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Impregnation of *Castanea creanata* Wood by Hydrophobic Oil[1]

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ABSTRACT

This paper investigates the penetration of essential oil into radial and longitudinal directions of *Castanea crenata*. Present study was performed to know the essential oil penetration depth in radial and longitudinal direction of *Castanea crenata*. Essential oil penetration depth was found higher in longitudinal direction than in radial direction and it was about 53 times high at 15.0 second of penetration. In earlywood, fiber conducted oil more than that of large vessel. In heartwood, fiber had played an important role for the conduction of oil. But in sapwood, small vessel conducted oil deeper than wood fiber, which was also significantly different from large. On the other hand, large vessel in heartwood had statistically lower penetration depth than that of fiber and small vessel. At the beginning of penetration the speed was high and gradually decreased in course of time.

Keywords: Pine oil, non-polar liquid, radial penetration, longitudinal penetration, surface tension.

INTRODUCTION

Penetration of chemicals into wood has been studied and modeled extensively (Comstock 1967; 1970; Petty 1975; 1978; Siau 1984, 1995). First, contaminant penetration into wood may be a combination of many different processes including capillary effects. Darcy's liquid flow, molecular diffusion and Knudsen diffusion (Comstock 1970; Petty 1975; Siau 1984), adsorption, and absorption (Mackay and Gschwend 2000; Tsuchikawa and Siesler 2003). Secondly, it occurs under poorly defined and changing conditions such as changes in available capillary pressure and changes in the amount of entrained air in wood capillaries that are crucial for wood permeability (Comstock 1967; Petty 1978; Siau 1984, 1995). To our knowledge, no data have been reported regarding essential oil penetration in wood under atmospheric pressure. But 1% safranine solution penetration were described by Ahmed et al. (2007), Ahmed and Chun (2007), Chong et al. (2007) and Choi et al. (2007).

Therefore the objective of the present study was to quantify the amount of hydrophobic oil taken up. Since anatomically and chemically investigate distinct wood tissues are likely to

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respond differently to the impregnation process, we also compared uptaken patterns in (1) heartwood and sapwood, and (2) earlywood and latewood. This study will help us to understand the permeability of essential oil in *Castanea crenata* and to compare the permeability difference of different liquid used in other experiments.

MATERIALS AND METHODS

Sample preparation

Wood samples of *Castanea crenata* Sieb. et Zucc. were obtained from Jiamri, Sabukmeyon, Chunchon, Kangwon do, Republic of Korea. Immediately after sample collection from defect free tree, discs were made and marked to identify top and bottom end. Discs were kept in air- tight cellophane bag to prevent the moisture loss. Moisture content of discs below fiber saturation point was obtained after air drying in the laboratory. To observe the longitudinal oil flow in tangential surface- 4 cm (longitudinal) x 0.5 cm (radial) x 1 cm (tangential) and to observe the radial flow- 4 cm (longitudinal) x 1 cm (radial) x 0.5 cm (tangential) were prepared after microtome shaving. In longitudinal penetration, liquid flow was observed from bottom to top and radial penetration flow was observed from bark to pit direction. Three replications were done by dividing sapwood and heartwood. In longitudinal direction, cells considered for measuring liquid penetration depth were fiber and vessel. Further more, fiber and vessel were divided into earlywood and latewood. In case of radial direction, marginal ray cell and procumbent ray cell were considered. At least three measurements were performed for the penetration depth in different cells. As a result, minimum nine measurement data were obtained for each cell liquid penetration. Except one cross and tangential surface for longitudinal and one radial and tangential surface for radial penetration, all surfaces were coated with silicon resin for preventing the leakage by other surfaces.

Estimation of moisture content

Wood sample were weighed and dried in an oven for 24 hours at 105 ^{O}C. Moisture content of wood block in terms of wet weight basis was calculated.

Essential oil

Generally this kind of oil is extracted form needles coniferous species like Pinus densiflora, Pinus koraiensis etc. Slightly reddish yellow oil density was 0.89g/cc and surface tension was measured to 26.17 dyne/cm.

