Effect of Pressure on Liquid Absorbance in Main Wood Species of Pinaceae Grown in Korea Using Safranine Under Vacuum[1)]

Sheikh Ali Ahmed[2)], Hyun Dae Park[3)] and Su Kyoung Chun[4)]†

Index

1. Introduction
2. Materials and Methods
   2-1 Wood block preparation
   2-2 Estimation of moisture content
   2-3 Coating of wood block with silicone resin
   2-4 Impregnation of colored solution(safranine)
   2-5 Data record
3. Result and Discussion
   3-1 Moisture content
   3-2 Vacuum pressure effect
   3-3 Combined effect of vacuum and pressure
4. Conclusions
References

ABSTRACT

본 실험은 한국산 주요 침엽수인 소나무, 잣나무, 리기다소나무, 낙엽송의 safranine의 침투도를 실험하였다. 진공, 압력 및 safranine의 침투시간을 각각 다르게 하여 수종별 침투도를 측정하였다. 실험 결과 진공조건의 변화에 따른 침투도 변이는 크게 나타나지 않았고, 압력조건의 차이에 의한 침투도는 다르게 나타났다. 목재의 방향별 침투도를 고찰한 결과 축방향, 방사방향, 접선방향의 순서로 침투도가 높았다. 변재와 심재의 사이의 침투성을 고찰 한 결과 변재가 심재보다 쉽게 침투 되었다. 수종별 침투성을 고찰한 결과 소나무가 가장 우수했다.

1) This Study was supported by technology Development Program for Agriculture and Forestry, Ministry of Agriculture and Forestry, Republic of Korea

2) Graduate student
3) Undergraduate student
4) Professor, Department of Wood Science & Engineering, College of Forest Sciences, Kangwon National University, Chunchon 200 - 701, Republic of Korea
† Corresponding author : Su Kyoung Chun (E-mail: chun@kangwon.ac.kr)

1. 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 and hardwood are consist 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 and vessel elements in hardwoods, also wood fiber, ray cell, resin canal and pit membrane play an important role in liquid penetration of wood (Kim and Park 1991). Beside 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).

Kim and Kim 2001, Kim and Park, 1991, Lee, 1983, conducted almost same kind of experiment for the treatment of different kinds of soft woods using different chemicals. In this experiment we used safranine to know the impregnation depth through different direction in both sap and heartwood and to compare the result with their findings. It will give us an idea for the treatment of main wood species belongs to Pinaceae grown in Korea. This experiment has also conducted to find out the suitable combination of vacuum and pressure effect at which greater amount of liquid can be impregnated into wood at a shortest possible time.

2. Materials and Methods

2-1 Wood block preparation

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 ④*Larix kaempferi* Carr. Wood blocks were made from both sap and heart wood maintaining the size 6cm (length) X 5cm (width) X 2cm (thickness).

2-2 Estimation of moisture content

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

$$M(\%) = \frac{w_m - 2_o}{2_m} \times 100$$

M = Moisture content

w_m= Weight of gree wood

w_O= Oven dry weight

2-3 Coating of wood block with silicone resin

As we want to know the penetration depth of liquid in three direction of wood block, we covered the entire surface with silicone resin except the considered surface which prevented the leakage of safranine through other surfaces.

2-4 Impregnation of colored solution (safranine)

The air dried wood blocks were used for safranine impregnation. The present work relates to a wood chip capsule, process and apparatus for producing the same by manufacturing a wood chip, drying the chip by air, and then infiltrating the chip containing safranine by immersion and pressurized method. The permeability in wood depends on the exposure time in liquid, pressure and vacuum pressure (-620 mmHg) used for the impregnation. For this reason, the penetration depth of safranine was measured in air dried wood blocks which were soaked in safranine for 10 minutes without pressure or vacuum followed by pressure.

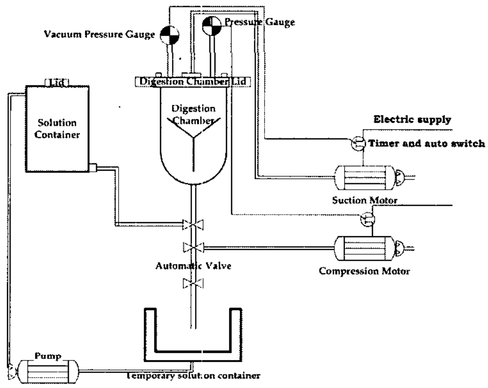


Fig. 1. Schematic diagram of a digester machine.

