EFFECTS OF A SURFACTANT ON THE MOTION OF A CONFINED GAS-LIQUID INTERFACE. THE INFLUENCE OF THE PECLET NUMBER

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Abstract—The displacement of a liquid initially contained in a capillary tube or between two closely spaced parallel plates by a gas phase, is largely affected by the presence of a soluble surfactant. The distribution of the surface active solute within the bulk and along the interface depends on the relative strength of convection, diffusion and the kinetics of adsorption/desorption. In this work, a complete description of the velocity and concentration fields in the bulk and along the interface is presented for several values of the Péclet number. The influence of this parameter on the film thickness is also analyzed.

Keywords—interfacial flow, surfactant, finite-elements, gas-liquid displacement.

I. INTRODUCTION

The displacement of a gas-liquid interface between two closely spaced parallel plates or inside a capillary tube is a model widely used to analyze complex multiphase problems. Two interesting examples are the process of oil recovery by chemical flooding and the expansion dynamics that occurs during the opening of collapsed pulmonary airways. The simplest model of both processes is the motion of a semi-infinite bubble in a capillary tube initially filled with a viscous liquid, a problem that has received considerable attention since the pioneering work of Bretherton (1961).

An important issue of many multiphase systems is the role played by a surface active agent that is present either as an impurity or as an additive. The surfactant largely affects the dynamic behavior of a deforming interface. In fact, the adsorption of minor amounts of a surface active solute at a free surface reduces its surface tension and induces the appearance of interfacial tension gradients when the distribution of solute is not uniform. In the first example mentioned above, the injection of a surfactant solution helps to remobilize the residual oil from the porous rock by lowering the surface forces. In the second one, the occlusion may result from an insufficient biosynthesis of surfactants.

The influence of a surface active agent on the displacement of a confined gas-liquid interface, has been analyzed both analytically and numerically. Among the works that employ the first methodology, the more comprehensive one is the study presented by Ratulowski and Chang (1988). These authors carried out an asymptotic analysis for both the hydrodynamics and the mass transfer problems and obtained solutions valid for very low motions and traces of surfactant. They detected five different cases depending on the relative magnitude of the transport mechanisms involved: bulk and surface diffusion, bulk and surface convection, and adsorption-desorption.

Other analytical works are those of Ginley and Radke (1988), Park (1992), and Stebe and Barthès-Biesel (1995). The former authors assumed that the concentration of surfactant in the bulk was uniform and that the interfacial concentration of surfactant was controlled by the kinetics of the adsorption-desorption process. Park, analyzed the case designated as diffusive-equilibrium model in Ratulowski and Chang’s work. Finally, Stebe and Barthès-Biesel carried out an asymptotic analysis of the problem valid when the exchange of solute between the phase and the interface is controlled by the adsorption-desorption kinetic process. The main objective or all these analysis —valid when viscous forces are negligible compared to capillary forces— was to establish the influence of the surfactant on the film thickness left behind by the moving front.

One of the first numerical works dealing with the effects of a surface active agent on the displacement of a gas-liquid interface was published by Wassmuth et al. (1993). These authors studied the motion of the interface between parallel plates with and without a constriction using two different tessellations: a variable one for the free surface and a fixed one for the bulk phase. They presented solutions for a limited set of values of the dimensionless parameters that did not include the case of small Capillary number.

Very recently, Ghadiali and Gaver (2003) used a computational model of a semi-infinite bubble moving in capillary tube filled with a surfactant solution. They showed results for the free surface shape, the flow field, the concentration profiles and the pressure drop as a function of the dimensionless parameters of the system. The range of Capillary number considered was 0.015-10