Preparation and Properties of Foaming Agent for Air Foam Flooding

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Abstract: In order to meet the requirements of air foam flooding in Dagang Gangdong Oilfield, two kinds of foaming agents, GFPA-1 and GFPA-2, were prepared by sulfonation, neutralization and high-temperature hydrolysis of α-olefins with different carbon chain lengths in the laboratory. The test results of foaming agents for its properties showed that when the concentration of foaming agent was over 0.5%, the initial foaming volumes of the two foaming agent systems were more than 500mL, and the foam half-life of GFPA-2 was about 3.5 hours, obviously longer than that of GFPA-1. Therefore, GFPA-2 was selected as the foaming agent for air foam flooding. The experimental results of static adsorption, plugging and core displacement performance of GFPA-2 foaming agent showed that the initial foaming volume of GFPA-2 foaming agent could still maintain 500mL after 48 hours of adsorption at a concentration of 0.5%, and when the ratio of gas to liquid was 1: 1, the resistance factor was more than 50. When a 0.4% foaming agent was injected with 0.35 PV slug, the displacement efficiency of air foaming flooding was 17.4% higher than that of water flooding.

Keywords: Foaming agent, air foam flooding, foaming property, foam stability, resistance factor, oil displacement efficiency.

1. INTRODUCTION

In addition to the nitrogen flooding mechanism, air flooding also had low- temperature oxidation mechanism, forming carboxylic acids, aldehydes, ketones, alcohols, and other compounds, and generating heat and CO_2 gas, with the emphasis on improving oil-displacement efficiency [1]. Foam flooding was mainly done to increase swept volume.

Air foam flooding technology combined air flooding and foam flooding organically and had dual functions of profile control and oil displacement [2]. From the point of view of gas source and safety, natural gas, carbon dioxide, and nitrogen are often selected as the gas phase in conventional foam flooding. Although as a gas source, the air is abundant and cheap, but it was seldom used in foam flooding due to safety factors.

The research results of air injection oil recovery in light reservoirs at home and abroad have shown that oxygen in air reacts with light crude oil at low temperature, known as low-temperature oxidation (LTO), most of the oxygen gets consumed, and therefore the oil well output could be controlled within the safe limit range [3]. Field tests have shown that the air foam flooding had a good effect and no safety accident occurred.

One of the key technologies of air foam flooding was to optimize the excellent foaming agent systems, which were required to have strong foaming ability, stable foaming performance, and good plugging ability under the selected reservoir conditions [4,5]. Air foam flooding was a kind of tertiary oil recovery method which was suitable for high water cut and a high degree of reserve recovery in the later stage of oilfield development. At present, the technology is still being explored internationally.

To promote the implementation of the air foam flooding project in Dagang Gangdong Oilfield, a foaming agent system suitable for the air foam flooding requirement of Dagang Oilfield had been developed and was screened based on the evaluation of the existing foaming agent performance, which laid a foundation for the successful pilot test project of air foam flooding in Dagang Gangdong Oilfield.

2. EXPERIMENT

2.1. Materials and Instruments

α-olefins of different carbon chain lengths (C_{14},C_{16}, industrial grade), purchased by Tianjin Haina International Trading Company. Sulfonating agent liquid sulfur trioxide (SO_3, industrial grade), produced by Tianjin Sulfuric Acid Plant. Sodium hydroxide, isopropyl alcohol (analytically pure), purchased by Beijing Chemical Reagent Company. Dagang crude oil with a density of 0.8878 g/cm^3, field injection water with a salinity of 5000mg/L and Dagang oil sands, particle

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size distribution 60-100 mesh, provided by Oil Production Technology Institute of Dagang Oilfield Company.

Sulfonation reaction device, self-made. High temperature and high-pressure reactor, produced by Dalian No.4 Instrument Factory. Resistance Factor Measurement and Core Displacement Unit, produced by Jiangsu Huaan Scientific Research Devices Co., LTD. WARING 34BL99 Mixer, produced by WARING Company, USA.

2.2. Preparation of GFPA-1 and GFPA-2

Two kinds of foaming agents, GFPA-1 and GFPA-2, were synthesized by sulfonation, neutralization and hydrolysis of α-olefins with different carbon chain lengths (C14 and C16) in different proportions (7: 3 and 3: 7) [6].

