Study on Influencing Factors of Throat-like Residual Oil

Peihui Han *
Research Institute of Daqing Oilfield Co., Ltd., Daqing 163712, Heilongjiang, China

*Corresponding author e-mail: hanph@petrochina.com.cn.

Abstract. The microscopic visualization model is used to carry out oil displacement experiments, to test the interfacial tension of the ASP system, and to study the effect of different conditions on the throat-like residual oil by recording dynamic images of the residual oil during the displacement process. The results show that: when the concentration of polymer and alkali is unchanged, the higher the concentration of surfactant, the lower the interfacial tension of the ASP system; the water-wet attribute model is more conducive to the oil displacement system's use of residual oil. The lower the interfacial tension of the ASP system, the better the effect on the throat-like residual oil. When the interfacial tension reaches 10-2, the effect is obvious; after water flooding, the pore-throat ratio and the maximum diameter of the pores have little effect on the residual oil distribution. It has an effect on the residual oil distribution of the minimum diameter of the pores. After the ASP flooding, the large pore-to-throat ratio, the small minimum diameter, and the small maximum diameter have a greater impact on pores with different wettability.

1. Introduction
ASP flooding is a tertiary oil recovery method that can greatly improve oil recovery. Scholars at China and abroad have studied the mechanism of ASP flooding from the influence of chemical agents on ASP flooding and the effect of interfacial tension properties. A lot of research has been carried out. At present, there are many ASP flooding projects in progress worldwide. The ASP flooding implemented in Daqing Oilfield can increase the oil recovery by more than 20%[1-3]. Xia Huifen et al. studied the effects of viscoelasticity and interfacial tension on oil displacement efficiency through experiments and analysis of oil-water interface viscoelasticity and interfacial tension through microscopic visualization oil displacement experiments. The interfacial tension and interfacial viscoelasticity of the ASP system all have an impact on the oil displacement efficiency. Reducing the interfacial tension and interfacial viscoelasticity is beneficial to the emulsification of residual oil and the improvement of displacement efficiency. The ASP system has low interfacial tension, low interfacial viscoelasticity, and high oil displacement efficiency. With the decrease of interfacial tension and interfacial viscoelasticity, the emulsification effect of the ASP system on the residual oil changes from emulsified oil droplets to emulsified oil filaments[4]. Through core physical simulation experiments and micro-displacement experiments, Jia Zhongwei et al. believed that the oil-water interfacial tension dropped to the order of 10-3mN/m and the water-oil viscosity ratio was greater than 2 during the ASP flooding. 20% necessary condition;The lower balance and instantaneous interfacial tension are beneficial to the ASP system to increase the oil recovery. The mechanism of the ASP system to increase the recovery is that low interfacial tension is beneficial to the start-up and migration of residual oil after water flood[5]. Hou Jirui
et al. calculated the influence of the reduction of the interfacial tension on the driving force of the oil droplets, and believed that when the length of the oil droplet is 100 times the radius, the interfacial tension change in the interval of 36~0.1 mN/m has a high influence on the external displacement power. When the interfacial tension varies from 0.01 to 0.001 mN/m, the influence of external displacement force is below 1%, and the longer the oil droplet is displaced, the smaller the influence of interfacial tension on the displacement force. Enough attention should be paid to the contribution of ASP system to enhanced oil recovery under non-ultra-low interfacial tension\cite{6}. Yue Xiangan et al. studied the effect of interfacial tension and rheology of the ASP system on oil recovery through indoor core displacement experiments. It is believed that with the increase of alkali concentration in the ASP system, the oil-water interfacial tension can reach ultra-low, but at the same time it also leads to the loss of viscoelasticity of the composite system, which makes the comprehensive effect of oil displacement worse. The highest value of oil recovery in the flooding experiment appears in the low alkali concentration area with an interfacial tension of $10^{-2}$ mN/m. The most ideal oil displacement effect appears in the scheme that best matches the interfacial characteristics of the ASP system and rheology. The above studies did not elaborate on the influence of wettability, interfacial tension, pore parameters and other factors on the initial migration of throat-like residual oil. In this paper, the microscopic visual model of glass etching is used to test the interfacial tension of the ASP system under different surface active mass concentrations to analyze the image of the effect of the throat-like residual oil under the conditions of different wettability, interfacial tension, and pore parameters. The effect of the oil displacement system solution properties and pore characteristics on the throat-like residual oil is clarified.

