Screening of imbibition surfactant in inter-salt shale reservoir

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\textbf{Abstract}: Under the current environment of low oil price, surfactant enhanced oil recovery technology is more economic and feasible without changing fracturing technology and adding special equipment. Surfactant enhanced oil recovery is induced by decreasing interfacial tension and changing wettability. However, there are many kinds of surfactant, and the reservoir conditions and rock types are different, so the first requirement of enhanced oil recovery is to select the surfactant which is suitable for the target reservoir. In view of the characteristics of high temperature and high salinity in inter-salt shale reservoir, in this paper, several surfactant types were selected and negative/non-composite surfactants were screened out by taking the adhesion work reduction factor related to imbibition resistance as the main index. This study is of practical significance for hydraulic fracturing reservoirs with surfactant enhanced oil recovery technology.

\section{Introduction}

Using surfactants to enhance oil recovery has become a widely used method in the development of tight shale reservoirs. Surfactants improve oil recovery by reducing oil-water interfacial tension (IFT) \cite{1} and controlling the wettability of the reservoir \cite{2}. Therefore, it is crucial to select an appropriate surfactant for the target reservoir environment.

At present, the harsh environment of high temperature and high salt reservoir restricts the use of most surfactants. In the environment of high temperature and high salinity reservoir, the surfactant must be temperature-resistant and salt-resistant. In this regard, many scholars have conducted a large number of studies on different surfactant types under different salinity and temperature conditions \cite{3-4}. Traditional single surfactant is difficult to meet the characteristics of temperature resistance and salt resistance. Therefore, it is very necessary to study the mixed surfactant system with strong synergistic effect. At present, most studies on the development of high temperature and high mineralization mainly focus on mixed anionic/nonionic surfactant system \cite{5-6}.

Jianghan inter-salt shale reservoir is a special low-porosity and low-permeability shale reservoir, which is characterized by high soluble salt mineral content. Salt solution occurs when the fracturing fluid is injected into the formation, resulting in high salinity fracturing fluid solution. At the same time, the fracturing fluid can be seeped into the rock matrix to drive oil. It displaces the non-flowing oil into
the channel so as to improve the oil recovery. In view of the low imbibition recovery of the fracturing fluid, adding surfactant to the fracturing fluid is a feasible method. Therefore, through simulating the conditions of Qianjiang inter-salt shale reservoir in Jianghan Oilfield, we test the interfacial tension and wettability of fracturing fluids with different surfactants and compare the adhesion work reduction factors of surfactants. It shows how to select surfactant suitable for target reservoir and provides theoretical guidance for using surfactant to enhance oil recovery in inter-salt shale reservoir.

2. Experimental Part:

2.1. Experimental instruments
FA-124 Electronic analytical balance (accuracy 0.0001g), BZ-y series automatic surface/interface tensiometer, SPACA-1 contact angle tester.

![Interface tensiometer](image1)
![Electronic analytical balance](image2)
![Contact angle measuring instrument](image3)

Figure.1 Experimental equipment diagram

2.2. Experimental materials
(1) experimental core: natural salt shale core (a block in Qianjiang sag, Jianghan Basin), gas permeability of 0.01-1mD, and reservoir natural porosity of 5.2%-7.8%.
(2) model oil: the viscosity of crude oil in Jianghan formation is 2.48mPa·s at formation temperature. Kerosene is used as experimental oil.
(3) simulation of water: the inter-salt shale backflow fluid in Jianghan Oilfield, with a salinity of 260 g/L. It belongs to ultra-high salinity formation water.

| Component       | K⁺+Na⁺ | Ca²⁺ | Mg²⁺ | SO₄²⁻ | HCO₃⁻ | CO₃²⁻ | Cl⁻ | Total salinity |
|-----------------|--------|------|------|-------|-------|-------|-----|----------------|
| Inter-salt shale| 99746  | 444  | 246  | 9592  | 1092  | 0     | 142038 | 264373         |

(4) fracturing fluid: The fracturing fluid used in the measure is composed of 0.5% clay stabilizer and 0.08% drag reducer provided by Jianghan Oilfield.
(5) surfactant: select commonly sold surfactant.

