WETTING AGENT AND ULTRASONIC CAVITATION EFFECTS ON DRYING CHARACTERISTICS OF THREE U.S. HARDWOODS[1]

Peter Y. S. Chen

Principal Forest Products Technologist
USDA Forest Service
North Central Forest Experiment Station
Forestry Sciences Laboratory, SIU
Carbondale, IL 62901

and

William T. Simpson

Principal Forest Products Technologist
USDA Forest Service
Forest Products Laboratory
Madison, WI 53705

(Received January 1993)

ABSTRACT

Newly formed outer sapwood in all trees is extremely permeable and therefore easy to dry. However, as sapwood becomes heartwood, extractives deposited in the cell lumens and on the pit membranes tend to block the flow of fluids in wood. As a result, drying rates of sapwood and heartwood differ greatly. This paper describes an evaluation of the combined effects of a wetting agent and ultrasonic cavitation on the drying characteristics of sugar maple, black walnut, and white oak. Soaking in a wetting agent for one week increased the subsequent drying rates of sugar maple and black walnut heartwood, but not white oak, around and below fiber saturation point (fsp). Ultrasonic cavitation did not increase the subsequent drying rate and shrinkage of sugar maple and white oak. Soaking in a wetting agent for one week increased thickness shrinkage of black walnut and white oak heartwood, and increased width shrinkage of sugar maple and white oak heartwood upon subsequent drying.

Keywords: Drying rate, shrinkage, extractives, cavitation, detergent.

INTRODUCTION

The newly formed outer sapwood in all trees is extremely permeable and therefore easy to dry. However, as sapwood becomes physiologically dead heartwood, extractives are deposited in the cell lumens and on the pit membranes and, in some species, tyloses are formed in the vessels (Panshin et al. 1964). These extractives and tyloses tend to block the flow of fluids in wood, thus creating a vast difference in the drying rate between sapwood and heartwood.

One potential way to increase the permeability of wood and reduce drying time is ultrasonic cavitation, the rapid formation and collapse of gas bubbles in a liquid at a rate corresponding to the frequency of ultrasonic waves. The rapid collapse of the bubbles generates high instantaneous pressures that can cause physical damage to solid surfaces in contact with the cavitation gas bubbles (Frederick 1965). Ultrasonic cavitation has been used to clean hard-to-reach surfaces, to homogenize immiscible liquids, to accelerate chemical reactions, and to deaerate liquids (Sonics & Ma-

---

[1] This article was written and prepared by U.S. Government employees on official time, and it is therefore in the public domain and not subject to copyright.

Wood and Fiber Science, 26(3), 1994, pp. 438–444

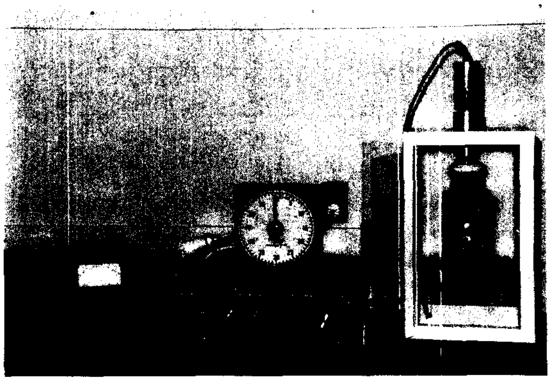

FIG. 1. The high-intensity ultrasonic processor used to cavitate wood blocks.

terials, Inc. 1984). Over two decades ago, ultrasonic cavitation was used as a pretreatment to successfully reduce the volumetric shrinkage of redwood upon drying (Erickson et al. 1970). Recently, ultrasonic cavitation was used to increase the permeability of sugar maple (Chen and Simpson 1992).

Another possible way to reduce drying time as well as shrinkage is to reduce polarity and surface tension in wood sap (Chen 1973). Wetting agents, such as common detergents, can lower surface tension of natural wood sap, may reduce the bonding between wood and water, and increase the effectiveness of water in wood as a solvent for water-soluble extractives in heartwood of many hardwoods.