2-5 Data record

After treating the wood block with safranine for certain pressure and time, they were sliced in the middle. The depth of colored area was measured in different direction. Three replications were conducted and finally data was analyzed by a statistical analysis software- SPSS version 11.5.0.

3. Result and Discussion

In all species both sap and heart woods were taken under consideration. In sap and heartwood, safranine penetration depth is not same because the permeability is lower in heartwood compared with sapwood (Minato 2004).

3-1 Moisture content

Moisture content plays an important role for the impregnation of liquid in wood block. 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 decrease with an 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). We are trying to fill up the cell cavity of wood with an increased pressure and vacuum.

Table 1. Average moisture content in different wood species.

Wood species	Moisture content (%)
P. koraiensis	7.2
P. densiflora	7.1
P. rigida	7.7
L. kaempferi	8.0

3-2 Vacuum pressure effect

When liquid starts to enter in the wood block, the air present inside the void spaces begin to compress. Penetration of liquid is slowed down and eventually stops of the growing back pressure. After pressure equilibrium is achieved, further penetration can be possible either due to an increase in the pressure applied or a decrease in the pressure of gaseous mixture. It is known that the air present in cell lumen is the main obstacle for rapid penetration of liquid (Maass 1953). Removal of air from dry woodchip is found effective (Stamn 1953). When penetration is allowed from both side of woodchip, the back-pressure of trapped air becomes compressed by capillary forces which check the penetration soon (Rydholm 1965). This can be done by vacuum pressure. But in practice, complete removal of air is difficult to achieve specially woodchip in normal moisture content. Removal of air can be limited by the specific characteristics of wood capillaries as some air can be trapped with in the capillaries which are sealed up by extractive. In our digester machine, vacuum pressure (-620 mmHg) was created on wood blocks and after that those blocks were allowed to immerse in safranine solution for 10 minutes. Then the safranine penetration depth was measured at different vacuum pressure. It was found that at no vacuum condition, safranine input was lower from those wood blocks which were treated by vacuum pressure for 5 or 10 minutes (Fig. 2) and the differences were found significant (Table 2 and Table 3). This is because air trapped in capillaries reduced the liquid penetration. In every case

Table 2. Safranine penetration depth in sapwood. *Condition: After vacuum (-620 mmHg) treatment wood blocks were soaked in safranine for 10 minutes.*

Wood species	Vacuum pressure (-620 mmHg) treatment	Tangential penetration depth (cm)	Radial penetration depth (cm)	Longitudinal penetration depth (cm)
P. koraiensis	0 min	0.06 c	0.13 b	2.12 b
	5 min	0.35 b	0.67 a	6.00 a
	10 min	0.56 a	0.73 a	6.00 a
P. densiflora	0 min	0.04 c	0.19 b	1.63 b
	5 min	0.76 b	0.80 a	6.00 a
	10 min	0.80 a	0.80 a	6.00 a
P. rigida	0 min	0.05 c	0.09 b	1.02 b
	5 min	0.12 b	0.80 a	6.00 a
	10 min	0.26 a	0.80 a	6.00 a
L. kaempferi	0 min	0.01 c	0.04 c	0.56 c
	5 min	0.24 b	0.31 b	4.50 b
	10 min	0.51 a	0.52 a	6.00 a

Mean with the same letter are not significantly different at p=0.01

Table 3. Safranine penetration depth in heartwood. *Condition: After vacuum (-620 mmHg) treatment wood blocks were soaked in safranine for 10 minutes.*

