IMPACT OF MOUNTAIN PINE BEETLE (MPB) ATTACK ON DRYING CHARACTERISTICS OF WOOD

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Abstract. Mountain pine beetle infested lodgepole pine (*Pinus contorta var. latifolia*) containing blue stain was used for the determination of permeability and diffusion coefficients. The results were then compared with the permeability and diffusion coefficients of noninfested wood that was free from the blue stain. The comparisons indicated that the blue stain in wood significantly increased the permeability of lodgepole pine, in both tangential and radial directions. Diffusion coefficients for blue-stained sapwood were greater than those observed for nonstained sapwood.

Keywords: Permeability; diffusion; MPB infestation; blue stain.

INTRODUCTION

The volume of lodgepole pine lumber from forestlands infested by mountain pine beetle (MPB) has exceeded the annual allowable harvesting volume in British Columbia (BC).

Sawmills throughout BC are processing increased volumes of MPB-killed wood. In general, the initial average moisture content exhibited by the MPB-infested sawn lumber tends to be lower than the lumber from noninfested trees. However, it is still necessary to carry out the process of drying (or heat treatment) before sending the MPB-infested lumber to market.

Drying characteristics such as permeability and diffusion coefficients that could be affected by MPB attack, are essential properties for drying practice and chemical treatment. The transverse permeability of wood can be an indicator of the drying rate in the lumber drying process.

There is a limited amount of current literature on the properties of MPB-infested wood. Woo et al (2005) studied the effects of MPB attack on lodgepole pine wood and fiber quality. They indicated that the MPB-infested wood had lower specific gravity, and lignin and hemicellulose contents, and lower concentrations of extractives than normal wood. They also determined longitudinal permeability using the falling water volume displacement method (Siau 1984, 1995) and found that the MPB-infested sapwood was more permeable than that of normal sapwood. In contrast to their results, Bradic and Avramidis (2007) found that there is no significant difference in permeability between MPB-attacked and noninfested wood.

Permeability and diffusion coefficients of blue-stained wood, which could be affected by MPB, are essential characteristics for the chemical treatment and drying process. However, the transverse permeability of blue-stained wood, which is a very important factor in lumber drying, is still not clear. The diffusion approach offers one generalized way to estimate the drying time required and the final moisture content distribution. Therefore, there is a need to study

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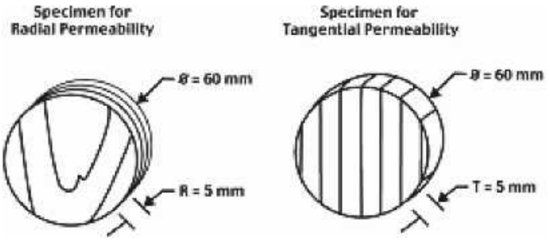

FIGURE 1. Specimens for permeability determination.

the permeability and diffusion coefficients of MPB-infested sapwood.

MATERIALS AND METHODS

Determination of Permeability

In this study, sapwood permeability in both radial (K_R) and tangential (K_T) directions was evaluated. Sapwood was chosen because of its inherent vulnerability to blue stain by MPB attack. Determinations of transverse permeability (radial and tangential) were carried out because of their importance to drying and chemical treatment. Sixteen 50-mm × 100-mm × 2.4-m lodgepole pine (*Pinus contorta var. latifolia*) lumber boards that exhibited blue-stained and nonstained sapwood regions were chosen from a mill in the Interior of BC. Based on their grain direction, 10 pieces of the lumber were selected for determination of $K_{R,}$ and the other 6 pieces were for determination of K_T.

Specimen discs of 60-mm-dia and 5-mm thickness were prepared for determination of permeability as shown in Fig 1. One disc was cut from the region exhibiting blue stain and matched with another extracted from a region without blue stain. The initial moisture contents of the discs ranged 12–27%. In general, it was observed that the blue-stained specimens were drier than nonstained specimens. Then these discs were slowly dried in an oven at 60°C (0% RH) for one week until they reached constant mass. The discs without visual defects or damage from machining and drying were selected as specimens. The sample sizes for each board are shown in Table 1 for K_R and Table 2 for K_T.

