EFFECT OF STEAMING AND HOT-WATER SOAKING ON EXTRACTIVE DISTRIBUTION AND MOISTURE DIFFUSIVITY IN SOUTHERN PINE DURING DRYING[1]

Elvin T. Choong

Professor
School of Forestry, Wildlife, and Fisheries
Louisiana State University Agricultural Center
Baton Rouge, LA 70803

Todd F. Shupe

Forest Products Specialist
Louisiana Cooperative Extension Service
Louisiana State University Agricultural Center
Baton Rouge, LA 70803

and

Yong Chen

Former Research Assistant
School of Forestry, Wildlife, and Fisheries
Louisiana State University Agricultural Center
Baton Rouge, LA 70803

(Received February 1998)

ABSTRACT

Samples of southern pine sapwood and heartwood were treated five different ways: steaming in the saturated condition for 1 h and 5 h, respectively, steaming at a moisture content near the fiber saturation point (FSP) for 1 h, hot-water soaking for 10 h, and steaming near 95% relative humidity at an equilibrium moisture content (EMC) slightly below the FSP for 1 h at 100°C. The samples were dried from near saturation condition to an EMC slightly below the FSP, and then to final 12% EMC. The results indicate that the amount of extractives removed tended to be evenly distributed along the flow direction before drying and after drying to near FSP, which suggests that extractives move with water in wood in response to moisture gradient during drying. Hot-water soaking and prolonged steaming increased the moisture diffusivities above and below the FSP. The variation in diffusion coefficient was partially due to changes in the extractive distribution profile.

Keywords: Southern pine, extractives, diffusivity, steaming, hot-water soaking.

INTRODUCTION

Steaming has been reported in the literature (Sharma and Bali 1969; Mackay 1971; Simpson 1975) to reduce drying times of wood. Hot-water soaking has also been reported (Chen and Choong 1994) to have the same effect as steaming. The change in drying properties as a result of steaming or hot-water soaking has been attributed to the removal (Chen and Workman 1980) or rearrangement (Nicholas and Thomas 1968; Kininmonth 1971) of extractives. However, little has been reported in the literature concerning the quantitative change of content and distribution of

[1] This paper (No. 98-22-0078) is published with the approval of the Director of the Louisiana Agricultural Experimental Station. This research was supported in part by the McIntire-Stennis Cooperative Forest Research Program.

extractives in southern pine during drying, before, and after these treatments, or its relationship to moisture diffusivity.

Spalt (1979) stated that at high temperature, the extractives in moist wood may become active adsorbates that move in response to moisture concentration gradients. In such a case, the distribution patterns of the extractives should differ at various drying stages. The change of extractives content and distribution patterns during practical drying conditions is important in an understanding of how moisture moves through wood, even though only a small amount of extractives can be removed by steaming and hot-water soaking treatments (most of the extractives in southern pine are not soluble in hot water but are in lipophilic solvents). For these reasons, a study was undertaken to: (1) measure the distribution of extractives in southern pine sapwood and heartwood treated by several steaming and hot-water soaking processes at two extractive stages, (2) determine their moisture diffusivities at two drying phases, i.e., above and below the fiber saturation point (FSP), and (3) examine the relationship of the distribution of extractives to the moisture diffusivity.

With regards to the second objective, Stamm (1964) stated that moisture diffusion below the FSP, though not itself a diffusion phenomenon, is controlled by diffusion below the FSP during drying, and appears as if it were a diffusion phenomenon because of the moisture gradient, i.e., the surface moisture content falls below the FSP first. The hypothesis to be tested for this project was that the change of moisture diffusivities by the treatment processes can be explained by the differences in the distribution patterns of extractives in southern pine woods.

