Study On Imbibition Fluid Preferred And Injection Parameters In Fractured Tight Reservoir— A Case From Daqing Toutai Oilfield

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Abstract. In the process of the development of fractured tight reservoir, there are some problems such as high injection pressure and poor effectiveness of production. At present, tight reservoirs mostly adopt fracturing development. When injection pressure is higher than fracture opening limit, connected oil wells show severe flooding, water-flooding efficiency is extremely poor. In order to solve the technical problems of fractured tight reservoir development, In this paper, based on the physical and chemical characteristics of surfactants, and by means of instrumental monitoring and numerical simulation, the optimization of the composition of the perming-absorbing liquid and the optimization of the injection process parameters in the tight oil reservoir in Daqing Toutai were studied and simulated. The results show that the capillary force is the main force in the process of osmosis and oil recovery, and the surfactant can change the rock into water wetness, which is beneficial to osmosis and absorption, and the oil washing effect of surfactant also improve the oil displacement efficiency. But it reduces the interfacial tension between oil and water, reduces the capillary force, and is not conducive to the imbibition. Therefore, it is necessary to choose a suitable concentration of the imbibition liquid to take account of both wettability and interfacial tension. Toutai oil field has poor sensitivity and stronger adaptability to solvent water mineralization. Nonionic surfactant solution(DWS, 0.2 %) is recommended for the imbibition in the target area of the Toutai oil field, injection process parameters range: the injection timing (water cut during injection) is 40 % to 60 %, the injection volume is 4000m3 to 5000m3, the well shut-in time is two months to three months, the cycle of huff and puff is 1.5 to 2.0 years, and the injection velocity is 30m3/d to 40m3/d. It provides the basis for the target reservoir technology decision and has important theory and application value.

1. Introduction
With the increase of national energy security and the development of technology, the proportion of tight oil reserves is gradually increasing[1-4]. The fractured tight reservoir outside Daqing has poor water absorption capacity, high water injection pressure, high cumulative injection-production ratio, poor water injection efficiency, decreased production without water injection, and easy water flooding by water injection, resulting in reduced oil production rate, insufficient long-term fluid supply, large proportion of long shut-in and low efficiency Wells, and poor development benefits. It is urgent to adopt effective and low-cost technical measures to enhance recovery[5]. The study shows that there is osmotic action in the tight reservoir, and capillary force is the main displacement force of osmotic action. When the rock pore surface is a water-wet reservoir, the wetting phase absorbs and discharges the non-wetting phase, and the osmotic oil recovery is one of the effective measures for the...
development of the low-permeability (weak) water-wet reservoir[6-10]. In recent years, because of its simple injection process, low operating cost and good oil increasing effect, the technology of percolating oil recovery has been paid great attention by oilfield development technicians, and a lot of research have been carried out[11-12]. In order to solve the technical problems of developing fractured tight reservoirs and using the physical and chemical properties of surfactants, studies and simulations were carried out in Daqing Toutai tight reservoirs, and the optimization of the permeability and absorption liquid system and the injection process parameters were studied.

2. **Experiment condition**

2.1. **Type and composition of percolating fluid are preferred**

2.1.1. **Experimental materials and equipment**

| classification | Cation (mg/L) | Anion (mg/L) | salinity (mg/L) |
|----------------|--------------|--------------|-----------------|
| water          | Na⁺: 321.62  | HCO₃⁻: 820.11| 1333.10         |
|                | Ca²⁺: 48.09  | Cl⁻: 70.33   |                 |
| sewage         | Mg²⁺: 8.90   | SO₄²⁻: 70.33 |                 |
|                | Na⁺: 1263.31 | HCO₃⁻: 1181.35| 3736.07        |
|                | Ca²⁺: 48.09  | Cl⁻: 1094.30 |                 |
|                | Mg²⁺: 8.92   | SO₄²⁻: 99.26 |                 |
|                | /            | CO₃²⁻: 53.30 |                 |

There are four kinds of surfactants: heavy alkyl benzene sulfonate (ZYB), nonionic surfactant (DWS), petroleum sulfonate (SYH) and nonionic surfactant (SUN). The experimental water was taken from the recycled sewage and clean water treated by toutai oilfield joint station, and the ion composition was shown in table 1. The experimental oil was well M503 in toutai oilfield, and the viscosity of crude oil on the surface was 4.2 mPa·s. The natural core used in the experiment was taken from the NO.4 core of well M61-J89 in toutai oilfield (strata FI7a ~ FI8a). The artificial core is a weak hydrophilic core cemented by epoxy resin and quartz sand[13]. The interfacial tension between the percolating fluid and the crude oil was measured by a droplet interfacial tensiometer. The video optical contact Angle meter measures the contact Angle between the percolation and the core surface.

