

Mechanism research on starting residual oil migration in ASP flooding with different Alkali concentration

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Abstract. The results illustrate that under the condition of the same viscosity of ASP system, oil displacement efficiency is different while the ASP system with different alkali concentration has the same order of magnitude as the interfacial tension of oil. In this paper, the microscopic simulation visual model is used to study the mechanism of starting migration of residual oil by doing ASP flooding experiments with different alkali concentration. The results indicate that the migration of residual oil is different from that in the ASP systems with different alkali concentration. ASP system with high alkali concentration can start the migration by means of emulsifying residual oil into oil droplets and oil threads, on this account, increasing the alkali concentration can make the recovery degree of ASP system higher, which will finally be beneficial to the oil recovery.

1. Introduction

The ASP flooding technology started to develop in the 1980s. Initially, Only Dome and several other oil companies took up research on it, however, their development of surfactant alkali polymer compound flooding systems has attracted widespread attention since they first appeared. A suitable concentration of polymer solution is added to the low concentration surfactant-alkali solution to maintain a sufficient viscosity of this system. Using this displacement system (ASP), the amount of chemical reagents can be reduced to 1/10. Moreover, almost the same recovery rate amplification as polymer surfactant SP flooding can be obtained.[1-5] Through the preliminary experimental research, the concept of ASP flooding was clearly put forward in the late 1980s. Besides, a more systematic and in-depth research work was carried out. Theory and field test has shown that the ASP flooding technology can dramatically improve the oil recovery. On one hand, it can play the role of alkali and surfactant in reducing interfacial tension, on the other hand, it can put the polymer to good use in fluidity and profile control. The synergistic effect between the chemicals in the ASP system greatly improves the oil displacement efficiency. In virtue of three chemicals involved in the system, the technology of ASP flooding is complicated with a great many influential factors.

Through the research on the ASP displacement system and its influence factors of oil efficiency, Niu Liwei, Jiang Guipu et al.[6] come to a conclusion that the alkali can change the polymer molecular aggregation, decrease the polymer molecular size, reduce its viscosity and retention characteristics and weaken the ability of expanding the sweep volume. By means of research on the influence mechanism of interface characteristics of ASP system effect on displacement efficiency



Cheng Jiecheng, Xia Huifen et al brought forth the conclusion that the ASP system can get higher displacement efficiency under conditions of low interfacial tension and low interface viscoelasticity, because the synergistic effect of the two factors can increase the emulsification of residual oil.[7] Through the experiment of emulsification degree evaluation and emulsion stability, Zhao Fenglan, Yue Xiangan et al.[8] drew the conclusion that with the increase of the alkali concentration, the emulsifying time will be shortened, the emulsification rate will be increased, the emulsifying ability will be enhanced and the stability of the emulsion will be deteriorated. Though microscopic displacement experiments of various types of residual oil started by ASP system, Wu Chenyu, Hou Jirui et al presented types and morphology of residual oil after water flooding and ideas that in pace with the decrease of the content of each component in ASP system, the performance of the system will gradually become worse, and the function of the residual oil after water flooding will gradually be weakened. [9] Through microscopic displacement experiment carried out by using ASP system with different interfacial dilational viscoelasticity and interfacial tension, Xia Huifen, Feng Haichao et al have gone deeply into the emulsification effect of interfacial dilational viscoelasticity and interfacial tension on residual oil after water flooding, analysis of interfacial dilational viscoelasticity on the startup and migration of residual oil after water flooding, and the synergistic emulsifying effect of interfacial tension and interfacial dilational viscoelasticity. [10] ASP system with different mass concentration will have different effects on final displacement results, however, under normal circumstances, general macro-displacement experiment can only compare the effects of different flooding systems by comparing the recovery, without explaining the migration of the displacement system under the formation conditions and the process how the system affects the oil. Therefore, in order to analyze the effect of alkali concentration on ASP displacement, micro-visual simulation technology is applied to implement all kinds of residual oil micro-displacement experiment started by ASP system, analysis ASP system flooding effect with various alkali concentration. So as to provide theoretical basis for the development of ASP flooding technology, through the observation of the displacement process the driving mechanism of displacement system for residual oil after waterflooding is analyzed and understood.