We conducted a study to evaluate the hypothesis that the combined effects of a wetting agent and ultrasonic cavitation will lower the bonding between wood and water, will enhance the disruption and dissolution of extractives encrusted on pit membranes, and will improve the permeability and subsequent drying characteristics of three U.S. hardwoods.

MATERIALS

Equipment

A Sonics VC1200[2] high-intensity ultrasonic processor with 20 kHz converter frequency and a 1-inch-diameter horn-tip were used to cavitate the wood sample blocks (Fig. 1). A VP-100 AT-1[2] controlled temperature and humidity chamber, with a temperature range of room ambient to 77 C (170.6 F) and humidity range from 20 to 98%, was used to dry all the sample blocks (Fig. 2).

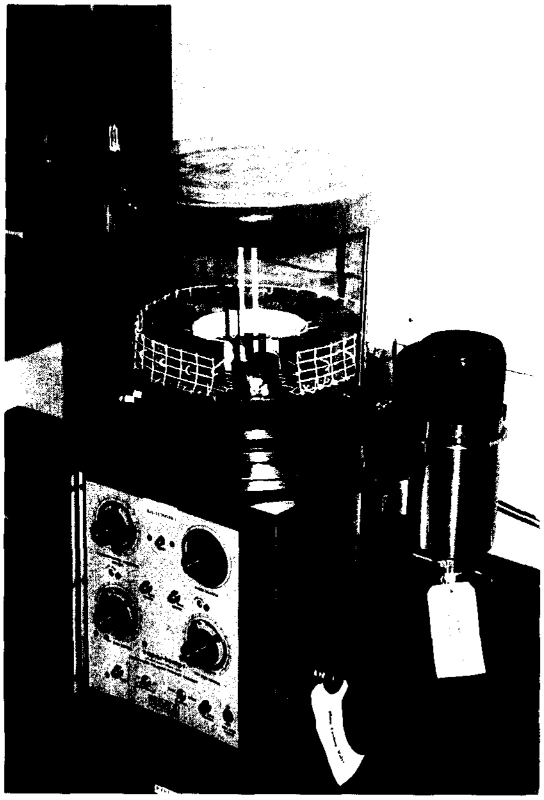

FIG. 2. The controlled temperature and humidity chamber used to dry sample blocks.

Wood samples

Sugar maple (*Acer saccharum* Marsh.), a diffuse-porous wood; black walnut (*Juglans nigra* L.), a semi-ring-porous wood; and white oak (*Quercus alba* L.), a ring-porous wood, were chosen for this study. One hundred sample blocks, 2 in. long by 2 in. wide by 1 in. thick (radial direction), per species were extracted from heartwood of one sugar maple, one black walnut, and two white oak trees.

---

[2] The use of company and trade names does not constitute endorsement by the USDA Forest Service.

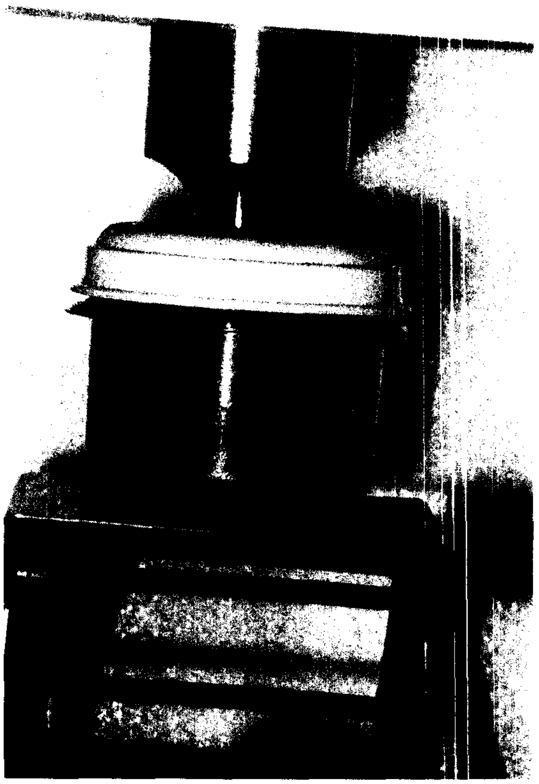

FIG. 3. Application of ultrasonic cavitation in a small plastic container while the sample block was submerged in the soaking solution.