EXPERIMENTAL PROCEDURE

Southern pine (*Pinus* sp.) sapwood and heartwood were used in this study. Moisture movement during drying was restricted in a unidirection. Five treatments were:

A—Control
B—Steaming in saturated condition for 1 h at 100°C,
C—Steaming in saturated condition for 5 h at 100°C,
D—Hot-water soaking for 10 h at 70°C, and
E—Steaming near 95% relative humidity at an equilibrium moisture content (EMC) slightly below the FSP for 1 h at 100°C.

The extractive distributions were examined at two stages: Extractive Stage A—after treatments at saturated condition before drying; Extractive Stage B—after drying from near saturation to near the FSP. Only the extractive distributions in the longitudinal and tangential directions were examined since considerable error would be involved in the radial direction due to difference between earlywood and latewood along the radial direction. The moisture diffusivities in each structural direction (longitudinal, radial, and tangential) were studied with separated samples. A completely randomized design with two replications was applied in the data analysis processes. The samples were dried in two phases: Drying Phase 1—Free Water Range, from near saturated condition to near the FSP; and Drying Phase 2—Hygroscopic Range, from near the FSP to the final EMC.

Two southern pine flat-sawn boards measuring about 5 cm thick, 20 cm wide, and 4 m long were obtained in green condition from the Miles Lumber Company in Bogalusa, Louisiana. From these boards, 72 specimens measuring 2.5 cm^3 were prepared. One half the samples were from sapwood and the other half from heartwood. An adjusting miter gauge was used to define the cutting direction to ensure that the movement of moisture followed the true principal direction. Since these samples came from air-dry boards, they were first saturated in water by periodic vacuum and atmospheric pressure treatment in a desiccator for three days. A 56-cm Hg vacuum was applied to evacuate the air in the desiccator for an hour, then released to atmospheric pressure. This process was carried out three times a day for two weeks, and the interval from the end

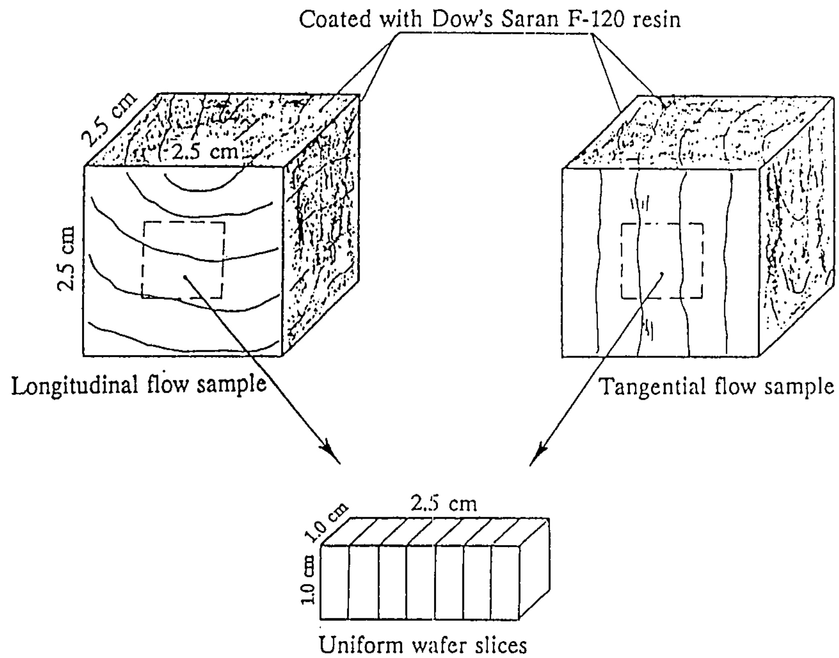

FIG. 1. Cutting scheme of extractive distribution profile samples.

of pressure recovery to the beginning of the next vacuum was at least 2 h. After this treatment, the southern pine samples were considered near saturation.

Half of the samples then were coated with a waterproof polymer substance (Dow's Saran F-120 resin) to restrict the moisture movement only in the longitudinal direction, and the other half in the tangential direction. After coating, these samples were subjected to the treatments described above. Treatments B, C, and D were carried out after the samples had been coated, whereas Treatment E was done after the samples had been dried slightly below the FSP. For the steaming treatments, the samples were randomly chosen from each corresponding group and placed inside a small pressure retort. High pressure steam was generated in an electric steam boiler, which was connected to a retort. Hot-water soaking was done in a thermostatically controlled water container.