Table 2 Surfactant types

| Surfactant type           | Surfactant name                                                                 |
|---------------------------|---------------------------------------------------------------------------------|
| Anion surfactant          | Sodium dodecyl benzene sulfonate (SDBS), Sodium dodecyl sulfate K12              |
| Non-ionic surfactant      | Tween 80, Coconut oil acid diethanol amine 6501 (CDEA)                         |
| Cationic surfactant       | Hexadecane cytrimethyl ammonium chloride 1631 (CTAC)                            |
| Anionic/nonionic surfactant| WLW (SAS60 : CDEA = 1:2)                                                        |
2.3. Experimental methods

2.3.1. Oil-water interface tension test
Surfactant solutions of different types and concentrations were prepared with simulated solution, and then BZ-Y series automatic surface/interfacial tension-meter was used to measure the interfacial tension of surfactant and evaluate the influence of surfactant on the interfacial tension of oil/water.

2.3.2. Contact Angle test
The natural core of the reservoir is washed and dried and cut into slices of the same size, and then the core slices are soaked in different types of imbibition solution for 24 hours, the contact angle of water drop on the surface of different core slices was measured by SDC-200 contact angle meter.

3. Experimental results and analysis

3.1. Screening of surfactants with good compatibility of salt resistance

3.1.1. The ability of surfactant to reduce the interfacial tension between oil and water
Oil/water Interfacial tension is not only an important index of reactive surfactant performance, but also an important factor affecting oil recovery. Selected concentration was 0.1% - 0.5% of K12, SDBS, CDEA, Tween 80, CTAC and WLW surfactants, as a supplement to simulate fluid flowback (salinity is 260 g/L). We measured the influence of surfactant on oil/water interfacial tension, and the salt resistance of different surfactants was characterized by the ability of surfactant to reduce oil-water interfacial tension. Kerosene is a simulated oil.

As can be seen in Figure 2, under the condition of high temperature and high salinity, all the six surfactants can significantly reduce the oil/water interfacial tension. However, anion surfactants K12 and SDBS have poor ability to reduce oil-water interfacial tension. This is because the anionic surfactant is not resistant to salt and easy to lose its activity and aggregation under the condition of high salinity of inter salt shale. The nonionic surfactant itself has no ion generation, and the cationic surfactant does not react with divalent ions. Both of them have good salt tolerance, good solubility and good ability to reduce oil/water IFT. It can be seen that the interfacial tension of oil/water decreases with the increase of surfactant concentration, but there is an optimal concentration of 0.3%, beyond which, the interfacial tension has little change.

![Figure 2 Influence of different concentrations of surfactants on the interfacial tension between oil and water.](image1)

![Figure 3 Influence of different concentrations of surfactant in different complex fracturing fluid systems on interfacial tension](image2)

3.2. Performance screening and evaluation of the fracturing fluid and surfactant composite system
In the process of developing inter-salt shale reservoir by injecting fracturing fluid, adding surfactant to fracturing fluid can give full play to the characteristics of hydrophilic and imbibition displacement in reservoir. The salt and temperature resistance of different surfactants were evaluated in previous
experiments. When different surfactants were added to the fracturing fluid, it was found in compatibility observation that only CDEA and fracturing fluid used in the field were stratified. It was not compatible, so we abandoned it.

3.2.1. Influence of composite fracturing fluid surfactant system on oil-water interfacial tension
From the above experimental results and the results of compatibility with fracturing fluid, Tween-80, CTAC and WLW surfactants were selected and added into the field fracturing fluid (salinity less than 1g/L). We measure IFT of three kinds of mixed solution system and model oil at 70°C, as shown in Figure. 3.

As shown in Figure. 3, the IFT of the solution decreases in varying degrees after adding different types of surfactants into the fracturing fluid. When the concentration is greater than 0.3%, the IFT remains stable and does not fluctuate. This is consistent with the trend of oil/water interfacial tension reduction shown in Figure 1. This shows that adding surfactant to the fracturing fluid is a feasible method to reduce the oil/water interfacial tension and improve the imbibition efficiency. It can be seen that WLW, a mixed surfactant, has a stronger ability to reduce oil/water IFT than the other two single surfactants in the fracturing fluid.

