The stability of gravity driven thin film flows: rivulet formation, growth and merger

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ABSTRACT

The flow of gravity driven thin liquid films down a planar substrate represents a topic of fundamental interest, having received continuing renewed attention over the years. If the film is encroaching onto a dry substrate the associated liquid front may become unstable as it advances, forming finger-like rivulets. The effect of gravity on the instability has generated considerable interest since it has a major influence on the dynamics that are observed. For example, if the substrate is tilted beyond a certain angle to the horizontal the finger like structures that arise continue to grow for all time; also affected is their number and size.

The present work revisits the above problem and considers also the case when the substrate contains heterogeneities in the form of micro-scale geometric irregularities or areas of differing wettability, as found in many naturally occurring, biological, medical and industrially related processes. Exploring them theoretically is a non-trivial task, hampered by the presence of a bounding free surface, the location of which forms part of the solution. To this end lubrication theory is adopted, forming the basis of the modelling approach; the singular nature associated with the moving contact line, typical of rivulet flow, is alleviated by specifying a very thin precursor film ahead of the advancing front. The governing equation set describing the evolution of the flow of interest is solved using an efficient multigrid formulation. A key feature of the solution strategy implemented is the incorporation of both automatic, error controlled space and time adaptivity, guaranteeing accurate, mesh-independent predictions – arguably, the first of their kind for the cases investigated.

The effect of gravity on the development of the liquid front is considered for long time evolutions of the flow. The results show, among other characteristic features, the merging of the finger-like structures under certain conditions, a feature that has received scant attention in the past. The influence of substrate heterogeneities on the flow is also investigated and the stability of the system explored via a linear stability analysis; factors affecting the evolution of the rivulet structures, such as the initial wavelength of the disturbances at the contact line and substrate inclination angle, are reported.

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