A new method for studying foam stability

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A new method for studying foam stability has been developed based on the evolution time for foam cells at a given horizontal level; the optical experimental technique and results for aqueous sodium dodecylsulfate are described.

In contrast with foaminess, which depends on the stability of the outer films of a foam, the internal stability of a foam depends on the life-time of the internal films separating the foam cells. Every break up of an internal film means the coalescence of neighbouring cells with the corresponding enlargement of a foam cell. The resulting state of polydispersity is characterised by cell volume ratios close to the ratios of integer numbers. Assuming, reasonably, the number of bursting films per unit time to be proportional to the total film number, the process of cell growth should proceed exponentially, and we may write equation (1):

$$R = R_0 \exp(t/T) \tag{1}$$

where R and R_0 are the average cell radius and its initial value, respectively, t is time and T is a coefficient which we call the evolution time and use as a quantity characterising the foam stability. The evolution time is the time needed for the enlargement of a foam bubble by exp(1). Since the probability of a film bursting depends little on the film area, T is very close to constancy even in a polydisperse foam.

Using an optical method, the foam cell radius is a directly measurable quantity as a function of time. Our experimental set-up is shown in Figure 1. A quasi-parallel beam of white light from the source *1* is formed, with the aid of the collimator *2* and the stop *3*, having a diameter of about 1 cm ($\geqslant$ ten cell diameters). The light beam is directed to a glass cuvette *4* containing the foam and, after passing through the foam, to the photoelectric cell *5*. The photocurrent is recorded by the galvanometer *6*. Comparing measurements for the empty cuvette and for the cuvette with a foam, the transmission factor $f \equiv I/I_0$ is readily calculated from experiment, where I is the intensity of the light passing through the foam and I_0 is the light intensity value in the absence of the foam.

The calculation of the main characteristics of a foam (cell radius, phase volume ratio, curvature radius of the Gibbs–Plateau borders, *etc.*) from experimental data on the transmission factor is based on the recent development of the theory of foams.[1,2] The light scattering from foams is of multiple character and corresponds to equation (2),[3]

$$f = e^{-\sigma_a nL}[e^{-\sigma_s nL} + q(1 - e^{-\sigma_s nL})] \tag{2}$$

where σ_a and σ_s are the cross-sections of absorption and scattering, respectively, n is the number of foam cells per unit volume, L is the linear dimension of the foam in the direction of propagation of the light beam (the thickness of the foam column), and q is the fraction of the scattered light intensity occurring at the aperture of the light receiver. For the limiting cases of very small and very large values of the foam thickness (marking these cases with subscripts 1 and 2), equation (2) yields:

$$\ln f_1 = -(\sigma_a + \sigma_s)nL_1 \tag{3}$$

$$\ln f_2 = -\sigma_a nL_2 + \ln q \tag{4}$$

Both these equations are linear. Equation (3) allows determination of $\sigma_a + \sigma_s$ and equation (4) allows the determination of σ_a and q from experimental values of f_1, f_2, n and L. The quantities σ_a and σ_s can be determined separately in this way. Comparing the optical and structural properties of foams in the bubble size range 0.1 to 1 mm leads to an empirical relationship[4] (which is close to theoretical estimations[5–7])

$$\sigma_a + \sigma_s \approx 0.12\,\sigma_g = 0.12\,\pi R^2 \tag{5}$$

where σ_g is the geometrical cross-section of a foam cell of a radius R. From equation (5) and the trivial relationship $n = 3/4\pi R^3$ in equation (3), we obtain:

$$\ln f_1 = -0.09\,L_1/R \tag{6}$$

Equation (6) allows the determination of the foam cell radius directly from the measurement of the transmission factor at small foam thickness.

For large foam thickness, an empirical relationship exists[4]

$$\ln f_2 = -2.08RL_2/K^{1/2} \tag{7}$$

where K is the phase volume ratio of a foam and R and L_2 are expressed in mm. Using both equations (6) and (7), the simultaneous determination of the foam cell radius and the phase volume ratio is possible from an optical experiment with a thin and a thick foam.

