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Atlanta, Georgia*

IPST Technical Paper Series Number 776

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under Low-Headspace Conditions

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March 1999

Submitted to
Holzforschung

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Summary

Dielectric heating of wood in a low-headspace environment moves chemicals placed on the surface of the wood into its matrix. The effect is absent in control experiments with thermal heating. It is believed that dielectric heating enhances the diffusion of water within the wood, thereby increasing the movement of water-soluble compounds.

Keywords: dielectric, diffusion, dye, headspace, microwave, mixing, rate, wood.

Introduction

The introduction of chemicals into green wood is industrially important in processes such as chemical pulping (Chen 1992; Parthasarathy 1996; Parthasarathy *et al.* 1996). We previously found that placing green pine flakes or board in a microwave or radiofrequency (RF) field in a low-headspace environment extracts pinenes and other organics from the wood while removing very little water. Since water absorbs microwave energy much more readily than does wood, the wood is principally heated by the water. The enhanced wood-water interaction transfers more VOC material into the aqueous phase than would be possible by thermal heating alone. In this paper we report the opposite effect - the introduction of chemicals from the surface into the wood matrix through dielectric heating.

Materials and Methods

Slices (3.0 x 3.4 cm area, 2-14 mm thick) were cut against the grain from green pine sapwood, with care being taken to exclude knots and visible imperfections. The pieces were spotted with 5.0 μ L of Versatint purple II (obtained from Milliken Chemicals) on the cross-section, tightly wrapped with plastic, and microwaved at 60W in a Cober model LBM unit operating at 2,450 MHz. A thermocouple was placed on one surface of the slice, and the power was

cycled to maintain the surface temperature at 80-95°C for 1 minute. The concentration of the dye on a spot on the surface was indirectly determined through lightness (L^*) measurements (Anon 1994). A 1.3 cm² in the region of the spot was analyzed before and after microwaving, as was the area on the reverse face of the slice just opposite the spot. Bourbois *et al.* (1991) have described an application where L^* parameters were related to the concentration of a constituent. The initial area of the spot was approximately 2.5 cm², but spreading occurred in some experiments. For control experiments where the wood was oven-heated, the slice was wrapped in aluminum foil and heated such that the wood surface temperature reached 85-90°C for 1 minute. A small weight loss of about 3% was incurred during either microwaving or heating.

Results and Discussion

L^* values of the spotted regions of the face and reverse side of microwaved and oven-heated slices are compared in Figure 1 for wood specimens of varying thicknesses. Note that L^* for the face increases with microwaving, while that for the reverse side decreases, demonstrating movement of the dye. In contrast, L^* for the oven-heated pieces is relatively unchanged after treatment, indicating that microwaving mobilizes the dye to a much greater extent than does heat alone. The size of the dye spot varies somewhat due to sample non-uniformity, and causes occasional anomalies. For instance, the back face L^* for the 5 mm oven-dried sample decreases significantly upon heating, in exception to all the other data. The surface area of the microwave-treated spotted area also grows much more in comparison to the heat-treated sample, as shown in Figure 2. The area of the microwaved sample grows the most for the thinnest piece, since z -directional movement is more limited. The rate of ingress of the dye into a 10 mm slice was monitored during both microwaving and oven-heating, and the results are illustrated in Figures 3 and 4, respectively. The face lightens and the back surface darkens during microwaving. No changes occurred in the face during oven-heating, and a much smaller darkening was recorded for the back area. Hence, all the evidence points to enhanced mixing of chemicals from the surface into the matrix of the wood.

Gibson *et al.* (1988) described a related application where the diffusion of ethylene oxide in polyvinyl chloride was enhanced by microwave. They compared diffusion rates in an oven to those in a cycled microwave field, and found that the activation energy for diffusion was lowered considerably during irradiation. A similar phenomenon likely occurs in our case. Microwaving

enhances the diffusion of water, probably by disrupting the association between water and wood surfaces. The low-headspace restriction is a necessity in our case, since, without it, the water would simply evaporate, and the wood would dry out (Chen *et al.*, 1990; Zhang *et al.*, 1997). Under low-headspace conditions, the water is forced to remain in the wood, and its diffusion rate (or mixing) within the wood increases. As a result, the movement of materials dissolved in water is also enhanced. This is, of course, an oversimplification; other interactions are also affected. For example, the dye has its own association with wood, and the wood-water, wood-dye and dye-water relationships must all be altered.

These results complement those of a study reported earlier (Su *et al.*, 1999) where turpentine was preferentially released from green softwood through dielectric heating under low-headspace conditions. It was hypothesized that since the water was unable to leave the wood because of the low-headspace restriction, it dissolved the turpentine from hydrophobic regions within the wood. Once dissolved, these hydrophobic materials moved rapidly outside. The practical implication of this separation of turpentine from green wood is that the turpentine, which normally represents an air pollutant during drying, is now extracted as a product. The turpentine-depleted wood can then be dried with much reduced emissions. Our work here extends this theme; instead of moving organics from the inside out, we describe the opposite process. The implications of this to chemical pulping are being explored.

