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Alcohol Permeability in *Castanea crenata* Sieb. et Zucc.[1]

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ABSTRACT

A study was conducted to know 99.5% ethyl alcohol penetration depth in radial and longitudinal direction of *Castanea crenata.* Alcohol penetration depth was found higher in longitudinal direction by about 12.47 times. In both earlywood and latewood, fiber conducted alcohol in higher depth than that of large and small vessel. Penetration depth of alcohol after 15.0 second of penetration in longitudinal direction, there was no significant difference among fiber in sapwood and heartwood, and vessel in sapwood. At the beginning of penetration the speed was high and then gradually decreased.

Key words: Alcohol penetration, longitudinal penetration, Radial penetration, Surface tension.

INTRODUCTION

Liquid penetration occurs due to capillary forces within the cell lumens. The fact of flow and diffusion is that flow and diffusion follow different laws and their effectiveness varies in different wood structures, the two subjects are considered separately. Flow varies not only with the combined effective cross section of the various paths but also with the square of the mean effective radius of the individual paths while diffusion, on the other hand, varies merely as the effective cross section of the diffusion paths (Stamm and Raleigh 1967a). So, it appears that diffusion is a simpler phenomenon than flow. This is not always true as more than one type of motivating mechanism may be simultaneously involved, as will be shown directly. Diffusion is the spontaneous movement of one material into another from a part of higher concentration to a part of lower concentration. In this case no external force or drying tension set up in an adjacent partially dried zone as is the case for flow. According to Stamm and Raleigh (1967a) diffusion in wood falls into one or more of three different types: (1) diffusion of a solute through the solvent saturated capillary structure of wood under a concentration gradient, (2) diffusion of a gas or vapor through the permanent void structure under a partial vapor pressure gradient, (not a hydrostatic pressure gradient), and (3) diffusion of an adsorbed liquid held in solid solution throughout the cell walls under a bound liquid gradient. Both liquids and vapors can move through the coarse capillary structure under two different means of motivation that follow different laws, namely by pressure permeability and by diffusion (Stamm and Raleigh 1967b).

The objectives of the present study were set to investigate the flow depth of alcohol considering combined effect of flow and diffusion in different cells of *Castanea crenata.* Depending on

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anatomical characteristics of this wood species, the penetration depth differences of alcohol in different cells were explained. This result will help us to compare the permeability differences in *Castanea crenata* using different liquids.

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. To observe the longitudinal alcohol flow in the tangential surface of the samples of 4cm (longitudinal) x 1cm (tangential) x 0.5cm (radial) and to observe the radial flow of the sample of 4cm (longitudinal) x 1cm (radial) x 0.5cm (tangential) were prepared after microtome shaving. In longitudinal penetration, flow was observed from bottom to top and for radial penetration flow was observed from bark to pit direction. 3 replications were done by dividing sapwood and heartwood for both directions. 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.

Considered liquid

99.5% ethyl alcohol was used for measuring liquid penetration depth. Its density was 0.77g/cc and surface tension was measured to 20.35 dyne/cm at 24^{0}C.

Camscopic observation

During the observation of alcohol flow, the room temperature was 24 ^{0}C, RH 60% and the wind speed was 0 m/s. Coated samples were fixed on a petridish and alcohol was poured on it. With ***i***-Solution software, the alcohol impregnation video file was captured by ***i***-camscope (SV32) for 5 minute. Using VitrualDub-MPEG2 software, the captured 5 minutes video file was divided in specific frames at 3.76, 7.52, 11.28 and 15.04 second for longitudinal direction and frames at 18.8, 37.6, 56.4 and 75.2 for radial direction.

Statistical analysis

Alcohol 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 ell as cell effects (SPSS, Version 12.0.1, 2003).

RESULTS AND DISCUSSION

Microscopic characteristics of *Castanea Crenata* Sieb. et Zucc. was found like distinct growth ring boundaries, ring-porous, vessel arranged in dendritic pattern with simple perforations, vessel-ray pits with much reduced borders to apparently simple; pits rounded or angular, Tyloses common in vessel, Vascular/vasicentric tracheids present, Non- septate fiber with simple to minutely bordered pits, Apotracheal axial parenchyma diffuse and also diffuse-in-aggregates, scanty paratracheal axial parenchyma, (3-4) cells per axial parenchyma strand, procumbent rays exclusively uniseriate, basic specific gravity medium, 0.40-0.75, heartwood colour darker than matured wood color, heartwood basically brown or shades of brown, water extract basically shades of red, ethanol extract basically colorless, froth test positive and splinter burns to charcoal.

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

Table 1. Alcohol 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	809.12b	938.69b	1013.67c	1184.11b
Fiber in latewood	1082.92a	1242.75a	1380.21a	1507.16a
Vessel in earlywood	376.29c	581.92c	753.07d	966.19c
Vessel in latewood	746.34b	939.11b	1201.58b	1489.50a

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

Table 2. Alcohol 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	795.73a	896.67b	872.11b	1168.77ab
Fiber in latewood	860.54a	996.44a	1108.24a	1263.40a
Vessel in earlywood	183.36b	224.76d	509.64c	707.62c
Vessel in latewood	448.41b	670.13c	916.89ab	1092.67b