2.1.2. **Experimental procedure**

- The permeability test is to weigh the saturated water of the dried core with known weight, and the mass and pore volume of the saturated water can be calculated;
- Oil displacement was simulated under reservoir temperature conditions. After displacement, the oil was immersed in crude oil for 1 day and the oil saturation was calculated;
- Under normal pressure, the percolating fluid is heated to the reservoir temperature, and then the saturated oil core is put into the percolating fluid for experiments to record the change of the amount of oil discharged.

2.2. **Optimization of process parameters of percolating fluid**

According to the reservoir characteristics of toutai oilfield, a double-permeability model suitable for the fluid flow characteristics of the target reservoir is selected. Fluid flows between substrates, substrates and fractures, and between fractures and fractures are more fully described.
3. Interpretation of result

3.1. System optimization of the imbibition injection fluid

3.1.1. Effect of the imbibition injection fluid system

Five concentrations of four kinds of surfactants were tested with clean water and sewage respectively. It can be seen from Figure 1 and Figure 2 that the concentration of surfactants has an influence on the interfacial tension between the percolating fluid and the crude oil. When the mass concentrations of the surfactants SYH and DWS prepared with water are greater than 0.025% and 0.20% respectively, when the mass concentrations of the surfactants SYH and DWS prepared with sewage are greater than 0.025% and 0.30% respectively, the interfacial tension reaches \(10^{-2}\) m\(^2\)/m order of magnitude.

3.1.2. The effect of surfactant on wettability

Core contact Angle less than 75° is a hydrophilic reservoir, between 75° and 105° is a neutral wetting reservoir, more than 105° is a hydrophilic reservoir. In figure, DWS, ZWB and SYH can reduce the contact Angle of water-wet rock and enhance the water-wet property.

| Concentration (mg.L\(^{-1}\)) | 0   | 0.05 | 0.1  | 0.2  | 0.3  |
|-------------------------------|-----|------|------|------|------|
| Contact angle(°)              |     |      |      |      |      |
| DWS (water)                   | 68.4| 23.2 | 19.5 | 16.0 | 14.7 |
| ZWB (sewage)                  | 65.0| 18.9 | 15.8 | 13.9 | 12.9 |
| SYH (sewage)                  | 65.0| 38.2 | 32.5 | 28.3 | 22.2 |

3.1.3. The influence of surfactant type, concentration and solvent water salinity on the efficiency of oil recovery

The experimental data of the production effect of the imbibition injection fluid in figure 3 and figure 4. Whether it is artificial core or natural core, sewage or clean water, surfactants can change the rock into water and wet, which is conducive to permeability, while the oil washing characteristics of surfactants can improve the oil displacement efficiency. However, the high concentration of surfactant will reduce the interfacial tension between oil and water, and decrease the capillary force, which is not conducive to the permeability. Therefore, it is necessary to choose an appropriate concentration to take into account both wettability and interfacial tension.
To sum up, considering the field preparation process and the source of agents, it is recommended to conduct the numerical simulation study on the injection process parameters optimization with DWS (0.2%) in clear water.