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Acknowledgments

This study was funded by the US Department of Energy through contract DE-FCO7-96IDI3439. We thank Georgia Power for loaning us the Cober microwave unit.

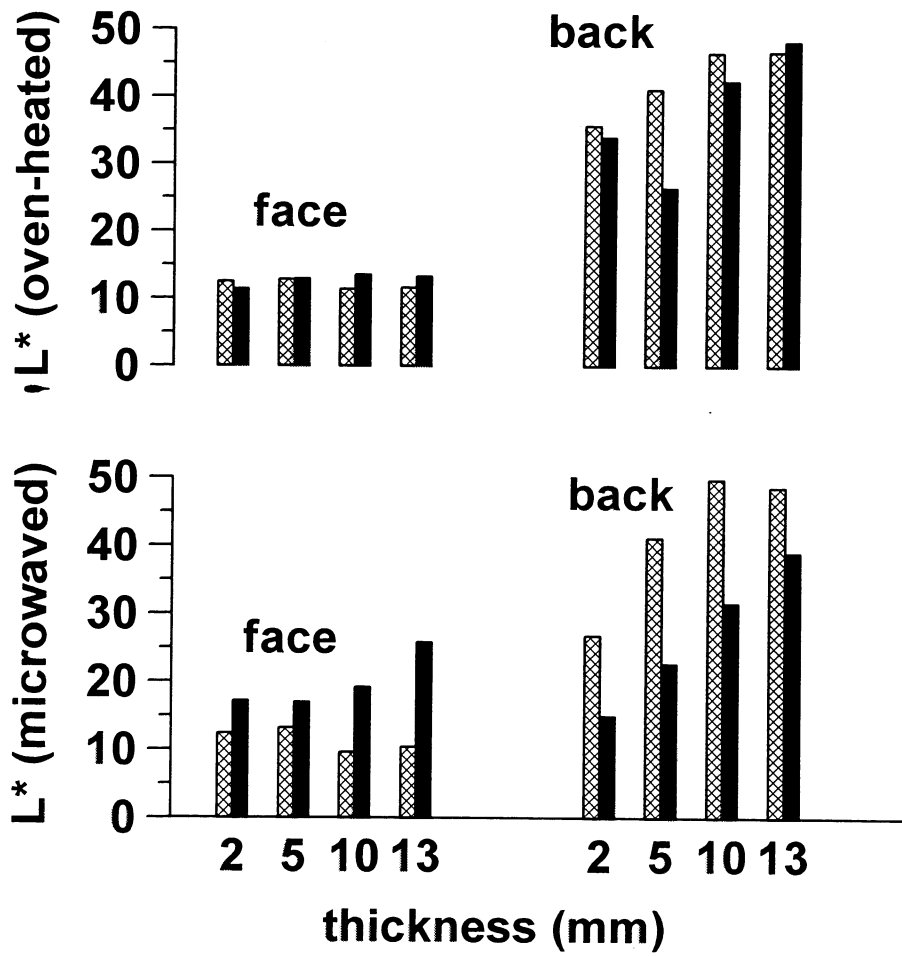


Figure 1: Lightness (L^*) values of microwaved and oven-heated slices. The hatched and dark bars represent pre- and post-treatment, respectively.

