404b Measurements of Surface Properties with Oscillating Supported Bubbles

Ying-Chih Liao, Elias I. Franses, and Osman Basaran

The dynamic surface tension (DST) is important in many industrial applications, such as foams, coatings, lung surfactants, and drop and jet breakup. Pulsating bubble surfactometers (PBS) have been widely used for measuring DSTs, because of their simplicity and small required sample amounts. The oscillation of a bubble supported by a small capillary gives rise to a surface expansion/contraction, and the DST can be determined by the pressure difference across the interface. In such measurements, it is assumed that hydrodynamic effects are negligible in the requisite balance of forces at the bubble surface. The validity of this assumption and possible errors in surface tension measurements are examined by solving simultaneously the convective diffusion equation and the Navier-Stokes system of equations that govern the interfacial transport of surfactants by a three-dimensional but axisymmetric finite element algorithm. The consistency and accuracy of the computational algorithm in describing the experimental system have been shown by the excellent agreement between the model predictions and DST data of aqueous solutions of C12E5 surfactant, obtained with the PBS method under standard operating conditions. Effects of important parameters, such as the forcing frequencies and amplitudes, liquid viscosity, and surfactant properties, on the adsorption dynamics are investigated via a parametric study. For aqueous surfactant solutions, the surface tension remains uniform on the bubble surface, and the measured or apparent dynamic surface tension (DST) from PBS measurements is found to be fairly accurate at frequencies lower than 10 Hz. At frequencies higher than 10 Hz, the surface tension is non-uniform and causes strong recirculation flows, or eddies, near the bubble interface. These flows make the pressure fields differ from the hydrostatic ones, and the DST from the PBS measurement is quite inaccurate even after accounting for the inertial effects. A decrease in the forcing volume amplitude is found to be the most effective remedy in increasing the accuracy of PBS measurements. Increasing the wall distance decreases only the inertial effects, but is not effective in reducing the strong eddies caused by the non-uniform surface tension. The limiting frequency for the surface density to remain uniform increases as the viscosity increases. At low frequencies, PBS measurements with a viscous fluid can be quite accurate after accounting for the viscous forces. For deformed bubbles at low surface tensions (< 5 mN/m), the calculated DST is lower than the actual value in the computation. The dynamic and static shapes for the low-DST bubbles overlap, and the pressure fields for low DST remain nearly the same as those from hydrostatics. Thus, it is appropriate to use the static Young-Laplace equation to evaluate the surface tension, and the value as determined is more accurate than that from the pressure jump method. These findings in the PBS may also provide guidelines for possible improvements of the apparatus design.