Drying was carried out in a AMINCO environmental chamber. In Drying Phase 1, the environmental condition in the chamber was adjusted to 45°C and 97% relative humidity (RH) (i.e., nominal 25% EMC), with an air velocity about 2 m/sec. After the samples had been dried to near FSP, they were placed temporarily inside a BLUE-M environmental chamber with the same drying temperature and RH. The drying condition in the AMINCO chamber was adjusted to 45°C and 30% RH (i.e., nominal 6% EMC); then the samples in the BLUE-M were transferred to the AMINCO chamber and dried to the final EMC.

At each extractive stage, the samples were cut into blocks 1.0 cm × 1.0 cm × 2.5 cm in dimension (Fig. 1). From each block, seven wafer pieces about 0.35 cm thick were obtained. Preliminary study indicated that if the wafer thickness was less than 0.35 cm, the amount of extractives removed would be too small for accurate determination of extractive distribution profiles of the extractives. Along the longitudinal direction, the wafer pieces were cut with a thin-blade band saw, whereas along the tangential direction they were cut with a sharp chisel. After their oven-dry weights had been recorded, these wafer pieces

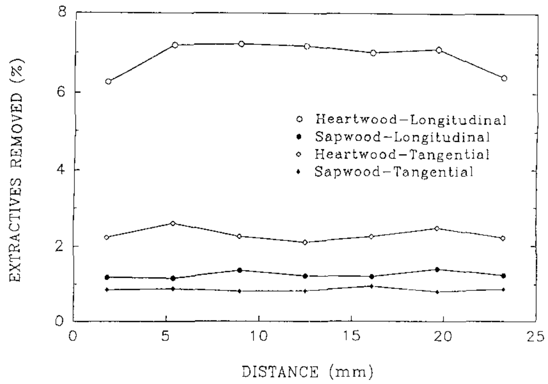

FIG. 2. Average extractive distribution profiles of southern pine heartwood and sapwood in the longitudinal and tangential directions at Extractive Stage A.

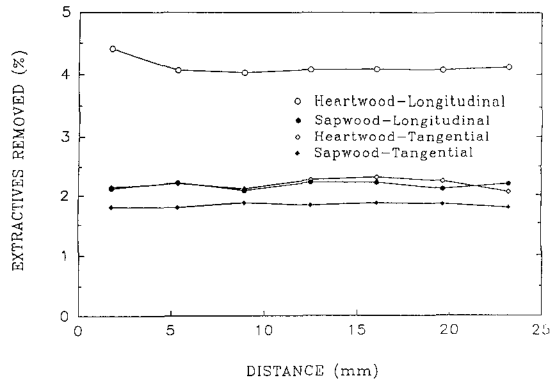

FIG. 3. Average extractive distribution profiles of southern pine heartwood and sapwood in the longitudinal and tangential directions at Extractive Stage B.

underwent hot-water extraction (75°C) in a Soxhlet extractor for 48 h, and then were oven-dried again to determine the amount of extractives removed in each wafer piece. This procedure enabled the extractive distribution profiles to be obtained.

For moisture diffusivities, 60 samples 2.5 cm × 2.5 cm × 2.0 cm in dimension were also obtained from the two boards. Half of the samples were from sapwood and the other half from heartwood. The waterproof polymer substance was applied to the four 2.5-cm × 2.0-cm sides to allow unidirectional movement of moisture from the two 2.5-cm × 2.5-cm sides. The treatments and drying processes were similar to those applied on the extractive distribution samples.