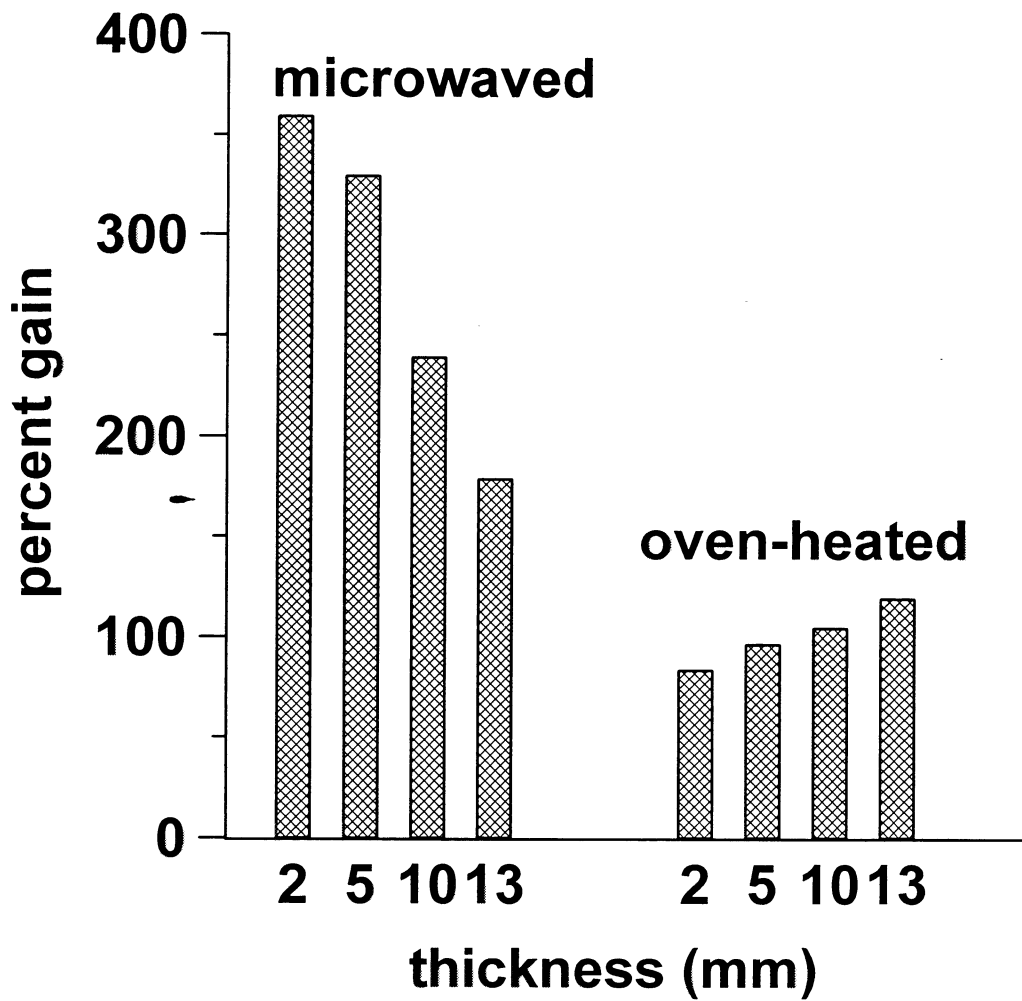


Figure 2: Gain in surface area of the spot (face side) after low-headspace microwaving and oven-heating.

