KFS Journal, Vol. 18(4), 2007: 307-311

Essential Oil Penetration Depth in *Prunus sargentii* Rehder[1]

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ABSTRACT

An experiment was conducted to know the essential oil penetration depth in radial and longitudinal direction of *Prunus sargentii*. Oil penetration depth was found greater than radial flow depth. Vessel conducted oil more than wood fiber. In radial direction, body ray parenchyma was found more permeable than marginal ray parenchyma and it was about 138% times higher. Furthermore penetration depth of oil in intercellular space was greater than ray parenchyma and it was about 250% higher than ray parenchymas. Initial flow speed was found high and then it gradually decreased.

Key words: Liquid penetration, Axial flow, Lateral flow, Surface tension.

INTRODUCTION

Liquid penetration in wood varies depending upon species characteristics and solution properties. So far, different techniques and methods are used to observe the liquid penetration behavior in wood as stated by Ahmed et al. (2007), Ahmed and Chun (2007), Chong et al. (2007) and Choi et al. (2007). In wood utilization, permeability plays an important role since it directly affects the wood processing like drying and treatment with liquid or gas. But the movement of fluid through is highly complicated as passage through structures varying different cell component. Harwood structure is more heterogeneous in nature than softwood. Softwoods have fairly homogenous cell structure and fluid flow occurs primarily through tracheids lumen, ray lumen and interconnecting pits while vessel is the principle vehicle for bulk flow in hardwood (Siau 1995). In hardwood for unknown reasons, conduction through ray tissue is not nearly as important, despite the grater abundance of rays (Siau 1995).

The polarity of liquid is also expected to affect penetration. Independent research by Walters and Cote (1960) and Mumanis and Chudnoff (1979) suggested that nonpolar liquids travel via bulk flow through cell lumens and pittngs. Polar compounds penetrate via both bulk flow and by diffusion through the wood cell wall. This raises an interesting question regarding the mechanism of essential oil penetration. Intercellular pitting becomes impermeable under dry conditions, suggesting that polar liquids must be present to facilitate penetration (Stamm 1953; Mumanis and Chudnoff 1979).

Received for publication: June 20, 2007.

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Permeability in wood is dependent on the nature of liquid. So, the objectives of the present study were to investigate the penetration depth differences of liquid in *Prunus sargentii* such as non polar essential oil and different cells which played and important role for liquid conduction in longitudinal and radial directions. Depending on microscopic characteristics of wood and essential oil, the flow depth variation was also explained here.

MATERIALS AND METHODS

Sample preparation

Wood samples of *Prunus sargentii* Rehder 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 protect the moisture loss. To observe the longitudinal oil flow in tangential surface- 4cm (long) x 1cm (tangential) x 0.5cm (radial) and to observe the radial flow samples 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 for each direction by dividing sapwood and heartwood. 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

Essential oil was taken to know the penetration depth. Generally this kind of oil is extracted form needles coniferous species like *Pinus densiflora*, *Pinus koraiensis* etc. Its density was 0.89g/cc and surface tension was measured to 26.170 dyne/cm.

Camscopic observation

During the observation of essential oil flow, the room temperature was 24 ^{o}C, RH 60% and the wind speed was 0 m/s. Coated samples were fixed on a petridish and oil was poured on it. With *i*-Solution software, the oil impregnation video file was captured by *i*-camscope (SV32) for 5 minute. 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 by VitrualDub-MPEG2 software.

Statistical analysis

Oil penetration depth differences in different cells and direction were tested 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 and cell effects (SPSS, Version 12.0.1, 2003).

RESULTS AND DISCUSSION

Microscopic characteristics of *Prunus sargentii* were distinct growth ring boundaries, diffuse-porous, vessel with simple perforations, alternate non-vestured intervessel pits, helical thickenings throughout body of vessel elements. Thin to thick walled non septate fibers with simple to minutely bordered pit which mainly confined in radial wall. Axial parenchyma scanty paratracheal and also scanty diffuse. Larger rays commonly 4 to 5 seriate are dominantly present where body ray cells procumbent with mostly two to four rows of square marginal cell.

Moisture content of *P. sargentii* was found in sapwood 28.02% and in heartwood 25.0%. In this experiment we measured the oil flow depth in above mentioned moisture level and the flow depth in radial and longitudinal direction were presented in Table 1 and Table 2.

Table 1. Oil flow depth in radial direction unit: μm

Cell type	Sapwood				Heartwood			
	18.8 Second	37.6 Second	56.4 Second	75.2 Second	18.8 Second	37.6 Second	56.4 Second	75.2 Second
Body ray cell	44.33b	51.84b	60.04b	63.94b	38.45b	45.56c	50.14c	52.51c
Marginal ray cell	38.34b	40.212b	45.84b	47.50b	30.42b	32.45b	33.75b	36.67b
Intercellular space	96.34a	120.96a	123.64a	131.84a	97.53a	107.12a	113.43a	120.77a

