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The Fiber Saturation Point of Various Morphological Subdivisions of Douglas-Fir and Aspen Wood

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Summary

In both Douglas-fir and aspen wood, the fiber saturation point of early wood is greater than that of late wood, solvent extraction lowers the fiber saturation point, and the fiber saturation point for reaction wood is less than that for whole wood.

During the course of a recent series of investigations in this laboratory [Ahlgren 1970; Fergus, Goring 1970; Fergus, Procter, Scott, Goring 1970; Wood, Goring 1971] measurements of the fiber saturation points (FSP) of different wood species were made by the "solute exclusion technique" [Feist, Tarkow 1967; Stone, Scallan 1967]. Interesting trends apparent in the initial results provided the motivation to study two species in more detail, namely Douglas-fir and aspen. This study included examinations of early wood, late wood and reaction wood. In addition, the effect of solvent extraction was investigated.

Solute exclusion measurements were made as previously described [Ahlgren 1970; Stone, Scallan 1967] on 40 – 60 mesh meal prepared by Wiley milling of air-dried wood. Experiments with spruce showed that identical FSP values were obtained for 3 mm thick shavings, 20 – 40 mesh meal, 40 – 60 mesh meal, < 60 mesh meal, and 100 μm microtome cross sections. Thus specimen size was not a factor in the determination of the FSP. Extraction was with benzene/ethanol and after extraction, samples were solvent exchanged to the water-swollen state for the solute exclusion measurement. The results of the FSP measurements are summarized in Table 1. The following features are common to both woods.

The FSP of early wood is greater than that of latewood. This is in agreement with results reported by other workers [Feist, Tarkow 1967; Smith, Miller 1964; Wellwood, Ifju, Wilson 1965].

Solvent extraction (ethanol/benzene) lowers the FSP and appears to remove the difference between early wood and late wood.

The FSP for reaction wood is less than that for whole wood.

The most unexpected result was the lowering of the FSP by solvent extraction. Removal of extractives would be expected to create pore space in the cell wall. Apparently, however, extracted wood does not swell as much as unextracted wood.

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Table 1. Lignin content and fiber saturation points for various wood subdivisions with different pre-extraction

		Lignin content (% on wood)*	Fiber saturation point (cm^3/g)	
			Water extr.	Solvent extr.
Douglas-fir (*Pseudotsuga menziesii*)	whole wood	27.9	0.56	0.46
	early wood	31.6	0.62	0.46
	late wood	26.3	0.54	0.46
	compression wood	40.4	—	0.39
Aspen (*Populus tremuloides*)	whole wood	21.6	0.81	0.66
	early wood	21.6	0.82	0.66
	late wood	20.5	0.74	0.66
	tension wood	17.3	—	0.55

* including acid soluble lignin.

Table 2. UV-absorbance for various tissue Regions of Douglas-fir early wood extracted by water or solvent. Average of six sections for each type of extraction

Morphological region	UV-absorbance (280 nm) Water extr.	Solvent extr.
Middle lamella, cell corner	0.452	0.482
Middle lamella, radial	0.303	0.336
Middle lamella, tangential	0.291	0.315
Secondary wall	0.150	0.155

The reality of this effect was supported by measurements of the UV-absorbance at 280 nm of microtome sections immersed in a glycerol/water medium. The results, presented in Table 2, indicate a greater absorbance for the extracted sample in all morphological regions. Such a trend would be expected if the extracted material swells less than the unextracted. A possible explanation for the effect is that, in unextracted wood, hydrophobic material is localized in small volumes at high concentration. Extraction may remove most of this material but, at the same time, may cause a small residual to be dispersed over the internal surface of the wood. This will have the effect of making the wood more hydrophobic and thus reducing the swelling tendency.

The higher FSP for early wood shown in Table 1 may result from the larger quantity of amorphous material that is present in early wood compared to late wood. The low FSP figures for reaction wood may be due to the denser and more rigid structure of fibers that have grown under stress.

The present measurements of the FSP were made with the samples fully immersed in water. On the other hand techniques which required extrapolation to 100% RH of trends observed at lower relative humidities have yielded results in contrast to those in Table 1. Boutelje [1962] has reported that for Scots pine the FSP of late wood is greater than that of early wood, and Choong [1969] found that solvent extraction increases the FSP of southern pines.

From Table 1 it is seen that the FSP for aspen is 1.4 times that of Douglas-fir. However, one is cautioned against the general conclusion that hardwoods have a higher FSP than softwoods. Values obtained for black spruce (0.48 cm^3/g) and white birch (0.49 cm^3/g) were similar to the FSP of extracted Douglas-fir (0.46 cm^3/g) indicating that these three woods all swell less than aspen.

The validity of the FSP data obtained by the solute exclusion technique was supported by a microscopic determination of the FSP of Douglas-fir late wood. The swollen tissue volume was estimated, as previously described, from UV-photomicrographs of late wood. The bulk density of the water-swollen wood was measured pycnometrically. The FSP was then calculated from:

$$\text{FSP} = \frac{\text{volume of wet wood} \times \text{volume fraction of cell wall}}{\text{weight of dry wood}} - \text{Specific volume of dry cell wall substance}$$

The volume fraction of cell wall was determined to be 0.825 and the specific volume of dry cell wall substance was taken to be 0.67 cm^3/g. The FSP so obtained was 0.53 cm^3/g. This is close to a figure of 0.51 cm^3/g similarly determined by Wellwood, Ifju and Wilson [1965] and in reasonable agreement with the FSP values for Douglas-fir late wood by the solute exclusion technique (Table 1).

Considerable confusion has arisen from early attempts to compare the tissue density of wood determined microscopically with densities determined by other methods. The details of this controversy have been reviewed and to some extent reconciled in a recent paper by Wangaard [1969]. In the present investigation the densities of the swollen wood cell walls determined by the solute exclusion technique and the microscopic method are 0.88 and 0.83 cm^3/g respectively. This good agreement supports the validity of both methods and is probably due to two important precautions in the present work.

(1) Both microscopy and solute exclusion were carried out on wood in a well-defined swollen state.

(2) The sections used in microscopy were thin enough (0.5 μm) to avoid major optical artifacts [Scott, Procter, Fergus and Goring 1969].

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