2. Experimental

2.1. Material

Chemicals: Polyacrylamide: molecular weight 25 million, effective content 90%; surfactant: petroleum sulfonate, effective content 40%; alkali: sodium carbonate, effective content 99%, the above chemical agents are produced by Daqing Refining & Chemical Company; Strong QQ-19 type lipophilic release agent.

Experimental core: The photo-etched glass model is made by photochemical etching technology. The photo of the pore structure is drawn on the glass and placed on the glass coated with photosensitive material. After exposure and development, the pore structure pattern is copied on the glass. Then, the exposed glass template was treated with hydrofluoric acid to show the impression of the pore structure. Finally, a cover plate is added and high-temperature sintering is performed to obtain the desired product. The developed glass model is basically consistent in size and shape with the actual core pore structure. After penetration, the fluid flow can be clearly observed. The model is in the form of one injection and one mining. The glass etching model was developed by a professional company and the size is 40×40mm.

Oil and water: Simulate formation water, clean water Nacl content 950mg/L, sewage Nacl content 4500mg/L, all systems use clean water to prepare mother liquor, sewage dilutes the target liquid, visualization model saturated water and displacement experiments use sewage; experimental oil: crude oil and kerosene according to A certain proportion of simulated oil has a viscosity of 10mPa·s at 45°C.

2.2. Experiment equipment

The American Texas-500 spinning drop interfacial tensiometer and Hacker rheometer were used to detect solution viscoelasticity and microscopic visualization system for oil displacement experiment. The experimental process is shown in Figure 1.
3. Result and Discussion

3.1. Interfacial tension test of ASP system

Interfacial tension test of ASP system. Under the condition that the polymer concentration is 2200 mg/L and the alkali mass concentration of 1.2% remain unchanged, the ASP system of petroleum sulfonate with different mass concentrations is prepared, and the interfacial tension is tested, see Table 1. The concentration of surfactant has a great influence on the interfacial tension of the ASP system. When the concentration of surfactant increases from 0% by 0.3%, the interfacial tension of the ASP system decreases from $10^{-1}$ to $10^{-3}$, which is mainly because the hydrophilic group and the lipophilic group determine that the surfactant has the characteristics of reducing the interfacial tension, its two groups with opposite affinity in the solution are arranged in an orderly manner according to specific rules and are not on the interface layer and in the bulk phase. In solution. When the concentration of surfactant molecules is lower than its critical micelle concentration, the hydrophilic groups and lipophilic groups in the surfactant are oriented in the oil-water interface layer, and the concentration increases, and the number of basic groups arranged on the interface layer will naturally increase. The ability to reduce the interfacial tension is greater. When the concentration is greater than the critical micelle concentration, the number of oriented surfactant molecules on the oil-water interface layer reaches the maximum, and a large number of micelles begin to form. The surfactant molecules aggregate to form lipophilic groups facing inward and hydrophilic groups facing outward. The micelles reduce the number of surfactant molecules arranged on the interface layer. Therefore, the oil-water interfacial tension reaches the lowest value when the critical micelle concentration is the lowest.

Table 1. Interfacial tension test results of ASP system.

| Polymer concentration/mg/L | Alkali mass concentration/% | Mass concentration of surfactant/% | Interfacial tension/mN/m |
|---------------------------|----------------------------|----------------------------------|--------------------------|
| 2200                      | 1.2                       | 0.00                             | 0.3500                   |
| 2200                      | 1.2                       | 0.02                             | 0.0230                   |
| 2200                      | 1.2                       | 0.30                             | 0.0059                   |

3.2. Study on Influencing Factors of Throat-like Residual Oil

3.2.1. Influence of wettability on throat-like residual oil. The ASP system with the same interfacial tension (0.3% petroleum sulfonate+1.2% sodium carbonate+2200 mg/L polymer) was used to displace the residual oil in the throat-like shape with different wettability, as shown in Figure 2. Under the action of the displacement fluid viscosity, the residual oil in the pores is gradually driven out, and an adherent oil film is formed along the lipophilic pore wall. As the displacement progresses, the adherent oil film...
gradually becomes shorter and thinner, and the residual oil. The migration along the adhering oil film to the production end, as shown in Figure 2 (a). With the ternary displacement, under the action of the tangential force of the ASP system, the residual oil in the parallel channels is gradually driven out and forms a bulge, which extends towards the production end under the drag of the displacement fluid. The residual oil in the tunnel gradually moves a certain distance toward the production end in a way of integral migration, but the residual oil cannot be completely driven out of the tunnel, and the residual oil will eventually remain in the tunnel, as shown in Figure 2(b). When the oil displacement system is the same, the water-wet channels are more conducive to displacing the residual oil.