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

Longitudinal penetration is mainly conducted by vessel along with wood fiber. In this experiment we found that alcohol penetration depth in vessel was higher than wood fiber especially in earlywood. This is because the narrow cell lumen has higher capillary pressure (Chun and Ahmed 2006). Heartwood alcohol penetration depth was found low due to presence of tyloses. Also, Tyloses and various gummy, resinous and chalky exudates often form in heartwood (Hillis 1987) and formation of this material reduces the treatability of heartwood (Kumar and Dobriyal 1993). Teesdale and MacLean (1918) found that the treatability of hardwood was directly related to whether the vessels contained tyloses and if tyloses were present the completeness of the vessel blockage by the tyloses. A practical example of the role of tyloses in blocking fluid flow is the use of white oak to make barrels for wine and whisky (Cote 1990). It worth nothing that since the tyloses and extractives are more likely to be found in the heartwood (Panshin and deZeeuw 1980), one would expect that these factors are responsible for the reduction of the heartwood treatability. As a result, sapwood was found more permeable than heartwood and sapwood alcohol penetration depth was 1.17 times higher than heartwood.

Rays and fiber occupy about 10 to 20% and 25t to 75% respectively of the total volume of hardwoods (Wang and DeGroot 1996). 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 found that when the heartwood vessel was occluded with tyloses, fiber played an important role for alcohol penetration and it was about 1.23 times higher. Though there was no significant difference, the reason of higher penetrability of wood fiber in sapwood was unknown. But it could be for considering short period of time to observe alcohol penetration depth.

Furthermore latewood was found more permeable that earlywood. Alcohol penetration depth in latewood was higher than that in earlywood by 1.37 times. It may due to the fact that the lumen diameter in latewood is narrower than in earlywood. Because of same reason, alcohol penetration depth in small vessel was found higher than large vessel elements.

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

Time, second	Sapwood	Heartwood
18.8	41.17c	43.50NS
37.6	46.92c	52.83NS
56.4	85.26b	68.25NS
75.2	120.14a	71.17NS

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

Compared with longitudinal flow depth, radial flow was found much more difficult. It has been reported that ray parenchyma cells are important channels for radial flow in some species (Chong et al. 2007). Siau (1995) stated that conduction though hardwood ray tissues were not nearly as important in softwood despite the greater abundance of rays. Even though we measured the radial penetration depth, it was found very low compared to longitudinal penetration and the depth was 12.47 times lower. Because of cell arrangement made this result. In radial direction, sapwood penetration depth was 1.69 times more than heartwood penetration. Penetration depth difference from starting pont to finishing time (75.2 second), statistical difference was observed for sapwood but due to low conductive ability of heartwood, significant difference was not observed in heartwood at different penetration time.

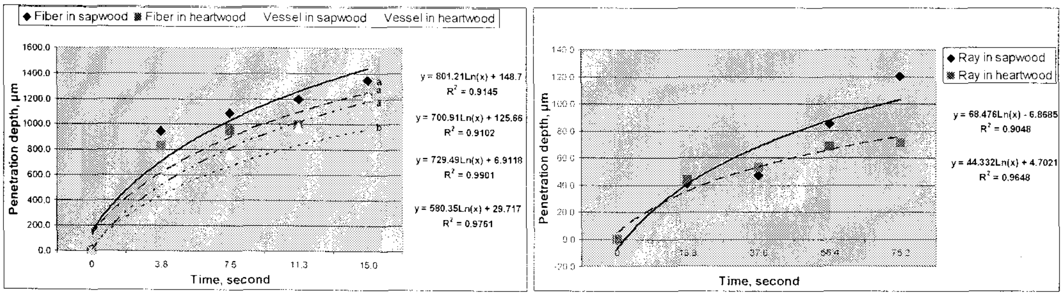

Fig.1. Comparison of alcohol penetration in longitudinal direction (left) and in radial direction (right).

From the above Fig.1 it is clear that after 15.0 seconds of penetration in longitudinal direction, alcohol penetration depth is the highest in sapwood fiber. Heartwood vessel conducted the lowest. At 15.0 seconds of penetration, no statistical difference was found among fiber and vessel except heartwood vessel. And the reason lower permeability of heartwood vessel was discussed earlier. Furthermore, surface tension of liquid also and important factor which determines the penetration depth in wood (Chun and Ahmed 2006). Lower the surface tension, higher the capillary pressure. In this experiment the 99.5% ethyl alcohol surface tension was found 20.35 dyne/cm at 24^0C. The penetration depth is thought to be low in this species at same moisture content level if we use other liquid which has high capillary pressure than alcohol.

In both direction, alcohol penetration rate was found high at the beginning and then gradually decreased. After 3.8 second of penetration, alcohol penetration depth decreased upto 84% at 7.5

second, 86% at 11.3 second and 83% at 15 second in longitudinal direction. While after 18.8 second of penetration in radial direction, it decreased upto 85% at 37.6 second, 65% at 56.4 second and 80% 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 alcohol created by cell lumen is equal to pressure of air above the air-alcohol interface. In this case the penetration will likely to be stopped.

SUMMARY

99.5% ethyl alcohol penetration depth was found high in sapwood compared to heartwood. Also longitudinal penetration depth was 12.47 times higher than in radial penetration. Penetration in latewood was found higher than that of earlywood. In heartwood, fiber played and important role for alcohol penetration and it was about 1.23 times higher than vessel. Initially alcohol penetration speed was found low and then gradually it decreased in an uneven rate. More research work is suggested using different liquid for measuring the penetration depths at same wood moisture content level.

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