2. Experimental materials, procedures and methods

2.1. Experimental materials

The polymer is a partially hydrolyzed polyacrylamide powder with a relative molecular mass of 1900×10^4 , which is produced by PetroChina Daqing Refining & Chemical Company. Surfactant is heavy alkylbenzene sulfonate (effective content 50%) and petroleum sulfonate (effective content 40%) produced by Daqing Refining & Chemical Company. The bases were NaOH (effective content 96%) and Na_2CO_3 (effective content 100%). The experimental water is a simulated brine with a salinity of 3700mg/L for distilled water. The experimental oil is simulated oil, and its viscosity is 10.0mPa·s, which is composed of crude oil and kerosene produced by Daqing oil field. ASP solution is a mixed solution composed of polymer, surfactant and alkali liquor into with three kinds of reagent according to a certain proportion, this experiment used ASP solution of surfactant concentration is 0.3%, the concentration of polymer is 1500mg/L and alkali concentration were 1.0% and 1.2%. The experimental temperature is 45°C.

The experimental apparatus and instruments include ISCO pump, thermostat, microscope, image processing system, and visual pore model for glass etching.

2.2. Experimental methods

Micro displacement experiment is implemented by using visual pore model of glass etching. Through the image acquisition system, the image in the process of oil displacement is transformed into the numerical signal of the computer, and the microscopic displacement process of ASP system is investigated by image analysis technology.

2.3. Experiment scheme

The formula for the ASP used in the experiment is shown in Table 1.

Table 1. Formula of ASP

Scheme	Type of surfactant/Mass concentration	Type of alkali/ Mass concentration	Viscosity (mPa.s)	Interfacial tension (10^{-3} mN/m)
1	HABS(0.3%)	NaOH (1.2%)	16.64	2.15
2		NaOH (1.0%)	17.53	4.01
3	Petroleum sulfonate (0.3%)	Na ₂ CO ₃ (1.2%)	13.71	1.57
4		Na ₂ CO ₃ (1.0%)	14.52	3.35

2.4. Experimental procedure

(1) Saturate oil after micro model evacuation;

(2) The end of water flooding is simulated by simulating the displacement rate (0.03ml/h) of the reservoir and the displacement of water to the remaining oil (60min) of the model no longer changes (shape change or decrease);

(3) After the injection of the first formula of ASP system, constant speed displacement (0.03ml/h) residual oil after water flooding to the model residual oil will no longer be the end of the experiment. Observe the microscopic percolation process, collect the dynamic image of residual oil in the process of displacement is in real-time and calculate recovery rate;

(4) Analyze the images and summarize the start-up and migration modes of residual oil;

(5) Clean core;

(6) Repeat (1)-(5) process with the Scheme 2-4 formula.

3. Experimental result analysis

3.1. Start method of migration of residual oil

Figure 1 shows the process of compound residual oil displaced by ASP solution of Scheme 1 in Table 1. Compound residual oil contains more oil. A single compound residual oil can be regarded as such a type of residual oil composed of multiple columnar residual oil, blind-end residual oil and / or membrane-like residual oil. [11] Not only the viscoelasticity of ASP system is larger than that of water flooding but the capillary resistance is reduced by reducing the interfacial tension between oil and water, which results in an increase in the driving force of the residual oil and a decrease in the blocking force, and the fact that the ASP system enters the pore of compound residual oil (Figure 1(b) below) and displaces the residual oil. As ASP flooding is in progress, the compound residual oil gradually reduces, oil silk is left at compound residual oil, and will eventually be driven out by the ASP system (Figure 1(d) below). In Scheme 2, ASP system enters the channel, and the residual oil expelled transports along the adherent film (Shown in Figure 2 (b)). With the reduction of residual oil, the ASP system first breaks through a channel of the compound residual oil, along which more residual oil will be driven out (Figure 2(c)), with a small amount of oil film remaining on the pore wall. Compared with the ternary system flooding process in Scheme 1, there is such little oil thread in the process to form a stable oil channel in Scheme 2. In Scheme 3, after the target of residual oil and that coerced by the ternary system coalescing (Figure 3(b)), the residual oil was affected by the coercing effect of the ASP system and partially recovered (Figure 3(c)). With the gradual decrease of oil-water interfacial tension, the ability of displacing fluid to enter the pore is enhanced Figure 3(d) showed the entry process of the oil displacement system along the channel of compound residual oil. The residual oil displaced by the ASP system that had entered the channel migrated along the adherent film and

stretched the oil thread, which had eventually been extracted. In Scheme 4, the ASP system divided the compound residual oil into small pieces when it entered one of the pore channels of the compound residual oil to displace it (Figure 4(c)). With the development of ASP flooding, the displacement liquid entered a majority of the residual oil channels, and therefore a large proportion of the compound residual oil was produced, leaving a small amount only (shown in Figure 4(d)). Adherent oil film was stretched out to form the oil thread channel to be extracted for the final target that only a small amount of residual oil remained.

