Laboratory study on high-efficiency viscosity reducer in high temperature and salinity of heavy oil reservoir

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Abstract. The Z70 reservoir of Huabei Oilfield is the typical heavy oil reservoir of high viscosity and high contents of gum and asphaltine, while there exists a serious problem that the effect of water injection is poor. In this paper, to increase oil displacement efficiency and improve reservoir development effects, the performance of seven different types of surfactants was studied, which combined with reservoir temperature and oil properties. Then, the emulsifying ability of the system was quantitatively characterized by water diversion rate combined with Turbiscan Lab. At the same time, the performance such as interfacial activity and static adsorption loss was studied under reservoir condition to obtain the viscosity reducing product with high-efficiency emulsification. Considering the performance such as interfacial activity and static adsorption loss, the viscosity reducing product with high-efficiency emulsification was preferred for high-temperature and high-salt heavy oil reservoirs. Thus, the surfactant experiment was carried out to test the performance and applicability. One kind of surfactant, nonionic-amphoteric-anionic, was selected, which showed good dispersity and could form super-low interfacial tension with the crude oil of fault block Z70 in Huabei Oilfield. The interfacial tension reached 5×10^{-4} mN/m when the concentration of the surfactants was 0.5%. And the No.1 combined system showed preferable emulsion performance with crude oil which stood for 30 minutes with no water precipitating out. It also provided, after 180 minutes, the emulsion system was completely demulsified, which could be re-emulsified after slight shaking. Good viscosity reducing property was showed with the oil-water ratio range of 1:1~1:9, which viscosity reduction rate was more than 99.5%. Furthermore, low static adsorption loss was showed when the adsorption capacity was less than 4.4mg/g. The experiments indicated that No.1 non-ionic-amphoteric-anionic composite surfactant could be determined to be the efficient viscosity reducer for fault block Z70 in Huabei Oilfield.

1. Introduction
Because of the influence of factors such as asphaltene and gum, heavy oil has a high viscosity, which increases the difficulty of exploitation and transportation of heavy oil fields[1]. The extraction and
transportation of domestic heavy oil mainly used thermal viscosity reduction methods, which have high energy consumption and high cost[2]. In view of the above situation, Chemical emulsification can be used to reduce viscosity, which contributes to decrease the difficulty of heavy oil extraction and transportation. This method can lessen energy consumption and thus cut down unnecessary expenses. That is to add a certain amount and concentration of surfactant aqueous solution to the heavy oil to make the heavy oil form Q/W emulsion, thereby reducing the friction between the fluid and the pipe wall, which can effectively decrease the viscosity of the heavy oil and improve the oil displacement efficiency [3,4]. Then cut down the energy consumption and cost of heavy oil exploitation [5]. In view of the large differences in the surfactants required for emulsification and viscosity reduction of heavy oils with different oil properties, the screening of surfactants suitable for the oil properties of heavy oil in specific block must be carried out [6].

The fault block Z70 of Huabei Oilfield is a heavy oil reservoir in the main block, with the gel content up to 50%, high crude oil viscosity and high reservoir temperature. As the fault block enters the later stage of water flooding and the number of multi-round profile control increases, it is more difficult to further improve the recovery rate. Therefore, there is an urgent need for a surfactant system suitable for the heavy oil in Z70 fault block to improve the oil displacement efficiency and thereby increase the oil recovery rate. In this article, the dispersibility, interfacial tension, and emulsification combined with properties such as viscosity reduction of seven surfactants for Z70 heavy oil were studied, so as to select the most suitable surfactant for the heavy oil system. And on this basis, the static adsorption loss on the clean sand was also studied, which would provide high-performance surfactants for tertiary recovery in oil fields.

2. Experiment

2.1. Reagents and materials
In the experiment, the oil phase used to determine the interfacial tension, emulsification and oil displacement was the dehydrated crude oil from fault block Z70 in Huabei Oilfield. The oil properties were shown in Table 1. The water phase was reinjected water after treatment in the station, which salinity 11529.0mg/L. The tested surfactants were seven different types of surfactants: No.1, No.2, No.3, No.4, No.5, No.6, and No.7, the specific types were shown in Table 2.

