186d Influence of Boundary Slip on the Dynamics and Stability of Thermally Driven Climbing Films with Significant Gravitational Counterflows

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Liquid films driven to spread on flat, homogeneous surfaces by either a body force or surface shear stress are susceptible to a fingering instability at the advancing solid-liquid-vapor contact line. Linear stability analysis has shown that the instability is linked to the development of a capillary ridge near the advancing front. The two most commonly used models for the advancing contact line are based on either the introduction of a precursor film or allowance of slip at the liquid-solid interface. The precursor film model assumes the presence of a thin, wetting layer that changes the contact line to an apparent contact line, while the slip model allows independent specification of the contact slope (C_s) and slip coefficient (□). Theoretical studies have shown quantitative agreement between the base state profiles and dispersion curves obtained from analyses based on these two models for thin films driven solely by an applied shear stress (Davis and Troian 2004). Predictions for the wavelength and growth rate of the instability are generally in good agreement with experimental data.

In this present work, the analysis of thermally driven climbing films with boundary slip is extended to include the effects of a counterflow due to gravitational drainage, which significantly modifies the film dynamics and stability. It is found that there are three qualitatively different regions in parameter space corresponding to the relative strength of gravitational drainage, which is represented by the parameter B. The two critical values of this parameter that separate these regions are denoted B_1 and B_2, with $0<B_1 < B_2 < 1$. For $0 < B < B_1$, similar traveling wave solutions to the case of negligible drainage are found (Davis and Troian 2004), and the gravitational drainage and contact slope C_s of the film can be independently specified for a given value of □. A capillary ridge develops near the advancing contact line, and a linear stability analysis reveals that these steady traveling wave solutions are unstable to spanwise disturbances, which evolve in to the well characterized fingering instability. Interestingly, the maximum amplitude of the capillary ridge increases as the amount of drainage increases, but the maximum growth rate of disturbances decreases. These results are explained via an energy analysis of the linearized operator.

For $B_1 < B < B_2$, there are no steady traveling wave solutions, as the free surface shape is a complex waveform that evolves temporally and spatially. If the drainage is increased further such that $B > B_2$, then steady traveling wave solutions can again be found. These solutions decrease monotonically toward the contact line due to the significant gravitational counterflow, and the film is linearly stable to spanwise disturbances, in agreement with predictions based on the precursor film model (Kataoka and Troian 1998). For a given value of the slip coefficient, the contact slope of the traveling wave solution is uniquely determined by the value of B. Numerical results reveal that C_s □ 0 as B □ B_2^+ and increases with increasing B until gravity balances the thermocapillary stresses and the film profile is stationary. An important result of this analysis is that traveling wave solutions cannot be found for a range of B for which such solutions exist for the precursor film model (*i.e.*, B_2(slip) > B_2(precursor)). These qualitative deviations between the predictions based on different contact line models do not occur for films with a single driving force.

References:

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