The Evaluation of Foam Performance and Flooding Efficiency

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Abstract. ROSS-Miles and spinning drop interfacial tensionmeter are used to select suitable foam system through foam composite index (FCI) and interfacial tension (IT). The selected foam system are taken to conduct further test. The further tests are evaluating the foam system resistance to adsorption with multi-round core flooding dynamic adsorption test and evaluating the performance of foam system with four kinds of different transport distance, quantitatively analyzing the foam system effective distance after dynamic adsorption. The result shows that the foaming ability and the mobilizing ability of the foam system decrease with the increase of the round of dynamic adsorption. As the transport distance increases, the foaming ability and the mobilizing ability of the foam system decrease. This result further reveals the flooding characteristics of nitrogen foam flooding, which provides a reference for the implementation of nitrogen foam flooding technology.

1. Introduction

Aqueous foams play an important role in many industrial processes, from ore separation by froth flotation to enhanced oil recovery (EOR), where the foam is used as a means of increasing sweep efficiency through oil-bearing rock.(Jones et al,2016; Hou, Q,2012) .Foam is a colloidal dispersion in which a gas is dispersed in a continuous liquid phase. In porous media they can be seen as finely-textured bubbles of gas such as nitrogen, carbon dioxide, and methane, dispersed within a brine containing surfactants (Batôt et al,2016; Mannhardt and Novosad,1994). Surfactants are added to the solution to stabilize foam by reducing interfacial tension. Many studies demonstrated that surfactant stabilized foam could drastically reduce the gas mobility in the porous media, consequently improving volumetric sweep efficiency and oil recovery (Liu et al,2006 ;Yu , 2012). Surfactant imbibition is a new method to improve the oil recovery from tight rocks. The idea of this method is to introduce diluted surfactant solution to stimulate the oil recovery from low or ultra-low permeability formations. The loss of surfactant from aqueous solutions during propagation into tight rocks with ultra-low permeability is a major concern for surfactant imbibition EOR.(Wang et al,2012) The loss of surfactant from aqueous solutions during the propagation in the reservoirs, especially carbonate reservoirs, is one of the major concerns with chemical oil recovery processes.

2. Evaluation of the foam system foaming ability

The foaming ability of the foam system will be evaluated through FCI.

2.1 Apparatus and condition

The full experimental set-up mainly includes MRM-RI ROSS-Miles, gas mass flow controller, mass flow indicator, thermostatic water tank, gas tank, electronic balance and beakers

The test is conducted at 64℃，including 9 kinds of solution, they are numbered from 1~9.The content of foam agent is 0.4% and the content of foam stabilizer is 0.1%. Simulated water

(12144.7mg/L) is used as the experimental water. The experimental method is flowing gas method. N_2 is used as experimental gas and the gas liquid ratio is 1:1.

2.2 Results and analysis

Based on the target block reservoir condition, 9 foam system solutions are prepared and investigated their foaming ability with ROSS-Miles. The FCI of these solutions are shown in Figure 1.
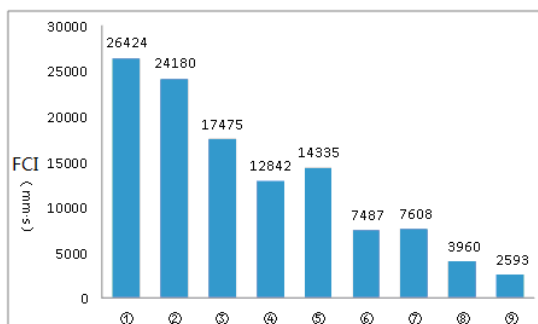
Figure.1 The FCI of foam in Honggang Gaotaizi block.

　　As is illustrated in Fig.1, under the Honggang Gaotaizi reservoir condition, No.3 and No.4 foam system have a lower FCI (less than 20000 mm • s), the foam system with higher FCI is ought to selected, so the No.1 and No.2 foam system are selected.

　　As a result of the Gaotaizi block's higher temperature and salinity, the foam FCI decreases to a certain degree. The water in Gaotaizi block with high content of divalent ion, makes No.3 and No.4 foam FCI decrease obviously. It illustrates that these 2 systems have poor resistance to divalent ion. On the contrary, No.1 and No.2 system FCI decrease lightly, it illustrates that these 2 systems have strong resistance to divalent ion.

