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# Understanding Water Transfers in Hygroscopic Fiber Stacks: Bound Water vs Vapor Transport

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## Résumé

Cellulose and fibers, as the primary constituents of textiles, paper and bio-based building materials, play a crucial role in our daily lives by influencing the comfort and functionality of clothing and building, as well as paper products due to their hygroscopic nature. In addition, vapor diffusion is commonly believed to drive water transfers. However, the water absorbed (inside the cell walls, forming nanopores between cellulose microfibrils), known as bound water in this study, and which can exchange with vapor via sorption-desorption processes, can account for up to 30% of the dry mass of cellulose fiber, but the diffusion of bound water remains poorly understood. To optimize the design and manufacturing processes of these materials, a comprehensive understanding of water transfers within cellulose is necessary. However, quantitative investigation of this phenomenon is challenging due to the limited availability of simple and effective methods for measuring water distribution within the materials.

This study presents an innovative experimental technique that combines Magnetic Resonance Imaging (MRI) and macroscopic measurements to simultaneously monitor water transfers in cellulose samples with varying porosities. By employing Nuclear Magnetic Resonance (NMR), the bound water diffusion was measured by drying cellulose fibers with a pore network filled with olive oil to prevent vapor diffusion. Surprisingly, our findings indicate a continuous diffusion of bound water through the cellulosic solid skeleton, allowing for the direct measurement of its diffusion coefficient.

Subsequently, specific tests were conducted under controlled boundary conditions (relative humidity) to estimate the vapor diffusion coefficient using macroscopic measurements. The constant mass flux, encompassing both vapor and bound water transfers, was determined once a steady state was reached. By subtracting the bound water diffusion flux from the overall diffusion flux, the vapor diffusion flux and its corresponding diffusion coefficient were obtained.

Furthermore, a simple diffusion model based on the conservation of water-vapor mass was employed to describe the transient water transfer process, incorporating both fluxes. By comparing the model predictions, utilizing the obtained diffusion coefficients, with the saturation profiles measured by MRI at different time intervals, we achieved excellent agreement across a broad range of sample porosities.

This original experimental protocol holds great potential for characterizing fabric properties and offers valuable insights for the textiles and paper manufacturing industries. By mastering

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the mechanisms of water transfers, advancements can be made in enhancing comfort, energy efficiency, and functional properties of textiles and paper products and bio-based building materials.