3.2.2. Influence of composite fracturing fluid surfactant system on wettability contact Angle of core
The inter-salt shale reservoir is hydrophilic and there exists imbibition and oil displacement phenomenon in the process of hydraulic development. The contact angle of core slices soaked with simulated water (low salinity) was measured to be 56.2°. Therefore, the contact angle of core slices soaked with different types of composite surfactant solutions (concentration of 0.3%) was measured to represent the ability of the surfactant to improve wettability.

It can be seen from Figure. 4 that the fracturing fluid itself can reduce the core contact angle, and the contact angle can be reduced more dramatically when surfactant is added. The mixed anionic/nonionic surfactant WLW of 0.3% made the contact angle lower and improved wettability best.

3.2.3. Evaluation of the ability of composite fracturing fluid surfactant system to reduce oil droplet adhesion
The process of oil imbibition is carried out under the interaction of the force of imbibition and the resistance of imbibition, the force of capillary is the force and the force of adhesion is the resistance.
The addition of surfactant in fracturing fluid can improve the wettability and reduce the oil/water interfacial tension, greatly reduce the adhesion resistance while reducing the capillary force, so as to increase the power of permeability and absorption and improve the efficiency of imbibition. Therefore, by characterizing the ability of the three surfactants to reduce imbibition resistance, the surfactants suitable for inter-salt shale reservoir can be screened out. The adhesive work reduction ability can be expressed by the adhesive work reduction factor $E$, namely:

$$E = \frac{W_e}{W_o} = \frac{\sigma_s}{\sigma_w} \cdot \frac{1 - \cos \theta_w}{1 - \cos \theta_o}$$

Where:
- $W_e$ - the adhesion work of oil on the rock surface in the mixed solution system of surfactant and fracturing fluid-oil-rock system;
- $W_o$ - adhesion work of oil on rock surface in fracturing fluid-oil-rock system;
- $\sigma_s$ - oil/fracturing fluid IFT;
- $\sigma_w$ - IFT between mixed solution system of surfactant and fracturing fluid and model oil;
- $\theta_w$ - the contact Angle of fracturing fluid on the rock surface;
- $\theta_o$ - the contact Angle of the mixed solution system of surfactant and fracturing fluid on the rock surface.

### Table 3 Adhesion reduction factors of four composite fracturing fluid systems

| Surfactant type | Fracturing fluid contact Angle (°) | Complex fracturing fluid contact Angle (°) | IFT (mN/m) | E   |
|----------------|------------------------------------|-------------------------------------------|------------|-----|
| 0.3%Tween80   | 44.21                              | 32.85                                     | 2.77       | 0.1806 |
| 0.3%CTAC      | 46.83                              | 44                                        | 2.28       | 0.2339 |
| 0.3%WLW       | 46.35                              | 30.55                                     | 0.45       | 0.0233 |

It can be seen from Table 3 that the adhesive work reduction factor of the mixed anionic/nonionic surfactant is lower, and 0.3% WLW can effectively reduce the adhesive work of oil droplets. Therefore, the mixed anionic/nonionic surfactant has the ability to reduce oil/water IFT, improve wettability, and reduce oil droplet adhesion.

### 4. Conclusion

1) Wettability determines the direction of the capillary force in the process of imbibition. The wettability does not change the direction of the capillary force in the inter-salt shale hydrophilic reservoir, so the interfacial tension is the main controlling factor affecting the permeability and suction efficiency of the hydrophilic reservoir.

2) Interfacial tension affects the efficiency of imbibition. It is mainly through reducing the adhesion resistance, so as to increase the difference of imbibition power and resistance. The adhesion work factor can be used to characterize the ability of the surfactant to reduce the imbibition resistance.

3) In hydrophilic reservoirs, oil/water IFT is the main principle for screening surfactants. The mixed anionic/nonionic surfactant with stronger ability to reduce the IFT is suitable for high temperature and high salinity inter-salt shale reservoir.

### Acknowledgements

Our work is supported by Study on characteristics of salt solution and salt plugging during fracturing flowback of inter-salt shale reservoir.

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