3. Evaluation of the foam system mobilization

In this test, the foam system mobilization will be evaluated through analyzing the changing regulation of the interfacial tension(IT), and select 2 suitable systems with better mobilization.

3.1 Apparatus and condition

The foam performance evaluation test mainly includes following apparatus: spinning drop interfacial tensionmeter, high precision electronic balance, beakers and so on.

　　The tension between oil surface and water surface is separated to instantaneous interfacial tension and equilibrium interfacial tension. Instantaneous interfacial tension represents the change of distribution of surfactant molecule in oil-water interface in macroscopic view. Equilibrium interfacial tension is the stable value of the interfacial tension, the fields currently use the interfacial tension in 2h as the standard equilibrium interfacial tension.

3.2 Results and analysis

Based on the target block reservoir condition, 9 foam system solutions are prepared and investigated their interfacial tensions with spinning drop interfacial tensionmeter. The results are shown in Figure.2.
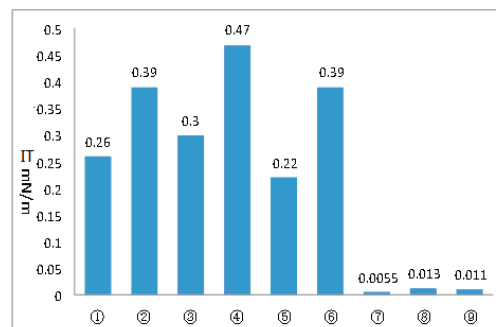
Figure. 2 The interfacial tension of foam in Honggang Gaotaizi block.

No.7 and No.9 foam systems are selected because of their lower interfacial tension. As is shown in Fig.2, the interfacial tension is not affected obviously by reservoir condition, it illustrates that all 9 kinds of foam system possess preferable resistance to high salinity and temperature in the aspect of decreasing interfacial tension.

Based on 2 tests above, No.1 and No.2 foam system are preliminarily selected as high blocking ability systems and No.7 and No.9 foam system are selected as high mobilization systems

4. Evaluation of foam core flooding performance with multi-round dynamic adsorption test

After one-time, two-time and three-time core dynamic adsorption, adsorption characteristics of various systems in different reservoirs will be analyzed, one system with high blocking ability and one system with high mobilization are selected from systems which have been selected above.

4.1 Apparatus and condition

The foam performance evaluation test mainly includes following equipments: high pressure and temperature foam performance evaluation device, ISCO pump, MRM-RI ROSS-Miles, gas mass flow controller, mass flow indicator, thermostatic water tank, gas tank, spinning drop interfacial tensionmeter, high precision electronic balance and beakers.

The test is conducted at 64℃, including 7 kinds of solution, they are No.1~No.4 and No.7~No.9 .The content of foam agent is 0.4% and the content of foam stabilizer is 0.1%. Simulated water (12144.7mg/L) is used as the experimental water. The experimental method is flowing gas method. N_2 is used as experimental gas and the gas liquid ratio is 1:1.

Taking the one-time adsorption test as an example, 4 PV foam solution is injected into a core to conduct one-time adsorption test and collect 4 PV produced fluid. 1PV fluid firstly flowing out is ignored to eliminate the effect of saturated water in the core. (Hypothesizing the first one PV fluid is water displaced by the foam). The rest of 3 PV produced fluid are finally taken to conduct FCI test and IT test. The two-time adsorption test and three-time adsorption test have the same testing procedure as one-time adsorption test.