Camscopic observation

Moisture content of samples was determined before liquid impregnation. While the observation of oil flow, the room temperature was 24 ^{0}C, RH 60% and the wind speed was 0 m/s. Silicon Coated samples were fixed on a petridish with glue and oil was poured upto the surface of wood sample to allow penetration through specific direction. With *i*-Solution software, the impregnation video file was captured by *i*-camscope (SV32) for about 2-3minutes. Using VitrualDub-MPEG2 software, the captured video file was divided in specific frames at 3.8, 7.5, 11.3 and 15.0 second for longitudinal direction and frames at 18.8, 37.6, 56.4 and 75.2 for radial direction. Because of high speed of longitudinal penetration, time interval was shorter than penetration interval in radial direction.

Statistical analysis

Oil penetration depth differences in different cells and direction were analyzed by using a one-way ANOVA. When significant differences occurred ($P \leq 0.05$), the ANOVA procedure was followed by a Duncan significant difference post hoc test to separate the time as cell effects (SPSS, Version 12.0.1,2003).

RESULTS AND DISCUSSION

Moisture content of *Castanea crenata* was recorded in sapwood 29.1% and in heartwood 27.9%. In this moisture level oil penetration depth longitudinal and in radial direction are presented below.

Table 1. Oil penetration depth of sapwood in longitudinal direction unit: μm

Cell type	3.8 Second	7.5 Second	11.3 Second	15.0 Second
Fiber in earlywood	691.93a	892.28a	971.38b	1104.76b
Fiber in latewood	704.33a	898.20a	978.01b	1108.02b
Vessel in earlywood	304.55b	522.76b	707.12c	1036.44b
Vessel in latewood	683.01a	866.90a	1075.59a	1292.59a

Note: Different lower case letters within in a column indicate significant difference (≤0.05).

Table 2. Oil penetration depth of heartwood in longitudinal direction unit: μm

Cell type	3.8 Second	7.5 Second	11.3 Second	15.0 Second
Fiber in earlywood	666.98a	876.44a	932.96a	1055.52a
Fiber in latewood	673.47a	783.67b	898.09a	1079.04a
Vessel in earlywood	142.05c	277.29d	567.84b	849.28b
Vessel in latewood	501.67b	656.23c	837.94a	1013.52a

Note: Different lower case letters within in a column indicate significant difference (≤0.05).

From the above table it is obvious that longitudinal flow depth varied from cell in earlywood to latewood and sapwood to heartwood. From the anatomical features of *Castanea crenata*, we know that it has non- septate fiber with simple to minutely bordered pits which can trap air in the cell lumen more frequently than vessel while liquid penetration. On the other hand, vessel lumen is much bigger than wood fiber and it has intervessel pittings through which liquid can also diffuse to the neighboring vessels. Vessels are connected together to form a tube and two vessels open through a simple perforation plate. A bulk flow of liquid can pass through this structure. But it has been reported by Wang and DeGroot (1996) that when the vessels are occluded with tyloses and extractives, the literature seems to indicate that the rays and fiber could function as fluid conducting channel. In this experiment we also found that the heartwood penetration depth was 1.14 times higher than sapwood. In heartwood, presence of tyloses in vessels reduced its permeability depth of oil. As a result wood fiber conducted 1.04 times higher than vessel. Though oil penetration depth was higher in sapwood fiber than large vessel, no statistical difference was observed between them.

In this experiment we found that latewood penetration depth was higher than earlywood. This is because the narrow cell lumen has higher capillary pressure (Chun and Ahmed 2006). Latewood penetration was found 1.11 times higher than earlywood penetration. Vessel in earlywood had the lower penetration depth than that of wood fiber. In presence of tyloses in heartwood vessels, wood fiber was found playing an effective role for oil penetration. But absence of tyloses and structure of vessel arrangement, heartwood small vessel should conduct liquid higher than wood fiber. Though there was no significant different after 15.0 second of penetration, heartwood small vessel had lower permeability than wood fiber. It could be for considering short period of time to observe oil penetration depth.

