Safranine Penetration Observed by Camscope in Main Wood Species of Pinaceae Grown in Korea

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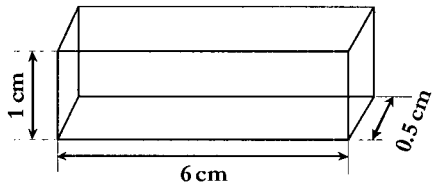
Introduction

A number of studies have been carried out to examine the process of liquid impregnation into different kinds of wood. Different techniques and methods have been developed so far to obtain quantitative and qualitative information about this process. Penetration of liquid in wood depends on several factors. In this report this phenomenon is discussed briefly. Softwood consists of different kinds of cells which conduct liquid. The rate and amount conducted by those cells varies from species to species. So, it is very important to know the liquid absorbance pathway and cells are responsible for liquid conduction of those species which are commercially viable for making wood products. Capillary structures are very important to determine the liquid penetration. Main capillary structures consist of tracheids in softwoods, also ray cells, resin canal and pit membrane play an important role in liquid penetration of wood (Kim and Park 1991). Besides, the amount of liquid penetration is not same in sap and heartwood. The solution uptake is affected by the poor wettablility of the surface of the cell lumen (Iida et al. 2002). Permeability is a function of the number of open pits per tracheid which coupled with tracheid length, determines the probability of occurrence of a continuous flow path through the wood specimen being permeated (Meyer 1970). Tang et al. 2000 found that the permeability to liquid of the wood of several commercial timber influenced by different factors like- size of the stain molecule, the affinity between stain solution and wood. Sapwood was more permeable than heartwood. Tangential penetration was more difficult than longitudinal penetration. It also depends on molecular weight of solute molecule, low molecular weight solute penetrate into the cell wall easily (Furuno et al. 2004). This experiment was conducted to know the difference of safranine impregnation in four pine wood species through radial and longitudinal direction.

Materials and Methods

Wood species used

Four kinds of wood block were taken under consideration from ① *Pinus koraiensis* Sieb. et Zucc. ② *Pinus densiflora* Sieb. et Zucc. ③ *Pinus rigida* Mill and ④ *Larix kaempferi* Carr. Wood samples were collected from Kangwon National University reserve forest at breast height. Immediately after collection, discs were made and kept in air tight cellophane bag to protect the moisture loss. In this observation, only radial and longitudinal directions of penetration were considered. 6x0.5x1cm samples were prepared for every species. For radial direction penetration, both cross sections were sealed with silicon resin for preventing the leakage by longitudinal penetration.



〈**Fig. 1**〉 Samples made for camscope observation.

Preparation of safranine solution

0.1g of safranine is added in 50ml water. Then 50% ethyl alcohol was added to make the volume 100ml. Thus 1% safranine solution was made.

Observation

While observing the safranine penetration, room temperature was 24°C and wind speed was 0m/s. 100 x magnifications was used for radial penetration and 40x magnification was used for longitudinal penetration. 1200x magnification was used for capturing the meniscus in longitudinal tracheid. Sample was fixed on a petridish and safranine was poured on it. With I-Solution software, safranine impregnation video file was captured for 5 minutes. These5 minutes video files consisted about 3,000 frames. Specific frame were selected at 1, 2, 3, 4 and 5 minutes by Vitrual Dub-MPEG2 software. Data were recorded and analyzed by statistical analysis software, SPSS (George and Mallery 2001).

Estimation of moisture content (%)

Wood block was weighed and dried in an oven for 24 hours maintaining the temperature 105 °C. Moisture content of wood block in terms of dry weight basis was calculated using the following formula (Skaar 1972a):

