AIR PERMEABILITY, SHRINKAGE, AND MOISTURE SORPTION OF LODGEPOLE PINE STEMWOOD

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ABSTRACT

The longitudinal air permeabilities, shrinkage (from fully swollen to oven-dry), and moisture sorption characteristics of two varieties (*latifolia* and *murrayana*) of lodgepole pine (*Pinus contorta*) were measured, based on wood samples taken from ten latitudes (37.5° to to 60°N) in western North America, from 279 trees of three diameter classes (76, 152, 228 mm DBH).

The mean permeabilities of the sapwood and heartwood were 0.13 and 0.014 darcy, respectively. Geographical latitude and elevation of trees did not affect permeability. The mean calculated radius of pit pores in the sapwood was 1.5 μm, with median values between 12–13 pit pores per mm^2. There was a fair correlation between water retention in an empirical water-soaking test and axial gas permeability.

The volumetric and radial shrinkages, as well as the ratio of radial to tangential shrinkage, all increased with increasing specific gravity for both varieties. Tree size and latitude also affected shrinkage somewhat, primarily through their effects on specific gravity. The mean ratio of percent volumetric shrinkage to specific gravity was 30.7 ± 2.9% for the two varieties combined.

The moisture sorption study gave adsorption and desorption equilibrium moisture content (EMC) values at 30 C at relative humidities of 34.4, 65.0, and 83.2% for both varieties, on each of 62 test samples, representing the three different tree sizes and nine different latitudes. The mean adsorption–desorption (A/D) ratio was 0.79. The EMCs generally decreased with increasing latitude, with no significant difference between varieties at corresponding latitudes.

Keywords: Permeability, lodgepole pine, latitude, elevation, specific gravity, sapwood, heartwood, shrinkage, moisture, sorption.

INTRODUCTION

This study is part of a decade-long research program by the Intermountain Research Station of the USDA Forest Service to improve the utilization of lodgepole pine (*Pinus contorta*) by providing data on its distribution and on the anatomical, physical, mechanical, and chemical properties of its wood. Details of the field material collected during the summers of 1983–1984 are given in Koch (1987) and in Kim et al. (1989).

The first portion of the study relates to the longitudinal or axial air permeabilities of the heartwood and sapwood of two varieties of *Pinus contorta*, var. *latifolia* and var. *murrayana*, sampled from over most of their geographical ranges. The permeability of wood is a good indicator of its treatability with preservatives and other chemicals used to improve its properties, as well as to convert it into pulp. It was decided to measure axial rather than transverse permeabilities because they are more reliable. Also gas rather than liquid permeabilities were measured for reasons of convenience and consistency, particularly in view of the large number (over 1,000) of individual specimens measured. The specific objectives (Hofmann 1986) were to determine the effects on longitudinal air permeability of tree diameter, latitude, elevation, and botanical variety for both sapwood and heartwood, to estimate the mean diameters and numbers of pores connecting the tracheids where practicable, and to determine if the air permeabilities are related to the rate of penetration of liquid water into the wood.

The second portion is concerned with shrinkage from the fully water-soaked (after having been air-dried) to the oven-dry condition. Shrinkages in the tangential, radial, and longitudinal or axial directions were measured. The research (Wiedenbeck 1988) was designed to detect the effect of tree latitude, elevation, and diameter on shrinkage in these three orthotropic directions. Certain relationships between these shrinkages and individual wood parameters such as specific gravity and radial location in the tree stem were also explored.

In the third portion, adsorption and desorption EMCs at 30 C were measured on groups of the same specimens used for shrinkage studies, at each of three different relative humidities, 34.4, 65.0, and 83.2%. This study was more limited in scope, in that specimens from individual trees were not measured, but were pooled such that there was a single pooled test specimen for all trees of a given latitude and diameter. Heartwood and sapwood were also pooled.

LITERATURE REVIEW

Air permeability

Darcy's law for the flow of compressible fluids (i.e., gases) through a permeable porous material, such as wood, may be expressed as

$$K_g = QPL(A\bar{P}\Delta P) \quad (1)$$

where K_g is the superficial gaseous permeability, Q the volume of air per unit time measured at the pressure P at which Q is measured through the wood specimen under steady-state conditions, L and A are the length and cross-sectional area of the specimen, and $\bar{P}$ and ΔP are the mean pressure in, and the pressure drop across, the specimen, respectively. The magnitude of K_g varies with the viscosity η of the gas used. The specific gaseous permeability K_{gd} in darcys is obtained by multiplying K_g and η (Siau 1984). Thus

$$K_{gd} = K_g(\eta) \quad (2)$$

Equations (1) and (2) are derived from the assumption that gas flow is viscous or laminar. Such is not the case for gas flow through pores sufficiently small that they are in the same order of magnitude as the mean free path or mean distance between collisions of individual gas molecules. In this case the measured or superficial permeability K_g consists of two components, the true permeability K, and a second pressure-dependent component known as slip flow. These are related by the equation (Siau 1984)

$$K_{gd} = K(1 + b/\bar{P}) \quad (3)$$

where K_{gd} is the measured gas permeability, K is the true permeability, b a constant and $\bar{P}$ the mean gas pressure in the sample. Thus Eq. (3) predicts a linear relationship between the measured gas permeability and $1/\bar{P}$, the intercept of which gives the true permeability K. The mean or effective radius r (micrometers) of the pores can be obtained from the slope bK, using the relation

$$r = 4(10^4)(K/bK) \tag{4}$$

when air at 20 C is used as the gas, and P is the mean gas pressure in Pa.