To achieve this, we used a cuvette of double width (Figure 2), with a smaller width of about 10 to 15 diameters of foam cells and a larger width of about 50 to 60 diameters (our cuvette has widths L_1 = 15 mm and L_2 = 52 mm). The experimental procedure was as follows. A surfactant solution is placed in a glass cylinder with a porous filter at the bottom, and the foam is produced by an air stream from a microcompressor (first passing the gas through pure water for saturation and purification). A number of porous filters were used to produce bubbles of 0.2 to 2.0 mm in diameter. A fresh foam with low volume ratio (about 4 to 10) is rather mobile and is easily transferred, through a glass tube, to the cuvette where the foam was at rest for 8 to 12 min before the

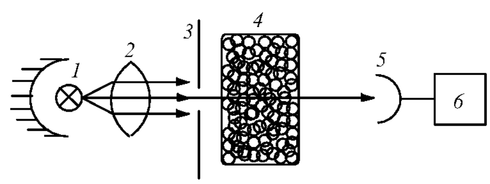

Figure 1 The experimental set-up for our study of foam stability: *1*, light source; *2*, collimator; *3*, stop; *4*, glass cuvette with foam; *5*, photomultiplier tube; *6*, galvanometer.

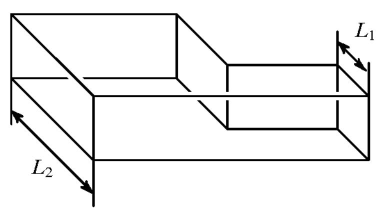

Figure 2 A double-width cuvette for measuring the parameters corresponding to equations (3) and (4).

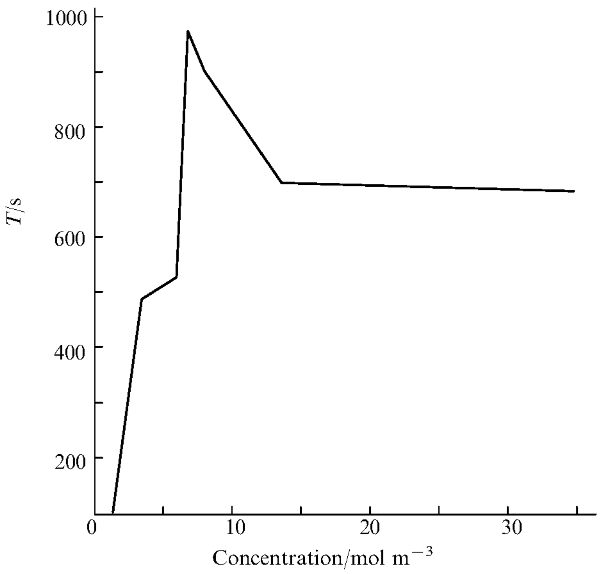

Figure 3 The evolution time, T, as a function of concentration for an aqueous solution of sodium dodecylsulfate.

optical experiment began. In the first few seconds, the foam loses about 95% of its liquid in the drainage process and soon (1 to 3 min) comes to a quasi-equilibrium state with a liquid layer at the cuvette bottom, further drainage proceeding at the expense of the destruction of internal foam cells. When such a state is achieved, the optical experiment may start.

With a foam column height of about 10 cm, we directed the light beam at a height of 6 to 7 cm to investigate the polyhedral part of the foam (our cuvette is capable of moving with respect to the light beam). The foam dispersity was varied by using corresponding porous filters, and the foam volume ratio was changed by regulating the gas consumption. The foam dispersity and volume ratio can also be regulated by using sieves with various sizes of meshes at the foam output.

The experimental results for an aqueous solution of commercial surfactant sodium dodecylsulfate (Fluka, >99% grade) are presented in Figure 3. As is typically observed for foam stability, the evolution time exhibits a maximum at the critical micelle concentration (8.3 mol m^{-3} for sodium dodecylsulfate).

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