$$M\ (\%) = \frac{W_m - W_O}{W_m} \times 100$$

M = Moisture content

W_m= Moist weight of wood

W_O= Oven dry weight

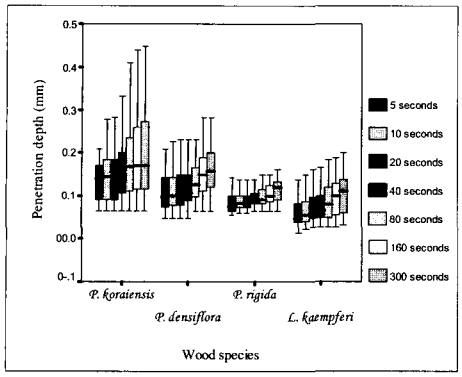
Results and Discussion

Sap and heartwood of all species were taken under consideration. In sap and heartwood, safranine penetration depth was not same because of the permeability (Minato 2004). Moisture content plays an important role for the impregnation of liquid in wood block. Moisture content of different wood species is shown in Table 1. Above the fiber saturation point, wood can still take up water by absorption or capillary action until the cell cavity are filled with liquid water (Browning 1963). The permeability of some wood species decreases with increased moisture content (Comstock 1968). Excess moisture in wood voids may also act as a physical barrier for the mass flow of liquid (Wirspa and Libby 1950).

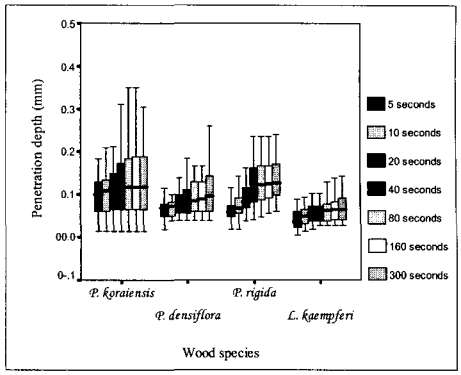
〈**Table 1**〉 Average moisture content (mean±SE) in different wood species.

Wood species	Moisture content (%)
P. koraiensis	6.9±0.36
P. densiflora	9.0±0.63
P. rigida	6.9±0.28
L. kaempferi	6.0±0.45

All wood species possess a capillary structure and its effect on fluid permeability varied considerably. Wood is a capillary porous medium. The pore structure is defined by the cell lumen and the cell wall openings (pits) which interconnect them. If the pit membrane opening is large and numerous, the permeability is higher (Comstock 1967). The primary paths for liquid penetration into wood are provided by these capillaries (Petty 1970; Behr et al. 1969 and Erickson and Balatinez 1964). Tracheid length and diameter are also important factors for longitudinal penetration. Following is the table showing data about the longitudinal tracheid length and diameter.



〈Fig. 2〉 Safranine penetration depth in radial direction of sapwood.



〈Fig. 3〉 Safranine penetration depth in radial direction of heartwood.

From the above graphs it is clear that safranine penetration depth was higher in sapwood compared with heartwood in radial direction. Besides, in this direction, *P. koraiensis* conducted highest amount of safranine in both sap and heartwood. Depth of impregnation sequence in descending order was *P. koraiensis*> *P. densiflora*> *P. rigida*> *L. kaempferi* in sapwood and *P. koraiensis*> *P. rigida*> *P. densiflora*> *L. kaempferi* in heartwood. *P. koraiensis* conducted safranine in higher depth than other species in radial direction due to it's long ray parenchyma and tracheid, large diameter of endwall pit in ray tracheid and thin lumen of ray parenchyma cell. The larger the length of ray parenchyma and ray tracheid, the higher is the penetration depth. It was found that *P. koraiensis* has the highest number of ray parenchyma (Table 2). Also pit aperture diameter of ray parenchyma, length of ray parenchyma and tracheid were found highest (Table 3) compared with other species. Ray parenchyma cell lumen also was found low which was related with easy conduction of safranine by capillary phenomenon. So, safranine impregnation was high in this species. Due to the endwall pitting of ray parenchyma in *L. kaempferi* observed under FE-SEM, reduced the safranine penetration depth. Vertical Resin duct also conducted safranine in longitudinal direction. It conducted safranine in a higher rate. Also, it is clear that safranine was diffused from ray parenchyma to longitudinal tracheid through cross field pitting. From longitudinal tracheid safranine was diffused to ray parenchyma through cross field pitting.

〈**Table 2**〉 Longitudinal penetration of safranine in sapwood of different wood species.

Unit: mm

Wood species	5 seconds	10 seconds	20 seconds	40 seconds	80 seconds	160 seconds	300 seconds
P. koraiensis	1.249b	1.740bc	1.828b	2.021b	2.089b	2.351b	2.598b
P. densiflora	1.181b	1.319c	1.424b	2.001b	2.387b	2.795b	3.254b
P. rigida	1.730a	1.850b	1.929b	2.137b	2.205b	2.487b	2.604b
L. kaempferi	2.066a	2.329a	2.775a	3.185a	3.521a	3.984a	4.279a

Mean with the same letter are not significantly different at p=0.05

NS: Non significant at 5% level of probability

〈**Table 3**〉 Longitudinal penetration of safranine in heartwood of different wood species.