Table 3. Oil penetration depth in radial direction unit: μm

Time, second	Sapwood	Heartwood
18.8	29.42c	23.33b
37.6	36.42bc	32.21ab
56.4	42.67ab	37.22a
75.2	50.25a	41.48a

Note: Different lower case letters within in a column indicate significant difference (≤ 0.05).

Even though the conduction though hardwood ray tissues is not nearly as important in softwood despite the greater abundance of rays (Siau 1995), we measured the radial penetration depth of oil and it was found about 53 times lower than longitudinal direction at 15.0 second of penetration. Ray cell structure and arrangement are responsible for this outcome. Ray cells are connected end to end through endwall with pits. Also through lateral wall pits it is connected to the neighboring ray cells. So, penetration depth through ray cells would be depended upon the number of endwall pits and diameter, ray cell diameter and length etc. Difference for heartwood and sapwood penetration depth would be for the presence of deposits, number and diameter difference of pits present in ray parenchyma etc.

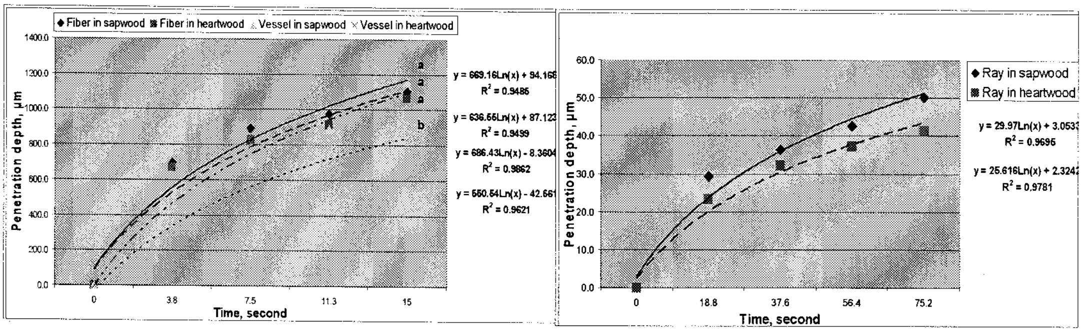

Fig. 1. Comparison of oil penetration in longitudinal direction (left) and in radial direction (right).

Penetration depth in rays present in sapwood was 1.21 times higher than that of heartwood. In this experiment we measured the surface tension of essential oil and it was found 26.17 dyne/cm which was lower than 1% safranine solution (36.10 dyne/cm). So, if we set an experiment with those two liquids, the penetration depth would be higher for essential oil.

From the above Fig.1 it is clear that after 15.0 seconds of penetration in longitudinal direction, penetration depth is the highest in sapwood fiber but there was no significant difference between sapwood and heartwood fiber. Vessel present in heartwood conducted the lowest. Oil penetration rate was found the highest at the beginning and then gradually decreased. After 3.8 second of penetration, oil penetration depth decreased upto 76% at 7.5 second, 83% at 11.3 second and 82% at 15 second in longitudinal direction. While after 18.8 second of penetration in radial direction, it decreased upto 77% at 37.6 second, 86% at 56.4 second and 87% at 75.2 second. It meant that liquid flow decreasing rate was not even. We can make conclusion from this result that, liquid flowing in radial or longitudinal direction followed a go-stop-go cycle until and unless the capillary pressure of oil created by cell lumen was equal to pressure of air above the air-oil interface. In this case the penetration would likely to be stopped.

CONCLUSIONS

The result of this study showed that essential oil penetration depth was found high in sapwood compared to heartwood. Longitudinal penetration depth was 46 times higher than in radial penetration. Penetration depth in latewood was found 1.11 times higher than that of earlywood. In heartwood, fiber played and important role for oil penetration and it was 1.04 times higher than vessel. Initially oil penetration speed was found high and then gradually it decreased in an uneven rate.

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