

Laboratory Analysis of Foam Generating Surfactants and Their Thermal Stability for Enhanced Oil Recovery Application

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ABSTRACT

The residual oil after primary or secondary oil recovery can be recovered by the methods of EOR (Enhanced Oil Recovery). The objective of this study is screening the surfactants that generate maximum stable foam in the presence of brine salinity at 92°C. Laboratory experiments have been performed to examine and compare the stability of generated foam by individual and blended surfactants in the synthetic brine water. AOS_{C14-16} (Alpha Olefin Sulfonate) and SDS (Sodium Dodecyl Sulfonate) were selected as main surfactants. Aqueous stability test of AOS_{C14-16} and SDS with brine water salinity 62070ppm was performed at 92°C. AAS (Alcohol Alkoxy Sulfate) was blended with SDS and AOS_{C14-16}. The solution was stable in the presence of brine salinity at same conditions. Salt tolerance experimental study revealed that AOS_{C14-16} did not produce precipitates at 92°C. Further, the foam stability of surfactant blend was performed. Result shows that, the maximum life time of generated foam was observed by using blend of 0.2wt% SDS+0.2wt% AOS+0.2wt% AS-1246 and 0.2wt% AOS+0.2wt% IOS_{C15-18}+0.2wt% AAS surfactants as compared to the foam generated by individual surfactants. The success of generated foam by these surfactant solutions in the presence of brine water is the primary screening of surfactant stability and foamability for EOR applications in reservoirs type of reservoirs.

Key Words: Aqueous Stability, Brine Salinity, Foam Stability, Surfactants, Surfactant Alternating Gas.

1. INTRODUCTION

During gas injection, viscous fingering and gravity override problems are introduced. These problems are caused by low viscosity and low density of gas as compared to the other fluids such as oil and water. The problems mentioned during gas injection process can be improved by foam. The injection of foam either by using any EOR method such as FAWAG (Foam Assisted Water Alternating Gas), SAG (Surfactant Alternating Gas), or foam

flooding has gained increasing attention by oil industry due to potential advantages over other methods used in EOR [1-4]. The blend of surfactant can generate more foam therefore, improve the foam stability. Bubble size and volume fraction of gas from the generated foam are considered important parameters. These two parameters depend on foam components and application requirements [5].

The SAG injection process is considered as a good method to sweep the residual oil. The process shows

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apparent viscosity much higher than its constituent phases: liquid and gas. The foam generated by this method has a mobility much lower than the mobility of gas alone due to high apparent viscosity. Therefore, this process affords an effective means of controlling gas mobility of the displacing fluid [6-9]. The gas mobility is improved by minimizing the relative permeability and increasing the effective gas viscosity. Therefore, the overall sweep efficiency of this injection process is improved [10-13].

In the chemical EOR, anionic surfactants are widely used because of their low adsorption on sandstone reservoirs. AOS_{C12-14} anionic surfactant is proved to be an excellent foam insensitive to brine composition and tolerant to presence of crude oil [14]. Nonionic surfactants are used as co surfactants to improve system phase behavior. These types of surfactant are more tolerant to high salinity but cannot reduce much IFT as anionic surfactants. Amphoteric surfactants also known as zwitterionic surfactants are temperature and salinity tolerant. Amphoteric surfactant was used for medium to high viscosity crude oil, Lauryl betaine was blended with 4:1 blend of Neodol67-7PO sulfate and IOS_{C15-18}. The blend was tested in the secondary and tertiary oil recovery with good result of oil displacement because of gas mobility control [15].

