

Supporting Information

Solution Preparation

Weigh 0.01 mol of each of the four samples separately and dissolve them in 100 mL volumetric flasks to prepare a 0.1 mol/L stock solution. Dilute the stock solution to concentrations of 10^{-7} mol/L, 3×10^{-7} mol/L, 7×10^{-7} mol/L, 10^{-6} mol/L, 3×10^{-6} mol/L, 7×10^{-6} mol/L, 10^{-5} mol/L, 3×10^{-5} mol/L, 7×10^{-5} mol/L, 10^{-4} mol/L, 2×10^{-4} mol/L, 3×10^{-4} mol/L, 4×10^{-4} mol/L, 5×10^{-4} mol/L, 6×10^{-4} mol/L, 7×10^{-4} mol/L, 8×10^{-4} mol/L, 10^{-3} mol/L, 2×10^{-3} mol/L, 3×10^{-3} mol/L, 4×10^{-3} mol/L, 6×10^{-3} mol/L, 7×10^{-3} mol/L, 8×10^{-3} mol/L, 10^{-2} mol/L, 1.1×10^{-2} mol/L, 1.2×10^{-2} mol/L, 1.3×10^{-2} mol/L, 1.4×10^{-2} mol/L, 1.5×10^{-2} mol/L, 1.6×10^{-2} mol/L, 1.7×10^{-2} mol/L, 1.8×10^{-2} mol/L, 2×10^{-2} mol/L, 3×10^{-2} mol/L, 4×10^{-2} mol/L, 5×10^{-2} mol/L, 6×10^{-2} mol/L, 7×10^{-2} mol/L, 8×10^{-2} mol/L. For each concentration, three parallel sets of solutions were prepared to minimize experimental errors arising from operational variations.

Weigh 1 g of each of the four samples separately and dissolve them in 1 L volumetric flasks to prepare a 1 g/L stock solution. Dilute the stock solution to concentrations of 0.05 g/L, 0.1 g/L, 0.2 g/L, 0.3 g/L, 0.4 g/L, 0.5 g/L, 0.6 g/L, 0.7 g/L, 0.8 g/L, 0.9 g/L.

Prepare four solutions of dodecyl fatty amine polyoxyethylene ether quaternary ammonium salts at a mass concentration of 1 g/L for testing wetting and foaming properties.

$$\Gamma_{max} = -\frac{1}{2.303nRT} \times \left(\frac{\partial \gamma}{\partial \lg C} \right)_T \quad \#(S1)$$

$$A_{min} = \frac{1}{\Gamma_{max} N_A} \quad \#(S2)$$

Where R is the gas constant ($8.314 \text{ J} \cdot \text{mol}^{-1} \cdot \text{K}^{-1}$), T is the absolute temperature (298.15 K), and N_A is the Avogadro constant (6.022×10^{23}). The term $(\partial \gamma / \partial \lg C)_T$ indicates the slope of the isotherm below the CMC. The value of n represents the number of species whose surface excess concentrations change simultaneously during the adsorption process. For 1:1 ionic surfactants in the absence of added electrolyte, n is theoretically taken as 2. However, considering the counterion binding effect (1- β) and the bulky polyoxyethylene (EO) chains which may screen the headgroup charge, the effective n might deviate from the ideal value. To maintain consistency with classical adsorption models for quaternary ammonium systems, n=2 was initially employed, while its impact on the calculated diffusion coefficients (D_{eff}) is further evaluated via sensitivity analysis^[1,2].

$$pC_{20} = -\lg C_{20} \quad \#(S3)$$

$$\Delta G_{mic} = RT \ln \left(\frac{CMC}{55.5} \right) \quad \#(S4)$$

$$\Delta G_{ads} = RT \ln \left(\frac{C_{\Pi}}{55.5} \right) - 6.022 \Pi A_{min} \quad \#(S5)$$

Where Π signifies the surface pressure of the saturated adsorption region ($\gamma_0 - \gamma_{cmc}$), and C_{Π} indicates the concentration of surfactant in the aqueous phase at surface pressure Π ^[3].

$$\Gamma(t) = 2c_0 \sqrt{\frac{Dt}{\pi}} - 2 \sqrt{\frac{D}{\pi}} \int_0^{\sqrt{t}} c_s d(\sqrt{t} - \tau) \quad \#(S6)$$

Where c_0 is the bulk surfactant concentration, and D is the monomer diffusion coefficient. $\pi = 3.142$, τ serves as a dummy variable of integration.

