A Successful Alkali/Surfactant/Polymer Flooding Test on Silica Sand

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Abstract. The Alkali/Surfactant/Polymer formulation is selected based on surfactant solubility tests, phase behavior experiments, IFT measurements, polymer viscosity measurements and alkali/surfactant/polymer compatibility tests. Ultralow IFT ($<10^{-3}$ mN/m) can be achieved at optimal condition. Water flooding recovers about 60% of the OOIP. About 40% OOIP incremental oil recovery is obtained by injecting 0.5 PV ASP slug followed by polymer slug and the cumulative oil recovery is almost 100% OOIP. This paper is beneficial for designing a successful ASP process.

1. Introduction

Chemical EOR has attached great importance in recent years. Among these Chemical EOR methods, Alkali/Surfactant/Polymer (ASP) process is believed to have large potential to recover significant amount of oil after water flooding. Several synergistic effects between the in-situ generated soap and the injected synthetic surfactant occur in an ASP flooding process, for example, reduction of surfactant adsorption and sequestration of divalent ions [1-3]. It was recently found that the optimal salinity of Alkali/Surfactant/Crude oil system in ASP process is a function of soap/surfactant ratio [3, 4], which in turn depends on the soap number, water-oil ratio (WOR) and surfactant concentration. Liu et al. [4, 5] developed a one-dimensional, two phase, and multi-component finite difference simulator for ASP flooding to evaluate the characteristics of ASP process considering the synergistic effect of synthetic surfactant and in situ generated soap. It was also found [5] that the existence of soap/surfactant gradient in a properly designed ASP process ensured the process passing through optimal conditions where an active region of minimum IFT would be reached and a low residual oil saturation would be attained. Soap generation was also added in the ASP module in UTCHEM [6], which is a chemical flooding compositional simulator, with particular attention to phase behavior and the effect of soap on optimal salinity and oil/water solubilization ratios. Therefore, optimal salinity as a function of soap fraction is of great importance in formulation design and simulation of alkali/surfactant/polymer flooding process for enhanced oil recovery.

2. Experimental Section

2.1 Materials

As a weak alkali, sodium carbonate has been considered of greater importance than other alkalis, because it is inexpensive and can also reduce the extent of mineral dissolution. Therefore, sodium carbonate is chosen and studied extensively. The crude oil with 27.5 API° is from an oilfield in California. The surfactants are PO Sulfate (S1) and IOS (S2) from Stepan. The polymer used here is partially hydrolyzed polyacrylamide (HPAM) from SNF. The sodium carbonate and sodium chloride are from Sigma Aldrich.

2.2 Procedures

The Alkali/Surfactant/Polymer formulation is selected based on surfactant solubility tests, phase behavior experiments, IFT measurements, polymer viscosity measurements and alkali/surfactant/polymer compatibility tests. Surfactant solubility tests samples with different sodium carbonate concentration and surfactant concentration were prepared in 20 ml ampules and placed at reservoir temperature (54°C). Clarity of these samples were checked every week. Phase behavior samples with different water oil ratio (WOR), sodium carbonate concentration and surfactant concentration were prepared in pipettes pre-sealed at the bottom. After sealing the top using acetylene torch, these samples were shaken for 48 hours. Then, they were equilibrated at 54°C. After equilibration for 60 days, no further changes were observed and thus these samples were assumed to reach equilibrium. IFT measurement samples were prepared similar as those phase behavior samples except that these samples were prepared in 17 ml vials. The promising alkali/surfactant formulation can be selected based on surfactant solubility tests, phase behavior tests and IFT tests. Viscosity measurements with different polymer concentration and salinity were conducted using a Brooks Field viscometer. The compatibility tests were prepared by mixing the HPAM polymer with selected promising alkali/surfactant formulation to see if there is phase separation under 54°C. After the ASP formulation has been chosen, a sandpack flooding test was performed to characterize the effectiveness of developed surfactant formulation in displacing residual oil under reservoir conditions.

2.3 Apparatus

The setup for water flooding and ASP flooding on silica sand is exhibited in Figure 1.