Table 1. The basic performance test results of crude oil

| Crude          | Reservoir temperature (℃) | Glue content (%) | Wax content (%) | Crude viscosity (50℃) (mPa.s) | Underground crude viscosity (mPa.s) | Crude acid value (mg/KOH.g) |
|----------------|---------------------------|------------------|-----------------|-------------------------------|------------------------------------|-----------------------------|
| Dehydrated crude oil | 93                        | 50               | 6               | 2831                          | 193                                | 1.5                         |

2.2. Experimental method

2.2.1. Dispersion. The surface active agent samples were treated with reinjection water to prepare 0.5% and 1% aqueous solutions, respectively, to observe the dispersibility of the solutions at the two concentrations.

2.2.2. pH value. Prepared 0.5% and 1% surfactant aqueous solutions with the reinjected water after treatment, and measured the pH value with an acid meter.

2.2.3. Interfacial tension. The surface active agent was formulated into 0.5% and 1% aqueous solutions, and the dehydrated crude oil of the Z70 block was heated for later use. The surface tension under the formation temperature was measured by the TX500C rotating drop interfacial tensiometer at a rotation speed of 3000r/min, and recorded at intervals.
2.2.4. emulsifying ability. The water diversion rate and Turbiscan Lab stability analyzer were used to quantitatively evaluate the emulsification ability of different types of surfactants in order to study the influence of different surfactants on the emulsification effect.

2.2.4.1. water diversion rate. The surfactant at a concentration of 0.5% was mixed with dehydrated crude oil according to an oil-water ratio of 1:9, which placed in a 100mL closed test tube, and preheated at the reservoir temperature for 30 minutes. At a speed of 120r/min, used a mixer to mix for 1 min. Let it stood still at the oil reservoir temperature, timing at the same time. Observed and recorded the water diversion situation regularly, until the volume no longer changes. The calculation formulas of water diversion rate is like following [7]:

\[ E = \frac{V_w}{V} \times 100\% \]  

(1)

E is the water diversion rate. Vw is the volume of water diversion. V is the volume of water phase in emulsion.

2.2.4.2. Stability analysis. Prepare the oil-water emulsion according to the same method and ratio as 2.2.4.1 and put it into the test bottle into the Turbiscan Lab stability analyzer for measurement at 90°C. Scanned every 30min for a total of 24h. Tested the variation curve of backscattered light intensity with time for different samples and different heights.

2.2.5. Viscosity reduction performance. Prepared the oil-water emulsion according to the same method and ratio as 2.2.4.1, and test the viscosity value with MARS rheometer under the conditions of 50°C and 27s\(^{-1}\). The viscosity of dehydrated crude oil was a blank value.

2.2.6. Static adsorption loss. Two-phase titration[8] was used to determine the concentration of the solution before and after adsorption. According to the difference between the initial concentration and equilibrium concentration of the surfactant before and after adsorption, the calculation formula is as follows [9, 10]:

\[ \eta = \frac{\left(C_0 - C\right) \times V}{G} \times 10^{-3} \]  

(2)

where \( \eta \) is the Static adsorption capacity. V is the volume of the surfactant solution. \( C_0 \) is the initial concentration of the surfactant solution. \( C \) is the equilibrium concentration of the surfactant solution. G is the Sand quality.

3. Results and discussion

3.1. The basic performance evaluation of surfactant

Each surfactant was prepared into 0.5% and 1% solutions with reinjection water, while the appearance, dispersibility and pH value were observed. The experimental results are shown in Table 2. It can be seen from the table that the 7 types of surfactant solutions were all weakly alkaline. Except for No.6, all of them could form a uniform precipitation-free solution with good compatibility.

Table 2. The basic performance evaluation of each surfactant

| Sample number | Types                      | Concentration (%) | Exterior                      | Dispersion                    | pH   |
|---------------|----------------------------|-------------------|-------------------------------|-------------------------------|------|
| No.1          | Nonionic-Amphoteric-Anionic| 0.5               | Emulsion                      | Uniform and no precipitation | 8.0  |
| No.2          | Non-ion-anion              | 0.5               | Colorless transparent liquid  | Uniform and no precipitation | 7.3  |
| No.3          | Alkyl Sulfonate            | 0.5               | Colorless                     | Uniform and no precipitation | 7.3  |
3.2. Investigation of interface activity

The formation temperature of the Z70 oil reservoir in Huabei Oilfield was as high as 90ºC, while the salinity was as high as 1.2×10^4mg/L, and the mass concentration of calcium and magnesium ions was 30~200mg/L. Thus, the surfactants for oil displacement required to have better temperature resistance, salt resistance, and high-valent ion resistance, and the interfacial tension should be used as an evaluation index for optimization.