2.3. Foam Performance Evaluation Methods

Waring Blender method was used to evaluate the foaming property and foam stability of the foaming agent. The experimental steps are as follows: 100 mL of the foaming agent solution was poured into a Waring Blender, stirred at 6500 r/min for 1 min, and the foam formed was then poured into a 1000 mL measuring cylinder. Record the foam volume at different times, and the time taken for the foam volume to decay by half was the half-life of the foam. The longer the half-life was, the more stable the foam was.

2.4. Static Adsorption Experiment of Foaming Agent

The static adsorption test method is as follows: 50g, 100g of Dagang oil sand, and 200mL of foaming agent solution were added into tapered flasks respectively, and were shaken in a round-trip oscillator at 65˚C for 48h. After 30 minutes' standing, the mass fraction of active substance in the foaming agent was analyzed by the two-phase titration method [7], and the adsorption amount of foaming agent was calculated from initial concentration and equilibrium concentration. At the same time, 100 mL supernatant was taken to evaluate the foam performance, and the foam performance before and after adsorption was compared.

2.5. Test Method and Procedure of the Resistance Factor

The test conditions of resistance factor are as follows: core permeability: 1300mD, porosity: 32%, core diameter: 30mm, core length: 600mm, Injection rate: 1 mL/min, experimental temperature: 65˚C, back pressure: 15MPa. A one-dimensional single-tube core model filled with oil sand was used in the dynamic evaluation. The single-tube model was placed horizontally in a constant temperature oven. First, the core was saturated with water, and the core water phase permeability was measured, then water and air were injected into the core at the same time according to a certain gas-liquid ratio. When the pressure difference between the two ends of the core reached a stable level, the pressure difference between the two ends of the core was recorded as the basic pressure difference. Finally, under the same conditions, air and foaming agent were injected, and when the pressure difference between the two ends of the core reached a stable level, the pressure difference between the two ends of the core was recorded again as the working pressure difference. The resistance factor is the index to measure whether the foaming agent could produce foam in the oil layer and whether it had the effect of changing the direction of the displacement medium. The resistance factor is defined as the ratio of working pressure difference to basic pressure difference. It is believed that in the process of injecting foaming agent solution when the resistance factor reaches above 4.0, the foaming agent could play a certain role in profile control in the oil layer.

2.6. Experiment of Air Foam Displacement Efficiency

1. Single-Pipe Core Displacement Test

Test conditions for single-pipe core flooding are as follows: Core permeability: 1300mD, core diameter: 30mm, core length: 600mm, oil saturation: 88.3%, injection rate: 1mL/min, experimental temperature: 65˚C, back pressure: 15 MPa. When 98% of water cut was reached by water flooding, air foam slug was injected with the ratio of gas to liquid 1:1 and water flooding was continued until the water cut was 98%.

2. Double-Pipe Core Displacement Test

Test conditions for double-pipe core flooding are as follows: permeability of the two cores: 1000mD and 5000mD, core diameter: 30mm, core length: 600mm, average oil saturation: 85.6%, injection rate: 1 mL/min, experimental temperature: 65˚C, back pressure: 15 MPa. When 98% water cut was reached by water flooding, air foam slug was injected with the ratio of gas to liquid 1:1 and water flooding was continued until the water cut was 98%.

3. RESULTS AND DISCUSSION

3.1. Foaming Properties of GFPA-1 and GFPA-2 Foaming Agents

The foaming properties of two kinds of foaming agents, GFPA-1 and GFPA-2, were evaluated at room temperature. The results are shown in Figures **1** and **2**. As can be seen from Figure **1**, the foam volume of GFPA-1 is slightly higher than that of GFPA-2 in the concentration range of 0.1%-0.7%, and the initial foam volume reached over 500mL when the foaming agent concentration was greater than 0.4%. As can be seen from Figure **2**, the foam half-life of GFPA-2 is over 2.5 hours, significantly higher than that of GFPA-1. Considering the foam comprehensive index [8], the performance of GFPA-2 is better than that of GFPA-1. Therefore, GFPA-2 is preferred as the foaming agent for air foam flooding.

