Study on property and stability mechanism of LAB-AEO-4 system

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Abstract. The behaviors of binary blending systems of fatty alcohol polyoxyethylene ether (AEO-4) blended with the laurel amide betaine (LAB) was investigated at 80°C, the results indicated that the optimal ratio of the mixed system of LAB-AEO-4 was 5:2. The stability mechanism of LAB-AEO-4 system was analyzed from three aspects of dynamic surface tension, gas permeation rate and surface rheology. The results showed that the tension of mixed system was easier to achieve balance, the constant of gas permeation rate of the mixed system decreased by about 7% and the elastic modulus and dilational modulus increased by about 2 times compared with the single LAB system.

1. Introduction

Anionic and non-ionic surfactant is most widely used in tertiary oil recovery\cite{1}, the alkylbenzene sulfonate has been used in tertiary oil recovery of Daqing field and has achieved good economic benefits\cite{2}. For high temperature and high salinity reservoirs such as Zhongyuan Oilfield, the temperature reaches 85°C, the concentration of salinity more than 5×10^6 mg/L, the concentrations of calcium ion and magnesium ion more than 0.1×10^6 mg/L; the temperature of Tahe oilfield also more than 90°C, the concentration of salinity is more than 1.7×10^5~2.1×10^6 mg/L.\cite{3-4} Anionic surfactant may occur saltout phenomenon under high salinity, nonionic surfactant due to its low cloud point may precipitate under high temperature. Therefore, these two surfactants are not suitable for the high temperature and high salinity reservoirs. It is very important to study the heat-resistant and salt-tolerant surfactant system for the high temperature and high salinity reservoirs\cite{5}.

Betaine is one of the most common amphoteric surfactants which has been used in the tertiary oil recovery, and with a good heat-resistant property; fatty alcohol polyoxyethylene ether nonionic surfactant (AEO-4) is the fastest growing nonionic surfactant and with a good anti-salt performance, but with poor heat-resistant and foaming property\cite{6-7}. Therefore, study of the properties of LAB-AEO-4 system can make up their weakness, which has an actual value for the exploitation of the high temperature and high salinity reservoirs\cite{8}.

2. Experimental materials

Laurel amide betaine (LAB, 35 wt% aqueous solution); fatty alcohol polyoxyethylene ether (AEO-4, 35% aqueous solution); NaCl (99 wt%) and CaCl2 (98 wt%), all materials were obtained from China National Pharmaceutical Group Corporation.

DSA100 interfacial rheometer (German KRUS company); 501A super thermostatic bath (Shanghai Precision Instruments Co., Ltd.); warming blender Agitator; Precision balance (0.0001 g); Constant temperature water bath; Cylinders (100 mL, 1000 mL); Stopwatch and et al.
3. Results and discussion

3.1 Study on the foam properties of LAB-AEO-4 system

The surfactant solution was prepared with simulated formation, the concentration was 1g/L, waring blender agitator was used to produce bubble, the speed and time were 3000r/min and 60s respectively, then recorded the change of bubble volume as a function of time, the concentration of LAB was 1g/L, and the concentration of AEO-4 was changed. Fig. 1 shows the optimal proportion of the system is 5:2 at 80°C.

Fig. 1 Bubble curve of mixed system of LAB-AEO-4 at 80°C

3.2 Dynamic surface tension

Dynamic surface tension experiments of LAB system and LAB-AEO-4 system have been done at 25°C with the DSA100 interfacial rheometer obtained German KRUSS company, and the concentration of LAB was 1g/L. Fig. 2 shows the result.