An estimate of n, the number of pit pores per unit cross-sectional area of the wood, can also be calculated from air permeability measurements, by the use of the equation

$$n = 8\eta K_p/\pi r^4) \tag{5}$$

where K_p is obtained by multiplying K by a number related to the pit-pore membrane thickness, the amount of tracheid overlap and tracheid length (Siau 1984).

A number of factors have been shown to affect the permeability of softwoods (Comstock 1970). These include: sapwood-heartwood differences, moisture content, growth rate, geographic factors, specific gravity, and variations among trees.

A number of different experimental techniques have been used to measure the permeability of wood. These fall into two general categories, liquid permeability techniques and gaseous techniques. Gas permeability measurements are more convenient than liquid measurements, provided they are adjusted for the factors given in Eqs. (1) to (3). A modification of a method proposed by Petty and Preston (1969) was used in this study.

Shrinkage

Normal shrinkage, associated with loss of bound or hygroscopic water from the cell wall, is often a linear function of the moisture loss over most of the moisture range below M_f. Several primary factors have been shown to affect shrinkage in normal wood. These include wood density or specific gravity, extractive content, differences between heartwood and sapwood, earlywood and latewood, and juvenile and mature wood. Other factors, including growth rate or ring width, radial position in the tree and tracheid length, are generally interrelated with the primary factors noted above. Detailed discussions of these factors are given in Choong (1969a), Koch (1972), Boyd (1977), and Skaar (1988).

Sorption isotherms

The mechanisms of moisture sorption and moisture isotherms are discussed in Stamm (1964), Siau (1984), and Skaar (1988). Specific isotherms related to this study are given under results and discussion.

MATERIAL AND PROCEDURES

All of the material came from short (150–200-mm) bolts taken from a height about 10% of the distance from the stump to the top of the tree. One air-dry bolt from each of the 279 trees of lodgepole pine, *Pinus contorta* (243 from var. *latifolia* and 36 from var. *murrayana*) was supplied by the Intermountain Research Station of the USDA Forest Service (Koch 1987).

The trees of var. *latifolia* had been sampled from nine different northern latitudes throughout its range as follows, 40, 42.5, 45, 47.5, 50, 52.5, 55, 57.5, and 60 degrees. At each latitude, trees were sampled from each of three elevations, designated as low, medium, and high. Three different trees were sampled for each of the three nominal diameters, 3, 6, and 9 inches, or 76, 152, and 228 mm, for a total of 243 trees.

The trees of var. *murrayana* were sampled from only four northern latitudes, 37.5, 40, 42.5, and 45 degrees, for a single elevation only, and with 3 replicates of each of the three diameters, for a total of 36 trees.

Air permeability

One end of each bolt was first trimmed to remove the end-coating applied to reduce the rate of moisture change after initial air drying. A single round disk, each of the bolt-diameter, and of thickness ranging from 9 to 17 mm, was cut from the trimmed end of each bolt. Four dowels were removed from each disk, using a 9.5-mm plugcutter, two from opposite sides of the sapwood, and two from opposite sides of the heartwood, sapwood and heartwood distinguished by color differences. Thus there was a total of 972 permeability samples of var. *latifolia* and 144 of var. *murrayana.*

For the 76-mm disks, the sapwood dowels were removed from the outermost portion of the disk and the heartwood dowels from as close as practicable to the pith. It was not possible to completely exclude heartwood from sapwood dowels in some cases for these disks, nor sapwood from heartwood, because of the small size and variable widths of sapwood. For the 152-mm disks, sapwood dowels were taken 10 mm from the outer edge and heartwood dowels 10 mm from the pith. The 228-mm disks were sampled similarly except that the respective distances were 20 rather than 10 mm. Each dowel specimen was microtomed on both ends to free it from loose fibers so as to reduce blockage of the lumens on the dowel ends (Choong et al. 1975).

Two different variations of the gas permeability apparatus described by Petty and Preston (1969) were used in this study, one (sapwood apparatus) for specimens with permeabilities above 0.01 darcy, generally sapwood, and the second (heartwood apparatus) for specimens with lower permeability, generally heartwood.

Both sets of apparatus were similar (Fig. 1) in that a microflowmeter (A) was used to measure the air flow rate through the test specimen (G). The air filter (I) removed particulate matter from the air which then passed through the specimen at a rate controlled manually by a needle valve (D). The air next passed through a Cartesian manostat (F) which regulated the low pressure provided by the vacuum pump (E).

The essential difference in the two measurement systems was in the magnitude and method of measuring the pressure differential ΔP. For the permeable sapwood specimens, ΔP was measured directly with a differential mercury manometer (C), whereas for the typical impermeable heartwood specimens, it was calculated from the difference between the absolute pressure measured by the mercury manometers on the high (B) and low (C′) ends of the specimen (G).

The specimen holder (G) consisted of thick-walled rubber tubing of 9.5-mm inside diameter. The sample was inserted into the center of the tubing and securely clamped so as to prevent air leaks around the edge. Trial measurements were