

PERMEABILITY AND DRYING BEHAVIOR OF WESTERN HEMLOCK¹

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INTRODUCTION

The permeability of wood is related to its rate of drying from a green condition, in that the greater the permeability, the more rapidly wood dries above the fiber saturation point (Hart, 1964). If this relation is true for western hemlock, one could use permeability of wood as determined in laboratory tests to segregate western hemlock heartwood according to its drying rate, because permeability of wood can be determined easily. Moreover, evaluation of permeability also will help us to understand better the drying mechanism of wood above the fiber saturation point.

Movement of moisture above the fiber saturation point is believed generally to be caused by capillary forces. Kollman and Coté (1968), however, pointed out that in some instances movement of free water as capillary water can take place within a limited zone of several fiber lengths. The drying rate then is controlled by movement of water vapor in and through the void structure and movement of bond water through gel substance, which are diffusion of water molecules through wood.

If the formation of wet pockets in western hemlock heartwood is caused by occlusion of the pit membrane by extractives, as is suggested by Lancaster (1971), movement of water because of capillarity may be limited, and diffusion of water through the "wall of a wet pocket" controls the drying rate. Diffusion in western hemlock may be reduced by the incrustation of cell walls by extractives and a reduction in the size and number of openings through which water vapor diffuses.

A recent development in drying of hardwood has been treating unseasoned birch boards by compression to improve the drying rate and quality of kiln dried birch (Cech, 1971).

The objectives of this study were: 1, to evaluate improvement in the drying rate and quality of western hemlock after compressive treatment and, 2, to measure the effect of compressive treatment on permeability of western hemlock.

This report presents results of a series of investigations conducted at the Forest Research Laboratory, Oregon State University. Objectives of this series were to study the relation between the diffusion coefficient and longitudinal permeability of water and air, and the effect of compressive treatments, steaming, and extraction on the diffusion coefficient and permeability to water and air of western hemlock.

MATERIALS

All test material was collected from the green sorting chain at Willamette Industries, Inc., in Dallas, Oregon. The material was old growth western hemlock harvested from the Snow Peak area due east of Albany, Oregon.

Initial moisture contents of the specimens were all above 100 percent. All materials were sinker heartwood except those used for water permeability, which included sapwood and normal heartwood.

Size of test specimens were as follows: Drying experiment; 1/4 inch (tangential) by 2 inches (radial) by 18 inches (longitudinal).

Effect of compression treatment on drying behavior; 3/4 inch (tangential) by 2 inches (radial) by 18 inches (longitudinal).

Air permeability; 1/4 inch (tangential) by 2 inches (radial) by 1 1/2 inches (longitudinal).

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Water permeability; 3/4 inch (tangential) by 1 1/2 inches (radial) by 1 1/2 inches (longitudinal).

PROCEDURE

Drying experiment

Drying experiments were conducted at 73° F, and 80 percent relative humidity with forced air circulation. Test specimens were weighed periodically and E-values were calculated according to the equation:

$$E = (W - W_f) / (W_i - W_f)$$

where W is the moisture content of test specimen at any given time, W_i is the initial moisture content of the test specimen, and W_f is the equilibrium moisture content of the drying conditions.

The diffusion coefficient was calculated from the equation

$$D = -(\underline{c}/\pi)^2 \left(\frac{d \ln E}{dt} \right)$$

where \underline{c}^2 is known as the square of the drying square and is calculated from the formula

$$2(a \times b)^2 / (a^2 + b^2),$$

where a is the thickness and b is the width of the specimen.

Permeability test

Longitudinal air permeability was measured after completing the drying experiment. Test specimens 1 1/2 inches along the grain were cut from one end of the drying specimens. All specimens were reconditioned at 70° F, and 50 percent relative humidity. Air permeability was measured with the apparatus shown in Figure 1. When air was permitted to flow through the test specimen and into or out of the pressure cell in Figure 1, the pressure across the test specimen increased or decreased with time. Average air permeability (\underline{K}) of the test specimen can be calculated from the equation (Lin, 1971)

$$K = C \left(\frac{d[\ln \Delta P]}{dt} \right),$$

where \underline{C} is a constant associated with molecular weight, viscosity, temperature, density of air at atmospheric condition, and volume of pressure cell, ΔP is the pressure difference across the test specimen, t is time, and $\frac{d[\ln \Delta P]}{dt}$ is the slope of the curve plotted between the natural logarithm of permeability and time.