The average diffusion coefficient, D, was calculated based on Eq. (1), the theoretical solution of Fick's second law under the equilibrium boundary condition, using the optimization method described by Chen et al. (1994)

$$\bar{E} = (8/\pi^2) \sum_{n=1}^{\infty} \frac{1}{(2n - 1)_2} e^{-[(2n-1)/2a]^2\pi^2 Dt} \quad (1)$$

where $\bar{E}$, a, D, and t represent the fraction of evaporable moisture present in wood, half-thickness of a wood sample, diffusion coefficient, and drying time, respectively. The application of the optimization method allows finding the representative D by which the derived theoretical drying curve best fits the experimental data, based on the least squares principle. The effects of treatments, species, and directions of moisture movement were statistically analyzed on each drying phase separately.

RESULTS AND DISCUSSION

The average extractive distribution profiles of southern pine heartwood and sapwood in the longitudinal and tangential directions at Extractive Stages A and B are shown in Figs. 2 and 3, respectively. These figures illustrate differences due to wood type and structural directions. The heartwood samples contained more extractives than sapwood samples. Also, the amount of extractives removed from the heartwood in the longitudinal direction were two to three times more than in the tangential direction. Those samples extracted in the tangential direction took considerable time (i.e., more than 48 h at 75°C) to reach the same level of extraction as in the longitudinal direction because the passageways for the movement of extractives are more effective in the longitudinal direction.

The effects of treatments for the two extractive stages are shown in Figs. 4 and 5, respectively. The extractives distribution profiles are generally flat for both sapwood and heartwood, indicating that the extractives were

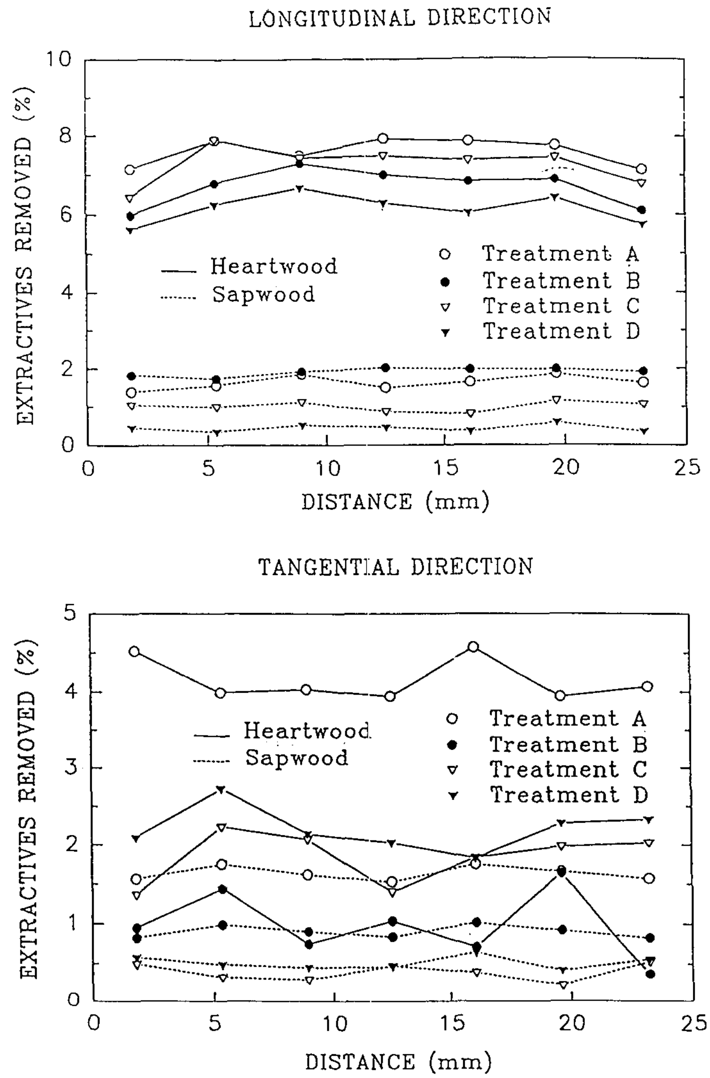

FIG. 4. Comparison of extractive distribution profiles of southern pine by four treatments at Extractive Stage A. Treatment A—control, Treatment B—steaming in green condition for 1 h at 100°C. Treatment C—steaming in green condition for 5 h at 100°C, Treatment D—hot-water soaking for 10 h at 70°C.