Lot of research have been performed on different types of surfactants that generate foam. Also, field testing and implementation were reported using expensive surfactants due to the decline of overall oil production and increases in the oil prices [16]. The blend of different type of surfactants synergistically exhibit better foaming properties than those of individual surfactants. This research deals with single and blended surfactants in the presence of different brine salinity to generate the maximum foam. To achieve the objective of this research study, anionic surfactants (AOS_{C14-16}, AS-1246, SDS, IOS_{C15-16}) and one additive AAS are selected. The foam stability and durability of single and blended surfactant solutions with low and high concentrations in the presence of brine water are tested under static conditions. The blended surfactant solutions are beneficial to control the gas mobility and improve the sweep efficiency during the water alternating gas injection process. The

usage of surfactant (stable foam generated by single or blended surfactant solutions) minimizes the problems of early gas breakthrough, gravity override and viscous fingering during the water alternating gas injection process. This research is helpful for selecting the surfactant through screening of individual and blended surfactant solutions in the presence of brine water that generates maximum foam. This generated stable foam will help in the gas mobility control during the water alternating gas injection as EOR processes.

2. MATERIALS

Five types of surfactants AOS_{C14-16}, AS-1246, SDS, IOS_{C15-18} (Internal Olefin Sulfonate), and AAS were used for the foam stability test without further purification. The synthetic brine solution contained Sodium Chloride (NaCl), Magnesium chloride (Mgcl₂.6H₂O), Potassium chloride (KCL), Sodium bicarbonate (NaHCO₃), Sodium sulphate (Na₂SO₄) and Calcium Chloride (Cacl₂.2H₂O) were used with different concentration of single and blended surfactants. Table 1 shows the composition of brine water prepared in the laboratory.

Salt	Weight (mg/liter)
Sodium	23590
Chloride	37833
Calcium	408
Magnesium	239
Potassium	-
Bicarbonate	-
Sulphate	-
Total Salinity	62070

2. METHODOLOGY

3.1 Foam Stability Test

Concentrated solution of surfactant and brine water was mixed in a glass test tube, agitated and then settled for one hour in an oven at reservoir temperature of 92°C. The surfactant solution was considered stable when no phase separation or clouds has been observed.

To achieve the objective of the research study preliminary foam stability test was performed. The aim of this test was to analyze the ability of surfactant to stabilize the foam in the presence of brine salinity at 25°C. 10 ml of each surfactant solution was transferred into the 25ml graduated test tube. The cap of the test tube was tighten. The foam was generated by shaking of the test tube up to 5 minutes. The test tube was settled on the stand to read the generated foam height at the initial stage. At the initial stage, the foam height is measured from top of generated foam in the 25ml graduated test tube to the level of drained liquid in the test tube. After that, the generated foam stability and longevity was noted with respect to time in minutes. **Fig. 1** shows the generated foam by surfactant solutions using 25ml graduated glass test tubes.

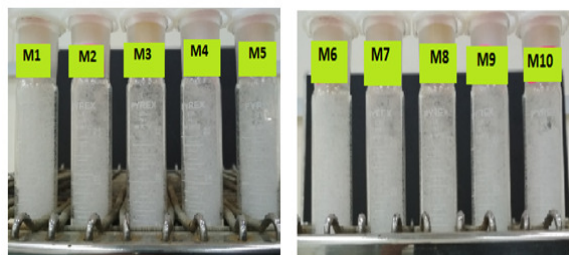


FIG. 1. FOAM GENERATED BY SURFACTANT SOLUTIONS AND FOAM STABILITY

4. RESULTS AND DISCUSSION

4.1 Foam Generation

Equal concentration of surfactant SDS was blended with additive AAS to maximize the range of brine salinity and strong foam generation. The test was performed with brine water at 25°C. Further, the surfactant IOS_{C15-18} was blended with equal concentration of AAS and SDS. This blend of surfactant solution was stable at the same conditions.

- (1) M1 = 0.2wt% SDS + 0.2wt% AAS
- (2) M2 = 0.2wt% SDS + 0.2wt% IOS_{C15-18} + 0.2wt% AAS

Fig. 2 shows the generated foam volume of surfactant solution at the initial stage and then decreased with time. 10ml solution of each sample was prepared in to the 25ml graduated glass test tube.