4.2 Results and analysis

The FCI of foam system measured with ROSS-Miles is shown in Figure.3. The interfacial tension of foam measured with spinning drop interfacial tensionmeter is shown in Figure.4.
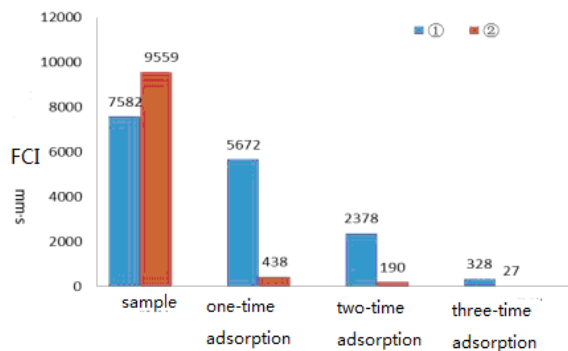
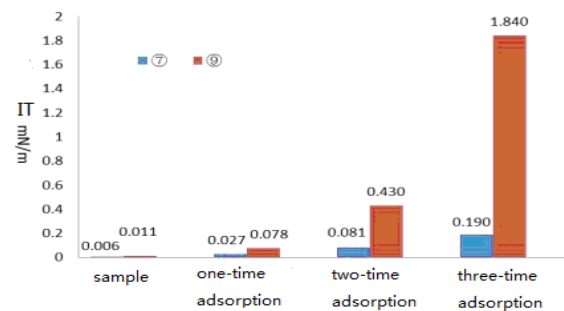**Figure.3** The FCI of foam system.   **Figure.4** The interfacial tension of foam system.

As is illustrated in Fig.3 and Fig.4, as the adsorption times increases, the foaming ability and the ability lowering the interfacial tension of foam both decline in different degree. It shows that the depletion of foaming agent solution during flowing in the core is a crucial factor for blocking efficiency and mobilizing efficiency.

As is shown in Fig.3, No.1 system has a better resistance to adsorption than No.2 system. No.1 system is selected as the high blocking ability foam system instead of No.2 system with high FCI. As is shown in Fig.4, No.7 system has a better resistance to adsorption than No.9. No.7 is selected as the high mobilizing ability foam system. Both foam systems are selected according with Honggang Gaotaizi reservoir condition.

5. Evaluation of foam system performance with various transport distances
In this test, the performance of No.1 and No.7 foam system with four kinds of transport distance will be evaluated. The foam system effective distance after dynamic adsorption will be quantitatively analyzed.

5.1 Apparatus and condition
The foam performance evaluation test mainly includes following equipments: high pressure and temperature foam performance evaluation device, ISCO pump, MRM-RI ROSS-Miles, gas mass flow controller, mass flow indicator, thermostatic water tank, gas tank, spinning drop interfacial tensionmeter, high precision electronic balance and beakers.

The test is conducted at 64℃，including 2 kinds of solution, they are No.1 and No.7.The content of foam agent is 0.4% and the content of foam stabilizer is 0.1%. The simulated water (12144.7mg/L) is used as the experimental water. The experimental method is flowing gas method. N_2 is used as experimental gas and the gas liquid ratio is 1:1

Model 1 is 0.3m long, the actual volume of injection foam system is equal to pore volume of the Module 1, and this injection volume amounts to 0.2PV injected to the model with 1m length. The entire injected foam system flows out at the region from the inlet 0.3m which is an equivalent distance of 30% of 1m-Model. The property of produced fluids from Model 1 represents the property of 0.2PV foam system transporting in reservoir for 30% of well distance. As an analogy, model 2, model 3, and model 4 are taken to conduct the same experiment, and the foam property of these 3 models is the equivalence of 0.2 PV foam transporting in reservoir for respectively 60%, 80% and 100% of the injector-producer distance.

5.2 Results and analysis
The FCI and IT of No.1 foam system and No.2 foam system are respectively shown in Figure.5 and Figure.6.
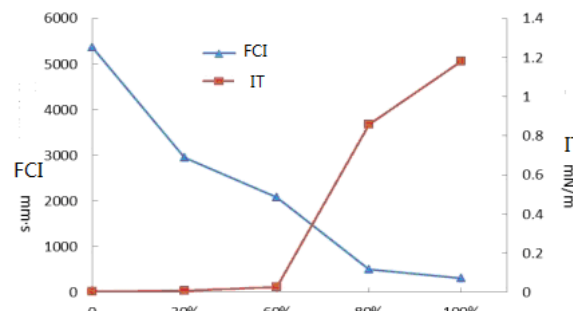
As is shown in Figure.5, the foaming ability and mobilization of No.1 foam system both decline with the increase of transport distance. It indicates the depletion of foam rises as distance increases. When front reaches 80% of distance, the FCI of No.1 foam is approached to 0, indicating No.1 foam

has lost blocking ability. When foam transport for 60% of distance, interfacial tension of No.1 foam shows greatly increasing, that means obvious decline of mobilization. We conclude that the effective distance proportion of No.1 foam system in Honggang Gaotaizi is 60%.

