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Foam films from hexylamine stabilized by the silica particles

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The stabilization of the foam films from hexylamine by the silica particles correlates with the rheological properties of the dispersion phase.

The stabilization of foams by solid particles has been studied previously.[1,2] We investigated the effect of solid concentrations on the stability of foams.[3] Here, we studied the bulk rheology of a frother solution using macroscopic foam films as model systems. Hexylamine was adsorbed on solid particles to impart the surface hydrophobicity. Note that the foam obtained upon shaking a hexylamine solution (without solid particles) collapsed within a few seconds after foaming.

The films were obtained from the suspensions of 0.5–6% Aerosil-380 silica (powder, aggregates 3 μm in diameter), 2–20% Ludox HS-40 (40% sol; particle diameter of 15 nm) and hexylamine (18–90 mM) as an amphiphilic substance. Foam films with solid contents lower than 0.5% cannot be obtained because the amount of particles is insufficient for the stabilization of bubbles. At aerosil concentrations of >6%, the suspension is difficult to stir. We used hexylamine concentrations at which stable foams were formed[3] (the contact angle was $\theta = 52°$ for all of the suspensions). A further increase in the concentration of hexylamine led to the coagulation of solid particles as a result of an increase in the radius of aggregates to 100 μm.[3]

To prepare the model foam films, we used the technique[4] of frame raising from the suspension containing the particles.

The film thickness was determined by conductivity[4] (5 mM NaCl in the suspension). The equilibrium thickness of a foam film was calculated by the formula[3,5]

$$h = \frac{\kappa_{f(e)} \ln(r_2/r_1)}{2\pi\kappa_0} nB, \tag{1}$$

where $\kappa_{f(e)}$ is the equilibrium film conductivity; κ_0 is the specific conductivity of a NaCl solution; r_2 and r_1 are the radii of the electrodes; n is the calculated ratio of the film;[5] and B = 1.2–2 is an experimental coefficient, which depends on the contact angle.[5] The thickness of the non-equilibrium thinning film is calculated by the formula $h = h_L + h_e$ given by:

$$h = \frac{(\kappa_f - \kappa_{f(e)})}{2\pi\kappa_0} \ln(r_2/r_1) + h_e, \tag{2}$$

were h_L is the thickness of the liquid layer, κ_f is the nonequilibrium film conductivity, h_e is the equilibrium thickness (the thickness of two adsorption layers).

Figure 1 shows the film electroconductivity in the course of film drainage.

The films obtained from 0.5% Aerosil and 2% Ludox suspensions are equilibrium films, and their thicknesses were calculated by equation (1). The thicknesses of the films obtained from 1–6% Aerosil and 20% Ludox suspensions were calculated by equation (2).

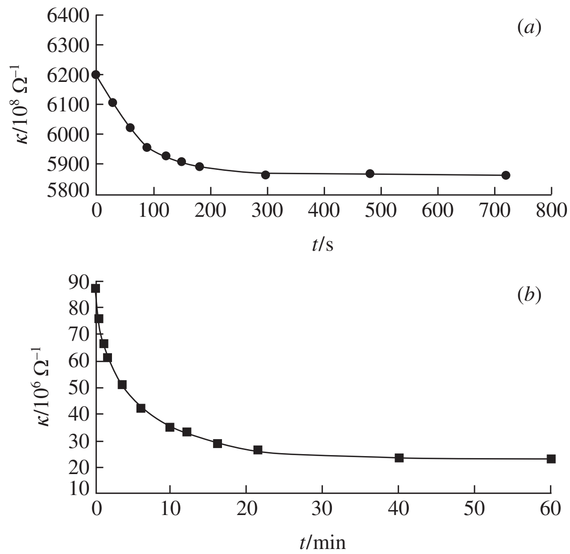

Figure 1 The time dependence of the electroconductivity of films under gravity: (*a*) 2% Aerosil, (*b*) 2% Ludox.

Table 1 Silica film characteristics.

Suspension		h/μm	Lifetime/min	Destruction mechanism
Aerosil	0.5%	56	1–30	Burst
	1%	78	60	Burst
	2%	132	190	Burst
	4%	155	Unlimited	Not destroyed
	6%	199	Unlimited	Not destroyed
Ludox	2%	8.9	1–70	Burst
	20%	10.2	1–50	Burst

Table 1 characterizes the films. The relatively thin films were prepared from Ludox, and they thinned under gravity for about 1 h. The film thickness decreased to 8.9 (for 2% Ludox) or 10.2 μm (for 20% Ludox).

