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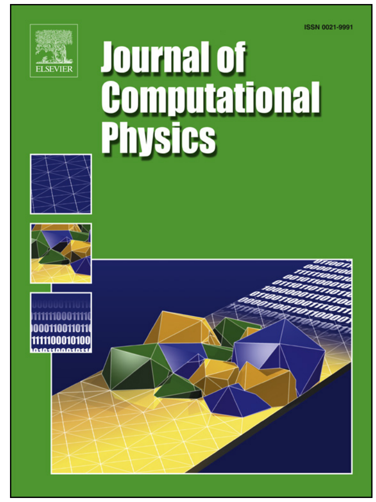

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Level-Set Simulations of Soluble Surfactant Driven Flows

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Abstract

We present an approach to simulate the diffusion, advection and adsorption-desorption of a material quantity defined on an interface in two and three spatial dimensions. We use a level-set approach to capture the interface motion and a Quad-/Oc-tree data structure to efficiently solve the equations describing the underlying physics. Coupling with a Navier-Stokes solver enables the study of the effect of soluble surfactants that locally modify the parameters of surface tension on different types of flows. The method is tested on several benchmarks and applied to three typical examples of flows in the presence of surfactant: a bubble in a shear flow, the well-known phenomenon of tears of wine, and the Landau-Levich coating problem.

Keywords: Navier-Stokes, Incompressible, Soluble Surfactants, Surfactant Driven Flows, Marangoni Forces, Quad/Octrees, Adaptive Mesh Refinement, Stable Projection Method

1. Introduction

Many problems in fluid dynamics exhibit a different behavior in the presence of surfactants at the interface between two phases or at a free surface. Surfactants are amphiphilic molecules, i.e. they possess both hydrophilic and hydrophobic groups, giving them properties that can affect the flow through two different mechanisms that have the same origin. First, surfactants at an interface lower its surface tension, thus altering the pressure jump at the interface. Second, when the surfactant concentration is not constant along the interface, it generates the so-called Marangoni forces, which are tangential stresses that can critically perturb the flow near the interface.

The computational modeling of the diffusion, the advection, the adsorption and the desorption processes of a material quantity on a moving interface, as well as its possible effects on a fluid flow, is a challenging task. Several computational studies have been undertaken since the early 1990s, involving more or less sophisticated numerical methods and more or less comprehensive physical models depending, for example, on whether or not the surfactant is considered soluble, which implies the presence of adsorption-desorption coupling between the bulk and the interface; whether the effect of surfactants on the surface tension are modeled by a linear or a nonlinear equation of state; or whether the full Navier-Stokes equations or the Stokes equations are considered.

In 1989, Stone and Leal [34] developed a boundary integral method for studying the effects of insoluble surfactant on drop deformation and breakup. One year later, He, Dagan and Maldarelli [14] investigated, using uniform retardation perturbation schemes, the retarding effect of the Marangoni forces due to soluble surfactant on the motion of a fluid sphere in creeping translation inside a tube. In 1992, Borhan and Mao [3] developed a boundary element method to study the effects of surfactant on drop deformation. The same year, Milliken, Stone and Leal [22] developed a boundary integral method for studying the evolution of viscous drops under the hypothesis of Stokes flow with arbitrary viscosity ratios in the presence of surfactant and using a nonlinear equation of state for the interfacial tension. In 1994, Leveque and Li [17] designed an immersed interface

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