Wetting agent

The wetting agent solution was prepared by diluting 100 ml of common liquid detergent (Cheer[2]) with distilled water to make one gallon (3.7854 liter) of solution with surface tension of 31.8 dynes/cm at room temperature (71 F). Liquid Cheer contains biodegradable cleaning agents (enzymes, anionic and nonionic surfactants), dispensing aids (ethyl alcohol, propylene glycol), soil suspending agent, and several other ingredients.

EXPERIMENTAL PROCEDURES

Because of space limitation of the drying chamber, each species was divided into four runs. In each run, 25 sample blocks from the same tree were extracted and randomly assigned to five different groups: (1) control, (2) soaking in wetting agent solution for one week, (3) soaking in wetting agent solution for one week, plus two ultrasonic cavitations for 5 min each at 120 watts (cavitation 1), (4) soaking in wetting agent solution for one week, plus two ultrasonic cavitations for 3 min each at 240 watts (cavitation 2), and (5) moisture content samples (samples used to estimate the green MC by oven-dry method). On the 3rd and 5th days of soaking, ultrasonic cavitation was applied while the sample block was submerged in the soaking solution in a small plastic container (Fig. 3). The horn-tip was inserted through a hole on the cover of the plastic container. No coupling, other than water (solution), was used.

TABLE 1. *Average initial moisture contents (%)[a] for various treatments of three U.S. hardwoods.*

Treatment	Sugar maple	Black walnut	White oak
Control	55.2**	78.7**	57.4**
	(2.40)	(2.08)	(4.44)
Soaking	76.6 A	80.7 A	70.0 A
	(2.42)	(3.46)	(4.65)
Soaking/cavitation 1	77.3 A	81.9 A	70.2 A
	(2.85)	(3.29)	(4.65)
Soaking/cavitation 2	78.6 A	82.5 A	70.4 A
	(2.61)	(3.19)	(4.72)

[a] Values represent means of 20 replicates. Figures in parentheses represent one standard deviation. Values within a column followed by the same capital letter are not significantly different by Duncan's multiple-range test ($\alpha = 0.05$).
** Significant at 0.01 probability level.

After soaking and ultrasonic cavitation, the first four groups (20 sample blocks in all) were placed in the controlled temperature and humidity chamber for drying (DB = 49 C, WB = 45 C; EMC = 14.1%) until the average MC reached near 15%. Weights and dimensions (thickness and width) were measured before drying, every 12 h for the first 3 days, and then every 24 h for the 4th and 5th days. During the second week, weights and dimensions were taken every other day (Monday, Wednesday, and Friday—the end of drying). No oven-dry weights or oven-dry dimensions were measured at the end of each experimental run.

The moisture content-time curve of each sample block was numerically differentiated using Stirling method (Scarborough 1962) to obtain drying rates (% MC/h) from 50 to 20% MC at 5% intervals.

Since the main purpose was to test the effect of various treatments on drying rate, not the effect of various times, a more powerful, completely randomized one-way design with 4 treatments and 20 observations per treatment yielding an error term with 76 degrees of freedom was used in all ANOVAs. Also, Duncan's multiple-range test was employed to compare the mean drying rates of various treatments at various moisture contents, and to compare the mean thickness and width shrinkage of various treatments after 11 days of drying. Separate ANOVAs and Duncan's tests were conducted for each species.

