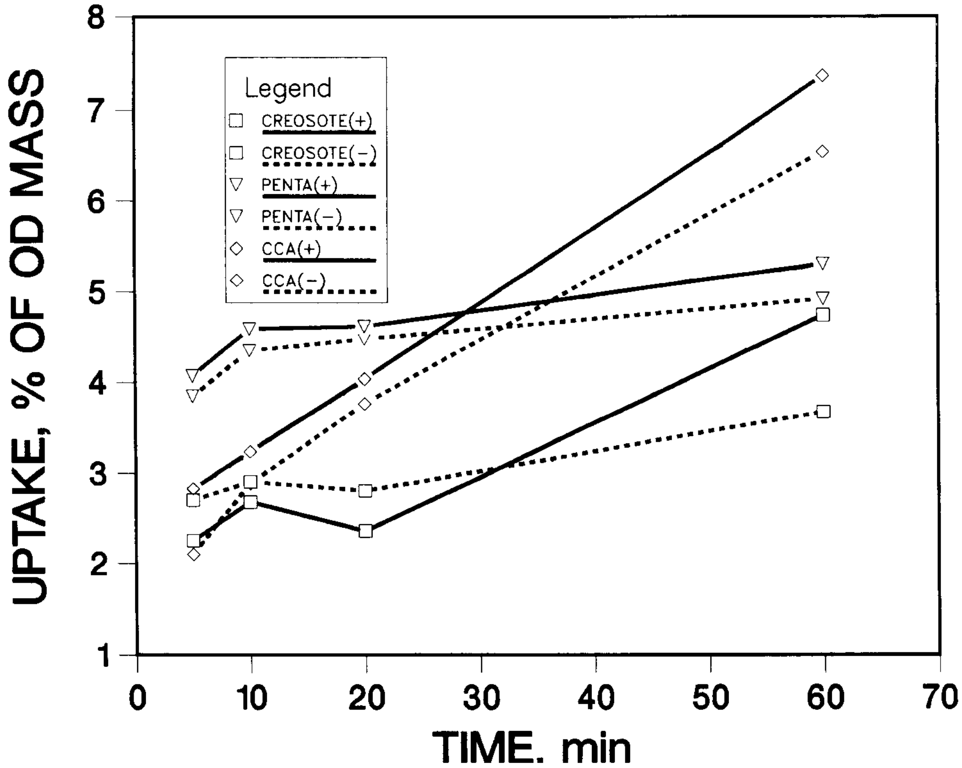

FIG. 2. Plot of average preservative uptake by ponderosa pine specimens against time. (+): with ultrasound; (−): without ultrasound.

pared to spruce (refractory) specimens for the same treating times. An analysis of variance regarding the gains of these two species was carried out. The results are given in Table 4. From the *F*-values it is concluded that the difference in mean gain between these two species is significant at the 0.05 level or better. No significant difference was established statistically between spruce and ponderosa pine mean gains. In the case of the Douglas-fir specimens, the fact that the boards from which the specimens were cut were slowly air-dried at low ambient temperatures could also have contributed to higher gains since aspiration would be expected to be lower than that of the higher temperature kiln-dried spruce and ponderosa pine specimens (Comstock and Côté 1968). As a result, the unaspirated pit membranes possibly behaved as vibrating valves increasing liquid penetration as has been speculated by Burdell and Barnett (1969).

In the case of pure immersion (controls), the major volume of the uptake was due to diffusion, which is the result of a concentration gradient. On the other hand, it is possible that when immersion was combined with ultrasonic energy, collapse of the formed bubbles introduced a pressure gradient and as a result, bulk flow; and therefore permeability of the specimen was the controlling factor. This could also explain the differences in gain between permeable and less permeable species.

In Fig. 1 the average CCA uptake is plotted against time for the three species.

The effect of time and treatment is quite clear. Surprisingly, the uptake of spruce was higher than that of Douglas-fir. According to previous investigators (Siau 1984), the permeability of spruce sapwood is approximately 10 times lower than that of Douglas-fir sapwood from the Pacific Coast. Therefore, it would be more reasonable for the Douglas-fir to absorb more CCA than the spruce for the same amount of impregnation time. Bystrov et al. (1960) reported the same kind of abnormality for beech and redwood when depth of penetration by an aqueous solution of a stain under the effect of ultrasound was examined.

Table 2 contains the average uptakes of CCA, pentachlorophenol, and creosote by ponderosa pine specimens under ultrasound as well as those of the controls. The uptakes are also plotted against time in Fig. 2. An analysis of variance showed that the mean uptakes between treatments were statistically significant at the 0.05 level for the three preservatives examined, except that for the creosote at the 60 min point. The ANOVA results are listed in Table 3.

The gain for the pentachlorophenol ranged between 3.12% and 7.91%, with an average value of 5.56%—much lower than the 16.59% CCA gain. Creosote, on the other hand, showed a negative gain for the first three groups and then became positive. Overall, creosote uptake was lower than that of penta and CCA for both treated specimens and controls. It must be kept in mind that the temperature of the preservatives during the experimental runs was kept at 20 C, far below that which is customary for creosote in industrial applications, and that might have caused its inconsistent behavior.

Further investigation is required regarding the effects of ultrasound on creosote absorption under elevated temperatures, as well as with large size specimens (sapwood and/or heartwood), under atmospheric and elevated pressures.

CONCLUSION

In the light of this investigation, ultrasonic energy enhanced CCA and pentachlorophenol absorption in small sapwood specimens under atmospheric pressure and ambient temperature. Ultrasonic steeping is probably more effective, as far as gains are concerned, on permeable species compared to refractory ones when waterborne preservatives are used. A practical application of this method could be seen in commercial immersion treatments like steeping of joinery products or wood staining.

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