Wood species	Vacuum pressure (-620 mmHg) treatment	Tangential penetration depth (cm)	Radial penetration depth (cm)	Longitudinal penetration depth (cm)
P. koraiensis	0 min	0.00 b	0.01 c	0.23
	5 min	0.03 a	0.06 b	0.61
	10 min	0.03 a	0.09 a	0.60
P. densiflora	0 min	0.00 c	0.06 b	0.18 b
	5 min	0.02 b	0.06 b	0.47 a
	10 min	0.04 a	0.09 a	0.31 ab
P. rigida	0 min	0.00	0.00 b	0.06 b
	5 min	0.00	0.02 b	0.12 a
	10 min	0.00	0.08 a	0.14 a
L. kaempferi	0 min	0.00 b	0.00 b	0.02 b
	5 min	0.01 a	0.02 a	0.52 a
	10 min	0.02 a	0.02 a	0.40 a

Mean with the same letter are not significantly different at p=0.01

sap wood permeability was found higher than heartwood. Heartwood penetration was found difficult than the sapwood. This is because for lack of water conductive capacity of heartwood. Out main objective was to findout a suitable combination at which solution can be impregnated in wood chip at a shortest possible time. As the difference between vacuum pressures retention time 5 minutes and 10 minutes was very low, so it is suggested to consider vacuum pressure for 5 minutes.

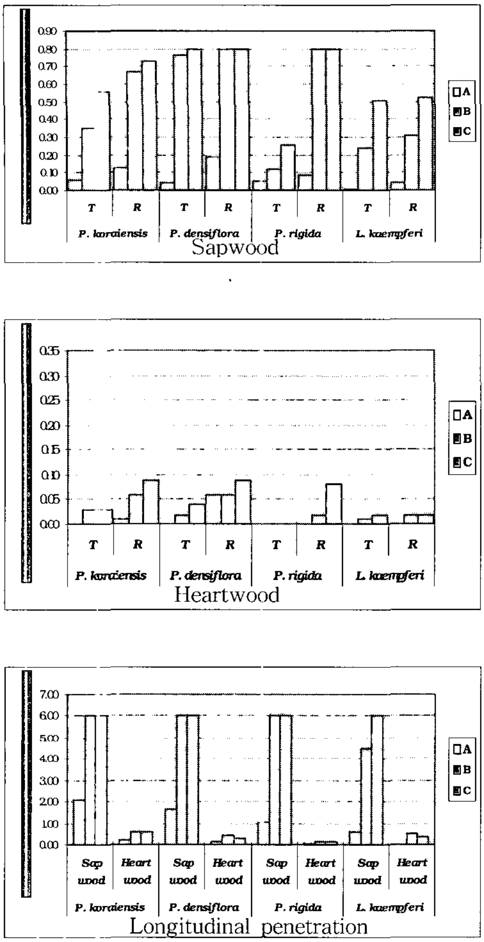


Fig. 2. Safranine penetration depth in sap and heartwood of different kinds of wood blocks under vacuum condition. *T- Tangential direction, R- Radial direction and A- Vacuum Pressure for 0 minutes, B- Vacuum Pressure for 5 minutes, C- Vacuum Pressure for 10 minutes.*

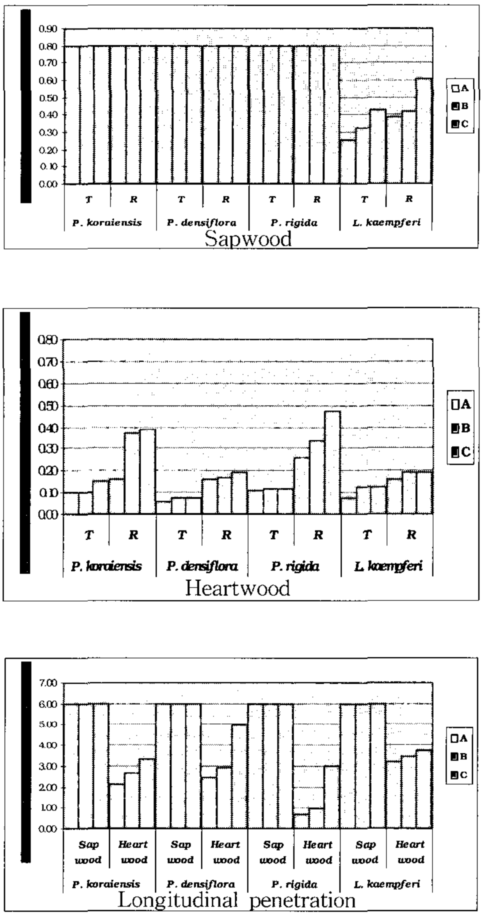


Fig. 3. Safranine penetration depth in sap and heartwood of different wood blocks. T- Tangential direction. R- Radial direction and A- 30 kgf/cm^2 pressure after vacuum treatment, B- 50 kgf/cm^2 pressure after vacuum treatment, C- 70 kgf/cm^2 pressure after vacuum treatment.