evenly distributed throughout the sample thicknesses regardless of treatments and extractive stages. For the heartwood samples in the longitudinal direction, the amount of extractives removed by the hot-water extraction were somewhat lower at the surface than in the interior of wood samples. The untreated control also showed the same tendency. This difference may have been caused by the removal of some extractives near the surface of wood during the cold-water soaking and subsequent periodic vacuum and atmospheric pressure. The extractives along the flow direction tended to display a uniform profile, which suggested that the extractives distribution depended on the even distribution of moisture contents, which are evenly distributed in the two extractive stages. Extractives in the samples might move with the water in wood driven by moisture content gradient during drying,

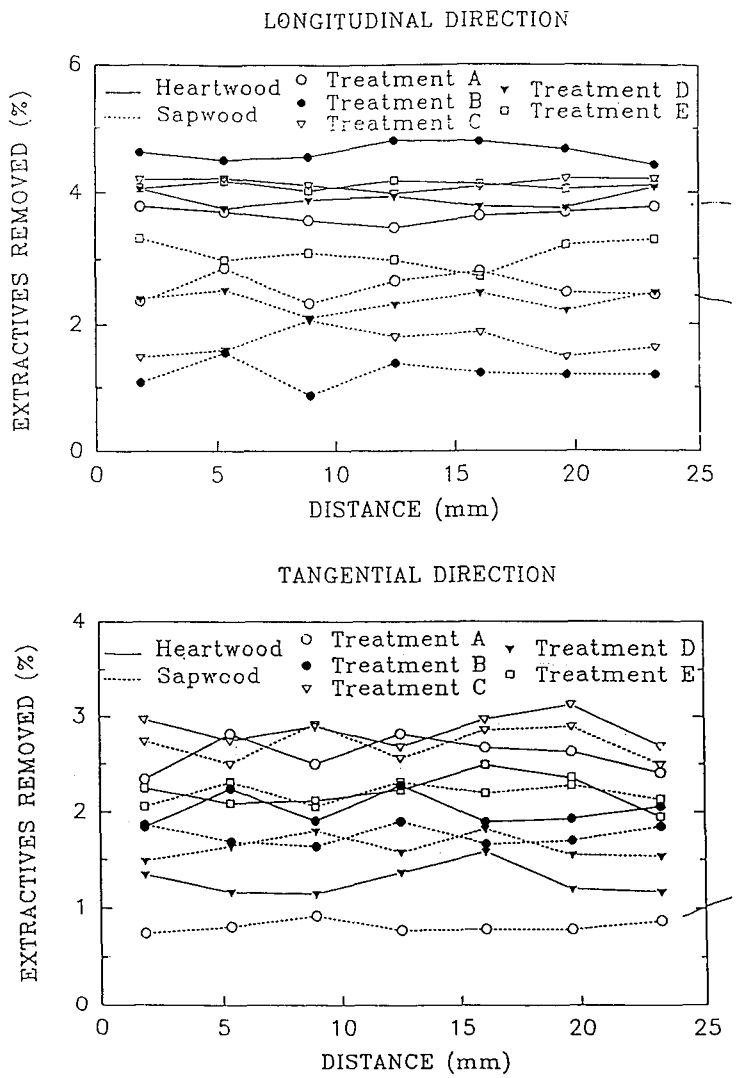

FIG. 5. Comparison of extractive distribution profiles of southern pine by five treatments at Extractive Stage B. Treatment A—control, Treatment B—steaming in green condition for 1 hour at 100° C, Treatment C—steaming in green condition for 5 hours at 100° C, Treatment D—hot-water soaking for 10 hours at 70° C, Treatment E—steaming at moisture content near the fiber saturation point for 1 hour at 100° C.

and arrive at a new equilibrium position within the wood.