At the limit as $t \rightarrow 0$, which represents the initial stage of the adsorption process, back diffusion is negligible^[4]. Therefore, the surfactant solution can be viewed as a dilute system, enabling the linear Henry's isotherm (Eq. S7) to relate the subsurface concentration to surface tension^[5].

$$\gamma_{t \rightarrow 0} = \gamma_0 - 2nRTc_0 \sqrt{\frac{Dt}{\pi}} \quad \#(S7)$$

At long times ($t \rightarrow \infty$), the subsurface concentration (c_s) approaches the bulk concentration (c_0)^[6]. In this regime, the variation in c_s can be separated from the diffusion integral, and the Gibbs equation (Eq. S8)^[7] can be used to unify the integral.

$$\gamma_{t \rightarrow \infty} = \gamma_{eq} + \frac{nRT\Gamma_{eq}^2}{c} \sqrt{\frac{\pi}{4Dt}} \quad \#(S8)$$

Rosen proposed an empirical equation to describe how surface tension diminishes over time^[8,9].

$$\frac{\gamma_0 - \gamma_t}{\gamma_t - \gamma_{eq}} = \left(\frac{t}{t^*}\right)^n \quad \#(S9)$$

Taking the logarithm of both sides gives.

$$\lg \frac{\gamma_0 - \gamma_t}{\gamma_t - \gamma_{eq}} = n \lg t - n \lg t^* \quad \#(S10)$$

Here, γ_0 is the surface tension of the pure solvent, γ_t is the surface tension at time t , γ_{eq} is the equilibrium surface tension, n is a dimensionless constant related to the adsorption mechanism, and t^* is a time constant representing the time required for the surface tension to drop halfway between γ_0 and γ_{eq} . By plotting $\log [(\gamma_0 - \gamma_t)/(\gamma_t - \gamma_{eq})]$ versus $\log t$, a linear relationship is obtained. [$k = (\gamma_0 - \gamma_t)/(\gamma_t - \gamma_{eq})$].

The induction time (t_i) and the time to reach equilibrium (t_m) are defined as follows.

$$\lg t_i = \lg t^* - \frac{1}{n} \quad \#(S11)$$

$$\lg t_m = \lg t^* + \frac{1}{n} \quad \#(S12)$$

The rate of surface tension reduction at t^* , called $R_{1/2}$, is calculated by^[10]:

$$R_{1/2} = \frac{\gamma_0 - \gamma_{eq}}{2t^*} \quad \#(S13)$$

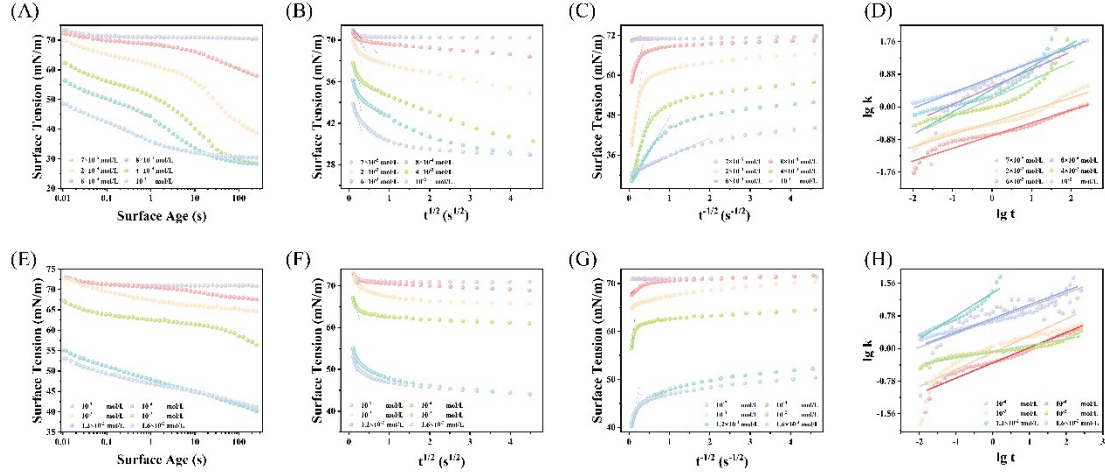


Fig. S1. The diffusion coefficients calculated for (A) S1202, (B) S1205, (C) S1210, and (D) S1215: $t \rightarrow 0$ and (E) S1202, (F) S1205, (G) S1210, and (H) S1215: $t \rightarrow \infty$. $\lg K$ as a function of $\lg t$ for different concentrations (mol/L) of (I) S1202, (J) S1205, (K) S1210, and (L) S1215.