3-3 Combined effect of vacuum and pressure

Increase in pressure will result in faster penetration (Stone and FÖrderreuther 1956). High pressure is required to overcome the negative effect of surface tension in the liquid-air menisci, which are formed by the capillary condensation of vapor (Stamm 1963). Vacuum pressure was applied on wood block for different time and then safranine was allowed to the digestion chamber. Different pressure was created on wood block during impregnation time. Pressure can be used for the impregnation of liquid effectively (Hoadley 2000). Three types of pressure were created on wood block while soaking after the vacuum treatment. And it was found that the wood which had difficulty for the impregnation only by vacuum treatment, that was overcome by increased pressure. Because high pressure may cause stretching and

Table 4. Safranine penetration depth in sapwood. *Condition: 5 minutes vacuum (-620 mmHg) treatment followed by pressure while soaking wood block in safranine for 10 minutes.*

Wood species	Pressure	Tangential penetration depth (cm)	Radial penetration depth (cm)	Longitudinal penetration depth (cm)
	30 kgf/cm^2	0.80	0.80	6.00
P. koraiensis	50 kgf/cm^2	0.80	0.80	6.00
	70 kgf/cm^2	0.80	0.80	6.00
	30 kgf/cm^2	0.80	0.80	6.00
P. densiflora	50 kgf/cm^2	0.80	0.80	6.00
	70 kgf/cm^2	0.80	0.80	6.00
	30 kgf/cm^2	0.80	0.80	6.00
P. rigida	50 kgf/cm^2	0.80	0.80	6.00
	70 kgf/cm^2	0.80	0.80	6.00
	30 kgf/cm^2	0.25 b	0.39 b	6.00
L. kaempferi	50 kgf/cm^2	0.32 ab	0.42 ab	6.00
	70 kgf/cm^2	0.43 a	0.61 a	6.00

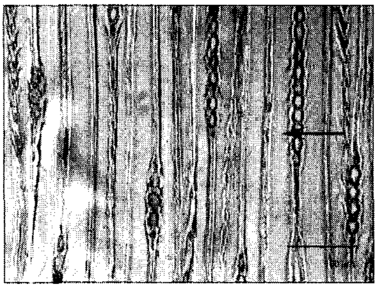
Mean with the same letter are not significantly different at p=0.01

Table 5. Safranine penetration depth in heartwood. *Condition: 5 minutes vacuum (-620 mmHg)treatment followed by pressure while soaking wood block in safranine for 10 minutes.*

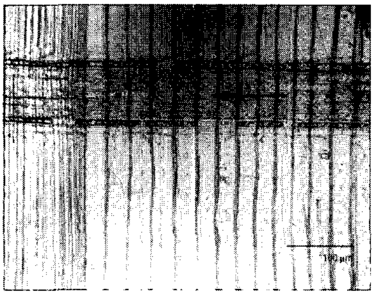
Wood species	Pressure	Tangential penetration depth (cm)	Radial penetration depth (cm)	Longitudinal penetration depth (cm)
	30 kgf/cm^2	0.10	0.16 b	2.08
P. koraiensis	50 kgf/cm^2	0.10	0.37 a	2.67
	70 kgf/cm^2	0.15	0.39 a	3.35
	30 kgf/cm^2	0.06	0.16	2.48 b
P. densiflora	50 kgf/cm^2	0.08	0.17	2.90 b
	70 kgf/cm^2	0.08	0.19	4.99 a
	30 kgf/cm^2	0.11	0.26 b	0.65 b
P. rigida	50 kgf/cm^2	0.12	0.34 ab	0.94 b
	70 kgf/cm^2	0.12	0.47 a	3.00 a
	30 kgf/cm^2	0.08	0.24	3.21
L. kaempferi	50 kgf/cm^2	0.13	0.19	3.48
	70 kgf/cm^2	0.13	0.19	3.75

Mean with the same letter are not significantly different at p=0.01

bulging of pit membranes due to plasticity of wood, thus making the pit membrane opening larger (Paranyi and Rabinovitch 1955). Higher pressure also results in solubility of air into liquid, thus allowing more air to be dissolved and a higher penetration degree to be reached. In both sap and heart wood, the liquid permeability was increased at pressure 70 kgf/cm2 (Fig. 3) and the differences were found significant (Table 4 and Table 5).