During the experiment, the reinjection water treated in the Z70 fault block station was used to configure seven surfactant systems with concentrations of 0.5% and 1%. The ability to reduce the interface of 7 surfactants was investigated.

| No.   | Surfactant Type          | Concentration | Emulsion Form | Interface Activity |
|-------|--------------------------|---------------|---------------|--------------------|
| No.4  | Non-ionic-Amphoteric     | 0.5           | Emulsion      | Uniform and no precipitation, 7.6 |
| No.5  | Enzyme                   | 0.5           | Transparent blue liquid | Uniform and no precipitation, 7.4 |
| No.6  | nanomaterials            | 0.5           | Black liquid  | Ultrasonic dispersion, 7.5    |
| No.7  | Amphoteric-anionic       | 0.5           | Colorless transparent liquid | Uniform and no precipitation, 7.6 |

Fig.1 Interfacial tension performance of 0.5% surfactant solution

It could be seen from Fig.1 and Fig.2 that, at the concentration of 0.5% and 1%, the interfacial tension of the No.1 decreased rapidly with time, and could reach ultra-low interfacial tension after stability. When the concentration was 0.5%, the interfacial tension value could be reduced to 5×10⁻⁴ mN/m in about 20min, showing good interfacial activity. The order of interface activity: No.1> No.7> No.5> No.4> No.6> No.3> No.2.

3.3. Inspection of emulsifying ability

The emulsification effect of surfactants on crude oil is one of the important principles of surfactant flooding. In the investigation of interfacial activity, the 0.5% concentration of No.1 surfactant system...
showed good interfacial activity, so 0.5% concentration is preferred for further investigation of the emulsifying ability of each surfactant. In this experiment, under the conditions of the Z70 reservoir, oil-water ratio of 1:9, surfactant concentration of 0.5%, speed at 120r/min, and shaking for 1 minute, the surfactants with higher emulsification stability were optimized.

### 3.3.1 Water diversion rate

Through the observation and recording of the emulsification experiment of seven kinds of surfactants, the change curve of water diversion rate under static conditions is shown in Fig.3.

![Fig.3 The changes of the water diversion rate in emulsion](image)

Under the same conditions, the seven surfactants also show different emulsifying properties. As shown in Fig.3, compared with the blank, the seven surfactants have a certain emulsification effect on crude oil. Surfactant No.1 had no water precipitation within 30 minutes, over 30 minutes, the water diversion rate gradually increased. As time went on, the system became stable. The amount of water separated from the emulsion is significantly less than that of other surfactant emulsions, and the demulsified system can be re-emulsified by slightly shaking, so the system has strong emulsification performance and good stability. The order of emulsion stability: No.1 > No.4 > No.6 > No.3 > No.5 > No.7 > No.2.

### 3.3.2 Stability analysis

The stability performance of the No.1 surfactant with the best emulsification performance was quantitatively analyzed. The Turbiscan was used to characterize the particle size change and movement law of the emulsion droplets. The results are shown in Fig.4.

![Fig.4 The changes of backscattered light rate for emulsion](image)

From Fig.4, it could be seen that, within 0–4h, the backscattered light from 0–15mm at the bottom had no change, and the emulsion is stable; at 15–34mm in the middle, the backscattered light grown rapidly at the start, and then gradually slowed down after a certain period of time; the upper 34–50mm, the backscattered light was increased slightly with some oil droplets floated up. It could be seen that
the upper part of the emulsion changed significantly. At 10~30 minutes, the backscattered light greatly increases, the droplets began to coalesce, and the particle size continued to increase; 30min later, the speed of the backscattered light began to slow down, the water droplets began to settle, while the oil droplets. over 2h, the change of backscattered light tended to be stable that is means the emulsion is basically completely demulsified. The change law of No.4 surfactant was consistent with the law of water diversion rate in section 3.3.1.