3.2. Optimization of the imbibition fluid injection parameters

3.2.1. The influence of the total injection amount of imbibition fluid on the efficiency of oil recovery

In table 3, with the increasing of the amount of imbibition fluid injected, the recovery rate of the oil well shows a trend of gradual increase, but the range gradually decreases. Analysis shows that with the increase of permeability imbibition fluid injection, the contact area of imbibition fluid and matrix increases, the probability of imbibition process increases, recovery degree increase gradually, but after injection amount to a certain degree, there will be a part of imbibition process in the areas far away from the bottom, the resistance that the oil flowing near the bottom bear is bigger, lead to slow recovery degree increase. From the perspective of technology and economy, the reasonable injection volume is 4000m$^3$ ~ 5000m$^3$.

| Parameter     | Serial number | Injection (m$^3$) | Recovery ratio (%) | Growth rate |
|---------------|----------------|------------------|-------------------|-------------|
|               |                | Before           | Final             |             |
| 1             | 2000           | 6.98             | 1.89              |             |
| 2             | 3000           | 8.85             | 3.76              |             |
| 3             | 4000           | 10.53            | 5.44              |             |
| 4             | 5000           | 11.88            | 6.79              |             |
| 5             | 6000           | 12.33            | 7.24              |             |

3.2.2. The influence of the injection speed of imbibition fluid on the efficiency of oil recovery

In table 4, with the increase of daily injection, the recovery increases first and then decreases. The analysis shows that with the increase of daily injection amount, the amount of water in the fracture entering into the reservoir to participate in the process of imbibition gradually increases, and the degree of production gradually increases. However, when the daily injection amount is large to a certain extent, the imbibition efficiency decreases. From the perspective of technology and economy, the reasonable daily injection volume is 30m$^3$ ~ 40m$^3$.

| Parameter     | Serial number | Injection (m$^3$/d) | Recovery ratio (%) | Growth rate |
|---------------|----------------|---------------------|-------------------|-------------|
|               |                | Before              | Final             |             |
| 1             | 10             | 7.87                | 2.78              |             |
| 2             | 20             | 9.02                | 3.93              |             |
| 3             | 30             | 9.98                | 4.89              |             |
| 4             | 40             | 10.53               | 5.44              |             |
| 5             | 50             | 10.38               | 5.29              |             |
3.2.3. The influence of the soaking time on the efficiency of oil recovery
In table 5, with the increase of soaking time, the oil recovery increases gradually, but decreases gradually. The analysis shows that the longer the soaking time is, the more time it takes for the fluid in the fracture to react with the crude oil in the formation matrix, the more oil is absorbed, and the better the development effect will be. However, due to the limitation of the remaining oil near the bottom of the well, when the soaking time is too long, the increase of the recovery rate slows down. Considering from the technical and economic point of view, the reasonable soaking time is from 2.0 to 3.0 months.

Table 5. Relationship between soaking time and recovery.

| Parameter  | Serial number | Soaking time (m³) | Recovery ratio (%) |
|------------|---------------|-------------------|-------------------|
|            |               | Before            | Final             | Growth rate     |
| 1          | 1.0           |                   | 8.16              | 3.07             |
| 2          | 1.5           |                   | 9.73              | 4.64             |
| 3          | 2.0           | 5.09              | 10.53             | 5.44             |
| 4          | 2.5           |                   | 10.99             | 5.90             |
| 5          | 3.0           |                   | 11.34             | 6.25             |

3.2.4. The influence of the well water cut on the efficiency of oil recovery
In table 6, with the increase of the well water cut, the increase of oil recovery decreases gradually. The analysis shows that when the water cut is high, the remaining oil saturation in the reservoir is low, the capillary force is small, the osmotic force is small, and the osmotic effect is weak. Considering from the technical and economic point of view, the reasonable injection time is 40% ~ 60%.

Table 6. Relationship between the well water cut and recovery.

| Parameter  | Serial number | Water cut (%) | Recovery ratio (%) |
|------------|---------------|---------------|-------------------|
|            |               | Before        | Final             | Growth rate     |
| 1          | 20            | 3.14          | 11.64             | 8.50             |
| 2          | 40            | 4.23          | 11.32             | 7.09             |
| 3          | 60            | 5.09          | 10.53             | 5.44             |
| 4          | 80            | 5.78          | 8.69              | 2.91             |
| 5          | 90            | 6.02          | 7.12              | 1.10             |

3.2.5. The influence of the stimulation period on the efficiency of oil recovery
In table 7, with the increase of stimulation period, the recovery rate increases gradually, but decreases gradually. The longer the pumping cycle is, the better the development effect is. When the huff and puff cycle is too long, most of the remaining oil in the substrate is recovered and the recovery rate increases slowly. From the technical and economic point of view, a reasonable handling cycle of 1.5 to 2.0 years.