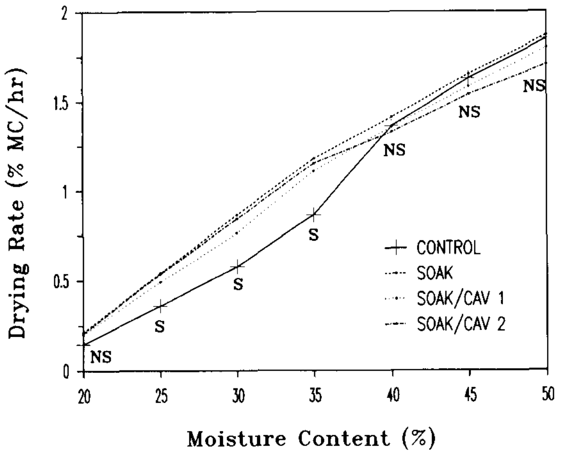

FIG. 4. Effects of wetting agent and ultrasonic cavitation on drying rates of sugar maple heartwood. S = significant, NS = nonsignificant.

RESULTS AND DISCUSSION

Soaking in a wetting agent for one week significantly increased the average initial moisture (AIMC) of sample blocks resulting in moisture content gains of 2% for black walnut, 13% for white oak, and up to 21% for sugar maple. Ultrasonic cavitation did not increase the AIMC of sample blocks beyond that of soaking alone for sugar maple, black walnut, and white oak (Table 1).

Effect on drying rate

All treated sample blocks of sugar maple dried significantly faster in the 25 to 35% MC range than the controls (Fig. 4). However, there was no difference in drying rate among the three treatments. Soaking in a wetting agent for one week seemed to increase the subsequent drying rate of sugar maple heartwood in the 25 to 35% MC range where the bound water drying became predominant. Ultrasonic cavitation did not increase the drying rate beyond that of soaking alone. The above phenomenon is similar to the effect of ultrasonic cavitation on the absorption of water during one week soaking in the wetting agent solution (Tables 1 and 2).

All or some treated black walnut sample blocks dried significantly faster in the 20 to 45% MC range than the controls (Table 3). In black walnut, unlike sugar maple, ultrasonic cavitation increased the drying rate beyond that of soaking alone at 25, 40, 45, and 50% MC. Furthermore, the more intense ultrasonic cavitation treatment also increased the drying rate of black walnut at 25, 45, and 50% MC. Our result is similar to what Kotok (1971) found in drying ponderosa pine. He vibrated the wood with a hammer at 60 Hz and found a 15% savings in drying time.

No significant difference in white oak drying rate was found between controls and all treated sample blocks. Also, no difference was detected between soaking alone and soaking plus cavitation treatments (Table 4).

Drying of wood near and below the fsp involves mostly the bound water flow. The mechanism for the increased drying rate near and below the fsp for sugar maple and black walnut may be related to the lowering of the wood-water interfacial free energy and the extractives removed in wood. The lowering of the wood-water interfacial free energy could reduce the bonding energy (hydrogen bonding) between wood and water. The anionic and nonionic surfactants present in the detergent may serve as charge and hydration barriers between wood and water (because of the orientation of the polyoxyethylene hydrophilic head and the alkyl hydrophobic tail), thus causing the bound water to behave somewhat

TABLE 2. *Average drying rates for various treatments of sugar maple.*

MC	Control	Soak	Soak/ cav 1	Soak/ cav 2	Standard error
%	%MC/hour				
20	0.1469	0.2143	0.2022	0.2068	0.0264
25	0.3593[a]**	0.5406[b]	0.4904	0.5353	0.0410
30	0.5780[a]**	0.8638[b]	0.7632	0.8410	0.0429
35	0.8618[a]**	1.1769[b]	1.1073	1.1500	0.0418
40	1.3616	1.4114	1.3572	1.3627	0.0366
45	1.6292	1.6530	1.5840	1.5398	0.0519
50	1.8497	1.8687	1.8002	1.7066	0.0613

[a] Control significantly less than any treatment at that MC.