As is shown in Figure.6, the foaming ability and mobilization of No.7 foam system both decline with the increase of transport distance. When front reaches 80% of distance, the FCI of No.7 foam is approached to 0, indicating No.7 foam has lost blocking ability. When foam transport for 60% of distance, interfacial tension of No.7 foam shows greatly increasing, that means obvious decline of mobilization. The conclusion is that the effective distance proportion of No.7 foam system in Honggang Gaotaizi block is 60%.
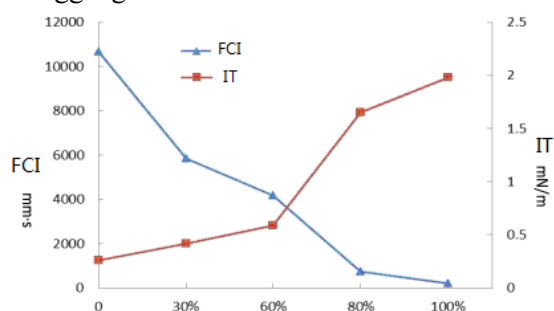
Figure.5 No.1 foam system.   **Figure.6** No.7 foam system.

The loss of chemical agent in formation has become the main factor affecting the development of foam flooding technology. From the experimental results, FCI declines drastically as foam system transport distance proportion is between 0~30%, indicating that main loss of foam occurs in the region less than 30% of distance from inlet. The effective distance of chemical agents governs the blocking efficiency and mobilizing efficiency during foam displacement.

6. Conclusions

(1) One kind of foam system with high blocking ability and one kind of foam system with high mobilizing ability are selected. Both selections are based on the condition of target block, that is the concentration of foaming agent is 0.4%, the concentration of foam stabilizer is 0.1%, and the gas liquid ration is 1:1. For Honggang Gaotaizi block, No.1 system and No.2 system are preliminarily selected as high blocking efficiency system. No.7 and No.9 are selected as high mobilizing efficiency system.

(2) A further selection for target block is conducted with one-time, two-time and three-time dynamic adsorption test. The high blocking efficiency system is No.1 system, and the high mobilizing efficiency system is No.7 system.

(3) The evaluation of foam performance with four different transport distances indicates, the effective distance proportion of No.1 system in Honggang Gaotaizi block is 60%; the effective distance proportion of No.7 system in Honggang Gaotaizi block is 80%. Effective distance will be shorten if core permeability decreases. Also, the rising of reservoir temperature and salinity will decline effective distance.

Acknowledgements

References

[1]   Jones, S. A., Laskaris, G., Vincent-Bonnieu, S., Farajzadeh, R. ,et al. (2016, April 11). Surfactant Effect on Foam: From Core Flood Experiments to Implicit-Texture Foam-Model Parameters. *Society of Petroleum Engineers*. doi:10.2118/179637-MS
[2]   Hou, Q., Zhu, Y., Luo, Y., Weng, R. ,et al. (2012, January 1). Studies on Nitrogen Foam Flooding For Conglomerate Reservoir. *Society of Petroleum Engineers*.

doi:10.2118/152010-MS

[3] Batôt, G., Delaplace, P., Bourbiaux, B. ,et al. (2016, November 7). WAG Management with Foams: Influence of Injected Gas Properties and Surfactant Adsorption. *Society of Petroleum Engineers.* doi:10.2118/183326-MS

[4] Mannhardt, K. and Novosad, J. J. (1994, February 1). Adsorption of Foam-forming Surfactants InBerea Sandstone. *Petroleum Society of Canada.* doi:10.2118/94-02-04

[5] Liu, Y., Grigg, R., and Svec, R. K. (2006, January 1). Foam Mobility and Adsorption in Carbonate Core. *Society of Petroleum Engineers.* doi:10.2118/99756-MS

[6] Yu,H. 2012. Transport and Retention of Surface-Modified Nanoparticles in Sedimentary Rocks. PhD dissertation, University of Texas at Austin, Austin, Texas (May 2012).

[7] Wang, D.M., Butler, R., Ahmed, S. and Liu, H., 2012. Wettability Survey in Bakken Shale Using Surfactant Imbibition. *SPE Reservoir Evaluation &amp*; Engineering, December, Volume 15 (6), 695–705. SPE-153858-PA.