P. koraiensis



L. kaempferi

Fig. 4. Penetration trend in tangential and radial direction treated with safranine in *P. koraiensis and L. kaempferi. Arrow bar showing the safranine impregnated from radial surface (up) and tangential surface (below).*

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 are large and numerous, the permeability is higher (Comstock 1967). The primary routes for liquid penetration into wood are provided by these capillaries (Smith and Banks 1971; Petty 1970; Behr et al. 1969; Buro and Buro 1965; Erickson and Balatinez 1964; Wardrop and Davis 1961 and Bailey 1913). There are several evidences that longitudinal penetration is easier than radial or tangential direction. Penetration difficulty depending on the impregnation direction was tangential <radial <longitudinal order. Among the soft wood, heartwood is less permeable than sapwood. It also depends on the moisture content. Kim and Kim, 2001 found that in P. densiflora retention was increased with decreasing moisture content. In our experiment we found that P. densiflora contained the lowest amount of moisture content (7.11%) which was far below than fiber saturation point. As a result the safranine penetration depth was found highest in all direction of sapwood of P. densiflora. Heartwood treatability was found poor due to pit aspiration and might be inherent wood characteristics results in low liquid conductivity. To overcome this situation, vacuum treatment and pressure was created on wood block. With increased pressure, the safranine impregnation was increased significantly.

Kim and Park, 1991 found that the depth of penetration of tangential section is deeper than that of radial section. But in our experiment we found that the depth of safranine penetration in radial direction was found higher than tangential direction. In radial direction, ray parenchyma conducted safranine first (Fig 4). Then it was diffused to other adjacent cells through simple and cross field pitting. This result is caused by the rays as capillary tube in radial direction. Also the difference among species to species in radial section may reflect on penetration being closely related to the size of cross field pitting. As for example, *P. densiflora* has window like pitting while *P. rigida* has pinoid type pitting. As a result, safranine input was found higher in *P. densiflora* than in *P. rigida*. Ray parenchyma and tracheid play a vital role for the impregnation of safranine. The radial and tangential penetration is performed by the ray parenchyma and then diffused to the adjacent tracheid through cross field pitting but the distance penetrated by safranine was varied from species to species because of ray arrangement. Through cross field pit, safranine was diffused to the adjacent tracheid. From that tracheid, safranine was diffused to next one through bordered pit. So, time is an important factor for the penetration depth. If soaking time along with increased pressure (70 kgf/cm^2) is prolonged then the distance traveled by safranine will be increased through any direction of impregnation.

4. Conclusions

The main objective of this research was to find out the appropriate condition for liquid penetration. It was found that only vacuum treatment did not increase the permeability to a higher extent. Vacuum treatment followed by an increased pressure (70 kgf/cm^2) showed an excellent result for the impregnation of safranine. Sap and heartwood permeability was found remarkably different. Sapwood permeability was higher than heartwood. Longitudinal penetration of safranine was easier than radial and tangential direction. Penetration in the radial and tangential direction, radial penetration was higher than tangential direction. Finally it can be concluded that, safranine impregnation in different wood species depend on several factors. Such as species, wood surface and kind, vacuum and pressure during impregnation, soaking time, moisture content etc. But at a given condition, permeability of liquid in wood can be increased by prolonging the soaking time.

References

Bailey, I. W. 1913. The structure of the pit membranes in the tracheids of conifers and their relation to the penetration of gases, liquids, and solids into green and seasoned wood. Forest Quarterly. 11: 5-21.

Behr, A. E., I. B. Sachs, B. F. Kukachka and J. O. Bleur. 1969. Microscopic examination of pressure treated wood. Forest Prod. J. 19: 31-40.