Table 7. Relationship between the stimulation period cut and recovery.

| Parameter  | Serial number | Stimulation period (y) | Recovery ratio (%) |
|------------|---------------|------------------------|-------------------|
|            |               | Before                 | Final             | Growth rate     |
| 1          | 1.0           |                        | 8.05              | 2.96             |
| 2          | 1.5           |                        | 9.52              | 4.43             |
| 3          | 2.0           | 5.09                   | 10.53             | 5.44             |
| 4          | 2.5           |                        | 11.03             | 5.94             |
| 5          | 3.0           |                        | 11.29             | 6.20             |

4. Conclusion
- In the imbibition process, the capillary force is mainly used, and the surfactant can make the rock change to water wetness, which is conducive to imbibition. At the same time, the oil washing effect of the surfactant can also improve the oil displacement efficiency. However, the surfactant can reduce the
interfacial tension between oil and water, and decrease the capillary force, which is not conducive to imbibition. Therefore, an appropriate concentration should be chosen for both wettability and interfacial tension.

- Compared with nonionic surfactants, petroleum sulfonate surfactants have better permeability and recovery effect, but the former is less sensitive to the salinity of solvent water and has stronger adaptability.

- It is recommended that the imbibition fluid in the target block of toutai oilfield should be non-ionic surfactant solution (DWS, 0.2%). The injection process parameters range from 40% to 60% water cut during injection, injection volume of 4000m³ to 5000m³, soaking time from 2.0 to 3.0 months, stimulation cycle from 1.5 to 2.0 years and daily injection volume from 30m³ to 40m³.

References
[1] CAI jianchao, zhao chunming, tan lu, et al. (2011) Fractal analysis of permeability coefficient of porous media in low permeability reservoirs. J. Geological science and technology information, 30(5): 54-58.
[2] Norman R. Morrow. (2001) Recovery of oil by spontaneous imbibitions. J. Current Opinion in Colloid in Colloid and Interface Sci, (6): 173-89.
[3] Yang zhengming. (2004) Study on seepage mechanism in low permeability reservoirs. Graduate university of Chinese academy of sciences(institute of seepage fluid mechanics), Beijing.
[4] Peng yu-qiang, he sheli, ju xiujuan, et al. (2010) Effect of injection velocity on permeability of sandstone. J. Xinjiang petroleum geology, 31(4): 399-401.
[5] CAI xidong, yao yodong. (2009) Study on the influencing factors of the infiltration process in low permeability fractured reservoir. J. China sci-tech paper online, 4(11): 806-812.
[6] Li jishan. (2006) The influence of surfactant system on the infiltration process. Graduate university of Chinese academy of sciences(institute of seepage fluid mechanics), Beijing.
[7] Li hong, li zhiping, wang xiangzeng. (2016) Influence of surfactant on permeability sensitivity factors in low permeability reservoirs. J. Oil drilling technology, 44(5): 100-103.
[8] Yao tongyu, li jishan, wang jian, et al. (2009) Mechanism of permeability and favorable conditions in fractured low permeability reservoirs. J. Journal of jilin university(engineering science), 39(4): 937-940.
[9] Yang zheng-ming, zhu weiyao, ju yan, et al. (2002) Mechanism of porous medium permeability in low permeability fractured sandstone reservoir. J. Acta petroleumica sinica, 23(6).
[10] Qin jishun, li aifen. (2001) Reservoir physics. University of petroleum publishing, Beijing.
[11] Hua fangqi, gong changlu, xiong wei, et al. (2003) Study on permeability and permeability of low permeability sandstone reservoir. J. Daqing petroleum geology and development, 22(3): 50-52.
[12] Cheng linsong, et al. (2003) Numerical simulation of wettability in water drive reservoirs. J. Research and development of hydrodynamics, 18(6): 786-791.
[13] Lu xiangguo, gao zhenhuan, frowning wenhua, et al. (1994) Experimental study on the factors affecting the permeability of artificial core. J. Petroleum geology and development in daqing, 13(4): 53-56.