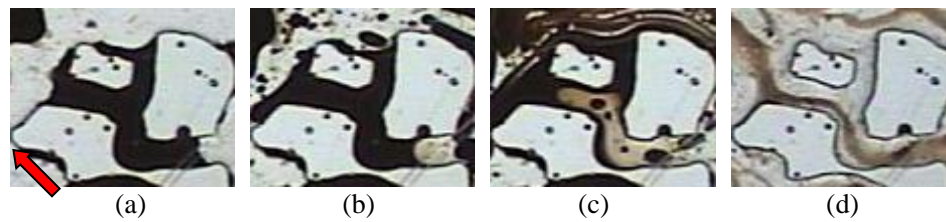


Figure 1. Displacement of compound residual oil (Scheme 1)

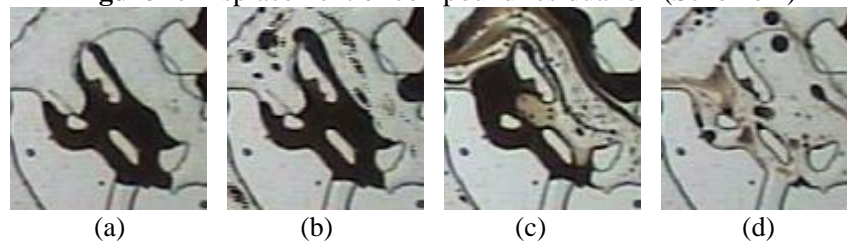


Figure 2. Displacement of compound residual oil (Scheme 2)

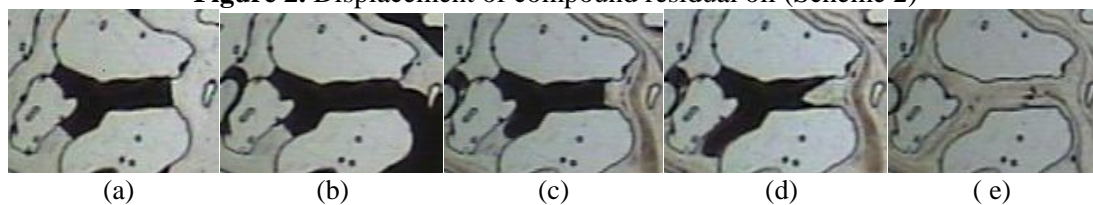


Figure 3. Displacement of compound residual oil (Scheme 3)

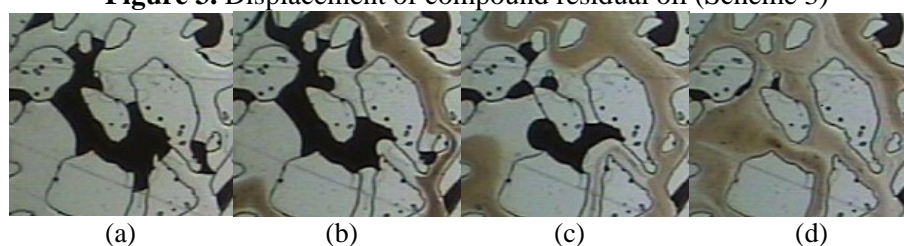


Figure 4. Displacement of compound residual oil (Scheme 4)

Figure 5 shows the process of displacing the columnar residual oil with the ASP system in Scheme 1. The ASP system entered the channel of the columnar residual oil gradually (shown in Figure 5(b)), and a phenomenon appeared obviously that residual oil displaced migrated along the oil film (Figure 5(c)). Under the effects of the tangential force of the ASP system, the front of the columnar oil gradually formed a bulge and emulsifies the oil until the columnar residual oil became shorter and thinner and formed an oil film to seal the pore passage (shown in Figure 5(d)). Columnar residual oil was driven out of the channel, the remaining oil was pulled out and the oil moved towards the outlet after the rupture of oil film. In Scheme 2, in the process of ASP system displacing the residual oil, residual oil was transported along the pore wall (Figure 6(c)), and a protrusion was stretched out, which fractured to generate oil droplets continuously. With the displacement in progress, the column

residual oil became short and disappeared, leaving a small amount of oil film attached to the hole wall. The ASP system in Scheme 3 entered the target residual oil channel to displace the residual oil, leaving the oil film at the residual oil (Figure 7(c)). The oil film was enriched in the direction of the near outlet and fractured to form oil droplets. Through the process of continuous enrichment and formation of oil drops, the oil film on both sides of the channel was eventually displaced completely and all the column oil was extracted (Figure 7(d)). After the ASP system of Scheme 4 started, the columnar residual oil moved slowly toward the outlet end (shown in Figure 8(b)). With the displacement being underway, the ASP system broke through the hole wall by which a great quantity of residual oil was swept forward leaving a small amount of residual oil in the hole wall, which was slowly produced by stretching out to form the oil thread.

