Master thesis

Water wicking in paper-based materials: Why temperature rises?

Did you know that if you throw water in a paper towel the temperature at the wetting front during water wicking increases? Depending on the paper material, the temperature rise can reach 10°C, or even more! Spontaneous imbibition (i.e. capillary driven flow against gravity) is encountered in many natural and industrial porous media. Since the introduction of Lucas-Washburn equation in 1908, which demonstrated that the propagation of the mean advancing front in a capillary tube is proportional to the square root of time ($z \sim \sqrt{t}$), the phenomenon has been put into scientific scrutiny in order to understand the mechanisms that affect spontaneous imbibition dynamics. Capillary driven flows are, however, a complex liquid transport process that also involve strong adsorptive interactions at the molecular scale. In case of a fibrous porous medium, this is associated with the available cellulose chains which have their free hydroxyl (OH^-) groups in an equatorial orientation in the glucopyranose rings, and hence, readily available for bonding.

Despite the wealth literature on imbibition kinetics in cellulosic materials, the thermal field during an isothermal imbibition process has been completely ignored. However, it was recently showed that the wetting of the fibers at the liquid front results in a temporary, but significant thermal spike that cannot be neglected from the process (see Figure). This means that “isothermal” spontaneous imbibition is not really isothermal as generally considered.

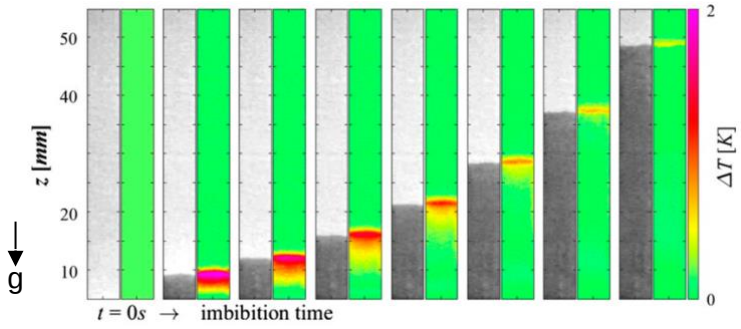

Figure: Optical (left) and thermal (right) imaging of water capillary driven flow in a paper substrate. The temperature at the wetting front increases even if the water and the paper are initially at the same temperature. What is the source of this thermal energy? Image from *Journal of Colloid and Interface Science, 2017, 504, 751–757.*

What is the source of this thermal energy? Can we quantify and use it in emerging technologies? How inaccurate are the numerous imbibition models that have been developed for decades? Apparently, the fundamental mechanisms of spontaneous imbibition (thermo-)dynamics are far from being well understood and the related physico-chemical processes have not been yet quantified. Here, thermodynamics of spontaneous imbibition in cellulosic materials will be explored for a range of imbibed liquids and paper-based materials. More specifically, the paper fibers will be molecularly modified by plasma treatment (O_2, H_2, etc.) examining the influence of plasma nature and activation time on the thermodynamic imbibition outcome. Experiments will be contacted with infrared thermography (IR camera), and the obtained results will be analyzed to develop the first imbibition model in the literature that incorporates the exothermic character of the process.

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