Drying of colloïdal suspension

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Summary

We address the problem of the drying of a colloïdal suspension in the vicinity of the contact line. Whereas most of the experiments reported so far were realized with droplets [1] for which the receding motion of the contact line is set only by evaporation, we designed an experimental set-up allowing to decouple the one from the other. More precisely, a capillary rise is achieved in a Hele-Shaw cell with a controlled air flow over the meniscus. We study systematically the influence of velocity on the thickness of the deposit left after drying.

Keywords: Evaporation, Suspensions, Contact line, Deposition

1. Introduction

The drying of a suspension is a common technique in order to realize the coating or covering of a solid surface. In industrial applications it is desirable to prevent as much as possible instabilities such as Marangoni effect [2]. However, as this process is governed by the competition between hydrodynamics, heat and mass transfer, it remains difficult to fully understand. If one considers the evaporation of a suspension droplet, it is known since Deegan [3] that the large value of evaporation rate in the vicinity of the contact line results in the accumulation of solute near the contact line (that may lead to pinning). The consequences of this phenomena on coating has been addressed by Rio [4] and Berteloot [5]. In a recent study [6], we have observed the formation of stripes network in the deposition pattern similar to the pattern observed by Adachi [7] with droplets. Moreover, we were able to evaluate the pinning force responsible for the slip-stick at the contact line. In the following, we extend this work by performing a systematic analysis of the thickness of deposit as a function of the contact line velocity.

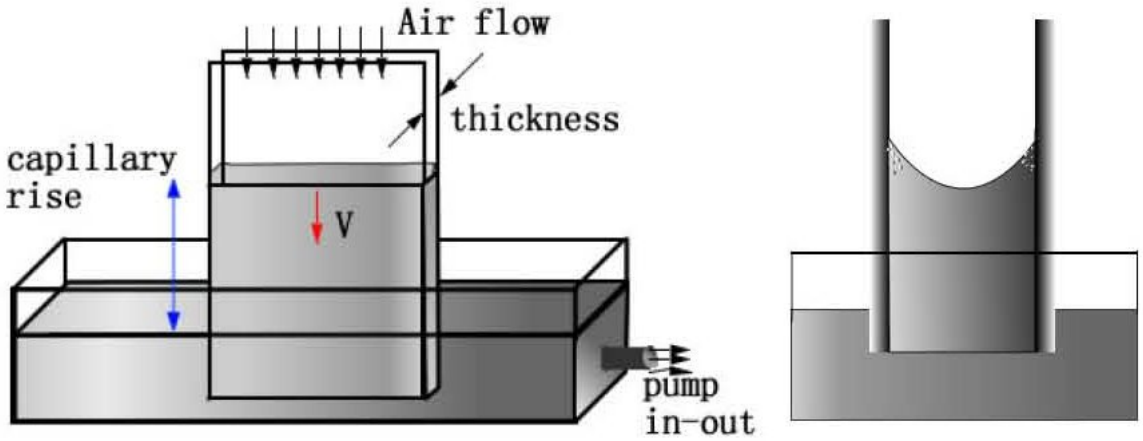

Figure 1: Scheme of the experimental setup. Left: front-view; Right: side-view of the system.

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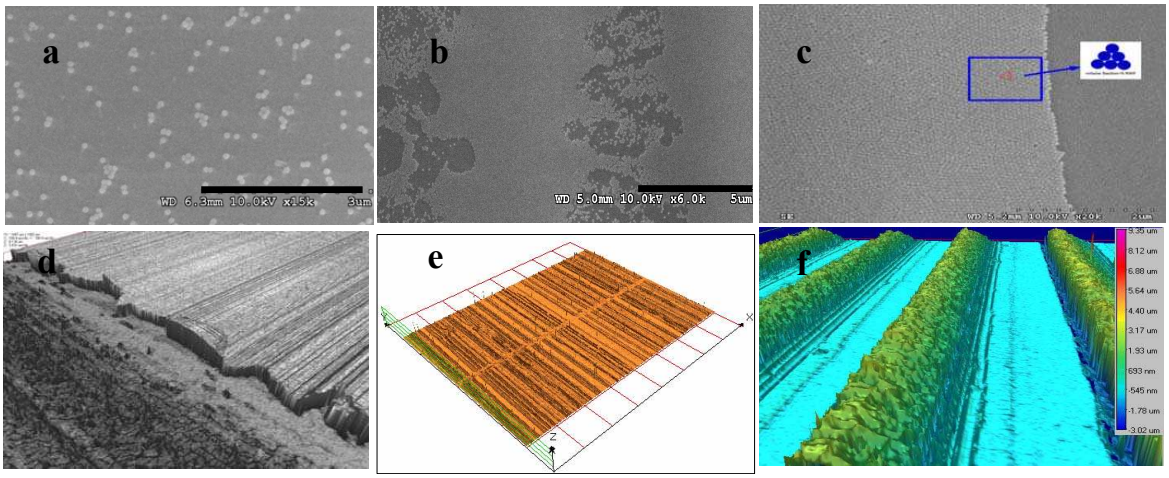

Figure 2: Scanning electron microscopy images of the deposition a. V=572μm/s, ϕ=0.47% b. V=29.4μm/s, ϕ=0.47% c. Zoom-in of image b. for sketch of typical closed-packed particle aggregation. Optical profile images of deposition pattern d. V=1μm/s, ϕ=1.4% e. V=4.5μm/s, ϕ=0.47% f. V=5 μm/s, ϕ=4.9%.