Surfactant No.1 had excellent interfacial activity and emulsifying properties, good dispersibility, and strong viscosity reducing ability. This may be because the No.1 surfactant is a nonionic-amphoteric-anionic compound, which combines nonionic salt resistance, zwitterionic emulsification and dispersion, and anionic temperature resistance and high interfacial activity. Taking into account the application of surfactants in actual oil displacement, the viscosity reduction performance and static adsorption loss of the No.1 surfactant were further investigated.

### 3.4. Investigation of viscosity reduction performance

Since crude oil and surfactants are mixed in any ratio in the formation, it is necessary for the surface activity to have good viscosity reduction performance in a wide range of oil-water ratio. In this paper, the 0.5% concentration of No.1 surfactant and crude oil of Z70 were mixed and stirred at different oil-water ratios. The viscosity of the mixed crude oil was measured at 50℃. Calculate the viscosity reduction rate and investigate the viscosity reduction effect. It can be seen from Table 3 that the No.1 surfactant with oil-to-water ratio of 1:1, 3:7 and 1:9 all had a good viscosity reduction effect on Z70 crude oil, with a viscosity reduction rate of over 99.5%. Therefore, it is believed that the No.1 surfactant in the range of 1:1 to 1:9 had viscosity-reducing effect on Z70 crude oil, and the viscosity-reducing effect is obvious.

| Initial viscosity of crude (mPa·s) | Oil-water ratio | Viscosity after adding surfactant (mPa·s) | Viscosity reduction rate (%) |
|-----------------------------------|----------------|------------------------------------------|----------------------------|
| 2831                              | 1: 1           | 15.5                                     | 99.5                       |
|                                   | 3: 7           | 6.5                                      | 99.8                       |
|                                   | 1: 9           | 3.0                                      | 99.9                       |

### 3.5. Investigation of static adsorption loss

In this paper, a static adsorption experiment was carried out to test the No.1 surfactant system, which has good interfacial activity and emulsification performance of Z70, a heavy oil system. The effect of surfactant concentration on the adsorption capacity was studied on the clean sand, and Draw the isotherm curve for the change of adsorption capacity with the equilibrium concentration. The experimental results are shown in Fig.5.

![Fig.5 Static adsorption loss of No.1 surfactant](image)

It can be seen from the figure that when the concentration of No.1 surfactant is low, with the increase of concentration, the adsorption capacity increased gradually. It means that when the
concentration of surfactant is small, its adsorption capacity on the clean sand is greatly affected by the concentration. When the concentration reached 0.6%, the adsorption capacity tended to be stable, indicating that the equilibrium between surfactant molecules-micelles-adsorption layer molecules had been got. The adsorption capacity of No.1 was between 2.6 and 4.4 mg/g, and the overall adsorption loss was low, which would have a positive impact on improving the oil displacement effect and reducing economic costs.

4. Conclusions
According to the actual situation of the Z70 reservoir in Huabei Oilfield, the performance and oil displacement effect of different types of surfactants were studied. The results showed that nonionic-amphoteric-anionic had good dispersity and could formed super-low interfacial tension of $5 \times 10^{-4}$ mN/m with the crude oil when the concentration of the surfactants was 0.5%. Under reservoir conditions, the surfactant showed good interfacial activity, while the interfacial tension can reach the order of $10^{-4}$ mN/m. The emulsion had no water precipitating out within 30 min and was demulsified completely out of 180 min, while the surfactant presented preferable emulsifying stability. And the demulsified system can be re-emulsified by slight shaking. Good viscosity reducing property was showed with the oil-water ratio range from 1:1~1:9, which viscosity reduction rate was more than 99.5%. Laboratory surfactant flooding experiment was proved that the static adsorption loss was less than 4.4mg/g, which could have a positive impact on improving the oil displacement effect and reducing economic costs. Therefore, through the research on the property of surfactant flooding, the nonionic-amphoteric-anionic combined systems were determined to be the object oil-displacement agent for Z70 in Huabei Oilfield.

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