Wicking and swelling in cellulose sponges

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Hydrophilic porous media absorb water, and the wicking velocity is determined based on the balance of capillary and viscous forces. Here we consider a porous material that swells with wicking, such as cellulose (kitchen) sponges, which have defied theoretical understanding until now. Fluid flows in deformable porous media, such as soils and hydrogels, are classically described based on the theories of Darcy and poroelasticity, where the expansion of media arises due to increased pore pressure. However, the situation is qualitatively different in cellulosic porous materials like sponges because the pore expansion is driven by wetting of the surrounding cellulose walls rather than by increase of the internal pore pressure. Our experiments uncover a power law of the wicking height versus time distinct from that for non-swelling materials. The observation using the environmental scanning electron microscopy (ESEM) reveals the coalescence of microscale wall pores with wetting, which allows us to build a mathematical model for pore size evolution and the consequent wicking dynamics. Our study sheds light on the physics of water absorption in hygroscopically responsive porous materials, which have far more implications than everyday activities (e.g. cleaning, writing and painting) carried out with cellulosic materials (paper and sponge), including absorbent hygiene products, biomedical cell cultures, building safety, cooking, and soft robotics.