

ASPEN WOOD ANATOMY AND FLUID TRANSPORT¹

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ABSTRACT

Measurements of vinyl monomer impregnation, air permeability, moisture diffusion, and extractives content were made on the wood of two aspen trees from northern New Brunswick. The anatomy of the same wood was studied using the scanning electron microscope. There was high extractives content in the core, and tyloses were present in the core and heartwood. These caused the fluids to move with progressively greater difficulty from sapwood to heartwood to core.

Keywords: Aspen wood, flow, diffusion, anatomy, tyloses, wood-polymer combinations, extractives, *Populus*, treatability, impregnation, permeability.

INTRODUCTION

Teasdale and MacLean (1918) found that largetooth aspen (*Populus grandidentata* Michx.) heartwood accepted pressure-impregnated creosote erratically. On average, ranked by absorption and penetration, the aspen was in the middle range of the 30 hardwoods tested. The authors categorized it as "moderately difficult to treat" (as contrasted to easily treated or very difficult to treat). The heartwood of aspen contained randomly distributed tyloses to which the authors attributed the erratic treatment.

Stone (1956) found that sapwood and some heartwood of trembling aspen (*Populus tremuloides* Michx.) accepted pulping liquor easily, while other parts of the heartwood were resistant to penetration. Light micrographs illustrate tyloses in aspen, and their abrupt appearance at the sapwood-heartwood boundary. The author suggests that the amount of tyloses is a genetic factor, and that some strains of aspen are free of tyloses.

Tesoro (1964) found that in a single specimen of trembling aspen heartwood treated well with creosote. Anon. (1966) reported erratic preservative penetration in *Populus* fenceposts' sapwood zones. Poorly penetrated sapwood was "wound heartwood," produced by the tree as a protection after insect attack. The wound heartwood had tyloses and extractives similar to those of normal heartwood.

In preliminary studies of woods that might be useful for production of wood-polymer combinations in New Brunswick, we noticed wide variability in sapwood thickness and monomer uptake in *Populus* wood obtained from various locations around the province. We chose some wood from a location that produced trees having wide sapwood and therefore best potential treatability. We took scanning

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FIG. 1. Aspen sapwood with diagonal vessel element ends projecting from the lumen walls and some pitting in the walls. Except for these wall sculpturings, the vessels are open for fluid transport.

electron micrographs illustrating this wood's anatomy and measured its extractives content, monomer uptake, air permeability, and moisture diffusion.

MATERIALS AND METHODS

Wood

Two straight, healthy 43-year-old trembling aspen trees, growing in Restigouche County of New Brunswick, were used for this study. Their dbhs were 32 cm and 35 cm. Bolts were removed between 1 and 2 meters of the base section of each tree. Seven-cm-thick pith-centered boards were cut from these bolts. The boards were air-dried to a final moisture content of approximately 6%. Defect-free sections were cut into 30-cm lengths and then split into sapwood, heartwood, and core blocks which were used for all of the studies reported herein. The core is a few annual rings wide just adjacent to the pith. It is probably what is called juvenile wood in conifers, although such terminology tends to be less applied to deciduous woods.



FIG. 2. A single vessel element end in the sapwood of aspen. The end, seen as the diagonal in the photomicrograph, protrudes from the vessel element wall but does not close the vessel.

Microscopic examination

Wood specimens were mounted on aluminum stubs, using silver paste. The specimens were sputter-coated with gold and then examined with a Cambridge S4-10 scanning electron microscope at 10 kV.

Polymer retention

Square aspen blocks 3 cm in cross section and 10 cm in the fiber direction were oven-dried and weighed. The blocks were anchored in an impregnation chamber and full vacuum was applied for 30 min. Styrene monomer (containing 0.3% azobisisobutyronitrile as polymerization initiator) was introduced into this chamber until the samples were covered. This was followed by a 24-h soak period at atmospheric pressure. The blocks were then removed, wiped free of excess monomer, and wrapped in aluminum foil to minimize evaporation losses. Curing was carried out at 70 C for 24 h. The samples were then unwrapped and vacuum dried for 3 h at 90 C to remove unpolymerized monomer. The polymer retention,



FIG. 3. Aspen heartwood showing numerous tyloses closing the vessels.

expressed as a percentage, is the ratio of the weight of polymer to the original OD weight of wood.

Steady-state air permeability

Squares 7 cm in cross section and 22 cm along the grain were turned on a lathe to 5-cm diameter cylinders. Finished lengths were either 10 cm or 18.5 cm. The side grain was sealed with a pourable silicone rubber (General Electric TRV-112).