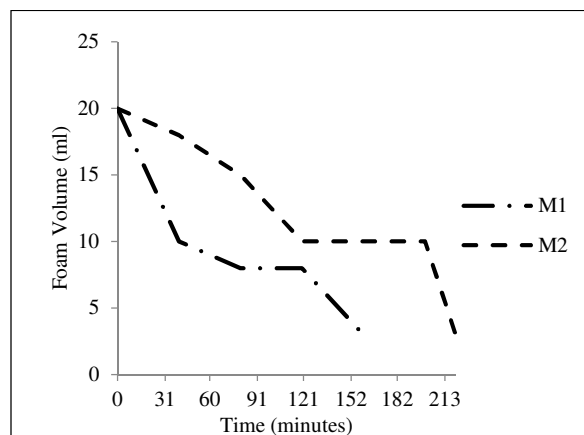


FIG. 2. GENERATED FOAM VOLUME AND ITS STABILITY BY SURFACTANT SOLUTION OF M1 AND M2

The foam was generated by shaking of 5 minutes and foam volume was recorded after drain out of liquid from the test tube. About 20ml foam was generated by M1 surfactant solution, whereas, M2 surfactant solution generated 22ml foam. Once the foam was generated in the test tube, the generated foam height was decreased due to the force of gravity (liquid drain through the lamellae). The foam volume of M1 was decreased continuously with time. Surfactant solution M2 was stable because of the surfactant SDS was blended with IOS_{C15-18} and AAS.

To maximize the foam stability and durability anionic surfactants SDS and AOS_{C14-16} were selected as the main surfactants. AS-1246 foamer was blended for stabilizing the maximum foam. Four surfactant solutions were tested for foam generating test.

- (1) M3 = 0.2wt% SDS
- (2) M4 = 0.2wt% SDS + 0.2wt% AS-1246
- (3) M5 = 0.2wt% SDS + 0.2wt% IOS_{C15-18} + 0.2wt% AS-1246
- (4) M6 = 0.2wt% SDS + 0.2wt% AOS_{C14-16} + 0.2wt% AS-1246

Fig. 3 shows the foam volume generated from these four individual and blended surfactant solutions.

22ml foam was generated from 10 ml solution of M3 individual surfactant. The same volume of foam was generated by surfactant solution of M4 blended surfactant, whereas 24ml foam was generated from M5 and 25ml foam height from M6 blended surfactant solutions in the graduated test tubes. Foam height generally increases with increase in the surfactant concentration.

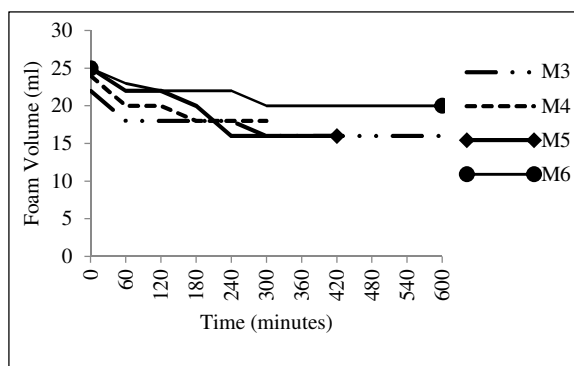


FIG. 3. GENERATED FOAM VOLUME AND ITS STABILITY BY SURFACTANT SOLUTION OF M3, M4, M5 AND M6

The foam volume generated from 10ml solution of M3 was stable with slowly decreased up to 600 minutes. The foam volume of M4 was decreased in 300 minutes, whereas, the foam volume generated by surfactant solution of M5 and M6 were stable up to 440 and 600 minutes. The solution of M3 was only the single surfactant SDS that has formed good foam volume 20ml at the initial time. The foam volume was stable and slowly decreased. The 16ml foam volume was noted in 600 minutes. The foam volume of M6 was more stable as compared to M3, because the SDS was blended with equal concentration of two

surfactants AOS_{C14-16} and AS-1246. The 20 ml foam volume was recorded in 600 minutes. The foam volume of M5 was stable up to 420 minutes and generated more foam volume as compared to M4. Further, four surfactant solution of AOS_{C14-16} were blended with IOS_{C15-18}, AS-1246 and AAS. The test was performed with brine water at 25°C.