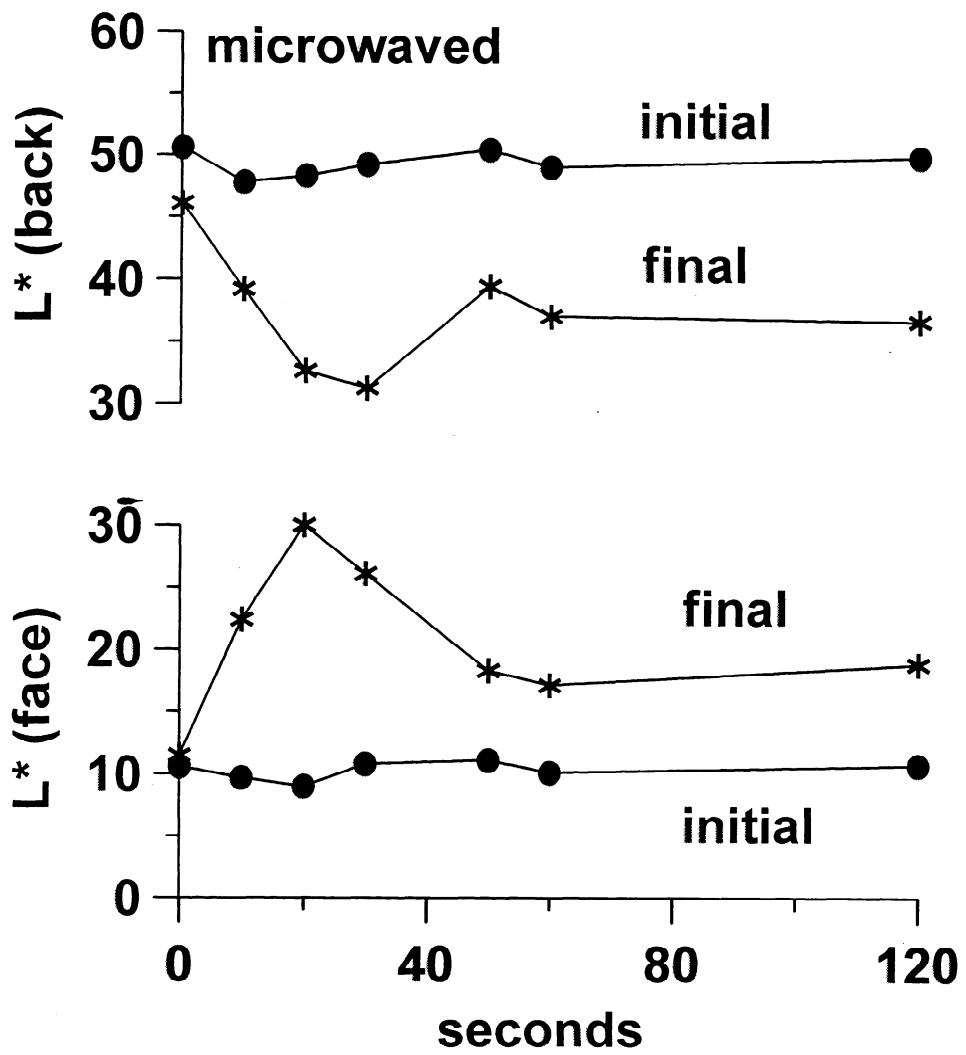


Figure 3: Rate of ingress of dye during microwaving.

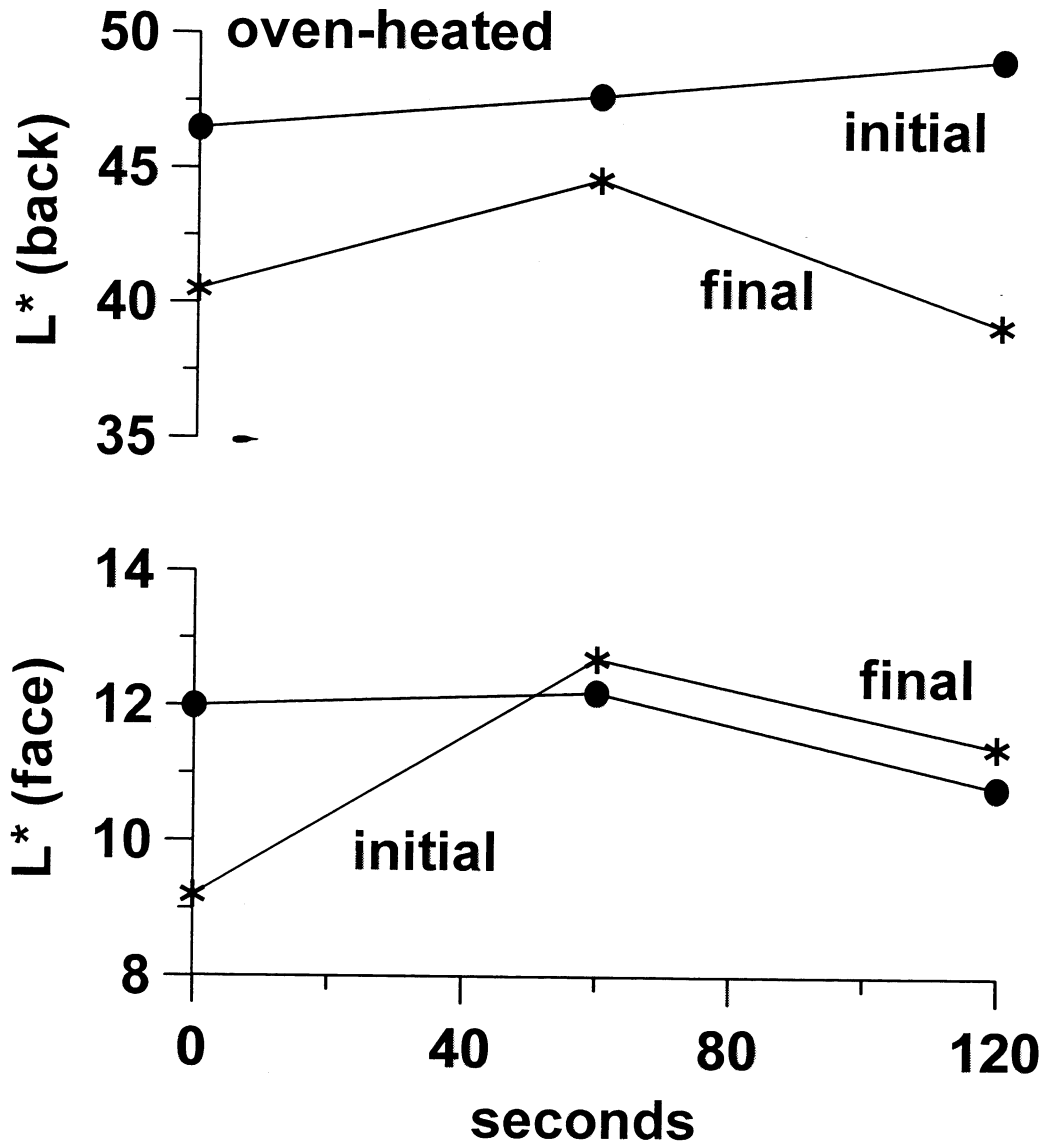


Figure 4: Rate of ingress of dye during oven-heating.