The experimental procedure for steady-state air flow measurements has been previously described by Perng (1980a). The longitudinal flow was measured under a constant pressure gradient ($\Delta P/L$) of 0.4 (cm Hg/cm) for sapwood and 1.2 (cm Hg/cm) for heartwood and core. All flow rate measurements were duplicated. Superficial gas permeabilities (kg) were calculated in accordance with Darcy's law, and the relationship of the permeability and reciprocal of mean pressure ($1/\bar{p}$) was used to determine the molecular slip flow factor, b , according to Klinkenberg's equation (1941). This was accomplished using a regression analysis of permeability versus the reciprocal of the mean pressure for each data set. The correlation

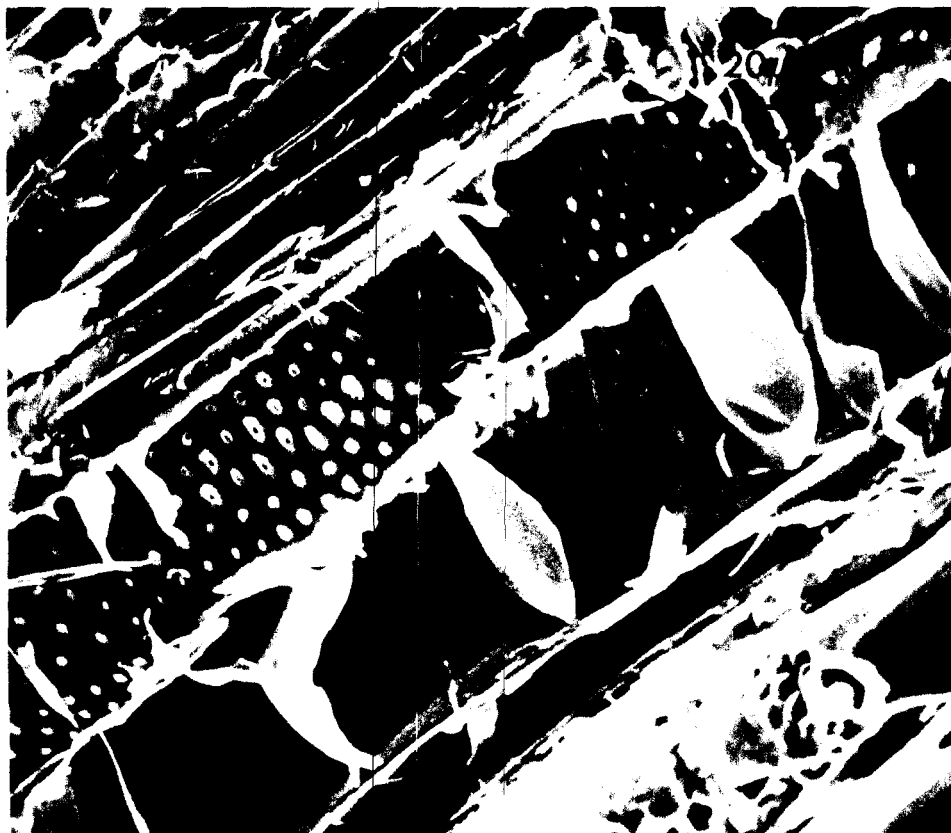


FIG. 4. Aspen heartwood showing tyloses in the vessel cavities. Pitting is visible in the vessel walls.

coefficients for this ranged from 0.80 to 1.00. The slopes of these regression equations were used to calculate permeability and b at a mean pressure of 0.5 atmosphere.

Moisture diffusion

Blocks, end-matched with those used for the flow measurements, and the same size (7 cm \times 7 cm \times 22 cm), were cut into discs 1 cm thick and 6.8 cm in diameter. The edges and both end grain surfaces, except a 5-cm diameter central circle of each disc, were sealed with silicone rubber. Each sample was mounted on a vapometer cup having a 5-cm diameter opening. The vapometer was subjected to constant room temperature (21 C) and a constant relative humidity (45%) for 11 days. The weight change due to water loss was determined at 24-h intervals. Evidence of a steady-state condition was found in the linear relationship between weight loss and time. Calculation of the water vapor diffusion coefficient (D_m) of wood was based on Fick's first law of diffusion, as described in previous papers (Schneider 1980; Perng 1980c).



FIG. 5. Two tyloses in a single vessel of aspen heartwood. Pits in the vessel wall are visible between the tyloses.

Alcohol-benzene extraction

Wood powder (40 mesh) from the sapwood, heartwood, and core was extracted with ethanol-benzene (1:2) solution in a soxhlet for 12 h with a 14-min cycle time.