Unit: mm

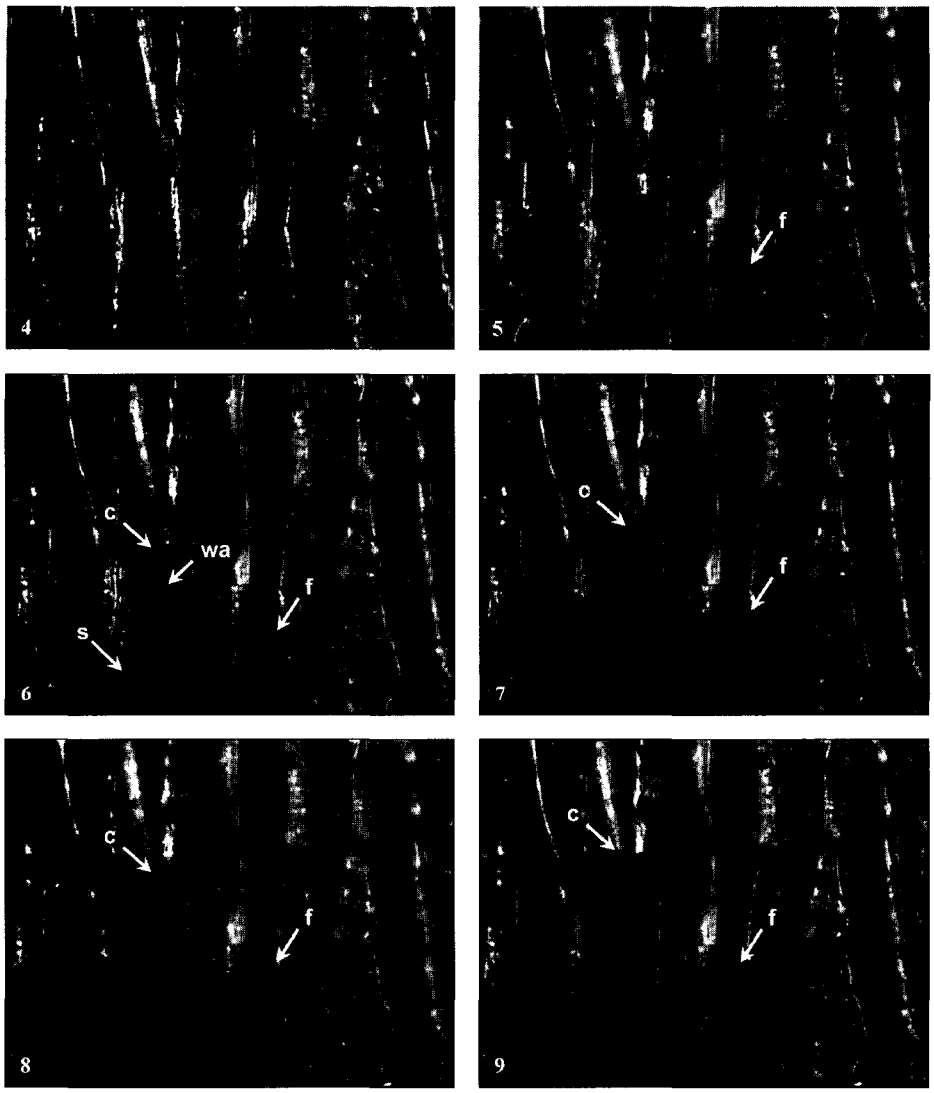
Wood species	5 seconds	10 seconds	20 seconds	40 seconds	80 seconds	160 seconds	300 seconds
P. koraiensis	1.168a	1.233ab	1.279ab	1.350a	1.425a	1.514a	1.557b
P. densiflora	0.354b	0.444c	0.548c	0.675b	0.742b	0.758b	0.799c
P. rigida	0.733b	0.957b	1.148b	1.314a	1.387a	1.433a	1.416b
L. kaempferi	1.139a	1.315a	1.514a	1.617a	1.702a	1.765a	1.898a