Longitudinal water permeability was measured on unseasoned test specimens. They were end-matched with those samples subjected to test the effect of compressive stress on drying rate.

Specimens were evacuated initially under freshly distilled water for more than 12 hours to minimize air pockets in the cell lumens. Water permeability was tested by the apparatus shown in Figure 2. Pressurizing the air chamber \underline{A} (Figure 2) provided the force necessary to cause water to flow through the specimen. The water pressure, \underline{P} , will drop as water flows out.

Water permeability can be calculated from the relation (Lancaster, 1971)

$$K = C' \frac{d \left(\frac{1}{P} \right)}{dt},$$

where \underline{C}' is a constant associated with viscosity and initial volume of air pocket, and $\frac{d \left(\frac{1}{P} \right)}{dt}$ is the slope of the curve plotted for $(1/P^2)$ and time, t .

Compressive treatment

Compressive treatment was applied with a cold press. Specimens were compressed to 90 percent of their original thickness, and the load was removed immediately. Thickness before pressing, immediately after the pressing, and after 24 hours was recorded.

To determine the effect of extreme compressive treatment on the longitudinal water permeability of western hemlock, specimens of unseasoned sapwood, normal heartwood, and sinker heartwood were compressed perpendicular to the grain by 33 percent of their original thickness. Longitudinal water permeability of test specimens was measured before and after compression. To avoid loss of water during compression, pressure was applied to the specimen while immersed in water.

Steam treatment

To determine the effect of steaming on the drying rate of sinker heartwood, specimens were steamed in a small kiln at 212° F. and 99 percent relative humidity for 6 hours. To restore the loss in moisture, they were placed in a pressure vessel, treated with water at a vacuum of 29.9 inches of mercury for 3 hours and held at 100 psi pressure for 18 hours. Specimens were then subjected to the drying study and air permeability test.

Extraction treatment

Specimens of sinker heartwood were extracted in a pressure vessel containing acetone at 145° F. and 4 to 5 psi for 168 hours. The solvent was changed after 80 hours. Specimens then were fan-dried for 10 days to remove excessive solvent. Water lost by the solvent extraction was restored by a water treatment as described in steaming. Specimens then were removed and their drying behavior was studied and air permeability measured.

RESULT AND DISCUSSION

Relation between longitudinal permeability to water and air and moisture diffusion above fiber saturation of sinker heartwood

The results of investigations for possible relations between longitudinal permeability to air and water and the diffusion coefficient above fiber saturation are shown in Figure 3 and in Tables 1 and 2. Data indicated no correlation between longitudinal permeability to water or air and the water diffusion coefficient above fiber saturation. Table 1 summarizes the square of the correlation coefficients (R^2) between permeability to water and the water diffusion coefficient for two different drying periods. The R^2 may be used as an index to measure the dependency of diffusion coefficients on permeability of wood, and ranges from 0.07 to 23.8 percent. Very poor correlation is shown graphically in Figure 3, which plots the diffusion coefficient against water permeability. The R^2 was higher for drying times between 23 and 79 hours than for drying times between 121 and 239 hours.

Table 2 shows the summary of R^2 for the relation between longitudinal air permeability and diffusion coefficient. The R^2 values ranged from 0.23 to 6.7 percent.

Based on results of this study, permeability was not a major factor controlling the drying behavior of wood above the fiber saturation point for sinker heartwood.