RESULTS AND DISCUSSION

Microscopy

Figure 1 is characteristic of sapwood. The diagonal ends of the vessel elements (which in aspen, have simple perforation plates) cause only a slight protrusion around the vessel wall. Vessels are therefore open tubes extending the length of wood, with walls roughened slightly by the vessel element ends and by pitting. Some vessel element ends and pit fields are visible in Fig. 1. Figure 2 is a closeup of a single end. There should be little obstruction to fluid transport in such wood. Figures 3, 4, and 5 show tyloses obstructing vessels of heartwood. They close the vessels at frequent intervals, thus decreasing fluid transport.

Alcohol-benzene extraction

The average percentages of extractives based on oven-dry wood weight for sapwood, heartwood, and core are given in Table 1. Extractives content increases

TABLE 1. Ranges, average values and number of observations for permeability, *b* factor, diffusion coefficient, polymer retention, and alcohol benzene extractives of sapwood, heartwood, and core wood of two neighboring aspen trees.

	Air permeability (cm ³ /cm atm sec)	<i>b</i> factor (cmHg)	Diffusion coefficient (cm ² /sec) × 10 ⁻⁴	Polymer retention (%)	Alcohol benzene extractive (%)
Sapwood					
Range	18.088–24.692	2.245–4.234	13.763–18.621	152.60–152.90	0.360–0.376
Average	21.808	3.056	16.705	152.76	0.368
No. of samples	8	8	5	3	2
Heartwood					
Range	0.814–2.568	4.834–8.510	1.559–2.732	75.16–76.93	0.554–0.598
Average	1.569	6.954	1.930	76.15	0.576
No. of samples	6	6	5	3	2
Core					
Range	0.023–0.037	20.193–26.522	0.698–1.277	51.61–52.73	1.505–1.589
Average	0.030	23.149	0.922	52.17	1.547
No. of samples	3	3	5	2	2

with distance from the outside of the tree, with the core having substantially more extractives than the other parts of the wood. The core contains nearly three times more extractives than the heartwood.

Air permeability

Air permeabilities of the aspen sapwood, heartwood, and core are given in Table 1. Sapwood has highest permeability, followed by heartwood and then core. This ranking is similar to that found with other woods (Erickson et al. 1938; Choong and Fogg 1968; Perng and Sebastian 1983). Isaacs et al. (1971) found that a southern cottonwood tree (*Populus deltoides* Bart.) had lower air permeability in the sapwood than in the heartwood. The authors speculated that this resulted from sapwood collapse during seasoning and from extremely rapid growth which did not allow intervessel element perforations to fully develop. Such conditions might not be common farther north, such as in New Brunswick.

*Slip flow factor *b**

The slip flow factor *b* of the aspen was highest in the core, lower in the heartwood, and lowest in the sapwood. The quantitative results are given in Table 1.

Generally, gas flow consists of both viscous and slip flow according to the Klinkenberg (1941) and Adzumi (1937) equations and depends upon the size of the effective openings in the porous material and the applied pressure. At high pressure or large effective openings, the flow is primarily viscous, whereas with smaller effective openings or lower pressures, slip flow predominates.

Previous studies by Perng (1980a, b) indicated that slip flow occurs not only in softwood but also in some hardwoods. For open-vessel hardwoods, air flow is mainly through the vessels with only a portion of the flow going through the fibers and parenchyma. Wood that contains numerous tyloses in the vessels has smaller openings and more tortuous flow paths. The contribution of fiber and parenchyma cells to the flow should therefore become more noticeable in woods containing



FIG. 6. Cross section of the heartwood/sapwood boundary region in aspen. The wood has been impregnated with polymer which has filled many of the sapwood vessels. The heartwood vessels are largely empty of polymer. There are tyloses visible in some of them.

tyloses. In this case, aspen heartwood has low air permeability but high slip flow as a result of the higher flow resistance and the smaller diameter of the effective openings.

Moisture diffusion

Table 1 lists the longitudinal diffusion coefficient for the three parts of the wood. Sapwood is highest, heartwood next, and core has the lowest coefficient.

Moisture movement through wood under steady-state conditions results from random molecular motion and is caused by a moisture concentration gradient. The open vessels of the sapwood allowed fast diffusion, whereas tyloses and extractives in the heartwood and core apparently blocked the moisture movement.

Polymer retention

The average polymer retentions within sapwood, heartwood, and the core are shown in Table 1. The wood with the greater obstructions to flow had the lower retention.

Figure 6 is a cross-section micrograph at the sapwood-heartwood boundary. Vessels in the sapwood are filled with polymer, while those of the heartwood are largely empty of polymer. Some tyloses are visible in the empty vessels.

Previous work has shown that oil retention in wood treated using a pressure process increases with increased wood air permeability (for example, Tesoro 1964, and Perng and Sebastian 1983). Such is the case in this study, using a monomer as the treating fluid and polymer retention as the measure of the success of treatment.

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