Mean with the same letter are not significantly different at p=0.05

NS: Non significant at 5% level of probability

From Table 2 and 3, it is clear that safranine penetration rate was higher in sapwood compared with heartwood in radial direction. Pit played an important role for the diffusion of safranine from one cell to neighboring cells. Due to the generally irreversible pit aspiration(Thomas and Nicholas 1966; Thomas and Kringstad 1971), small pore size (Stamm 1970; Petty and Peterson 1969), the amount and type of extractive deposited on pit membrane during the formation of heartwood (Panshin and DeZeeuw 1980). First minute, penetration rate was found highest and gradually decreased with the increase of time. *L. kaempferi* has the longest longitudinal tracheid compared with other species (Park et al. 1990) and tracheid length is directly related with the treatability of softwood (Wang and DeGroot 1996). As a result, the longitudinal penetration depth of safranine was found highest in *L. kaempferi* both sap and heartwood. Besides, moisture content of *L. kaempferi* played a role for the higher penetration. Significant difference of safranine penetration was not found among the sapwood of *P. koraiensis, P. densiflora* and *P. rigida*. The shortest longitudinal tracheid was found in *P. densiflora*. So, in longitudinal direction heartwood penetration was found the lowest. Due

highest pit aperture diameter of *P. densiflora* (5.89μm) it conducted safranine higher than *P. rigida* and *P. koraiensis* sapwood.



〈**Fig. 4-9**〉 Meniscus observed at 0, 1, 2, 3, 4 and 5 minute respectively in longitudinal tracheid of *P. densiflora* heartwood. c- curved air-safranine meniscus, f- flat air-safranine meniscus, s-safranine molecules, water- alcohol solution.

According to Jurin's law, the capillary pressure is defined as a function of surface tension, γ, contact angle, Θ and capillary radius, r-

$$P_c = \frac{2\,\gamma \cos \Theta}{r}$$

Contact angel of liquid to a surface determines the wettablility. The geometry of the capillaries varies significantly within a single softwood chip, resulting in different values for capillary pressure (Malkov et al. 2003). Considering the tracheid radius of above two cells 16-20 μm, surface tension of water at 72 dynes/cm at 23 °C and a contact angle 30° (Scheikl and Dunky 1998), the capillary pressure range was 0.06-0.08 bar. Thus lumen diameter related with capillary pressure. The lower the lumen diameter, the higher the capillary pressure. Longitudinal tracheid forms a capillary tube by interconnecting them with pits. Liquid penetration efficiency was high for this capillary phenomenon. The surface tension of the undiluted sap in green wood of four species measured by Stamm and Arganbright (1970) ranged from 45.5 to 57.3 dynes/cm at room temperature of 23±1 °C, considerably lower than the value of 71 dynes/cm for distilled water at the same temperature. Due to the difference of total pressure of water just under the air-water interface and total pressure of the air just above the interface, curved meniscus is formed in the pore of rigid permeable membrane (Skaar, 1972b). Considering this phenomenon, curved meniscus was formed in the lumen of longitudinal tracheid (Fig. 6, 7, 8 and 9). For the pit aspiration, the pressure of safranine and air in the lumen of tracheid was found equal which the reason was behind to get the air-safranine meniscus flat (Fig. 5, 6, 7, 8 and 9).

Conclusions

In camscope observation, sap and heartwood of *P. koraiensis* conducted safranine in higher depth in radial direction. On the other hand, lowest depth was traveled by *L. kaempferi*. Penetration rate was found highest within 5 seconds and gradually decreased with increase of time. In longitudinal penetration depth was depended upon the longitudinal tracheid length and it was found highest in both sap and heartwood of *L. kaempferi*. Besides in sapwood penetration, pit aperture diameter was found another factor for the variation of penetration depth in different wood species. Sapwood penetration was found higher than heartwood penetration. Due the difference of air pressure and total pressure of safranine just above and below the air-safranine interface respectively, curved meniscus was formed in the lumen of longitudinal tracheid and flat air-safranine meniscus was found for the equal pressure. Lumen diameter of tracheid determined the capillary pressure of safranine. Finally it can be concluded that, safranine impregnation in different wood species depend on several factors such as species, anatomical features, soaking time and moisture content. But at a given

condition, permeability of liquid in wood can be increased by prolonging the soaking time.

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