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

Ray cells are connected together end to end and form a capillary. Liquid while passing through this ray parenchyma it is interrupted by endwall. So, if endwall pits are numerous with large diameter, the radial flow will be easier than other wood species where the endwall pit number and diameter are less. Not only this endwall pit there are numerous lateral wall pits present in ray parenchyma through which liquid can pass to its neighboring ray cells. It makes a net like structure. In radial direction except ray cells no other structure can conduct liquid efficiently because of cell arrangement. As a result, ray parenchyma plays an important role for lateral conduction. Even in same wood species the endwall pit number and diameter, ray parenchyma diameter and length varied from juvenile wood to matured wood and earlywood to matured wood. Along with this, liquid flow varies due to molecular weight, nature and surface tension of liquid being used. In this regard Tang et al. (2000) found that the permeability of liquid in wood was influenced by different factors like- size of the stain molecule, the affinity between stain solution and wood. Further more sapwood is more permeable than heartwood. In this experiment we found that sapwood was 1.16 times more permeable than heartwood. Also oil penetration depth differences were not in same for body and square marginal ray cells. Body ray cells penetration depth of oil was higher than marginal ray cells and it was about 138% high. Wood cell lumen diameter is an important factor for the liquid conduction which was reported by Chun and Ahmed 2006 where the mentioned that if the cell lumen diameter was narrow than it would have high capillary pressure compared with the wider one which force the liquid to penetrate more. As the intercellular space has no endwall pit and very narrow lumen diameter it can penetrate liquid in higher depth compare to ray parenchyma. In this experiment we found that oil penetration depth in intercellular space was 2.5 times higher than ray parenchyma. Following the same methodology, safranine solution penetration depth was explained in radial direction of *Populus tomentiglandulosa* T. Lee by Ahmed et al. (2007) at 23.27% wood moisture content. If we compare the anatomical features between two species, it will explain the reason behind for high permeability of oil in *P. sargentii* for narrow lumen diameter and presence of numerous pits in endwall of procumbent ray cell which made this species more permeable for oil than of *Populus tomentiglandulosa*. Besides, surface tension differences were also responsible for the variation of penetration depth.

Table 2. Oil flow depth in longitudinal direction unit: µm

Time (second)	Vessel		Wood fiber	
	Sapwood	Heartwood	Sapwood	Heartwood
3.8	798.47d	780.99c	451.15d	410.15d
7.5	881.22c	881.61b	521.78c	482.38c
11.3	978.77b	937.46b	616.98b	537.38b
15.0	1100.28a	1076.90a	725.57a	610.11a

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

We found that longitudinal penetration depth was longer than radial penetration depth. Because of cell arrangement made longitudinal permeability higher than radial or tangential direction. Vessels are joined end to end direction connected with perforated ray cells. Also intervessel pittings help liquid diffuse to adjacent vessels. In longitudinal flow, liquid does not need to pass through pits. As a result liquid faces fewer obstacles to flow. After the vessel, wood fiber also play and important role for longitudinal penetration though it is not continuous like vessel. Fiber lumen is very narrow. As a result it has higher capillary pressure than vessel. But air trapped in fiber reduces the permeability of liquid. But in vessel this trapped air can by pass through intervessel pittings or to the next vessel elements. As a result, vessel has higher permeability than wood fiber.

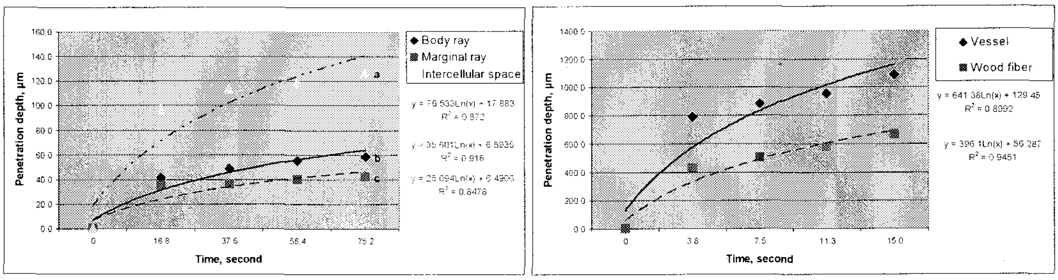

Fig.1. Comparison of oil flow in radial direction (left) and in longitudinal direction (right).

In this experiment we found that oil penetration depth in vessel was 1.63 times higher than wood fiber. Various gummy, resinous and chalky exudates often form in vessel lumens with the heartwood (Hillis, 1987) and the formation of these materials substantially reduces the treatability of heartwood (Kumar and Dobriyal, 1993; Preng et al. 1985). In this experiment oil penetration depth in sapwood was 1.08 times higher than that of heartwood. Furthermore, surface tension of liquid also and important factor which determines the penetration depth in wood. Lower the surface tension, higher the capillary pressure. In this experiment the considered oil surface tension was found 26.17 dyne/cm which was lower than 1% safranine solution (36.10 dyne/cm). For this reason the result obtained was higher than the experiment stated by Ahmed et al. (2007).

In both direction, oil penetration flow rate was found high at the beginning and then gradually decreased. After 3.8 second of penetration, oil penetration depth decreased upto 88% at 7.5 second, 93% at 11.3 second and 94% at 15 second in longitudinal direction. While after 18.8 second of penetration in radial direction, it decreased upto 88% at 37.6 second, 90% at 56.4 second and 87% at 75.2 second.

SUMMARY

Essential oil penetration depth was found high in sapwood compared to heartwood. In radial direction, penetration depth was found higher in intercellular space than ray parenchyma. Marginal ray parenchyma conducted oil in lower depth compare to body ray parenchyma. Vessel was found the main avenue for oil penetration in longitudinal flow and also it conducted oil in higher depth than that of wood fiber. Initially oil flow speed was found high and gradually decreased in the course of time.

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