![Figure 2. Different wettability pores](image)

**Figure 2. Different wettability pores**

3.2.2. The effect of interfacial tension on throat-like residual oil. Parallel channels with water-wet properties are used to study the effect of interfacial tension of the oil displacement system on the throat-like residual oil as show in Figure 3. When the oil-water interfacial tension is reduced to $10^{-1}$ mN/m, the throat-like residual oil is still difficult to start. In Figure 3(a), it is observed that the throat-like residual oil is slightly reduced, and the shape of the right liquid surface changes from a uniform concave surface to one side The thicker asymmetric liquid level on the thinner side is due to the viscoelastic effect of the ASP system. The residual oil in the pores is squeezed out, and the displaced residual oil migrates along the oil film attached to the pore wall, and The ASP system relies on its own elastic squeeze liquid level, and the closer to the production end, the deeper the ASP system enters the pore. When the interfacial tension of the ASP system is high, the role of the interfacial tension in the residual oil displacement process is not obvious, and the viscoelasticity of the ASP system plays a large role in the displacement process. Figure 3(b) shows the process of displacement of throat-like residual oil by a ASP system with an interfacial tension of $10^{-2}$ mN/m. During the displacement of the ASP system, the throat-like residual oil gradually shortened to disappear. When the interfacial tension is low ($10^{-2}$ mN/m), the capillary force is small, the resistance of the ASP system into the pores is small, there is an adherent oil film in the lipophilic pores, and the ASP system enters the pores to drive out the throat-like residual oil Moving along the adhering oil film to the production end, with the progress of the ASP flooding, throat-like residual oil is gradually produced. Reducing the oil-water interfacial tension to $10^{-3}$ mN/m greatly reduces the capillary resistance of the ASP system entering the pores, so that the throat-like residual oil can be produced. Figure 3(c) shows the process of displacement of throat-like residual oil by a ASP system with an interfacial tension of $10^{-3}$ mN/m. After the interfacial tension of the ASP system reaches an ultra-low level, it can fully displace the throat-like residual oil. The process of recovering the throat-like residual oil is similar to that of the ASP system with an interfacial tension of $10^{-2}$ mN/m. The oil
process is similar: the ASP system enters the throat-like residual oil pores, the throat-like residual oil gradually becomes shorter, and the displaced throat-like residual oil migrates along the adherent oil film to the production end.

![Interfacial tension](image)

(a) Interfacial tension $10^{-1}$mN/m

(b) Interfacial tension $10^{-2}$mN/m

(c) Interfacial tension $10^{-3}$mN/m

**Figure 3.** Displacement dynamic process of ASP system with different interfacial tension

3.2.3. Influence of pore parameters on the distribution of throat-like residual oil. The percentages of throat-like residual oil locations in the model with different wettability were counted separately after water flooding and after ASP flooding. The statistical results are shown in Table 2. It can be seen that the pore-throat ratio and the maximum diameter of the pores after water flooding basically have no effect on the residual oil distribution in the different wettability attribute models, and the minimum diameter of the pores has an effect on the residual oil distribution in the different wettability attribute models. After ASP flooding, the wettability of the three types of pores with a large pore-to-throat ratio, a small minimum diameter and a small maximum diameter is greatly affected.

| Displacement method | Wettability | Large pore-throat ratio | Small pore-throat ratio | Big smallest diameter | Small smallest diameter | Big biggest diameter | Small smallest diameter |
|---------------------|-------------|-------------------------|------------------------|-----------------------|------------------------|----------------------|------------------------|
| Water flooding      | Water wet   | 36.7                    | 29.2                   | 0.0                   | 65.8                   | 12.5                 | 53.3                   |
|                     | Oil wet     | 23.3                    | 25.0                   | 3.3                   | 45.0                   | 11.7                 | 36.7                   |
| ASP flooding        | Water wet   | 41.7                    | 53.3                   | 2.5                   | 92.5                   | 30.0                 | 65.0                   |
|                     | Oil wet     | 42.5                    | 50.0                   | 10.8                  | 81.7                   | 30.8                 | 61.7                   |

**Table 2.** The location statistics of throat-like residual oil after ASP flooding.
4. Conclusion
(1) Under the same conditions of polymer and alkali concentration, the interfacial tension of the ASP system decreases with the increase of surfactant concentration.

(2) The pore channel model with water-wet properties is more conducive to the production of throat-like residual oil. When the interfacial tension level of the ASP system reaches $10^{-2}$, it has an obvious effect on the residual oil. The wettability of the three types of pores, the smallest diameter and the largest diameter, has a great influence.

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