Surfactant spreading on spatially confined thin liquid films

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Injection of surfactant solutions is considered a potential means for extracting more oil from sub-surface oil reservoirs. Non-uniform surfactant distributions at fluid-fluid interfaces give rise to interfacial tension gradients and associated Marangoni stresses, which locally cause flow from regions of lower to regions of higher interfacial tension. Since the confinement effects are of great importance in the porous structure of reservoirs, we study, using both experiments and numerical simulations, surfactant spreading on spatially confined thin liquid films. Figure (a-b) below shows an interference microscope image of a 1.5 mm wide liquid rivulet, upon which a droplet of surfactant is deposited. Subsequently a rim develops in the rivulet height profile moving along the rivulet away from the deposited surfactant droplet [Fig. c-d)].

(a) Interference microscope images of glycerol rivulet. (b) Surfactant deposition using a microsyringe. (c) Propagating rim. (d) Numerical simulation of a rim formation.

We monitor rim propagation to evaluate and optimize the surfactant spreading dynamics. Rim position \(x_{\text{rim}}(t)\) follows a power law behavior \(x_{\text{rim}}(t) \sim t^\alpha\), where the spreading exponent \(\alpha\) quantifies the displacement efficiency of a given surfactant and a certain geometry of the chemical surface patterning. Experimental results for the insoluble surfactant oleic acid spreading on straight glycerol rivulets show spreading exponents in the range \(\alpha = 0.32-0.33\) independent of initial height. Results from numerical model with appropriate initial conditions for this insoluble surfactant yield comparable spreading exponents [1]. For comparison, the soluble surfactant sodium dodecyl sulfate yields higher values around \(\alpha = 0.41\), which compare favorably with those numerically obtained if we consider appropriately chosen initial conditions, and apparently are independent of initial film height and surfactant concentration in the range studied [2]. The lateral confinement induces non-uniform height- and surface velocity profiles, which manifest themselves in a pronounced transition of the evolving rivulet morphology that is absent in unconfined one-dimensional surfactant spreading.