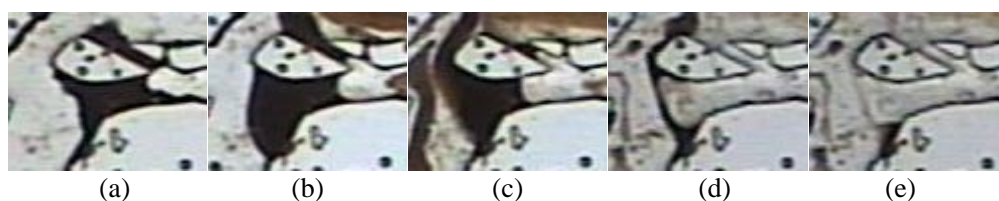


Figure 5. Displacement of columnar residual oil (Scheme 1)

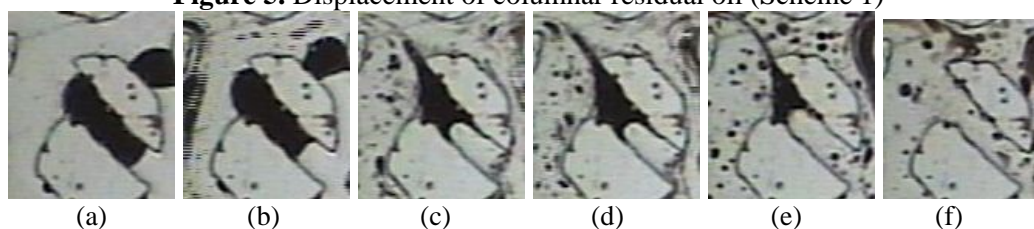


Figure 6. Displacement of columnar residual oil (Scheme 2)

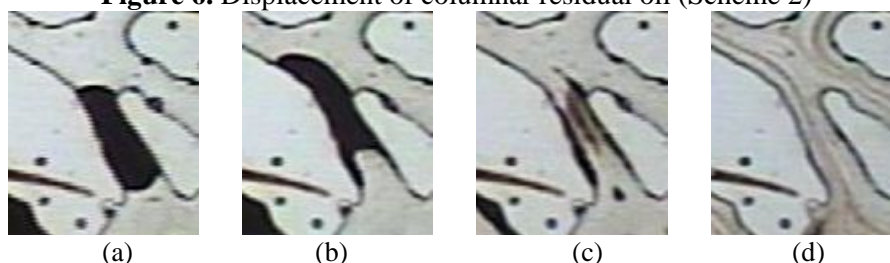


Figure 7. Displacement of columnar residual oil (Scheme 3)

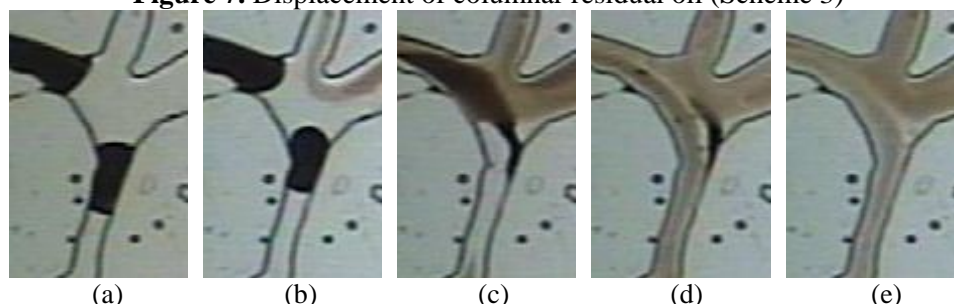


Figure 8. Displacement of columnar residual oil (Scheme 4)

Through the analysis above, ASP system with high alkali concentration start the migration of the residual oil by means of emulsifying the residual oil to oil drop or thread. It is common that residual oil migrates along the emulsified oil thread in high-concentration ternary flooding. It can be observed in the model that under the circumstance of low alkali concentration ternary flooding the oil flow can

also be observed, but the amount is decreasing. Besides, under the condition of low alkali concentration, part of the residual oil cannot be completely displaced, and a small amount of residual oil still remain in the pores in the form of oil film.