Effect of compressive treatment on drying rate of sinker heartwood

Cech (1971) reported that compressing unseasoned birch before drying improved the drying rate and quality of dried products when dried at temperatures above 212° F. The result of compressing unseasoned western hemlock sinker heartwood is shown in Table 3. The compressed specimens showed slightly higher diffusion coefficients during the initial 79 hours of drying at room temperature. Analysis of variance, however, indicated no significant difference in the diffusion coefficient between control and compressed specimens above the fiber saturation point. Calculations showed that the degree of compression applied exceeded the average stress to the proportional limit of unseasoned western hemlock perpendicular to the grain, which is 390 psi (Wood Handbook, 1955). Use of a higher degree of compression apparently would induce severe damage in wood.

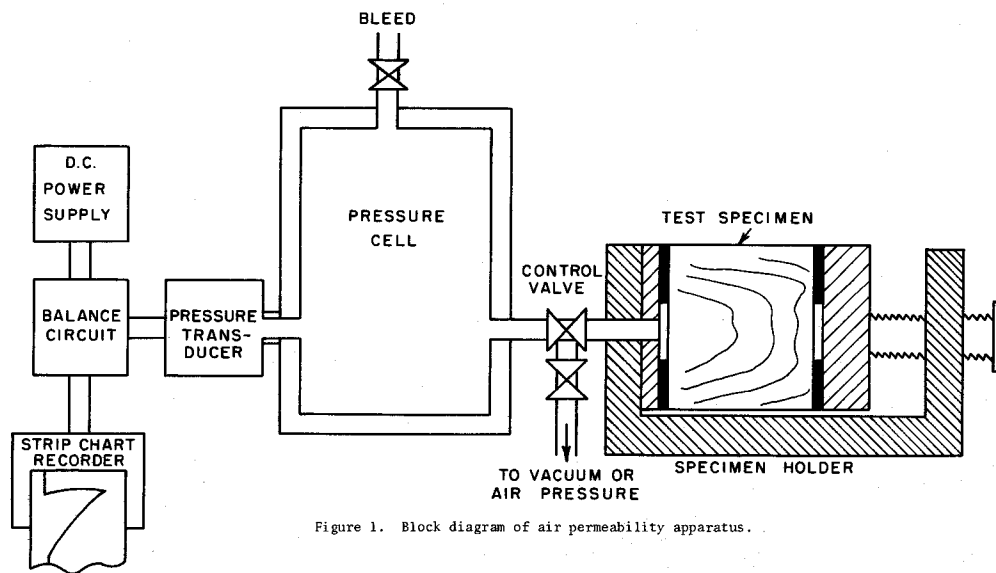


Figure 1. Block diagram of air permeability apparatus.

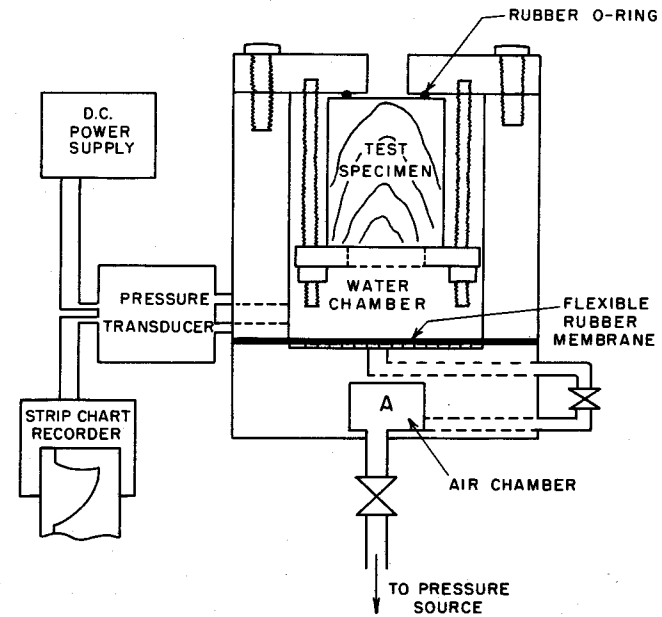


Figure 2. Diagram of water permeability apparatus.