- (1) M7 = 0.2wt% AOS_{C14-16}
- (2) M8 = 0.2wt% AOS_{C14-16} + 0.2wt% AS-1246
- (3) M9 = 0.2wt% AOS_{C14-16} + 0.2wt% AAS
- (4) M10 = 0.2wt% AOS_{C14-16} + 0.2wt% IOS_{C15-18} + 0.2wt% AAS

25ml foam volume was generated from 10 ml surfactant solution of M7 and M8. Surfactant solution M8 was the blend of AOS_{C14-16} and AS-1246 foam stabilizer but the solution of M7 was single surfactant AOS_{C14-16} only. Fig. 4 shows foam volume generated from four surfactant solution.

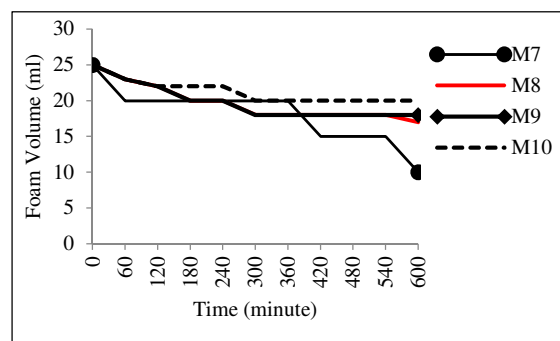


FIG. 4. GENERATED FOAM VOLUME AND ITS STABILITY BY SURFACTANT SOLUTION OF M7, M8, M9 AND M10

Surfactant solution of M10 produced good foam volume and was stable with long time duration. The surfactant solution M9 produced 20ml foam, whereas, M10 surfactant solution produced 22ml foam. The same foam volume was generated as foam generated by M1 and M2 surfactant solution. The foam volume generated from M9 was stable up to 160 minutes, and the foam volume of M10 was stable up to 220 minutes. The solution of M7 was only the AOS_{C14-16} that has formed good foam volume 25ml at the initial time. The foam volume was stable with long duration and slowly decreased with time. M8 solution was stable with long duration. At 600 minutes the foam volume of M8

surfactant solution was 18ml whereas, at the same time 10ml foam volume was noted by M7 surfactant solution. Surfactant solution M10 was considered as good foamer. The foam generated by the surfactant solution M10 is more stable due to high disjoining pressure and the electrostatic repulsion between the surfactant and enclosed bubble surfaces [17]. Surfactant solution either individual or blended surfactants that generates foam with maximum volume at the initial stage are considered to have a good foamability and those tested surfactant solution which produced foam with a less initial volume are considered to have a poor foamability. Less amount of generated foam by surfactant solution provides a moderate reduction in a gas mobility due to the coarsely textured foam. This type of generated foam contains small number of lamellae with large bubbles. Foam height at the initial stage by surfactant solutions increases due to the increase in kinetic energy. It leads that, the adsorption of surfactant molecules on the interface increases, so that the foam height increases.

5. CONCLUSIONS

- (i) No precipitation was observed by tested individual and blended surfactant solution in brine water at 92°C.
- (ii) The blended surfactant solution of M6 (0.2wt% SDS, 0.2wt% AOS, 0.2wt% AS-1246) and M10 (0.2wt% AOS, 0.2wt% IOS_{C15-18}, 0.2wt% AAS) improves the performance of generated foam and its stability.
- (iii) Blend of surfactants can lead to generate more stable foam than foam generated by individual surfactants.
- (iv) The study of surfactant structure with effects of head and tail group is recommended.

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