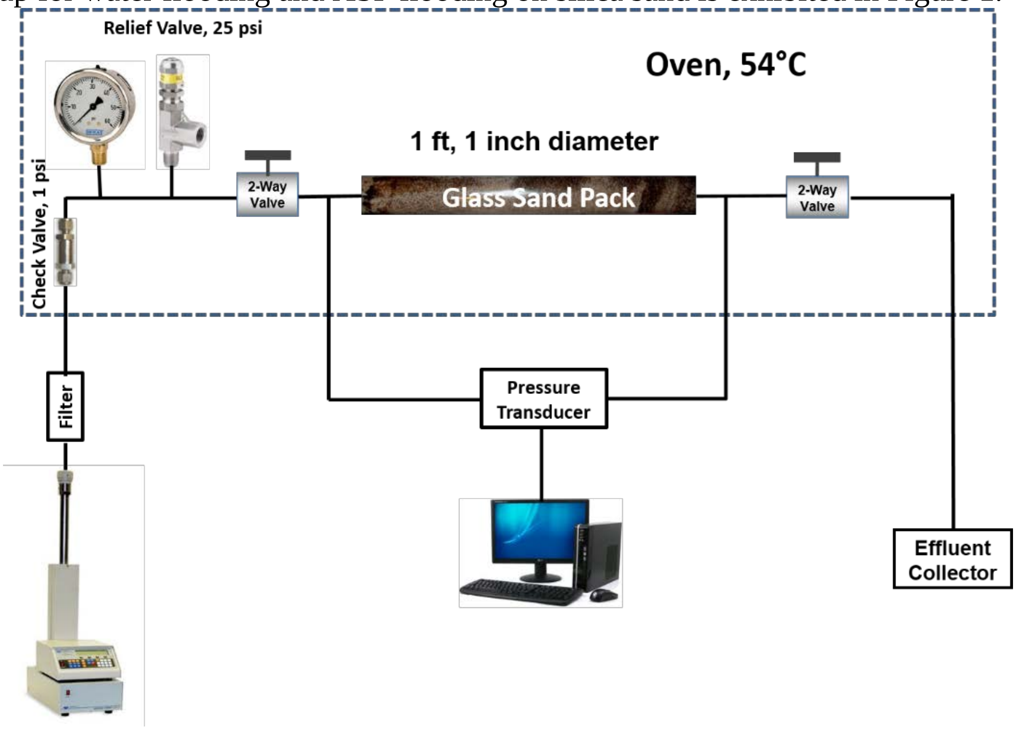

Figure 1 Schematic of Sandpack Flooding Apparatus

2.4 Results and Discussion

2.4.1 Formulation Design

The injection formulation should be clear, otherwise it may plug the formation. The solubility tests of surfactant mixtures indicate that mixture of S1 and S2 can be further studied if 1.0% Na_2CO_3 (or less) is proposed for injection. The desirable soap surfactant ratio gradient developed in a properly designed ASP flooding makes the process robust and permits injection at conditions well below optimal salinity of the synthetic surfactant, thereby reducing surfactant adsorption and improving compatibility with polymer. The phase behavior samples of 0.3% S1 and S2 (weight ratio, 4:1), containing 1.0% Na_2CO_3 concentration in aqueous phase and mixed with crude oil at a water to oil ratio (WOR) of 1 were prepared and equilibrated at 54°C for 60 days. The appearance of phase behavior samples is generally that of a conventional Winsor I, III, and II microemulsion sequence with some remaining emulsion that has not been yet coalesced. The optimal condition generally refers to the condition where the water solubilization parameter V_o/V_s and oil solubilization parameter V_w/V_s in middle phase microemulsion are equal.

The viscosity of aqueous phase determines the mobility ratio, which is very important for a successful ASP process. The aqueous phase viscosity is adjusted by changing the polymer concentration. The polymer concentration in ASP slug is 0.3%, and the viscosity of injection formulation is 20 cp at 54°C. Moreover, the alkali/surfactant/polymer should be compatible such that no phase separation occurred after long time equilibration, since the flooding process is slow and long, taking may be half a year or even longer. No phase separation occurred when ASP slug is prepared using the injection brine.

Samples for IFT measurements were first prepared and equilibrated at 54°C until equilibrium. Equilibrium IFT measurements using pre-equilibrated samples were conducted. The interfacial tension of crude oil against the optimized Na_2CO_3/surfactant formulation was studied. It is found that ultralow IFT (<10^{-3} mN/m) can be achieved at optimal condition.

Chemical consumption tests is important to measure the surfactant adsorption capacity of the rock to ensure enough surfactant is used in core flood experiments to offset the loss of surfactant to the rock surface. It is hypothesized that the surfactant adsorption on silica sand is negligible because the surface area is small and alkali can significantly reduce the surfactant adsorption.

