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Synthesis and properties of multilayered films foams

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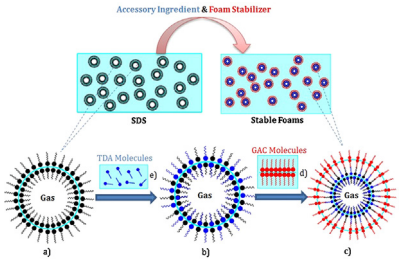
HIGHLIGHTS

- This innocuous system combines a good foamability and remarkable foam stability.
- The generated foams are multilayered liquid films.
- The stabilization mechanism relies on solubilization of TDA and hydrophobicity, hydrophobicity of GAC.

GRAPHICAL ABSTRACT



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ABSTRACT

The unstable nature of liquid foams is hampering their use in all the applications. This work presents a simple and versatile approach to prepare an innocuous system that combines a good foamability and remarkable foam stability. Anionic surfactant sodium dodecyl sulfate (SDS), gum acacia (GAC) and 1-Tetradecanol (TDA) were selected as main foaming agent, foam stabilizer and accessory ingredient respectively, which allowed the foams to present the performance of remarkable stabilization and multilayered liquid films. Besides, the differences of foam sizes have been obviously reduced, and bubble sizes are small and in range of 20–60 μm.

1. Introduction

Due to their outstanding properties, foams play an important role in a variety of different applications, ranging from porous materials [1–3] to cosmetics, food [4,5], fire protection, and oil recovery [6]. The thermodynamically unstable nature of liquid foams is a critical issue in all these applications [7]. Foam instability arises from the high interfacial area of the gas–liquid interface, and several physical processes take place in foams to decrease the overall system free energy, and those factors lead to foam destabilization [8]. A lot of strong efforts have been paid to understand the influencing factors of foam stability [9–13], and it is widely believed that the main destabilization mechanisms of liquid foams are drainage, coalescence and disproportionation [14]. Drainage is the liquid flow from foams due to the gravity and surface tension. As a result of drainage, foams change from spherical structure to polyhedral structure and the liquid films become thinner and thinner. Coalescence is the merging of two neighboring bubbles due to the rupture of the thin liquid films, as a consequence of which, larger bubbles appear in the foam and the number of bubbles decreases [14]. Disproportionation is the gas diffusion in foams as the result of different internal pressures between bubbles of different sizes [15]. Consequently, large bubbles grow and small bubbles shrink simultaneously, and all of them will disappear eventually.

Based on the study of the main destabilization mechanisms, abundant literatures have reported the study for the

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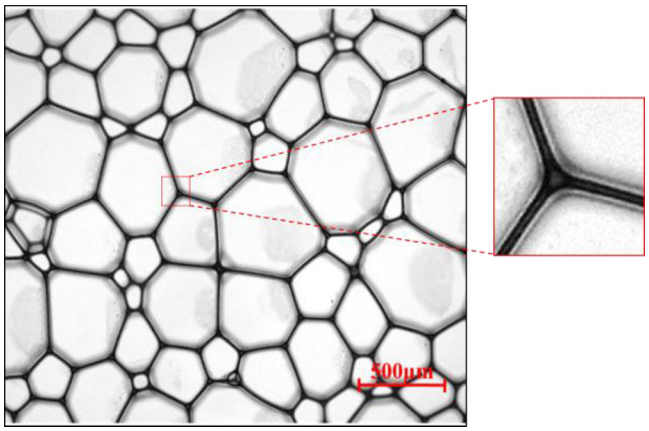

Fig. 1. The microstructure of normal foams.

improvement of foam stability. Approaches used for foam stabilization in past years can be mainly summarized as two kinds: stabilization with surfactants [16–19] and with particles [20–22]. Low molecular weight surfactants can be more easily adsorbed at the surface of the gas bubbles lead to good foamability. However, they can just be used to stabilize wet aqueous foams by preventing drainage and coalescence processes which is because low molecular weight surfactant molecules are dynamic with fluctuations when absorbed in surface of films so that air molecules can easily diffuse between two bubbles. When surface active macromolecules, such as proteins, are adsorbed at the surface of the gas bubbles to form adsorbed layers, the rate of disproportionation is reduced via the interfacial elastic mechanism yet often with quite low foamability [23]. In addition to being stabilized by surfactants, partially hydrophobic solid particles can be dispersed in water to form very long-lived foams [24–26] by generating aggregates at the surfaces of bubbles. These aggregates form a quite solid layer, and prevent the disproportionation. Nevertheless, the stabilization with particles is not sufficiently high to stop liquid drainage of foams, merely limit the liquid drainage by the aggregation of hydrophobic solid particles in the plateau borders [7,27]. Furthermore, the solutions of solid particles exhibit poor foamability due to the high adsorption barriers of those particles. Hence, it is a burning question to find a simple system exhibiting both high foamability and stability. Moreover, all the foams mentioned above are monolayer as is presented in Fig. 1.

