THE EVAPORATION-DRIVEN FLOW IN A 2D MENISCUS ON A MOVING SUBSTRATE

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Summary A 2D model has been constructed to simulate the flow in a dip-coating like system. Concentration distribution and velocity field can be obtained by solving Stokes equation and Fick's law. Numerical results show consistent with our previous experimental results.

Self-assembly of complex fluids (colloidal suspensions or polymer solutions) induced by solvent evaporation in a Hele-Shaw cell has been experimentally studied in our past reports [1-2]. The Hele-Shaw cell (shown in figure1) made of two paralleled glass plates separated by 1mm spacers is vertically immersed into a reservoir which contains the solution. Due to the 1mm-thin gap, there is a spontaneous capillary rise. The meniscus displacement is controlled by pumping out the solution from the reservoir. In our experiment, the contact line of the meniscus is thus always receding. The receding velocity V can be controlled between 0.1µm/sec to 1000 µm/sec. The setup is put inside a close chamber, where temperature and humidity are regulated by a PID system. For low Capillary numbers, there is a regime dominated by evaporation where the film thickness is proportional to the inverse of the substrate velocity [2].

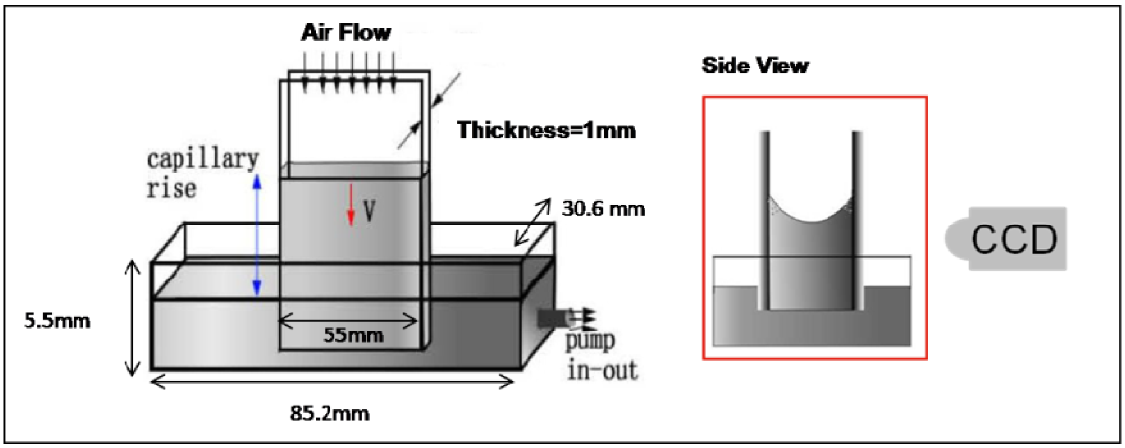

Figure 1. Experimental setup.

A 2D model is developed to simulate our experiment. In the first step presented here, we assume the following simplifying assumptions: isothermal problem, no buoyancy or Marangoni effect. The velocity and concentration fields are thus only induced by the moving substrate and evaporation. The liquid phase flow and concentration gradients are obtained by solving the Stokes equations and Fick's law. At the meniscus free surface, a known but non uniform evaporation flux is imposed. The description for the tip (the contact line point) of the meniscus is achieved by introducing an a priori cut-off where boundary conditions result from a small scale description using lubrication approximation [3]. Coupling the two models requires an iterative procedure to define the boundary conditions, based on a global mass balance for the tip region. COMSOL software is used to solve the equations. The concentration distribution and velocity field are analyzed as a function of several parameters including: the solute bulk volume fraction c_0, the evaporation rate V_{ev}, and the substrate moving velocity V. An example of velocity field is shown in figure 2 for the following parameters: V=10µm/sec, C_0=3% , V_{ev}= 0.4um/sec.

