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Investigation of Foam Destruction in a Centrifugal Field

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A method has been developed to investigate the kinetics of increase in the expansion ratio, the establishment of pressure in Plateau–Gibbs borders and the corresponding disjoining pressure in films as well as the destruction of a foam in a centrifugal field.

The creation of a pressure difference in the liquid phase of a foam using porous plates produces polyhedral foams with a large expansion ratio $n \approx 10^4$ with a controlled radius of curvature of the Plateau–Gibbs borders and high capillary pressure.[1] The time required to establish high surplus pressures in foam borders ($\Delta p > 10^4$ Pa) is extremely long and pressures of more than 2×10^4 Pa are unattainable. Therefore, we developed a method to investigate the kinetics of increase of the expansion rate, the establishment of pressure in the Plateau–Gibbs borders and the corresponding disjoining pressure in films. We also investigated the destruction of a foam in a centrifugal field, where, in the process of foam drainage, the border profile provides a lower hydrodynamic resistance and quicker establishment of both pressure and foam destruction. In known methods for the destruction of emulsions in a centrifugal field it is only possible to investigate the dependence of the lifetime of the emulsion of the height of a column on time.[2]

Our investigations were carried out in an MPW-2 centrifuge (Poland), the number of revolutions being increased from 500 to 6000 rev min^{-1}. Foam from a foam generator is introduced into a metal cell, which simultaneously functions as one electrode. The second electrode, which is made in the shape of a round metal pivot, is placed coaxially into the cell. By changing the position of the pivot, it is possible to measure the resistance of the foam layer at different distances from the axis of rotation of the centrifuge. The dependence of the expansion ratio on the distance to the axis of rotation is given in ref. 1 by eqn. (1),

$$\sqrt{n(l)} = [\sqrt{n(0)} - (\rho a \omega^2/2\sigma\sqrt{C_B})l^2] \quad (1)$$

where l is the coordinate from the axis of rotation, $n(0)$, $n(l)$ are the expansion ratios when $l=0$ and l, a is the dispersity of the foam (length of the edges of the polyhedra), ρ is the density of the liquid, ω the angular speed of rotation and $C_B = 0.315$ (for a model of a foam in the form of compact pentadecahedra).

During the rotation of the cell, the foam has the maximum expansion ratio n_{max}, when the distance from the axis of rotation is at a minimum l_{min}. Taking $n_{min} = 4$ at the bottom of the cell ($l = l_{max}$) and introducing l_{max} and l into eqn. (1), the system of equations (2) is obtained.

$$\left.\begin{aligned} 2 &= \sqrt{n(0)} - (\rho a\omega^2/2\sigma\sqrt{C_B})l_{max}^2 \\ \sqrt{n(l)} &= \sqrt{n(0)} - (\rho a\omega^2/2\sigma\sqrt{C_B})l^2 \end{aligned}\right\} \quad (2)$$

Eliminating the unknown value $\sqrt{n(0)}$ leads to eqn. (3) and

$$\sqrt{n(l)} = 2 + (\rho a\omega^2/2\sigma\sqrt{C_B})(l_{max}^2 - l^2) \quad (3)$$

thence to eqn. (3*a*) because the value $(\rho a\omega^2/2\sigma\sqrt{C_B})(l_{max}^2 - l^2)$ is usually >2.

$$\sqrt{n(l)} = (\rho a\omega^2/2\sigma\sqrt{C_B})(l_{max}^2 - l^2) = A(l_{max}{}^2 - l^2) \quad (3a)$$

The average expansion ratio $\bar{n}_{exp}$ was determined experimentally by measuring the electrical resistance of the foam layer R_F

$$\bar{n}_{exp} = R_F/R_0B \quad (4)$$

and was calculated using eqn. (4), where R_0 is the resistance of a

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Table 1 Values of expansion ratios n_{max}, n_{min}, $\bar{n}_{exp}$ and $\bar{n}_{th}$ and corresponding capillary pressures