[b] No difference between soaking and soaking plus cavitation treatments.

** Significant at 0.01 probability level.

TABLE 4. *Average drying rates for various treatments of white oak.*

MC	Control	Soak	Soak/ cav 1	Soak/ cav 2	Standard error
%	% MC/hour				
20	0.0773	0.0973	0.0812	0.0852	0.0072
25	0.1731	0.1991	0.1780	0.1841	0.0111
30	0.3080	0.3438	0.3250	0.3217	0.0159
35	0.5489	0.5378	0.4850	0.4945	0.0303
40	0.8595	0.8484	0.7876	0.7759	0.0500
45	1.1722	1.2743	1.1670	1.1551	0.0635
50	1.3953	1.6162	1.4389	1.4357	0.0658

No significant difference was found among any treatments.

like free water and facilitating moisture removal near and below the fsp.

The cleaning, dispensing, and suspending agents present in the detergent, coupled with the ultrasonic cavitation which is known to cause pulverization, to clean hard-to-reach surfaces and to accelerate chemical reactions, most likely increased the removal of extractives from the cell walls and the encrusted pit-membranes much like the mechanism behind the dirt removal action of detergent. Extractives removed from black walnut heartwood have been indirectly linked to the increase of wood permeability (Chen 1975). Improved permeability would also facilitate the removal of bound water near and below the fsp. This explains why the drying rate increase near and below fsp was observed in sugar maple and black walnut. Because of the higher extractive content in black walnut, the more intense ultrasonic cavitation treatments increased the drying rate beyond the effect of soaking alone. During the week-long soaking and two cavitation treatments of black walnut sample blocks, the color of the soaking solution changed from light blue to creamy brown—strong evidence of extractives removal. However, the lowering of the wood-water interfacial free energy and removal of extractives did not improve the drying rate of white oak heartwood. The profuse tyloses in the vessels of white oak heartwood have a greater controlling effect on moisture flow both above and below the fsp.

The reduction in surface tension did not contribute much to the observed increase in drying rates of sugar maple and black walnut

TABLE 3. *Average drying rates for various treatments of black walnut.*

MC	Control	Soak	Soak/cav 1	Soak/cav 2	Standard error
%	% MC/hour				
20	0.1167	0.1375	0.1780[c]**	0.1848	0.0160
25	0.1770	0.1977	0.1911	0.2489[e]**	0.0153
30	0.3220	0.4015	0.3613	0.4142	0.0287
35	0.4041[a]**	0.5304[b]	0.5570	0.6260	0.0355
40	0.5572	0.6029[d]**	0.7070	0.7964	0.0356
45	0.8199	0.7654	0.7948	0.9812[e]**	0.0405
50	1.0929	1.0141	0.9626	1.1889[f]**	0.0440

[a] Control significantly less than any treatment at that MC.

[b] No difference between soaking and soaking plus cavitation treatments.

[c] Control significantly less than soak plus cavitation treatments.

[d] Control and soak significantly less than soak plus cavitation treatments.

[e] Soak/cav 2 significantly greater than any other treatments.

[f] Soak/cav 2 significantly greater than soak and soak/cav 1.

** Significant at 0.01 probability level.

TABLE 5. *Average total thickness and width shrinkage from green to EMC for various treatments of three U.S. hardwoods.*

Species	Shrinkage	Control	Soak	Soak/cav 1	Soak/cav 2
		%			
Sugar maple	Thickness	2.30 (0.83)[c]	2.85 (1.07)	2.73 (1.00)	2.59 (0.86)
	Width	5.23[a]** (0.58)	6.41[b] (0.72)	6.47 (0.86)	6.22 (0.68)
Black walnut	Thickness	3.05[a]** (0.54)	3.73[b] (0.63)	3.68 (0.78)	3.86 (0.64)
	Width	5.58 (0.69)	5.92 (0.84)	5.80 (0.79)	5.81 (0.75)
White oak	Thickness	3.10[a]* (0.68)	3.82[b] (0.79)	3.85 (0.95)	3.79 (0.86)
	Width	5.10[a]** (0.71)	5.85[b] (0.66)	5.84 (0.68)	5.95 (0.86)