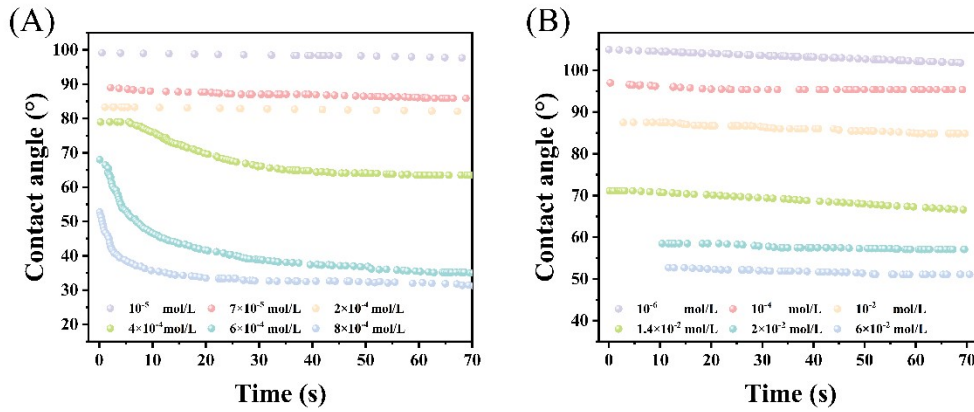


Fig. S2. The Contact angle of (A), (E) S1202, (B), (F) S1205, (C), (G) S1210 and (D), (H) S1215 in different concentrations (mol/L) at 298.15 K.

Young's equation:

$$\gamma_{LG} \cos \theta = \gamma_{SG} - \gamma_{SL} \quad \#(S14)$$

Where γ_{LG} , γ_{SG} and γ_{SL} represent the interfacial tensions of the solid-vapor, solid-liquid, and liquid-vapor interfaces, respectively.

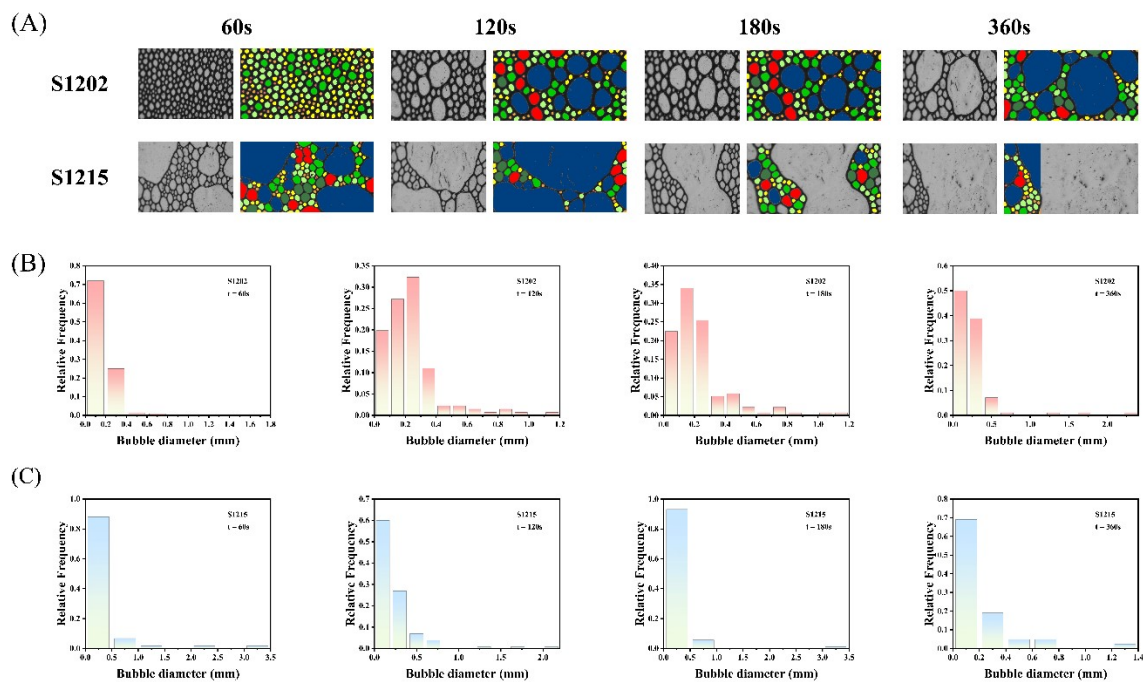


Fig. S3. (A) Images of foam produced by EDQS at different times, and statistical images of foam diameter at 298.15K. (B), (C) Frequency distribution of bubble diameters for EDQS at different time points at 1 g/L at 298.15 k

References

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