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Vapor and bound water transport in textiles and paper: observation by MRI and modelling

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Textiles and paper are ubiquitous in our daily lives. The comfort of clothing is essentially determined by the hygrothermal behavior of textiles, as fabric sorption clothing can play a significant role in the moisture transport and heat loss caused by sweating. For paper production, the extraction of the final bound water fraction consumes large amounts of energy, and the majority of the functional properties of paper are developed during this stage. To assist with the correct design and manufacture of textiles and paper, we must master the mechanisms of water transfers in them.
However, it is difficult to quantitatively investigate this phenomenon due to the lack of simple measurements of water distribution inside the material. One of the major complexities in the process investigation lies in the fact that for these hygroscopic materials, water molecules can be absorbed by the cellulose fibers from vapor in the surrounding air. Water transfers can occur as vapor diffusion in pore net-work and/or bound water diffusion in cellulosic fiber skeleton, with additional adsorption and desorption in such materials. Standard measurements rely on monitoring global mass variations of the sample under more or less controlled humidity boundary condition, but hardly distinguish the bound water diffusion from vapor diffusion.
Here, we have developed an original experimental technique based on Magnetic Resonance Imaging (MRI) and Macroscopic measurement to simultaneously monitor the water transfers in pure cellulose samples with various porosities. Firstly, with the help of Nuclear Magnetic Resonance (NMR), we have measured the bound water diffusion by drying a stack of cellulose fibers whose pore network was filled with olive oil, which blocks vapor diffusion. Surprisingly, it appears that there is in general a continuity of bound water diffusion through the cellulosic solid skeleton, and we can directly measure the diffusion coefficient of bound water. In a second step, we have implemented specific tests under fully controlled boundary conditions (in terms of relative humidity) to estimate the vapor diffusion coefficient. The mass transport is deduced from the constant mass flux including vapor and bound water transfers through the sample once the steady state is reached. By subtracting the bound water diffusion flux from the global diffusion flux, we obtain the vapor diffusion flux and the corresponding diffusion coefficient.
Finally, the predictions of a simple diffusion model relying on the conservation of water-vapor mass to fully describe the transient water transfer process with both fluxes, and using these diffusion coefficients, are compared with saturation profiles at different times measured by MRI. The excellent agreement over a wide range of sample porosities validates our model and the obtained diffusion coefficients. We expect that this original experimental protocol opens a way for the characterization of fabric properties and that our results to be broadly useful for the textiles and paper manufacture.

Participation

In-Person

References

Ma, Xiaoyan, et al. "Vapor-sorption coupled diffusion in cellulose fiber pile revealed by magnetic resonance imaging." Physical Review Applied 17.2 (2022): 024048.

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