There has been already abundant literatures reporting about self-assemblies made of surfactants or gels in the past, however, only a few literatures has been reported on foams until recently [28–30]. For instance, there has been a study use a fatty acid system made of the 12 hydroxy stearic acid (12-HSA) as foam stabilizer and successfully obtains ultrastable foams finally [31]. However, a large number of carboxyl occurring in the solution will be harmful to the environment and increase costs. Miller et al. [32] prepared mini-emulsions by employing SDS–hexadecanol (HDA) surfactant-cosurfactant system and the system showed an excellent stability. However, the rigidity of foam liquid film which prepared by hexadecanol is so large that it is easy to brittle fracture in the external disturbances.

Herein, this work presents a simple and versatile approach to prepare an innocuous system that combines a good foamability and remarkable foam stability. In order to achieve this goal, anionic surfactant sodium dodecyl sulfate (SDS), gum acacia (GAC) and 1-Tetradecanol (TDA) were selected as main foaming agent, foam stabilizer and accessory ingredient respectively. In addition, various properties of the foaming agent solutions and the stable bubbles were characterized.

2. Experimental

2.1. Materials

SDS (sodium dodecyl sulfate, ≥99% purity), GAC (gum acacia, ≥99% purity) and TDA (1-Tetradecanol, 97% purity) were purchased from Sigma Aldrich and selected as main foaming agent, foam stabilizer and accessory ingredient respectively. Deionized water was supplied from Aquapro Ultra-pure Water System.

2.2. Preparation and foaming of foaming agent bulk solution

The preparation of foams consists of two basic steps. Firstly, SDS, GAC, TDA and deionized water were successively added into a 500 mL beaker. The mixture was heated at 60 °C for 20 min to ensure all the solutes dispersed evenly in the solvent and then cooled at room temperature. Secondly, the mixture was stirred rapidly to generate foams for 8–10 min by JJ-1 numerical show precise power mixer at room temperature, and the speed was 1200–1300 rpm.

2.3. Characterization of the foaming agent bulk solution

2.3.1. Foamability

Foaming expansion of foaming agent bulk solution was selected to estimate foamability and can be calculated from the Eq. (1).

$$n = \frac{V}{V_0} \tag{1}$$

where V_0 is the volume of foaming agent bulk solution; V is the total volume of bubbles after stirred rapidly.

2.3.2. Surface tension

Surface tension of foaming agent bulk solution was tested by DCA315 Thermo Cahn Sigma Tensiometers and Wilhelmy Plate method was selected to measure the surface tension in this experiment. The measuring principle of the method is as follow: the platinum plate will be pulled down as far as possible due to the effect of surface tension around it when immersed into the liquid to be measured. The platinum plate stops immersing into the liquid when surface tension of liquid is equal to balance force. At that time, balance sensor of the instrument will measure the immersion depth of the platinum plate, and convert it into the values of surface tension.

Foamability and surface tension of SDS solution were measured by using the method as the same as bulk solution.

2.4. Characterization of the generated foams

2.4.1. Foam stability

The stabilities of the generated foams were estimated by measuring the bleeding and collapse of bubbles at different times. The generated foams were put into a 250 mL measuring cylinder which was placed in an environment of no wind, vibration and sunshine. The bleeding and collapse of bubbles were measured after standing in 1 h, 4 h, 12 h and 24 h. In order to show the stability of the foams better, the photographs of appearance structure of foams after standing in 0 h, 1 h, 4 h, 12 h and 24 h were taken with SONY camera TX-10.

2.4.2. Microscope photographs

Polarization microscope photograph of stable foams were taken with an Axioskop 40 Polarization Microscope. Fluorescence microscope photograph of stable foams were taken with OLYMPUS-BX51 fluorescence microscope.