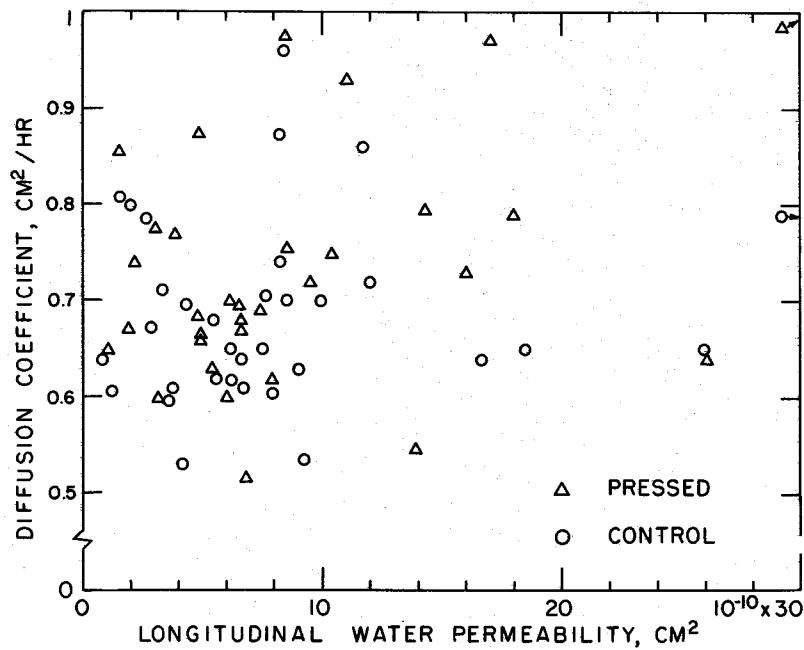


Figure 3. Diffusion coefficient of wood above the fiber saturation point and longitudinal water permeability of western hemlock sinker heartwood. Diffusion coefficient was calculated for drying times between 23 and 79 hours.

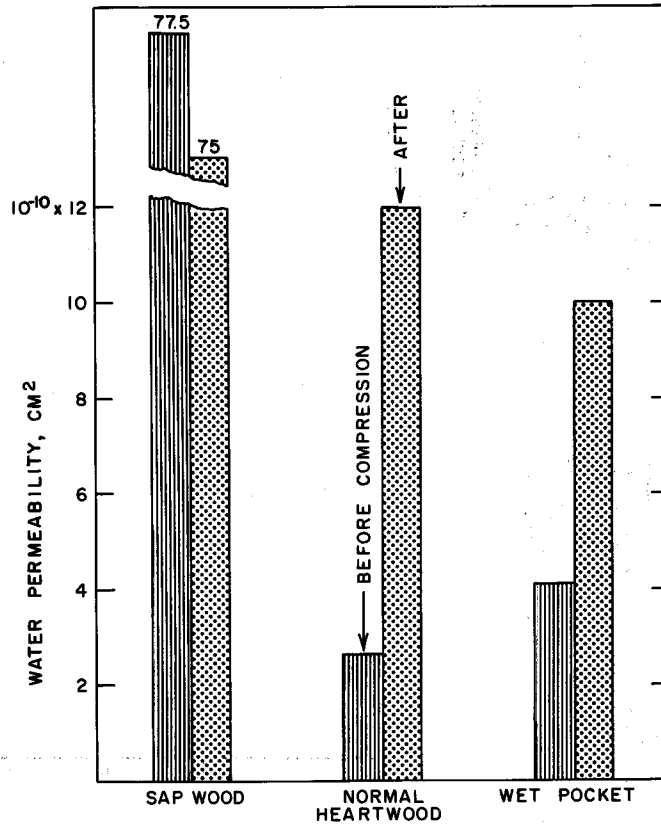


Figure 4. Longitudinal water permeability of western hemlock before and after being treated with transverse compression to 1/3 of original thickness.