Browning, B. L. 1963. The Chemistry of Wood. Interscience Publishers, NY. 48pp.

Buro, A. and E. A. Buro. 1965. Contribution to the knowledge of how liquids penetrate into pine wood. Holzforschung. 13: 71-77.

Chudnoff, M. 1984. Tropical Timbers of the Wood. USDA, Forest Services, Agric. Handb. No. 607: 436pp.

Comstock, G. L. 1968. Longitudinal

permeability of gases and non swelling liquids. Forest Prod. J. 17(10): 41-46.

Comstock, G. L. 1967. Relationship between permeability of green and dry Eastern hemlock. Forest Prod. J. 18(8): 20-23.

Erickson, H. D. and J. J. Balatinez. 1964. Liquid flow path into wood using polymer techniques. Forest Prod. J. 14: 293-299.

Furano,T., Y. Imamura and H. Kajita. 2004. The modification of wood by treatment with low molecular weight phenol-formaldehyde resin: a properties enhancement with neutralized phenolic-resin and resin penetration into wood cell walls. Wood Sci. Technol. 37: 349-361.

Hoadley, R. B. 2000. Understanding Wood. The Taunton Press, Newtown. 211pp.

Iida, I., S. Yusuf, U. Watanabe and Y. Imamura. 2002. Liquid penetration of pre compressed wood VII: combined treatment of precompression and extraction in hot water on the liquid penetration of wood. J. Wood Sci.48(1): 81-85.

Kim, Y. J.and S. J. Park. 1991. An anatomical research on liquid-penetration and penetration- path of wood. J. Korean Wood Sci. Technol. 19(3): 7-18.

Kim, G. H. and J. J. Kim. 2001. Effect of moisture content on treatability of Japanese red pine, Japanese larch, and Ezo spruce with chromated copper arsenate. Forest Prod. J. 51(6): 64-66.

Lee, W. Y. 1983. Study on wood-plastic combination - on the penetration of MMA polymer and dimensional stability. J. Korean Wood Sci. Technol. 11(3): 49-57.

Maass, O. 1953. The problem of penetration. Pulp and Paper Magazine of Canada. 54(8): 98-103.

Meyer, R. W. 1970. Influence of pit aspiration on earlywood permeability of Douglas-fir. Wood Fiber Sci. 2(4): 328-339.

Minato K., N. Nauro and J. Konishi. 2004. How far does a gaseous reagent penetrate into wood. Holz Roh Werkst. 62: 120-125.

Paranyi, N. I. and W. Rabinovitch. 1955. Determination of penetration rate of liquid media into wood using a quartz spiral balance. Pulp and Paper Magazine of Canada. 56(3): 1164-1170.

Petty, J. A. 1970. Permeability and structure of the wood of Sitka spruce. Proceeding of the Royal Society of London. B. 175: 149-166.

Skaar, C. 1972. Water in Wood. Syracuse University Press, Syracuse, NY. 27pp.

Smith, D. N. R. and W. B. Banks. 1971. The mechanisms of flow of gasses through coniferous wood. Proceeding of the Royal Society of London, B. 177: 197-223.

Stamn, A. J. 1963. Permeability of wood to fluids. Forest Prod. J. 13(11): 503-507.

Stamn, A. J. 1953. Diffusion and penetration mechanism of liquids into wood. Pulp and Paper Magazine of Canada. 54(2): 54-63.

Stone, J. E. and C. FÖrderreuther. 1956. Studies of penetration and diffusion into wood. Tappi. 39(10): 679-683.

Tang, X. S., L. W. Sheng and Z. G. Jie. 2000. Liquid permeability of several important northeastern China species. J. of Beijing Forestry Univ. 22(5): 86-90.

Wardrop, A. B. and G. W. Davis. 1961. Morphological factors relating to the penetration of liquids into wood. Holzforschung. 15: 129-141.

Wirspa, V. J. and C. E. Libby. 1950. Penetration of neutral sulphite cooking liquors into yellow birch wood. Tappi. 33(5): 225-231.

Rydholm, S. A. 1965. Pulping Processes. Interscience Publishers, NY. 1269pp.