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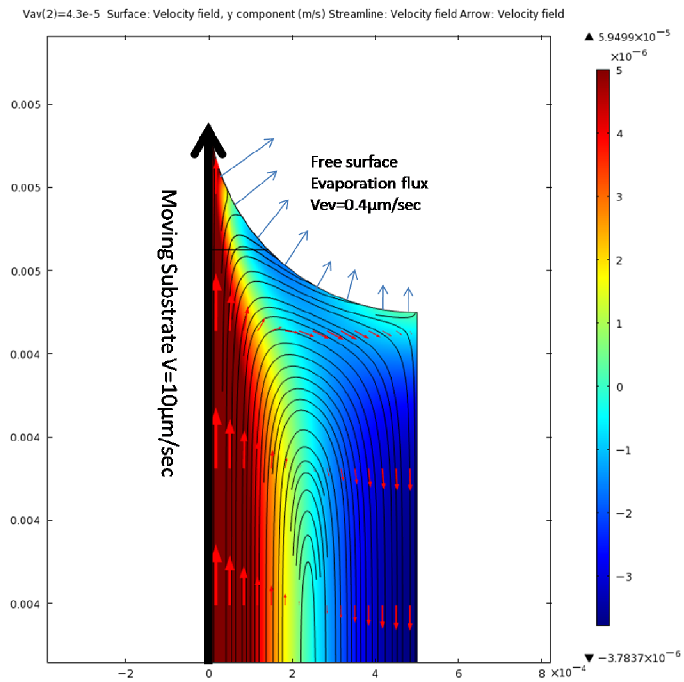

Figure 2. Velocity field distribution from simulation result.

Beside of predicting flow field, the deposition thicknesses $h_{d,}$ can be estimated by solute mass conservation. The thin film thicknesses are compared with our experimental results [2] shown in figure 3. Overall, numerical results are in agreement with experimental results: the film thickness is proportional to the inverse of the substrate velocity except at the largest velocities. Simulations give the right order of magnitude for the dried film thicknesses but overestimate them compared to experimental results. The next step should be to remove some of the simplifying assumptions to go towards a model closer to the experimental configuration.

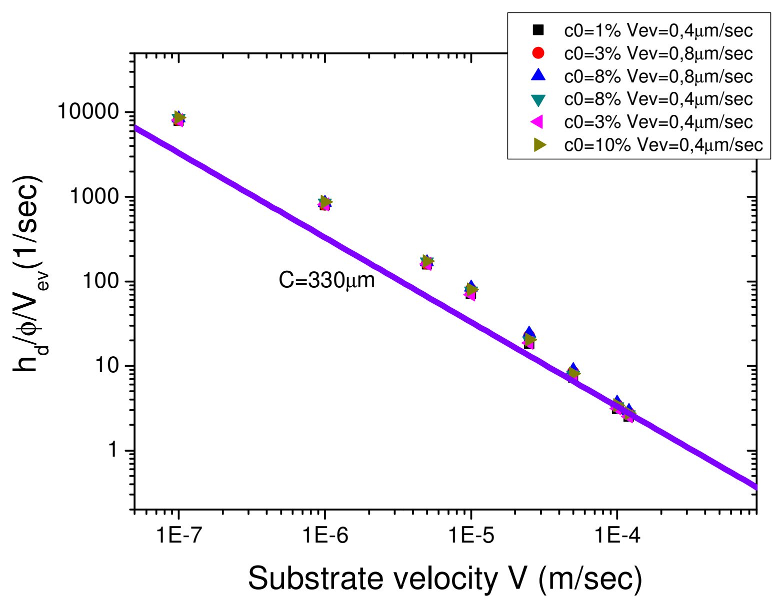

Figure3. Simulation results (spots) compare to experimental fitting (line).

Reference:

[1] G. Jing, H. Bodiguel, F. Doumenc, E. Sultan, B. Guerrier, *Langmuir* 26,4 (2010).

[2] H. Bodiguel, F. Doumenc, B. Guerrier, *Langmuir* 26,13, 10758-10763 (2010)

[3] F. Doumenc, B. Guerrier, *Langmuir* 26,17, 13959-13967 (2010).