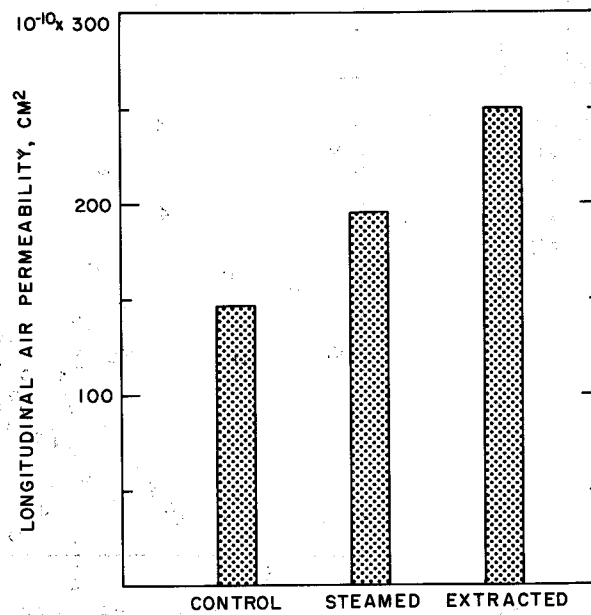


Figure 5. Longitudinal air permeability of airdried western hemlock sinker heartwood steamed, extracted, or untreated before drying.

Table 1. Correlation between Water Diffusion Coefficient above the Fiber Saturation Point and Longitudinal Water Permeability of Western Hemlock Sinker Heartwood.

Drying time Hours	Diffusion coefficients		Permeability coefficients		R ²	Degrees of freedom
	Mean	Standard deviation	Mean	Standard deviation		
Control (No Treatment)						
23-79	0.689	0.0974	8.209x10 ⁻¹⁰	7.054x10 ⁻¹⁰	1.38	31
121-239	0.859	0.141	8.209x10 ⁻¹⁰	7.054x10 ⁻¹⁰	0.47	31
Compressed						
23-79	0.737	0.122	9.096x10 ⁻¹⁰	8.592x10 ⁻¹⁰	23.84	31
121-239	0.828	0.180	9.096x10 ⁻¹⁰	8.592x10 ⁻¹⁰	11.15	31
Both Control and Compressed						
23-79	0.713	0.112	8.653x10 ⁻¹⁰	7.813x10 ⁻¹⁰	11.9	64
121-239	0.844	0.161	8.653x10 ⁻¹⁰	7.813x10 ⁻¹⁰	0.07	64

Table 2. Correlation between Water Diffusion Coefficient above the Fiber Saturation Point and Longitudinal Air Permeability of Western Hemlock Sinker Heartwood of Control, Steamed, and Extracted Samples.

Treatment	Diffusion coefficient		Air permeability coefficients		R ²	Degrees of freedom
	Mean	Standard deviation	Mean	Standard deviation		
Control	0.474	0.04548	1.442x10 ⁻⁸	1.174x10 ⁻⁸	6.73	32
Steamed	0.512	0.04549	1.856x10 ⁻⁸	0.936x10 ⁻⁸	0.71	25
Extracted	0.496	0.03178	2.500x10 ⁻⁸	1.423x10 ⁻⁸	3.66	31
All, pooled	0.492	0.04358	1.932x10 ⁻⁸	1.279x10 ⁻⁸	0.23	92

Table 3. The Effect of Compression Treatment on the Water Diffusion Coefficient of Unseasoned Western Hemlock Sinker Heartwood.

A. Drying time from 23 to 79 hours.

Treatment	Mean	No. of samples	Standard deviation
Control	0.689	33	0.0974
Compressed	0.737	33	0.122

ANALYSIS OF VARIANCE

Source of variation	Degrees of freedom	Sum of squares	Mean squares	F-ratio
Treatment	1	0.03871	0.03871	3.17 ¹
Within samples	64	0.779656	0.01218	
Total	65	0.818366		

B. Drying time from 121 to 239 hours.

Treatment	Mean	No. of samples	Standard deviation
Control	0.859	33	0.141
Compressed	0.844	33	0.180

ANALYSIS OF VARIANCE

Source of variation	Degrees of freedom	Sum of squares	Mean squares	F-ratio
Treatment	1	0.000035	0.000035	0.0017 ¹
Within samples	64	1.288607	0.02013	
Total	65	1.288642		

¹Not significant.

Measurements of thickness of test specimens before and after the compressive treatments indicated that specimens recovered to an average of 95 percent of the original thickness immediately after removing the load, and recovered to 99.5 percent after 24 hours.

