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The Remobilization of Bubbles Rising in Aqueous Surfactant Solutions

The measured terminal rise velocity of bubbles in surfactant solutions is usually found to be much smaller than the values predicted assuming the surface of the bubble is mobile. The reason for this reduction in velocity is that surfactants adsorb form the continuous phase onto the bubble surface to create a molecular monolayer or “skin” which retards the bubble motion. Surfactant adsorbs onto the surface of a moving bubble by diffusing to the sublayer adjacent to the bubble surface, and then kinetically adsorbing onto the surface. Once adsorbed, surfactant is convected to the back end of the bubble, where it accumulates, until kinetic desorption and diffusion away from the bubble surface bring the surface mass balance to a steady state. At low bulk concentrations of surfactant – as for example when a surfactant impurity is present in a liquid which is otherwise assumed to be “clean” - the diffusive transport to the bubble is slow relative to the surface convection, and a significant gradient in surface concentration exists on the bubble surface as surfactant accumulates at the back end. The surface tension therefore decreases from the front to the back end, creating an interfacial tension gradient (Marangoni force) that is directed opposite to the surface flow. This force reduces the surface velocity and increases the drag on the bubble, which accounts for the reduction in the terminal velocity of the bubble. Even trace amounts of surfactant impurities in a continuous phase caused bubbles to move with completely immobile surfaces (i.e. as a solid particle), with drastic consequences: For example, the immobilization of the surface flow severely reduces interphase mass transfer rates in bubble extraction processes, and complicates thermocapillary methods for moving bubbles in microgravity environments.

In this presentation, we will outline a theoretical framework and detail supporting experiments that demonstrate how the reduction in interfacial mobility can be eliminated, allowing bubbles to move at higher terminal velocities. The key to remobilizing the interface is to dissolve in the continuous phase surfactants that do not accumulate at the back end of the bubble, but instead, upon adsorption, give rise to a uniform concentration along the bubble surface. A uniform distribution does not create gradients in interfacial tension, and therefore the surface flow is unimpeded. Remobilizing surfactants are characterized by two properties: First, their kinetic rates of exchange at a surface are much faster than surface convection, so the surface and sublayer are in quasi-equilibrium. Second, they can be dissolved at sufficiently high concentrations so as to eliminate diffusive resistance to mass transfer. Two cases are studied. In the first, which is illustrated with a polyethylene oxide surfactant, at high concentrations, the surfactant forms aggregates (micelles) which act as reservoirs to reduce diffusion gradients in the bulk and maintain a uniform surface concentration. In the second, which is illustrated with intermediate chain alcohols, elevated concentrations alone without aggregate formation eliminate diffusion gradients. We present measurements of the terminal velocity of rising bubbles with identified remobilizing surfactants that demonstrate large terminal velocities. The results are also compared favorably to theoretical calculations that compute the mass transport of surfactant and the associated hydrodynamic drag and terminal velocity of the bubble.

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