2.4.2 ASP Flooding Results

The reservoir brine contains about 30,000 Total Dissolved Substance (TDS). A synthetic reservoir brine with the same TDS is prepared by sodium chloride and is used for sandpack flooding test. The sandpack flooding test was performed on a 15 Darcy sandpack to characterize the effectiveness of ASP formulation under reservoir conditions. The crude oil is the same as studied before with a viscosity of 8 cp at 54°C. Conventional water flooding recovers about 60% of the OOIP. About 40% OOIP incremental oil recovery is obtained by injecting 0.5 PV ASP slug followed by polymer slug and the cumulative oil recovery is almost 100% OOIP. The oil cut and cumulative oil recovery during ASP flooding test are exhibited in Figure 2. The oil bank breakthroughs at around 0.54 PV with the highest oil cut at around 80%. Moreover, the surfactant breakthroughs at approximately 0.83 PV, which is favorable because a significant amount of ‘clean oil’ free of emulsion problems can be obtained.

3. Conclusion

The procedure for development of an ASP process is proposed. The cumulative oil recovery is almost 100% OOIP by injecting 0.5 PV ASP slug followed by polymer slug. This paper is beneficial for designing a successful ASP process.

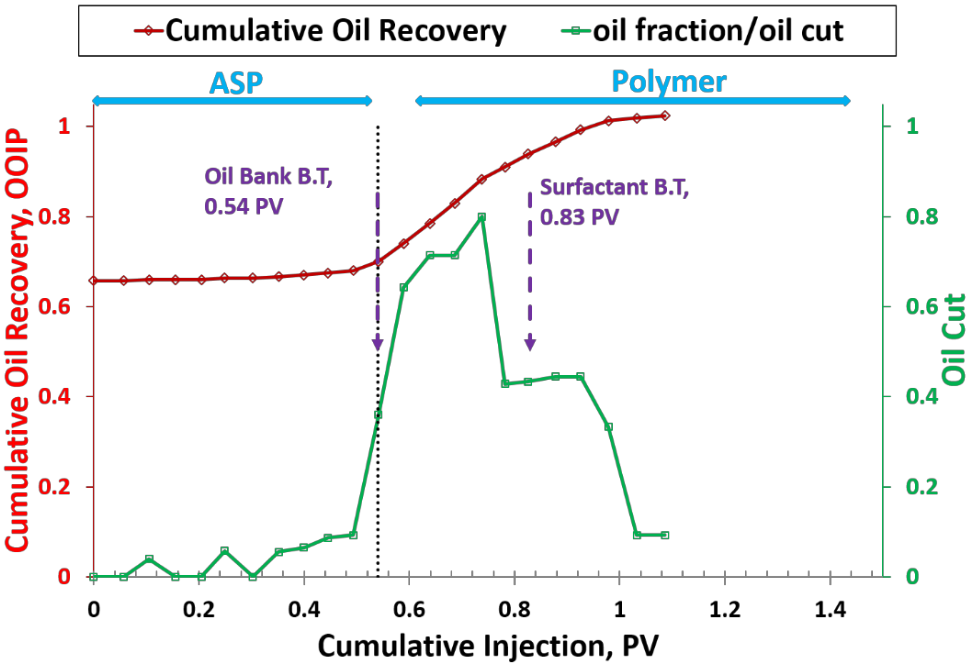

Figure 2 Oil Cut and Cumulative Oil Recovery during Chemical Flooding

REFERENCES

[1]. Nelson, R. C., Lawson, J. B., Thigpen, D. R., et al., Cosurfactant-enhanced alkaline flooding. Paper SPE 12672 presented at the SPE/DOE Enhanced Oil Recovery Symposium, Tulsa, April 15-18, 1984.

[2]. Flaaten, A., Nguyen, Q. P., Pope, G. A., et al., A systematic laboratory approach to low-cost, high-performance chemical flooding. SPE Reservoir Evaluation & Engineering, 12(5), 2009, 713-723.

[3]. Hirasaki, G. J., Miller, C. A., and Puerto, M., Recent advances in surfactant EOR. SPE Journal, 16(4), 2011, 889-907.

[4]. Liu, S., Zhang, D., Yan, W., Puerto, M., et al., Favorable attributes of alkaline-surfactant-polymer flooding. SPE Journal, 13(01), 2008, pp.5-16.

[5]. Liu, S., Miller, C. A., Li, R. F., et al., Alkaline/surfactant/polymer processes: wide range of conditions for good recovery. SPE Journal, 15(02), 2010, pp.282-293.

[6]. Mohammadi, H., Delshad, M. and Pope, G. A., Mechanistic modeling of alkaline/surfactant/polymer floods. SPE Reservoir Evaluation & Engineering, 12(04), 2009, pp.518-527.