Theoretical and experimental study of dynamic boundary conditions at surfactant-laden interfaces: dip-coating problem

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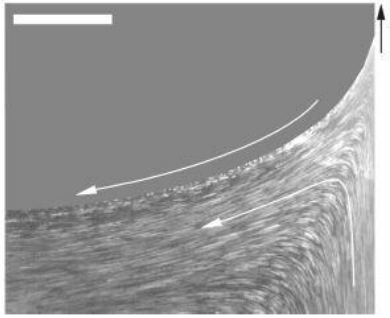
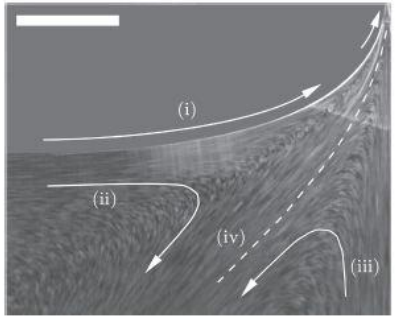
Dip-coating, in which a substrate is withdrawn from a bath, is perhaps the oldest and simplest form of liquid film deposition. The question posed in the original proposal was on resolving the long-standing controversy on surfactant effects in the classical dip-coating (Landau-Levich) problem, namely on the origin of the film thickening effect, which occurs in the presence of surfactants

With the support of ACS PRF, we performed direct flow visualization of the Landau-Levich problem. The results presented in our work suggest that the dip-coating with the soluble ionic surfactant SDS, under the conditions when the transport of surfactant is sorption limited and in the low capillary number regime, has the flow topology that can only be explained with a stagnation point residing in the bulk as shown in Figure 1b and not at the interface as in the clean interface case, cf. Figure 1a.



(a) $c = 0.0$. The small black arrow in the upper right hand corner indicates that the fluid near the substrate is carried into the film deposited on the moving substrate.



(b) $c = 0.5$. The small white arrow in the upper right hand corner indicates that fluid near the surface is swept into the film deposited on the moving substrate.

Figure 1: Flow field patterns in the clean 1(a) and surfactant-laden 1(b) interface cases. The velocity of withdrawal is $U = 1.27\,\mathrm{cm/s}$. Scale bar represents 2 mm.

As opposed to patterns with an interfacial stagnation point, the observed flow fields allow for the increase in film thickness due to the presence of surfactants compared to the clean interface case. Namely, such a flow field allows Marangoni stresses to be the mechanism responsible for the increase in film thickness over that predicted by the Landau-Levich law.