Fig. 2 Curve of the dynamic surface tension

The dynamic surface tension curve can be divided into four zones: the induced area, the rapid subsidence area, the over balanced region and the equilibrium region. Using equation (1) to fit and analyze the first three zones, then obtained the Curve of the dynamic surface tension fitting, and calculate the dynamic surface tension decrease rate $n$, $t_1$, $t^*$ and $t_{1/2}$, which were used to measure dynamic interfacial adsorption process.

$$\gamma_t = \gamma_m + \frac{(\gamma_0 - \gamma_m)}{[1+(t/t^*)^n]}$$  \hspace{1cm} (1)
\[ R_{1/2} = \gamma_0 - \gamma / 2 t_{1/2} \]  

\( \gamma_0 \): surface tension under excessive equilibrium; \( \gamma \): dynamic surface tension at any moment; \( \gamma_0 \): initial surface tension; \( t^* \): constant; \( n \): no unit constant; \( R_{1/2} \): the decreasing rate of dynamic surface tension at \( t_{1/2} \).

The dynamic adsorption index were calculated as shown in Table 1. The result shows that the mixed components of LAB and AEO-4 do not effectively accelerate the decline of the surface tension, while the surface tension of single LAB system decreases slightly. The possible reason is that the interaction of the two surfactant molecules increases the molecular mass of the complex, thereby reducing the diffusion coefficient of the surfactants. Therefore, the adsorption of the new interface is decreased, and the volume of foam is lower than that of the single surfactant.

**Table 1** The dynamic surface adsorption index of the LAB-AEO-4 system

| m(LAB):m(AEO-4) | n  | t*  | R_{1/2} |
|-----------------|----|-----|--------|
| 1:0             | 1.2| 46.8| 46     |
| 5:2             | 0.6| 75.8| 39     |

### 3.3 Gas permeability

As everyone knows that the pressure in the small bubbles is higher than that in the large bubbles due to the existence of capillary pressure. Therefore, the gas from the high-pressure bubbles through the liquid film diffuses into the low-pressure bubbles, which results that the small bubbles become smaller, the large bubbles become larger, and bubble burst at the end. In order to further learn the stability mechanism of the mixed system, the gas permeation rate of LAB system and LAB-AEO-4 mixed system were studied.

Curve \( r_2^-t \) was drewed according to equation (3). Fig. 3 shows that the curve slope of LAB system and LAB-AEO-4 system were -0.00764 and -0.00752 respectively. Surface tension of LAB system is 37 mN/m, and the surface tension of LAB-AEO-4 mixed system is 30 mN/m, by calculating the gas permeability constant of LAB system and LAB-AEO-4 system are 0.014 cm/s and 0.013 cm/s respectively. The experimental results show that the gas permeability of LAB system is stronger than that of LAB-AEO-4 system. The reason may be that the liquid film of LAB-AEO-4 system become more compact due to the presence of AEO-4.

\[ r^2 = r_0^2 - 3k t \gamma / \rho \]  

![Fig. 3 Curve of bubble radius change with time](image)

#### 3.3.3 Surface dilational rheology

Study on the surface dilational rheology of LAB-AEO-4 system and LAB system at 25°C, Fig. 4 indicates that when the interface deformation rate is relative low, there is enough time to repair interfacial tension gradient through the relaxation process which caused by interfacial area change, so the dilational modulus slows down with the deformation speed decreases. When the dilational frequency is smaller than the characteristic frequency, the double logarithm curve of the expansion frequency and dilational
modulus is almost linear, the change range of curve slope is different for different relaxation process. The results show that the slope of the line is less than 0.5, which indicates that the main relaxation mechanism is the diffusion relaxation process between the interface and the bulk phase\(^{[10]}\). One of the key factor that affects the stability of foams is the film strength which mainly depends on the interaction between molecules that adsorb on the film surface, the elastic modulus is determined mainly by the interfacial molecular interaction, the interaction is greater, the greater the elastic modulus.

![Figure 4](image_url)

**Fig. 4** Effect of frequency on dilational modulus of different systems

4. Conclusion
The optimal mixed ratio of LAB-AEO-4 system was 5:2 at 80°C, the foam volume was 500mL, and the stable time was 30min. The tension of mixed system is more easy to achieve balance, the gas permeation rate constant of the mixed system decreased by about 7% and the elastic modulus and dilational modulus increased by about 2 times compared with that of the single LAB system.

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