Compression treatments on longitudinal water permeability of sapwood, sinker and normal heartwood

Table 4 shows the analysis of variance of longitudinal permeability to water of control and matched specimens compressed perpendicular to the grain. The average permeability for control specimens was $8.209 \times 10^{-10} \text{ cm}^2$ and for the compressed samples was $9.096 \times 10^{-10} \text{ cm}^2$. The F-value, however, indicated no significant difference between the two values at the 5 percent level of probability. Results indicated that compression to 90 percent of its original dimension will not improve the permeability of wood.

When the degree of compressive treatment was increased to 1/3 of its original dimension, as in Figure 4, longitudinal permeability to water of normal and sinker heartwood improved by more than 50 percent, but, for sapwood, degraded the longitudinal permeability to water. Excessive compressive treatment no doubt exceeded the proportional limit and probably induced small cracks along ray cells because of shear. This was substantiated because 1/3 of the sinker heartwood specimens were discarded for cracks along wood rays visible by the naked eye and extended through the length of the test specimens.

Sapwood of western hemlock is very permeable, so the excessive compressive treatment probably closed some of the flow paths for water in sapwood.

Effect of steaming and extraction on longitudinal air permeability of sinker heartwood

Extraction and steaming improve longitudinal permeability to air for some species (Buro and Buro, 1959; Ellwood and Ecklund, 1961). The results shown in Table 5 and Figure 5 confirmed these observations. Analysis of variance indicated that values of longitudinal permeability to air of sinker heartwood specimens treated by steaming and extraction before drying were significantly different from those of the untreated specimens at the 5 percent level of probability. The values for permeability to air of extracted specimens were significantly different from those of the steamed specimens at the 5 percent level of probability. Air permeability control specimens have the lowest longitudinal permeability.

CONCLUSIONS

1. Longitudinal permeability to water and air of western hemlock cannot be used to estimate the drying characteristics of the wood above the fiber saturation point.
2. Extracting the wood with acetone or steaming improved the longitudinal permeability to air.
3. Compressive treatment perpendicular to the grain by 10 percent of original dimensions did not improve the permeability to water nor the water diffusion coefficient of western hemlock. Compressive treatment by 33 percent of original dimension improved the permeability to water of heartwood, but degraded permeability of sapwood.

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Table 4. The Effect of Compression Treatment on the Longitudinal Water Permeability of Western Hemlock Sinker Heartwood.

Treatment	Mean	No. of samples	Standard deviation
Control	8.209×10^{-10}	33	7.054×10^{-10}
Compressed	9.096×10^{-10}	33	8.592×10^{-10}

ANALYSIS OF VARIANCE

Source of variation	Degrees of freedom	Sum of squares	Mean squares	F-ratio
Treatment	1	12.98×10^{-20}	12.98×10^{-20}	0.21 ¹
Within samples	64	3954.89×10^{-20}	61.80×10^{-20}	
Total	65	3967.87×10^{-20}		

¹Not significant.

Table 5. Analysis of Variance on Air Permeability of Airdried Western Hemlock Sinker Heartwood of Control, Steamed, and Extracted Specimens.

Treatment	Mean	Degrees of freedom	Standard deviation
Control	$1.442 \times 10^{-8} \text{ cm}^2$	33	1.174×10^{-8}
Steamed	$1.856 \times 10^{-8} \text{ cm}^2$	26	0.936×10^{-8}
Extracted	$2.500 \times 10^{-8} \text{ cm}^2$	32	1.279×10^{-8}

ANALYSIS OF VARIANCE

Source	Degrees of freedom	Sum of S_f	Mean squares	F
Treatment	2	18.972×10^{-16}	9.486×10^{-16}	6.483*
Control vs. treat.	1	12.800×10^{-16}	12.800×10^{-16}	8.748**
Steam vs. Ext.	1	1.172×10^{-16}	6.172×10^{-16}	4.218*
Individuals	91	133.154×10^{-16}	1.4632×10^{-16}	
Total	93	152.1269×10^{-16}		

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