Capillarity and dynamic wetting

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Doctoral Thesis
Stockholm, Sweden 2012
Abstract

In this thesis capillary dominated two-phase flow is studied by means of numerical simulations and experiments. The theoretical basis for the simulations consists of a phase field model, which is derived from the system’s thermodynamics, and coupled with the Navier Stokes equations. Two types of interfacial flow are investigated, droplet dynamics in a bifurcating channel and spontaneous capillary driven spreading of drops.

Microfluidic and biomedical applications often rely on a precise control of droplets as they traverse through complicated networks of bifurcating channels. Three-dimensional simulations of droplet dynamics in a bifurcating channel are performed for a set of parameters, to describe their influence on the resulting droplet dynamics. Two distinct flow regimes are identified as the droplet interacts with the tip of the channel junction, namely, droplet splitting and non-splitting. A flow map based on droplet size and Capillary number is proposed to predict whether the droplet splits or not in such a geometry.

A commonly occurring flow is the dynamic wetting of a dry solid substrate. Both experiments and numerical simulations of the spreading of a drop are presented here. A direct comparison of the two identifies a new parameter in the phase field model that is required to accurately predict the experimental spreading behavior. This parameter \( \mu_f \) \([\text{Pa} \cdot \text{s}]\), is interpreted as a friction factor at the moving contact line. Comparison of simulations and experiments for different liquids and surface wetting properties enabled a measurement of the contact line friction factor for a wide parameter space. Values for the contact line friction factor from phase field theory are reported here for the first time.

To identify the physical mechanism that governs the droplet spreading, the different contributions to the flow are measured from the simulations. An important part of the dissipation may arise from a friction related to the motion of the contact line itself, and this is found to be dominating both inertia and viscous friction adjacent to the contact line. A scaling law based on the contact line friction factor collapses the experimental data, whereas a conventional inertial or viscous scaling fails to rationalize the experimental observation, supporting the numerical finding.