The gas permeability determinations (Siau 1984; Cai and Oliveira 2007) were carried out with an apparatus that included:

TABLE 1. *Permeability in radial direction (K_R) of blue-stained and nonstained wood ($\times 10^{-14}$ m^3/m).*

Board no.	Type of wood	Sample size	Density* (kg/m^3)	Average permeability	Standard deviation	P-value	Null hypothesis
1	Nonstained	22	439.0	0.88	0.10	0.007	Reject
	Blue-stained	22	404.6	6.49	1.86		
2	Nonstained	47	454.9	0.40	0.23	0.003	Reject
	Blue-stained	47	435.8	6.63	1.68		
3	Nonstained	42	454.6	0.27	0.13	0.018	Reject
	Blue-stained	42	434.5	2.44	0.71		
4	Nonstained	37	438.6	0.21	0.10	0.009	Reject
	Blue-stained	37	402.5	4.86	1.20		
5	Nonstained	30	439.8	0.28	0.12	0.004	Reject
	Blue-stained	30	429.8	3.78	1.20		
6	Nonstained	47	448.1	0.47	0.20	0.012	Reject
	Blue-stained	47	421.0	3.12	1.03		
7	Nonstained	51	433.6	1.21	0.75	0.091	*Retain*
	Blue-stained	51	432.1	2.89	1.44		
8	Nonstained	41	439.5	0.76	0.19	0.006	Reject
	Blue-stained	41	409.5	3.42	0.82		
9	Nonstained	28	458.1	0.59	0.33	0.015	Reject
	Blue-stained	28	444.2	4.12	1.18		
10	Nonstained	25	431.1	0.87	0.23	0.008	Reject
	Blue-stained	25	412.8	3.44	1.54		

* Oven-dry density = Oven-dry mass / Oven-dry volume

TABLE 2. *Permeability in tangential direction (K_T) of blue-stained and nonstained wood ($\times 10^{-14}$ m^3/m).*

Board no.	Type of wood	Sample size	Density* (kg/m^3)	Average permeability	Standard deviation	P-value	Null hypothesis
1	Nonstained	26	452.1	0.41	0.20	0.003	Reject
	Blue-stained	26	436.9	5.27	1.86		
2	Nonstained	22	439.6	0.53	0.09	0.002	Reject
	Blue-stained	22	418.3	5.19	2.92		
3	Nonstained	45	439.1	0.61	0.12	0.018	Reject
	Blue-stained	45	428.3	3.77	0.46		
4	Nonstained	40	450.7	0.50	0.17	0.014	Reject
	Blue-stained	40	422.9	3.86	0.98		
5	Nonstained	36	436.5	0.46	0.20	0.004	Reject
	Blue-stained	36	433.8	2.29	1.08		
6	Nonstained	42	409.2	0.48	0.21	0.012	Reject
	Blue-stained	42	403.4	3.48	1.00		

* Oven-dry density = Oven-dry mass / Oven-dry volume

1) Two mercury manometers to determine the pressure difference between the sides of specimen, and
2) A flowmeter to indicate the airflow rate.

The superficial gas permeability (K) was calculated by following equation:

$$K = \frac{\mu \cdot L \cdot Q \cdot P_2}{A \cdot \Delta P \cdot \overline{P}} \tag{1}$$

where K is the superficial permeability, m^3/m ; $\Delta P = (P_1\text{-}P_2)$; $\overline{P} = (P_1+P_2)/2$; P_1 and P_2 are the pressures at air entrance and exit sides of the specimen, Pa; Q is the flow rate of volume, m^3/s; L is the thickness of specimen, m; A is the cross-section area of the specimen, m^2; μ is the dynamical viscosity of fluid, $N \cdot s/m^2$.

Determination of Diffusion Coefficient

From the same source material used for the permeability determination, the specimens used for the transverse diffusion coefficient (D) test were cut to 50 mm (width) ×10 mm (thickness) × 100 mm (length). Matched specimens were obtained from blue-stained and nonstained regions. Twenty replicates were used for each specimen type and at each temperature level. All specimens were free from any visual defects. They were edge-coated with two layers of epoxy to restrict moisture movement in the longitudinal and transverse directions.

A conditioning chamber was used where the temperature and relative humidity (RH) were kept constant to ±1°C and ±2%, respectively. Drying (desorption) experiments were carried out at three dry/wet bulb temperature combinations, namely, 50/42, 70/62, and 90/78°C at about 62% RH. To minimize the effect of surface resistance on the diffusion coefficient, a high air velocity, about 5 m/s, was set for the chamber.

The initial moisture content of the specimens ranged 25 to 36%. Before the tests of desorption (drying), the specimens were equilibrated at 20°C and 96% RH for 8 wk. Upon reaching equilibrium, the specimens for both blue-stained and nonstained wood were placed in the chamber. During desorption, the mass of each specimen was monitored with a digital balance. To obtain their oven-dry mass, the specimens were subsequently dried at 103 ± 2°C to constant mass.

