Synergistic Interaction of n-Hexane Vapors and Surfactants on Liquid-Gas Interfacial Dynamic

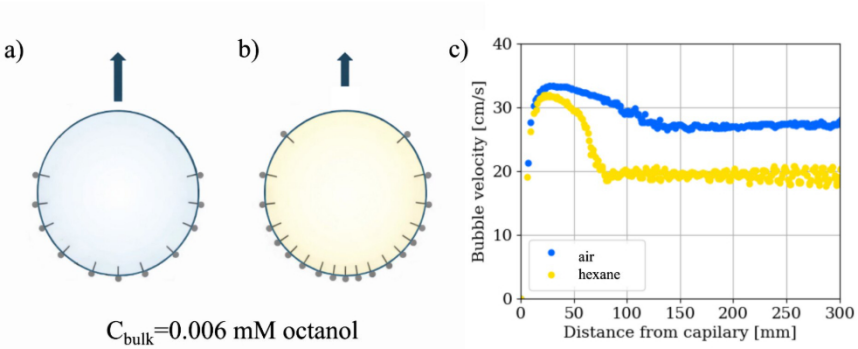
Łukasz Witkowski [1], Dominik Kosior [1], Georgi Gochev[1,2], Piotr Batys [1], Piotr Warszyński [1], Jan Zawała [1]

[1] Jerzy Haber Institute of Catalysis and Surface Chemistry, Polish Academy of Sciences, 30-239 Krakow, Poland
[2] Institute of Physical Chemistry, Bulgarian Academy of Sciences, 1113 Sofia, Bulgaria

lukasz.witkowski@ikifp.edu.pl

The motion of a single gas bubble in a liquid strongly depends on the hydrodynamic conditions at the liquid–gas interface. When amphiphilic compounds are present in the liquid, they adsorb at the surface of a rising bubble and form a so-called dynamic adsorption layer (DAL). This layer is not uniform along the bubble surface and therefore partly reduces the mobility of the interface. As a result, the bubble does not rise at a constant speed. Instead, its motion shows characteristic velocity profiles with distinct stages: acceleration after bubble release, reaching a maximum velocity, subsequent deceleration, and finally establishment of a terminal velocity. The shape of these velocity profiles and the time needed to reach the steady state provide an indirect but very sensitive measure of adsorption kinetics and interfacial immobilization. An important and still not well understood problem is the influence of organic vapors present inside the bubble on adsorption processes and interfacial dynamics under non-steady conditions. In this work, we study the effect of n-hexane vapors on the behavior of a rising air bubble in pure water and in aqueous solutions of ionic and non-ionic surfactants. Bubble dynamics were analyzed using local velocity profiles and terminal velocities. In addition, adsorption processes were studied on a stationary buoyant bubble by bubble profile analysis tensiometry, which allowed us to follow adsorption kinetics and changes in surface tension in the presence of n-hexane vapors. The experimental results were supported by molecular dynamics simulations, providing insight into surfactant adsorption energies and the co-adsorption of surfactant molecules and n-hexane at the molecular scale. The results show that in pure water the presence of n-hexane vapors, although they adsorb at a stationary interface, does not significantly affect the motion of a rising bubble. In contrast, a clear synergistic effect is observed in surfactant solutions. The presence of n-hexane vapors strongly accelerates the formation of the dynamic adsorption layer at the bubble surface and leads to faster and stronger immobilization of the liquid–gas interface. This behavior results in lower bubble velocities and a shorter time needed to reach steady-state conditions. Molecular simulations indicate that this effect is caused by limited desorption of surfactant molecules from the interface when n-hexane molecules are also present, which promotes faster buildup of the adsorption layer. These findings improve the understanding of how volatile organic compounds and surfactants interact at the liquid–gas interface under dynamic conditions, especially in relation to the formation and stabilization of the dynamic adsorption layer. The observed synergistic effect suggests that organic vapors can significantly change adsorption kinetics. From an applied perspective, these results may be relevant for industrial processes based on foams, such as flotation or froth separation, where the controlled use of organic vapors could reduce surfactant consumption while preserving the required hydrodynamic behavior of the system.

Keywords:
Bubble, Surfactant solution, Organic vapor, Synergistic effect



a) Diagram of surfactant adsorption on a bubble containing clean air b) Diagram of enhanced surfactant adsorption on a bubble containing hexane vapor c) Comparison of velocity profiles of a bubble with clean air and one with hexane vapor at the same octanol concentration.

Acknowledgements:
Participation partially covered by a travel award sponsored by the open access journal Colloids and Interfaces published by MDPI.