2. Experimental set-up

A capillary rise is achieved between two glass plates separated by a 1mm gap. The plates are partially immersed in a reservoir filled with a water suspension of silica spheres of diameter 74nm. The schematic setup is represented in Fig. 1. A mixture of hydrogen peroxide and sulfuric acid is used for cleaning the plates. In order to control the evaporation flux, and for the sake of uniformity along the direction parallel to the plate, a vertical air flow is imposed between the two plates, humidity and temperature being controlled by a standard PID system. Depending on the experimental conditions (air flow, temperature, humidity), the evaporation rate $v_{\rm evap}$ can be varied from 1 μm/s to 40 μm/s. The average velocity of the contact line V is imposed by pumping out the liquid from the reservoir thanks to a push-pull syringe. The velocity V can be varied from 0.2 μm/s to 1 cm/s. CCD camera is employed to record the movement of the contact line. The main advantages of the present experimental set-up are twofold : the evaporation rate and the contact line velocity can be imposed separately, and the ratio $v_{\rm evap}/V$ is allowed to vary on a wide range (up to 5 orders of magnitude). The effect of particle volume fraction ϕ has been investigated too. After complete drying of the deposit, optical profilometer (Fogale Microsurf 3D) and scanning electron microscopy (JEOL JSM-5200) are used for pattern characterization and mean thickness measurement.

At high velocity, we observe no stick-slip and randomly dispersed particles are left on the substrate (Fig. 2a). When decreasing the velocity, we observe the formation of a discontinuous mono-layer. The particles deposited onto the glass plate are structured in typical close-packed organization. (Fig. 2b-2c). At smaller velocities, a wavy multi-layer surface appears, then a strong patterning occurs (see Fig. 2d to 2f). The contact line movement in this case is not continuous, but exhibits a stick-slip. The characteristic velocities below which the stick-slip is observed increase with the particle concentration. It can be shown that the pinning force that sticks the contact line has a geometrical origin [6]. The full characterization of this transition is under study.

3. Deposit mean thickness

The mean thickness of multi-layer coating is measured by optical profilometry (the reference is obtained by scratching the coating with a steel needle, see Fig. 2d), while the mean thickness of discontinuous monolayer is obtained by measuring the coverage ratio from SEM images. Figure 3 shows results corresponding to $v_{\rm evap} \approx 5$ μm/s. A master curve is obtained when dividing the deposit mean thickness by the particle volume fraction. At

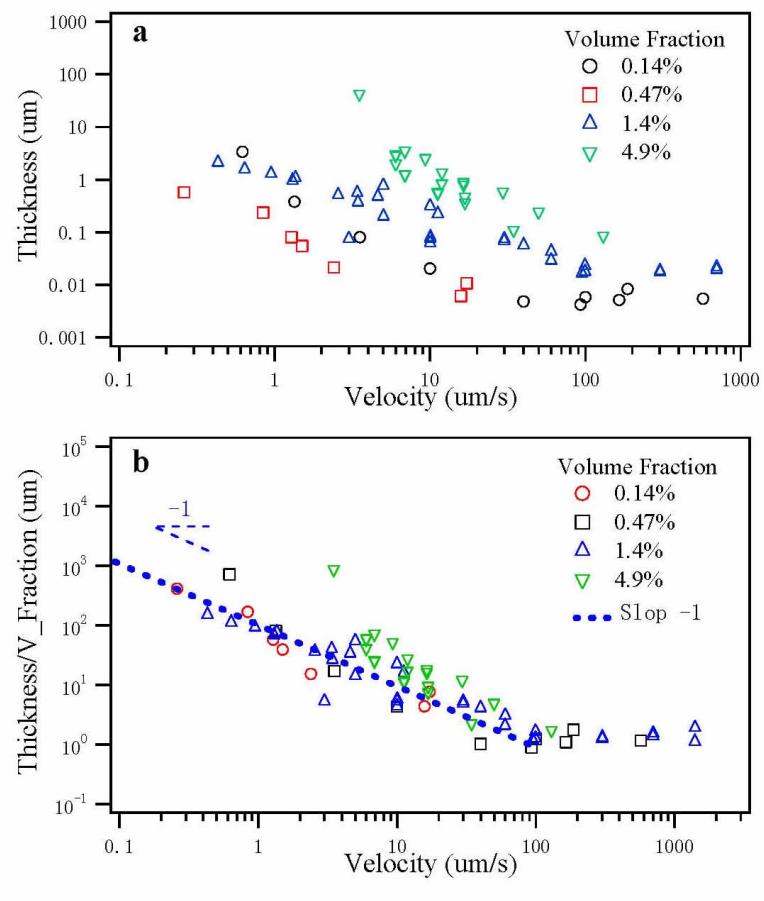

Figure 3: a. Mean thickness as a function of velocity for various particle volume fraction. b. Mean thickness over particle volume fraction ratio as a function of velocity.

low contact line velocity ($V \lesssim 100$ μm/s), coating mean thickness exhibits power law dependence on velocity

$$\frac{e}{\phi} \approx \frac{100\ \mu\mathrm{m}^2/\mathrm{s}}{V}$$

while a plateau $e/\phi \approx 1$ μm is reached at high velocity ($V \gtrsim 100$ μm/s).

The figure 3 clearly shows two regimes. At low velocity, the fluid flow should be mainly driven by evaporation, while the velocity imposed by the contact line should dominate at high velocity. Detailed modelization of the flow is currently under study.

Acknowledgements

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