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Fluid Self-Diffusion in Scots Pine Sapwood and Silica Wood Replicas

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1 Introduction

The study of self-diffusion in biological tissue is growing into an important area of research.[1] Scots pine sapwood consists of more than 90 % tracheid cells. These cells have hollow cores called lumens. Tracheid cells are of average length just below 3 mm, while the cross sectional diameter varies from 20 to 30 μm. The wood matrix thus resembles an anisotropic structure with two-dimensional symmetry. The cross sectional shape of the cells is either square-like or circle-like. For Scots pine the shape tends to be more square-like. Diffusion of liquids confined in the cell lumens is thus free in the direction parallel to the cell lengths, and affected by the cell wall restriction orthogonal to the cell lengths as observed on the PFG-NMR time scale. This is visualised in Figure 1.

In this work PFG-NMR has been utilised to observe diffusion coefficients of liquids confined in Scots pine sapwood and silica replicas of the same wood. The replicas were synthesised according to the method of Shin et al.[2], and they resemble the original wood's structure positively.

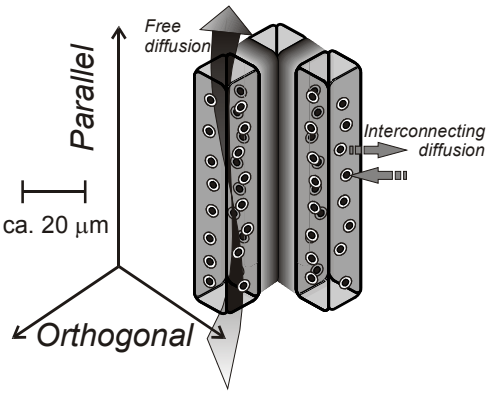

Figure 1. Principal structure of tracheid cells. The two anisotropic self-diffusion paths are shown.

2 Methods

Plugs of 8 mm diameter from Scots pine greenwood were created using a hollow bore. They were saturated with water or toluene using gentle vacuum penetration. Measurements on these plugs were done at 30 °C on a Maran Ultra bench top PFG-NMR instrument running at 23 MHz. The pulse sequence used was a bipolar sequence optimised for proper performance in the presence of significant eddy current transients and unstable mains.

The wood replica silica monoliths were saturated with water using gentle vacuum penetration and inserted into 5 mm NMR tubes. PFG-NMR experiments were then performed at 30 °C on a Bruker DMX-200 using a classic stimulated echo sequence with the cell replica lengths either parallel or orthogonal to the gradient field.

3 Results and Discussion

Mean diffusion coefficients of liquid confined in the tracheid cells were extracted from the echo decays acquainted during the PFG-NMR experiments. Diffusion parallel to the cell lengths was as expected free, while the observed diffusion coefficients from diffusion orthogonal to the cell lengths clearly was decreasing as a function of diffusion time. The latter effect was unambiguously ascribed to diffusion obstruction by the cell walls. Short time diffusion coefficients gave surface-to-volume ratios indicating cross sectional cell structures close to being square-like. This information was in close agreement with long time diffusion coefficients which depend directly on the cell lumen diameter and cell wall permeability. The cell wall permeability was found to be very low using the relation between the intrinsic self-diffusion coefficient and the effective long time diffusion coefficient. Short time and long time diffusion data was successfully interpolated using a Padé-approximant.

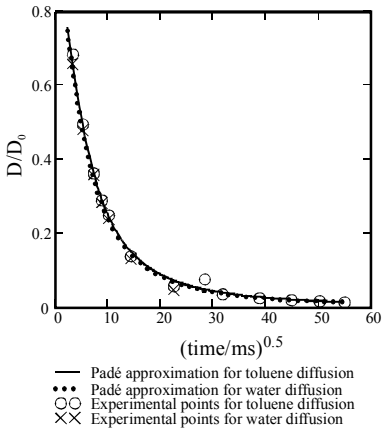

Figure 2. Experimental diffusion coefficients of toluene and water in sapwood. The lines are fits to Padé-approximants.

3 Conclusions

The observed diffusion coefficients were used to extract information on the cellular geometry of Scots pine sapwood and its silica replica. Interpolation of the diffusion coefficients using Padé-approximants was a good basis for interpreting surface-to-volume ratios, cell lumen diameters, and cell wall permeability. There was good consistency between short time and long time diffusion.

References

1. Sen, P.N., *Diffusion and tissue microstructure.* Journal of Physics-Condensed Matter, 2004. **16**(44): p. S5213-S5220.
2. Shin, Y., et al. *Control of hierarchically ordered positive and negative replicas of wood cellular structures by surfactant-directed sol-gel mineralization*. in *Organic/Inorganic Hybrid Materials - 2002*. 2002. San Francisco, California, U.S.A.: Materials Research Society.