Surfactant solution	Angular speed ω/s^{-1}	$10^{-4}\,n_{max}$	$10^{-4}\,n_{min}$	$10^{-4}\,\bar{n}_{th}$	$10^{-4}\,\bar{n}_{exp}$	$P_{\sigma,max}$/kPa	$\bar{P}_{\sigma,th}$/kPa	$\bar{P}_{\sigma,exp}$/kPa
Triton X-100 + 1 mol dm^{-3} NaCl	52.3	10.3	2.9	5.5	6.4	8.5	5.8	6.7
	471	2.26×10^4	1.63×10^4	1.2×10^4	21	732	502	21

liquid with the same layer thickness and B is a coefficient of the form described in ref. 1.

In the border variant[2] the expansion ratio is related to the

$$n = 4.78a^2/\tau^2 \qquad (5)$$

parameters of the elementary cell [eqn. (5)], where τ is the radius of curvature of the Plateau–Gibbs border.

From eqns. (4) and (5) we can find the radius of the border. The average capillary pressure is given by eqn. (6). Note that

$$P_{\sigma,exp} = \sigma\sqrt{\bar{n}_{exp}}/2.19a \qquad (6)$$

$P_\sigma = P_g - P_L$, where P_g is the pressure in the gas bubbles and P_L is the pressure in the Plateau–Gibbs borders.

The expansion ratio n_{exp}, calculated from eqn. (5), was compared with the average theoretical expansion ratio n_{th},

$$\bar{n}_{th} = A^2\Delta l/\int_{l_{min}}^{l_{el}} dl/(l_{max}^2 - l^2)^2 \qquad (7)$$

obtained from eqn. (7), where $\Delta l = (l_{el} - l_{min})$ is the depth of the foam layer ($\Delta l = 0.5\times10^{-2}$ m), l_{el} is the distance from the axis of rotation to the point of immersion of the electrode (the depth of immersion of the electrode), and l_{min} is the distance from the axis of rotation to the upper foam layer.

With the help of eqn. (3), it is possible to determine the maximum expansion ratio n_{max}, when the distance $l = l_{min}$, and the minimum expansion ratio (when the distance $l = l_{max}$) are

$$\sqrt{n_{max}} = A(l_{max}^2 - l_{min}^2) \qquad (8)$$

$$\sqrt{n_{min}} = A(l_{max}^2 - l_{el}^2) \qquad (9)$$

given by eqns. (8) and (9). The calculation of the values of $\bar{n}_{exp}$, $\bar{n}_{th}$, n_{max} and n_{min} by the eqns. (5), (7), (8) and (9) for a foam generated from a 5×10^{-4} mol dm^{-3} solution of Triton X-100 (+1 mol dm^{-3} NaCl) is represented in Table 1. The values of the capillary pressures were calculated from eqn. (6) using the corresponding expansion factors.

Note that the dispersity values from which the capillary pressures $P_{\sigma,max}$, $\bar{P}_{\sigma,th}$ and $\bar{P}_{\sigma,exp}$ were calculated correspond to the minimum foam dispersity at the moment of its destruction in a cell with a porous plate.

In a foam from a solution of sodium dodecylsulfate (DDSNa) and Triton X-100, when the angular speed of rotation is low ($\omega \leq 100\ s^{-1}$) the equilibrium capillary pressure is achieved, at which the foam lives for more than 10 min. With the further increase in the speed, the expansion ratio grows to $n = (10–20)\times10^4$ and the foam collapses after less than one minute, not reaching the theoretically possible pressure.

The maximum capillary pressure $\bar{P}_{B,exp}$ in the foam from a solution of DDSNa was 16 kPa; in the foam from a Triton X-100 solution it as 20 kPa. In a foam from a solution of a mixture of sodium alkylsulfonate, oleic acid monoester and triethanolamine (2:3) with total holding surfactant 30 vol.% and kerosine 27 vol.%, the capillary pressure $\bar{P}_{\sigma,exp}$ was 3.8 kPa, and 8 kPa in a foam from solution of a lizocime, which is greater than that in the same foam after drying with the help of a porous plate.

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