Dynamics of a 2D droplet in a Hele-Shaw cell

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Droplet microfluidics is a growing field of research. However, the dynamics of these objects remain misunderstood. Indeed, a question as fundamental as predicting the droplet velocity while pushed by an external fluid at a given velocity (Fig.1) is still not answered [1] [2]. Understanding the dynamics of a droplet requires characterizing the viscous dissipation mechanisms (friction) within the droplet and in the lubrication film. As this dissipation is related to the geometry and to the physicochemical properties of the interface separating the inner phase of the droplet from the outer phase, predicting a droplet velocity requires determining both the lubrication film topography and the boundary condition at the interface.

This work presents a characterization of the dynamics of 2D droplets in a Hele-Shaw cell (Fig. 1), by taking advantage of the double measurement of the lubrication film profile by interference microscopy [3] and of the droplet velocity. We consider fluorinated oil droplets in an aqueous solution containing C_{10}TAB above the CMC (990 mM) and NaCl at 1 M to screen the electrostatic interactions (Fig. 2). Interestingly, in the central axis of droplet migration, the lubrication film is recovered at the front considering a stress-free boundary condition, while the rear meniscus requires a rigid boundary condition. This is the signature that the surfactant surface concentration is not homogeneous along the interface and accumulates at the rear. The measured profile allows extracting the boundary condition at the interface (interfacial velocity and corresponding surface tension gradient). Furthermore, in a transverse direction, the profile displays a vault shape that can be modeled considering a Bretherton [4] like model, involving the normal velocity to the contour of the droplet.

In a second part, it is possible to calculate the dissipation in each part of the lubrication film thanks to the profiles that have been previously described. We present a model that allows to reproduce the droplet velocity without any fitting parameter, by considering the different boundary conditions from the front meniscus to the rear one. We show that the model is very sensitive to the local boundary condition at the interface. This result clearly shows that predicting droplet velocity calls for the knowledge of the local boundary condition at the interface that is likely to be altered by the presence of surfactants.

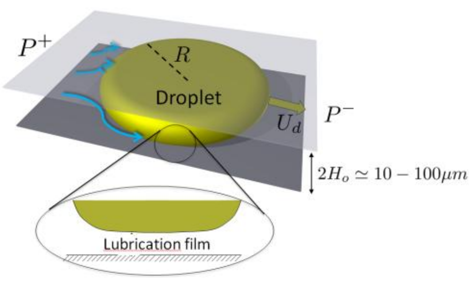

Fig.1 Squeezed droplet in a Hele-Shaw cell

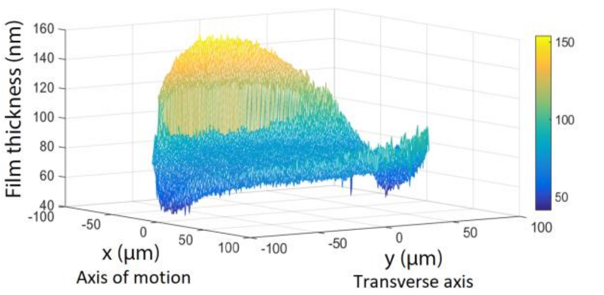

Fig.2 Experimental topography of the lubrication film

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