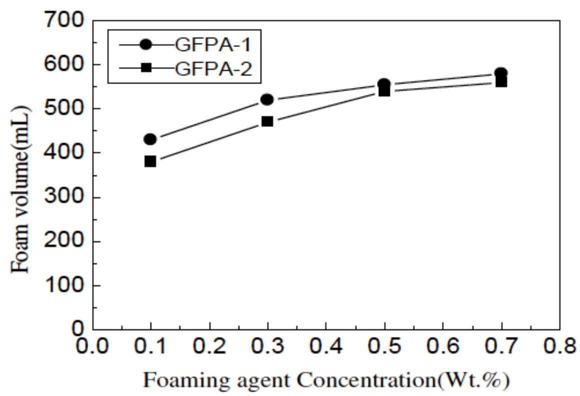

Figure 1: Foaming properties of GFPA-1 and GFPA-2.

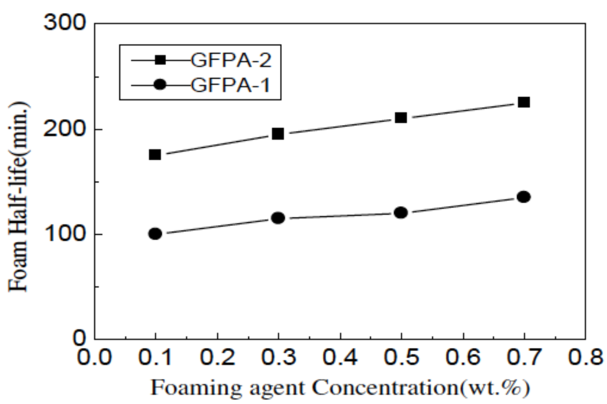

Figure 2: Foam stability of GFPA-1 and GFPA-2.

3.2. Static Adsorption Experiment of GFPA-2 Foaming Agent

The static adsorption test results of the GFPA-2 foaming agent on Dagang oil sand are shown in Figure **3**. The foaming properties of GFPA-2 changed slightly in the concentration range of 0.3%-0.7% after 48 hours of adsorption with different amounts of oil sands (0g, 50g, 100g) added into 200ml foaming agent solution, and the foaming volume of the foam system could reach over 500ml when the concentration of foaming agent was 0.5% or above. The two-phase titration method [7] was used to analyze the mass fraction of the active substance in the foaming agent, and the adsorption capacity of the foaming agent on the Dagang oil sand was less than 1.0 mg/g, which could meet the field requirements of the Dagang oil field.

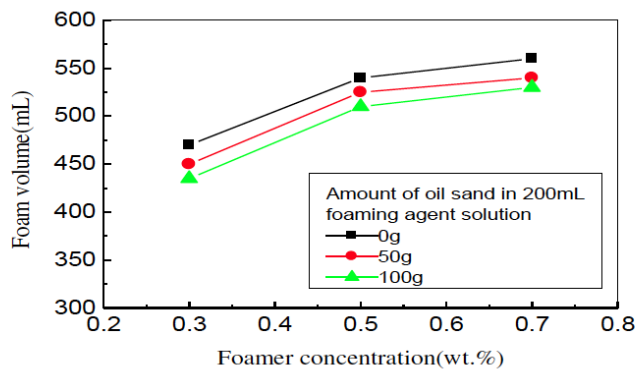

Figure 3: Foaming properties of GFPA-2 foaming agent after 48 hours of adsorption.

3.3. Resistance Factor Test of GFPA-2 Foaming Agent

Figure **4** shows that the resistance factor of GFPA-2 varied with injection volume at different gas-liquid ratios and a concentration of 0.3% foaming agent. It can be seen that the resistance factor of the system increased with increasing PV number, and the trend of increase gradually slowed down. When the ratio of gas to liquid is 1: 1, the resistance factor is the largest, and the profile control and plugging ability of the system is the strongest. Therefore, it was suggested that the optimum gas-liquid ratio should be 1: 1.