Assuming that the diffusion coefficient is independent of moisture content, the following equation (Siau 1984) can be used:

$$D = \frac{705.88 \times (\overline{E})^2 L^2}{t} \tag{2}$$

where D is the diffusion coefficient, m^2/s; L is the half thickness in moisture diffusion direction, m; t is the time, s; and $\overline{E}$ is the fractional change in average moisture content at time t and can be described as follows:

$$\overline{E} = \frac{\overline{C} - C_e}{C_0 - C_e} \qquad (3)$$

where $\overline{C}$ is the moisture concentration at time t, kg/m^3; C_e is the moisture concentration in equilibrium with the water vapor pressure in the surrounding air, kg/m^3; C_0 is the initial moisture concentration, kg/m^3.

It can be seen in Eq (2) that a plot of $\overline{E}^2$ vs t is linear with a slope of D/705.88L^2, so D may be calculated from the slope of a linear regression fitted to the experimental data. Therefore, D can be obtained as follows:

$$D = 705.88\ L^2 \times \text{Slope} \qquad (4)$$

where Slope $= \dfrac{(\overline{E})^2}{t}$.

RESULTS

Permeability

The results for the permeability of the blue-stained and nonstained wood in the radial direction (K_R) are presented in Table 1. Although considerable variations in K_R values were observed, blue stain in wood, in general, significantly increased the permeability. By statistical analysis, at the probability value (P-value) < 0.05, null hypotheses were rejected in 9 of 10 boards. Although the null hypothesis is retained in one board, the increase in the average K_R was still substantial, as observed in Table 1. The permeability in the tangential direction (K_T) is presented in Table 2. Similarly to the results observed for K_R, at the probability value (P-value) < 0.05, the null hypotheses were rejected in all boards. The K_T values obtained for blue-stained wood were also significantly greater when compared with the permeability of nonstained wood.

It was presumed that the radial and tangential permeability values were increased by the blue stain associated with MPB attack as a result of:

a) Rupture in the walls of ray parenchyma cells;

b) Rupture of pit membranes;

c) Checking in the middle lamella of tracheids;

d) Openings in the aspirated pits.

The higher transverse permeability observed for blue-stained wood is similar to the results found by Woo et al (2005) for longitudinal permeability in MPB-infested sapwood. The K_R in the current study appears to be higher than the K_T in both blue-stained and nonstained wood. These results are consistent with the findings presented by Siau (1995) and Pang (2002) for nonstained wood. Additional pathways along the rays by blue-stain fungi probably contribute to the larger values of K_R.

Diffusion Coefficients

Diffusion coefficient (D) values for blue-stained wood and nonstained wood are shown in Table 3. Irrespective of the dry/wet bulb temperatures used, diffusion coefficients for blue-stained wood were significantly different from those measured for nonstained wood. The diffusion coefficients of blue-stained wood increased by 23.5–70.5% when compared with that of nonstained wood as illustrated in Fig 2 and Table 3.

The higher diffusion coefficients for blue-stained wood can probably be attributed to the lower density observed for blue-stained wood (423 kg/m^3) in relation to nonstained wood (442 kg/m^3). According to Siau (1995) lower density reduces resistance to flow, which in turn is reflected by the increase in the diffusion coefficient.

Since the occurrence of blue stain in wood is rarely uniform, different drying rates might oc-

TABLE 3. *Diffusion coefficients at different temperatures.*

Dry/wet bulb temperatures (°C)	Transverse D ($\times 10^{-10}$ m^2/s) Nonstained wood	Blue-stained wood	Increase (%)
50/42	1.36	1.99	46.0
70/62	1.56	2.6	70.5
90/78	2.45	3.02	23.5

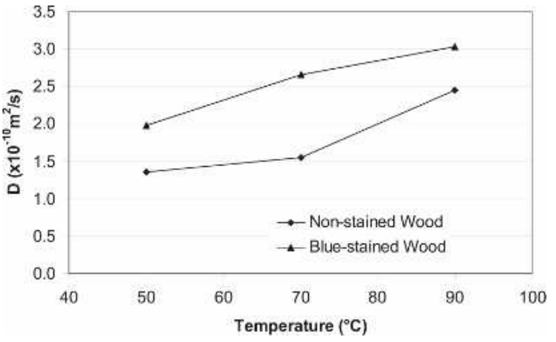

FIGURE 2. Diffusion coefficient changes with temperature.

cur within a single piece of lumber. Blue-stained regions will dry faster than nonstained regions due to the differences in the diffusion rates. However, since the permeability is also increased in blue-stained regions, equalizing the lumber after drying will permit the moisture to redistribute from the nonstained regions into the drier, stained regions. This will increase the probability of having uniform moisture content throughout the lumber after drying and equalizing.

CONCLUSIONS

The following conclusions were made in this study:

1. MPB infestation significantly increases permeability. The radial and tangential permeability of blue-stained wood increased 2.4–23 times, and 5–13 times, respectively, when compared with that of nonstained wood.
2. Diffusion coefficients for blue-stained sapwood increased by 23.5–70.5% when compared with that of nonstained wood.

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