The films with an Aerosil content of 0.5–2% ruptured within 0.5–2.5 h, but those obtained from 4–6% suspensions were thicker and stable. Probably, in such films, the continuous phase with the adsorption layers is a gel and an increase in the Aerosil concentration in the initial suspension causes the formation of a network of adsorbed particles. To test this hypothesis, we investigated the rheological properties of suspensions (Table 2). The suspension yield stress, $\tau_{c(s)}$, was determined by the method of the tangential displacement of a corrugated metal plate.[6] The viscosity (η) was measured using the velocity of ball sedimentation in suspensions.[6]

Table 2 Rheological properties of suspensions.

Suspension	$\tau_{c(s)}$/N m^{-2}	η/Pa s	Suspension	$\tau_{c(s)}$/N m^{-2}	η/Pa s
1% Aerosil	0.085	0.0146	6% Aerosil	7.860	—
2% Aerosil	0.200	0.151	2% Ludox	0.041	0.051
4% Aerosil	0.890	0.830	20% Ludox	0.200	0.078

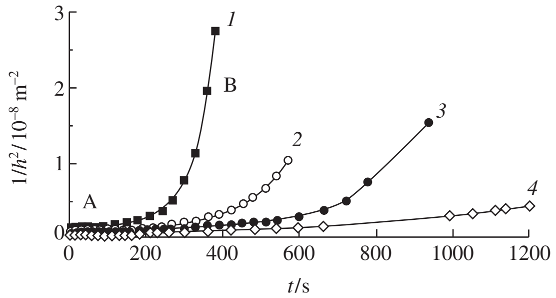

Figure 2 The time dependence of $1/h^2$ (2% Aerosil + 49 mM hexylamine) at Δp: (*1*) 3, (*2*) 2, (*3*) 1 and (*4*) 0.5 kPa. A – beginning of the structure destruction, B – liquid flow when the gel in the continues phase is destructed.

The measured viscosity values were higher than the values calculated from the Einstein equation.[7] The yield stress of the foam aqueous phase may differ from the measured one in the suspensions. Investigating the foam film under the conditions of a pressure drop (Δp) in its liquid phase,[3] we determined the yield stress (Figure 2).

At the silica concentration of 4–6%, the foam film reaches a constant film thickness (Figure 3) accompanied by film solidification. Cracks in these solidified films were observed. At Δp = 3–5 kPa, these cracks became larger, but at Δp < 2 kPa these films remained stable. This fact confirms the assumption on the gel structure of the film. The analysis of the function $1/h^2(t)$ showed that the liquid contains hardened structures at silica concentrations of >1%. The films stabilized by Ludox were destroyed at any values Δp within a few seconds.

Figure 4 shows the rate of film drainage. The critical yield stress is

$$\tau_c = h_w P_c / r,$$

where h_w is the thickness of the water layer; P_c is the critical pressure; and r is the film radius. The τ_c values obtained for the films stabilized by 1, 2, 4 and 6% Aerosil are given in Table 3.

However, the nature of the thinning and thickness of the films obtained from a 20% Ludox sol (with nanosized particles) are the same as those of the films obtained from a 2% sol. The films (regardless of the solid content) obtained from a Ludox sol are stable bilayer films.

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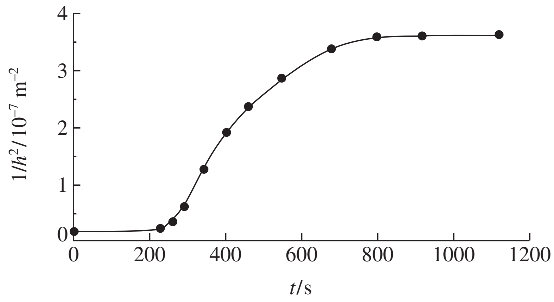

Figure 3 The time dependence of $1/h^2$ (4% Aerosil + 56 mM hexylamine) at Δp = 1 kPa.

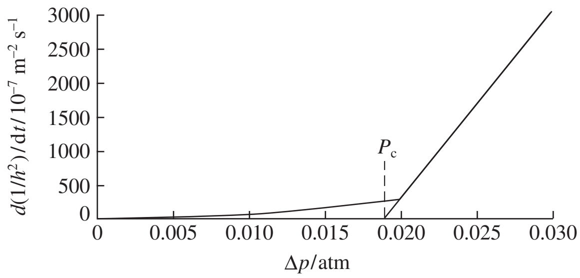

Figure 4 The film thinning rate *vs.* the Δp (2% Aerosil + 49 mM hexylamine). P_c is the critical pressure required for the complete structure destruction.

Table 3 Yield stresses in the films.

Suspension	τ_c/N m^{-2}	Suspension	τ_c/N m^{-2}
1% Aerosil	1.55	4% Aerosil	91
2% Aerosil	19.8	6% Aerosil	232.7

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