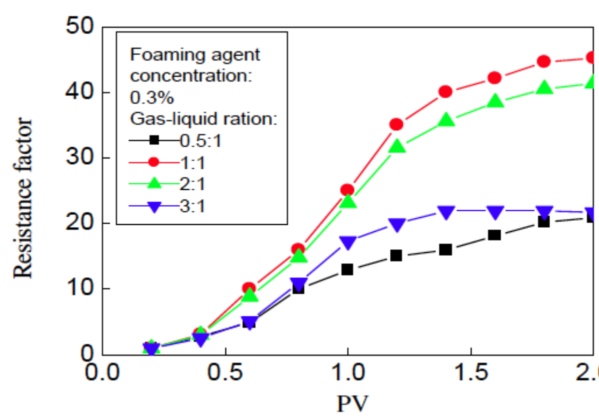

Figure 4: Variation of resistance factor with PV number at different gas-liquid ratios.

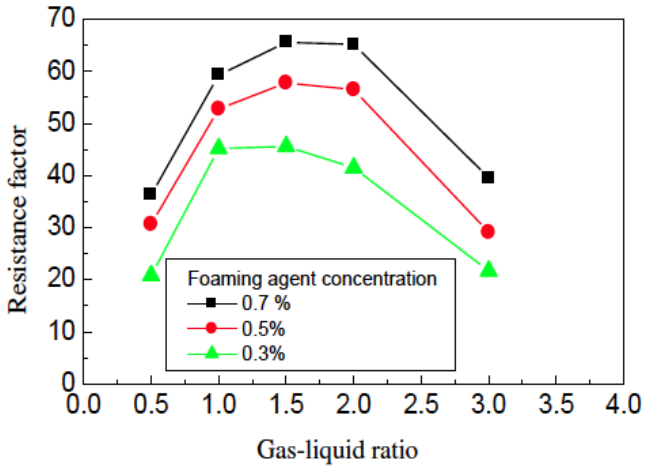

Figure 5: Variation of resistance factor with gas-liquid ratio at different foaming agent concentrations.

Figure **5** shows the resistance factor of GFPA-2 varied with gas-liquid ratios at different foaming agent concentrations. It can be seen that the resistance factor of the system is higher in the gas-liquid ratio range of 1:1-2:1, which is basically consistent with the results of Figure **4**. At the same time, it can be seen that with the increase of the concentration of the foaming agent, the resistance factor of the system is increasing, but the trend is slowing. Considering the economic factors, it was recommended that the concentration of GFPA-2 foaming agent should be within the range of 0.3%-0.5%, i.e. 0.4%.

3.4. Experiment of Air Foam Displacement Efficiency

Single-pipe core and double-pipe core displacement experiments were carried out in the laboratory with GFPA-2 foaming agent. The permeability, pipe diameter, and pipe length of the cores were listed in Table **1**. Foaming agent concentration and slug size: 0.4% and 0.35PV. The experimental results are shown in Table **1**. It can be seen that the oil-displacement efficiency in the single-pipe core is 11.1%, and the oil-displacement efficiency in the double-pipe core is 17.4%. The double-pipe core displacement experiment could better reflect the profile control effect of cores with different permeability. The high permeability layer was plugged by foam to a certain extent, and the low permeability layer was produced, thus achieving a better displacement effect.

4. CONCLUSIONS

(1) GFPA-2 foaming agent was developed and screened as the foaming agent for air foam flooding, the initial foaming volume was over 500mL, and the half-life of foam was more than 2.5 hours at a concentration of 0.4%, which could meet the requirements of air foam flooding in Dagang Gangdong Oilfield.

(2) The static adsorption experimental results showed that after 48 hours of adsorption, the foam volume of GFPA-2 could reach over 500ml at a concentration of 0.5% and the static adsorption amount was below 1.0 mg/g core sand.

(3) The experiment of resistance factor showed that the optimal injection conditions for air foam flooding are: gas-liquid ratio 1:1, foaming agent concentration range 0.3%-0.5%.

(4) Core displacement experimental results showed that air foam flooding could effectively improve the displacement efficiency of cores. When a 0.4% foaming agent with 0.35 PV slug size was injected, the double-pipe core enhanced oil recovery by 17.4%.

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Table 1: Oil Displacement Test Results of Single-Pipe Core and Double-Pipe Core

Core	Core permeability	Average oil saturation	Core diameter	Core length	Oil recovery of water flooding	Oil recovery of air foam flooding	Total oil recovery
Single-pipe	1300mD	88.3%	30mm	600mm	47.3%	11.1%	58.4%
Double-pipe	1000mD	85.6%	30mm	600mm	44.2%	17.4%	61.6%
	5000mD						

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