Drying of a water-filled channel within an artificial leaf

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1. Introduction

The transport of sap in the vascular network of leaves is driven by evaporation at the surface of leaves, and it has been shown [1] that a relevant analogous physical system is a network of liquid-filled channels in a permeable polymer. As such, microfluidic systems made of PDMS are particularly suited. In our study, to understand how a leaf is susceptible to dry out if its supply of sap is stopped, we investigate the drying of water-filled channels, looking at the entry of air.

2. Experiments and results

We create a series of isolated channels of different widths in PDMS, using standard microfluidic techniques. All channels are open at one end and closed at the other hand. They are initially filled with water, then placed under a dry atmosphere. They progressively dry as a meniscus separating the still liquid-filled part and the newly dried part advances in the channel (Fig. 1). We record the motion of the meniscus with a camera, thereby measuring the rate of evaporation as a function of time. This rate decreases as the channel progressively dries, but surprisingly does not vanish at the moment where liquid water disappears in the channel. We rationalize our measurements by a model combining two contributions: (i) direct diffusion of water to the atmosphere through the thin layer of PDMS; (ii) diffusion between newly dried parts containing humid air and the dry atmosphere. In particular, we derive an asymptotic analytical prediction for the evaporation rate due to this latter process, using the fact that diffusivity of water is much lower in PDMS than in air. The data and the model are found to be in excellent agreement, thereby providing a good physical description for the drying-up of leaves. Preliminary results in more complex networks will also be presented.

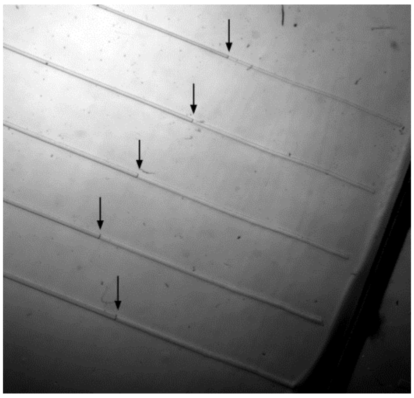

Figure 1: Drying channels (from top to bottom, 60, 80, 100, 120 and 140 μm in width). Arrows show the menisci.

References

[1] Noblin, Mahadevan, Coomaraswamy, Weitz, Holbrook & Zwieniecki, Optimal vein density in artificial and real leaves, Proc. Natl. Acad. Sci., 105, 9140-9144 (2008).