3.2. Experiment analysis of oil recovery

Table 2 shows the experiment results of oil displacement of ASP flooding system with different alkali concentrations. Figure 9, Figure 10, Figure 11 and Figure 12 provide the retention of residual oil in the model before and after the chemical system displacement respectively.

Table 2. ASP flooding system flooding experiment results

Scheme	Water flooding Recovery (%)	Chemical flooding Recovery (%)	Incremental oil recovery (%)
1	41.19	84.42	43.23
2	38.26	70.84	32.58
3	41.21	76.76	35.55
4	39.56	68.92	29.36

The chemical flooding recovery in the table above is the overall recovery after the ASP flooding on the basis of water flooding. The recovery value of the remaining oil after the water flooding is carried out by the ASP flooding. The rate increased after the displacement of four types of ASP systems are different from the each other, which can reflect the oil displacement effect of each system respectively.

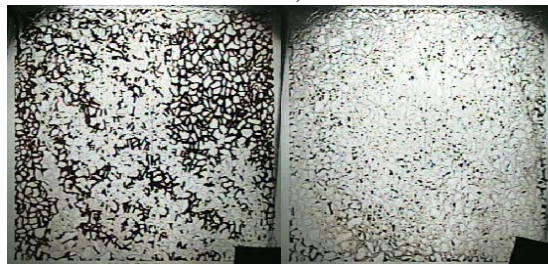


Figure 9 Before and after flooding by Scheme 1

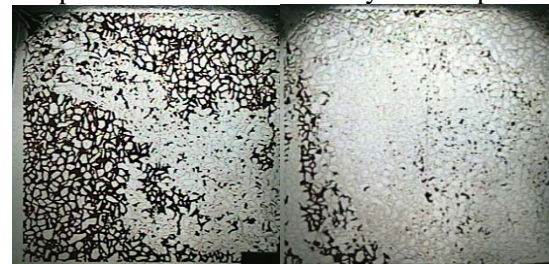


Figure 10 Before and after flooding by Scheme 2

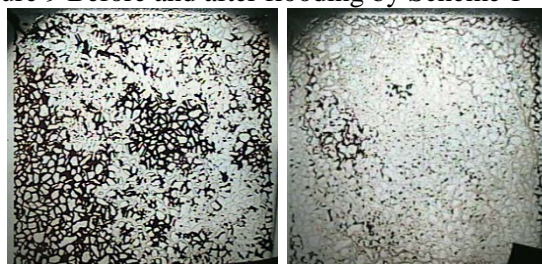


Figure 11 Before and after flooding by Scheme 3

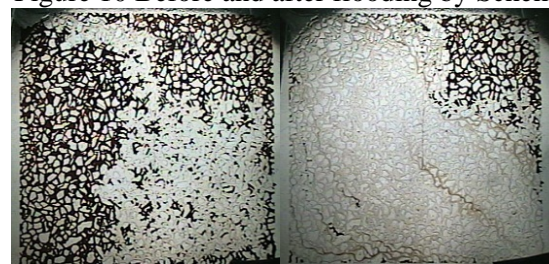


Figure 12 Before and after flooding by Scheme 4

It can be observed that from Table 2 and Figure 9-Figure 12, the swept volume can be expanded and the oil washing efficiency can be improved effectively. However, by contrast of Figure 9 and Figure 10 or Figure 11 and Figure 12, in terms of expanding swept volume, the effect of ASP system with strong alkali is more obvious than that of ASP system with weak alkali. By contrast of Figure 9 and Figure 10, Figure 11 and Figure 12, the ASP system with high alkali concentration can get higher recovery of residual oil. Therefore, increasing the concentration of alkali is beneficial to improve recovery ratio of ASP system.

4. Conclusions

ASP system with high alkali concentration can start the migration by means of emulsifying residual oil into oil droplets and oil threads. It is common that residual oil migrates along the emulsified oil thread in high-concentration ternary flooding. It can be observed in the model that under the circumstance of

low alkali concentration ternary flooding the oil flow can also be observed, but the amount is decreasing.

The residual oil which cannot be extracted at low alkali concentration can be started up by means of increasing the concentration of alkali. Increasing the alkali concentration can make the recovery degree of ASP system higher, which will finally be beneficial to the oil recovery.

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