The average diffusion coefficients of southern pine heartwood and sapwood in Drying Phases 1 and 2 are given in Table 1. Pairwise *t*-tests (LSD) indicate that steaming in saturated condition for 5 h or hot-water soaking for 10 h generally led to higher diffusion coefficients than the control for both Drying Phases 1 and 2. Steaming in the saturated condition for 1 h, however, was generally not effective.

Steaming at near the FSP was generally as effective for removing the extractives as the 5-h steaming or the 10-h hot-water soaking. The results therefore indicate that both steaming and hot water treatments for several hours caused major changes in wood extractives. These treatments resulted in the redistribution

TABLE 1. *Average diffusion coefficients of southern pine heartwood and sapwood by five treatments in Drying Phase 1 and Drying Phase 2.*

Drying phase	Treatment[a]	Longitudinal direction		Radial direction		Tangential direction	
		Sapwood	Heartwood	Sapwood	Heartwood	Sapwood	Heartwood
		$\times 10^{-6}$ cm²/sec					
1	A	0.546[b] B[c]	0.424 B	0.443 C	0.389 B	0.398 B	0.365 B
	B	0.563 AB	0.443 AB	0.451 BC	0.394 AB	0.434 AB	0.374 AB
	C	0.594 A	0.484 A	0.514 A	0.410 A	0.472 A	0.380 A
	D	0.587 A	0.478 A	0.509 AB	0.402 AB	0.455 A	0.383 A
2	A	17.31 B	14.31 C	5.25 B	3.42 B	5.12 B	3.49 B
	B	23.47 A	16.61 BC	5.92 AB	4.04 AB	6.09 AB	3.65 AB
	C	20.76 A	18.38 AB	6.32 A	4.24 AB	6.44 A	3.98 A
	D	21.73 A	19.60 AB	5.72 AB	4.45 A	6.12 AB	3.98 A
	E	22.61	21.36 A	6.01 A	4.55 A	6.76 A	3.54 B

[a] Treatment A—control, Treatment B—steaming in green condition for 1 h at 100°C, Treatment C—steaming in green condition for 5 h at 100°C, Treatment D—hot-water soaking for 10 h at 70°C, Treatment E—steaming, near 95% relative humidity, at an equilibrium moisture content slightly below the fiber saturation point for 1 h at 100°C.

[b] Each value represents the mean of two replicates.

[c] Means within columns (For Drying Phase 1 or 2) having common letters are not significantly different (α = 0.05) by the LSD test procedure.

and partial removal of extractives from wood, but they also dissolved some extractives and degraded certain easily hydrolyzable components. The combined effects opened the moisture passageways in southern pine wood, and thus increased the moisture diffusivity.

Drying could also affect the extractive distribution profiles by partially removing the volatile components of extractives and by causing pit aspiration. The earlywood in southern pine sapwood is especially susceptible to aspiration (Bolton and Petty 1978). The control sapwood samples in the tangential direction (Fig. 5) contain low amounts of extractives, which could be due to the presence of aspirated pits. Steaming and hot water treatments for the sapwood either de-aspirated the pits or reduced the possibility of pit aspiration. The heartwood, however, does not show such tendency, possibly because of low moisture content.

CONCLUSIONS

1. The amounts of extractives in southern pine wood in longitudinal and tangential flow directions tended to form a uniform profile before drying or after drying to near the fiber saturation point.
2. The variation in extractive distribution could be explained by the combined effects of steaming and hot-water treatments, which removed some of the outer extractives in wood. This affected drying due to changes in the internal structure of wood.
3. Hot-water soaking and prolonged steaming increased moisture diffusivities in southern pine heartwood and sapwood, both above and below the fiber saturation point. The variation in diffusion coefficients could be partially explained by changes in extractive distribution profiles.

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