A REVIEW OF THE PERMEABILITY, FLUID FLOW, AND ANATOMY OF SPRUCE (*PICEA* SPP.)

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ABSTRACT

This paper reviews the literature discussing some of the qualities and properties of spruce that characterize its refractory nature and influence its treatability. Topics discussed include a review of the permeability of spruce, fluid flow through wood, and the anatomy of spruce.

Permeability and liquid flow through wood are discussed, with an emphasis on differences in flow between sapwood and heartwood and between earlywood and latewood. Literature covering the effects of reversing the direction of flow and decreases in flow with time are also reviewed. Permeability through earlywood and latewood was variable, with neither being more or less treatable than the other. Reversing the direction of flow through wood was shown to increase the rate of flow, which normally tapers off over time.

Discussion of wood anatomy and the path of flow includes a review of longitudinal flow and transverse flow. Pit aspiration and the effects of surface tension, the rigidity of pit membrane, and the adhesion of the torus to pit border are also addressed.

Keywords: Spruce (*Picea* spp.), permeability, refractory, preservative treatment, flow, aspiration, surface tension.

INTRODUCTION

This paper discusses some of the factors that influence the treatability of spruce and was written to provide a background and a summary of the factors that may influence its refractory nature. Many of these factors relate to the anatomical structure of the wood and the path through which preservatives penetrate the material or to the properties of the preservative.

PERMEABILITY AND LIQUID FLOW THROUGH WOOD

Flow in sapwood and heartwood

Preservative treatment of spruce heartwood is a problem because of its nondurable classification and need for treatment to get a long service life. Sapwood is known to be several times more permeable than heartwood (Erickson 1970; Krahmer and Côté 1963), and in conifers, the moisture content (MC) of sapwood is greater than the MC of heartwood (Bamber and Fukazawa 1985). The sapwood in Norway spruce (*Picea abies*) proved readily treatable (Smith 1986). "The primary causes of heartwood and sapwood permeability differences are due to differences in aspiration, and to the amounts and character of the extractives, especially in the heartwood in cases of liquid flow" (Erickson 1970).

Extractives in wood tend to reduce permeability, especially in heartwood (Erickson 1970; Krahmer and Côté 1963), and can have a significant effect on the treating results (Baines and Saur 1985; Nicholas 1982). It is generally agreed that the deposition of extractives in the heartwood of spruce does not confer appreciable durability (Erickson 1970; Krahmer and Côté 1963).

In addition to the general differences between heartwood and sapwood, other anatomical and site influences have been noted to affect treatability. Permeable, treatable spruce (*Picea* spp.) and Douglas-fir (*Pseudotsuga menzeisii*) specimens are known to have longer tracheids (Baines 1986; Fleischer 1950; Liese and Bauch 1967), and to have larger lumina (Fleischer 1950). The difference in fiber length has been documented to be as high as 27% (Liese and Bauch 1967). Several studies have found variations in the permeability of Norway spruce (*P. abies*) from different growth sites (Baines and Saur 1985; Peyresaubes 1985). Another study confirms the site influence on the longitudinal treatability of spruce (*P. abies*), but reported it to be of minor importance because it was not seen to affect flow in the radial or tangential directions (Liese and Bauch 1967).

Flow in earlywood and latewood

As with most discussion of the characteristics of spruce, the differences in permeability and fluid flow through earlywood and latewood are also in debate. One study found the lateral movement of preservative in white spruce (*P. glauca*) to be the same in earlywood and latewood (Keith and Chauret 1988). Other authors cite more random variability, where sometimes the earlywood from an annual ring is more permeable than the latewood, and sometimes vice versa (Baines and Saur 1985; Baines 1986). The length of ray tracheids in latewood is about half that of the earlywood cells and is one explanation of why preservative penetration in spruce (*Picea* spp.) is often better in the earlywood than in the latewood (Baines 1986; Liese and Bauch 1967).

The thicker strands and tighter margo texture in latewood pits, their smaller diameter, and the configuration of the pit chamber contribute to their stiffness and resistance to aspiration (Comstock and Côté 1968; Liese and Bauch 1966; Petty 1970). "From observation of dye through the thin sections it seems that the flow was confined to the last-formed earlywood region in which the pits are larger in latewood and have larger gaps between the radial strands in the membranes" (Petty 1970).

Reversal of flow

Reversal of flow direction is a known method of improving the rate of flow through wood. It works even after flow in the original direction has tapered off (Anderson et al. 1941; Erickson and Crawford 1959; Hudson and Henriksson 1956; Nicholas 1982), and the effect has been seen in both hardwoods and softwoods and in filter media (Anderson et al. 1941). One study of Douglas-fir permeability found a hysteresis effect with flow rates (Bailey 1965). The general reasons cited for this change in flow rates include blockage of the pathways by particles or air bubbles and movement of the torus, so that it blocks the opening of the bordered pit.

This increase in flow has been seen in both directions (Anderson et al. 1941; Hudson and Henriksson 1956), and "The efficacy of reversal of the flow in re-establishing the original high rate of flow in permeable woods is a well established fact, which has tended to strengthen the belief that the use of fluctuating pressures would improve penetration in woods that are difficult to treat by ordinary means" (Hudson and Henriksson 1956).

Decrease in flow with time

There are many scenarios suggested to account for the decrease in flow through wood with time. Wood can act as a filter, with small particles or air bubbles in the water gradually blocking the pathways; or polar liquids can cause swelling of the wood fibers. An obvious factor appears to be the fact that "the permeability of spruce (*P. abies*) is related mostly to the structure and condition of the bordered pits in the tracheids" (Liese and Bauch 1967), and that "most of the pits of (black and white) spruce (*Picea* spp.) heartwood are aspirated and therefore cannot be bulged" (Anderson et al. 1941). Various theories have reportedly been eliminated as causes, while others are supported in various conflicting studies.

Many studies agree that entrapped air in wood complicates the measurement of liquid permeability (Anderson et al. 1941; Sebastion et al. 1965; Stamm 1963). Air is believed to be trapped in small openings, such as pits, in the wood structure and block flow (Bailey 1965; Erickson 1970; Sebastion et al. 1965; Stamm 1963). High pressures are required to over-