[a] Control significantly less than any treatment at the end of drying.
[b] No difference between soaking and soaking plus cavitation treatments.
[c] Figures in parentheses represent one standard deviation.
* Significant at 0.05 probability level.
** Significant at 0.01 probability level.

for two reasons: (1) the surface tension of the soaking solution (31.8 dynes/cm) is not far removed from that of the sap present in wood (51.1 dynes/cm for black walnut heartwood—Chen and Workman 1980); and (2) if reduction in surface tension is the major factor causing the increase in drying rate, then we should have observed a more significant increase occurring above fsp considering that surface tension has a greater effect on free water flow than bound water flow.

Effect on shrinkage

Samples soaked in a wetting agent at room temperature for one week had greater thickness (radial) shrinkage than the controls for black walnut and white oak. Soaking also caused a greater width (tangential) shrinkage for sugar maple and white oak. However, ultrasonic cavitation did not increase the shrinkage beyond that of soaking alone (Table 5). The week-long soaking in a wetting agent solution removed a substantial portion of water-soluble extractives, as evidenced by the darker color of the soaking solution at the end of the week. It would appear that these water-soluble extractives acted as bulking agents when hardwoods were dried at the relatively low temperature of 120 F. Demaree and Erickson (1976) found that when redwood heartwood samples were dried at room temperature and 110 F, the quantity of extractives in wood was inversely related to volumetric shrinkage. That is, at low drying temperature the extractives act primarily as bulking agents.

CONCLUSIONS

Soaking in a wetting agent for one week increased the subsequent drying rates of sugar maple and black walnut heartwood, but not white oak, around and below the fiber saturation point.

Ultrasonic cavitation increased the subsequent drying rate of black walnut but not sugar maple and white oak beyond the effect of soaking.

Soaking in a wetting agent for one week increased thickness (radial) shrinkage of black walnut and white oak, and width (tangential) shrinkage of sugar maple, and white oak heartwood upon subsequent drying.

REFERENCES

Chen, P. Y. S. 1973. Investigation of pressure-solvent-displacement of moisture in wood. Wood Sci. 6(1):61–64.

———. 1975. The effect of steaming time and temperature on the longitudinal permeability of black walnut. Wood Fiber 7(3):222–225.

———, and W. T. Simpson. 1992. Effects of ultrasonic cavitation on rate of heat propagation and longitudinal permeability of three U.S. hardwoods. Forest Prod. J. 42(4):55–58.

———, and E. C. Workman, Jr. 1980. Effect of steaming on some physical and chemical properties of black walnut heartwood. Wood Fiber 11(4):218–227.

Demaree, L. A., and R. W. Erickson. 1976. Temperature-dependent effect of extractive content on redwood shrinkage. Wood Sci. 8(4):227–233.

ERICKSON, R. W., R. L. HOSSFELD, AND R. M. ANTHONY. 1970. Pretreatment with ultrasonic energy—Its effect upon volumetric shrinkage of redwood. Wood Fiber 2(1):12–18.

FREDERICK, J. R. 1965. Ultrasonic engineering. John Wiley & Sons, Inc., New York, NY.

KOTOK, E. S. 1971. The effect of resonating wood during drying. Forest Prod. J. 21(2):24–25.

PANSHIN, A. J., C. DEZEEUW, AND H. P. BROWN. 1964. Textbook of wood technology, 2nd ed. McGraw-Hill Book Company, New York, NY.

SCARBOROUGH, J. B. 1962. Numerical mathematical analysis. The Johns Hopkins Press, Baltimore, MD.

SONICS & MATERIALS, INC. 1984. High intensity ultrasonic processor (machine instruction pamphlet). Danbury, CT 06810.