Linear stability of falling films in the presence of soluble surfactants

George Karapetsas*, Vasilis Bontozoglou

Department of Mechanical Engineering, University of Thessaly, Volos 38334, Greece

* - gkarapetsas@gmail.com

We model the dynamics of a liquid film flowing along an inclined planar substrate. The liquid contains a surfactant, soluble in the bulk, which adsorbs at the interface and locally decreases surface tension. Interfacial gradients in surface tension produce tangential stresses (Marangoni stresses), which attribute to the interface elastic properties. The present paper aims at expanding earlier studies in the literature to include solubility effects, in particular by taking into account the adsorption and desorption kinetics. To this end, we assume that the surfactant monomers are present in the bulk or can be adsorbed at the liquid-air and liquid-solid interfaces. The evolution of surfactant concentrations is modeled by advection-diffusion equations and the flow is modeled by the continuity and the Navier-Stokes equations of motion with appropriate boundary conditions. The model is linearized around a base solution corresponding to an undisturbed film with uniform surfactant concentration (Nusselt flow). The resulting Orr-Sommerfeld stability problem is solved numerically for arbitrary disturbances by a finite-element method. An analytic solution is obtained in the limit of disturbances of infinite wavelength. The effect of various parameters is investigated, and a maximum is predicted in the critical Reynolds number as function of amount of surfactant. The location and intensity of this maximum depends on surfactant solubility. Short-wave disturbances are found to stabilize very strongly with the addition of a soluble surfactant.
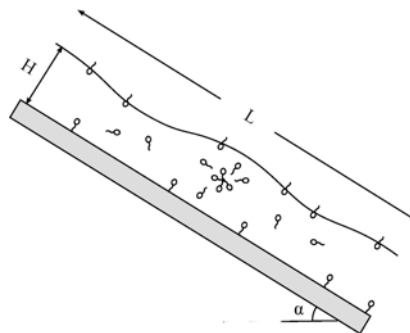
Fig. 1 Schematic of a falling film in the presence of soluble surfactants