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The Influence of ASP Flooding on Reservoir Formation Sensitivity

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Abstract: As an enhance oil recovery method, Alkali, surfactant and polymer (ASP) flooding has been already widely used in Daqing oilfield. However, there are many challenges to reservoir formation by using the ASP flooding, such as the reaction between alkali and clay mineral, adsorption of surfactant and retention of polymer, which may cause damage to oil and gas formation. In order to evaluate the formation damage, reservoir sensitivity is researched.

Through the core flow testing, the sensitivity of velocity, water, alkali and acid of core sample has been studied. The core samples are taken from the formation in Daqing oilfield with or without ASP flooding. Moreover, the reason for the change of reservoir sensitivity also has been studied by using scanning electron microscope and X-ray diffraction method.

The experimental formation has the weak velocity sensitivity, strong to medium water, acid sensitivity and weak to medium alkali sensitivity before ASP flooding. However, when comparing the result with the reservoir sensitivity after ASP flooding, it is found that the velocity sensitivity disappears because of the decreasing water sensitive minerals kaolinite, which has been corroded by alkali mostly. The water sensitivity becomes more serious due to the increasing illite/smectite layer, which has strong expansion ratio and cation exchange capacity, and can absorb a large amount of polar water molecules. After the long time reaction between the alkaline fluids and rocks after ASP flooding, both the acid and the alkali sensitivity reduce relatively.

According to analyzing results, the components of reservoir stratum and clay mineral have been changed after the ASP flooding. Due to the Erosion of alkali on formation Minerals, the content of kaolinite reduces, and some minerals increase, such as illite/smectite layer, chlorite and plagioclase. In conclusion, alkali corro-

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sion and scale-forming is considered to be the main reason for reservoir sensitivity changing.

Keywords: ASP flooding, formation damage, sensitivity, clay mineral.

1 Introduction

After decades of production, the enhance oil recovery (EOR) technique have been conducted widely in Daqing oil field in China. Alkali, surfactant, polymer(ASP) flooding can improve the recovery efficiency 20% higher than water flooding by using the cooperation effect of ASP, which has been become the major EOR technique used in Daqing oil field [Yuan (2010); Wang (2002)].

However, some studies [Ehrlich, Wygal and Sydansk (1974); Southwick, Mohnot and Thomt (1985)] suggest that the reservoir formation have been changed because of the alkali in the process of ASP flooding, such as formation damage and scale deposition etc. [Ma (2009); Xiong (2011)].Reservoir sensitivity is considered to be one of the most effective methods to study the reservoir changes. And reservoir sensitivity includes acid sensitivity, water sensitivity, alkali sensitivity, velocity sensitive and stress sensitivity. In this paper, reservoir sensitivity testing before and after ASP flooding were conducted by using Daqing oilfield natural core. By comparing the change of core sensitivity, physical properties and pore structure in the ASP flooding were studied. The reason for the change of reservoir sensitivity also has been researched by using scanning electron microscope and X-ray diffraction method.

2 Experimental method

A schematic flow diagram of the equipment used is illustrated in Fig.1. The experimental apparatus is consists of high-pressure displacement pump (0.001ml/min-50ml/min), piston container (0$\sim$30MPa) and core holder (diameter 2.5cm). All experiment were done in a HW-II automatic control thermostat of 45°. The X–ray and scanning electron microscope was used to analysis the mineral composition of rocks.

The experimental nature core sample was taken from the N-2-FP30 wells of Daqing oilfield. The liquid is simulating salt of formation water. HCL and NaOH solution were needed as displacement fluid in the experiment. The detail of Experimental methods and processes can be seen in the petroleum industry standard – Formation damage evaluation by flow test [SY / T 5358(2002)].

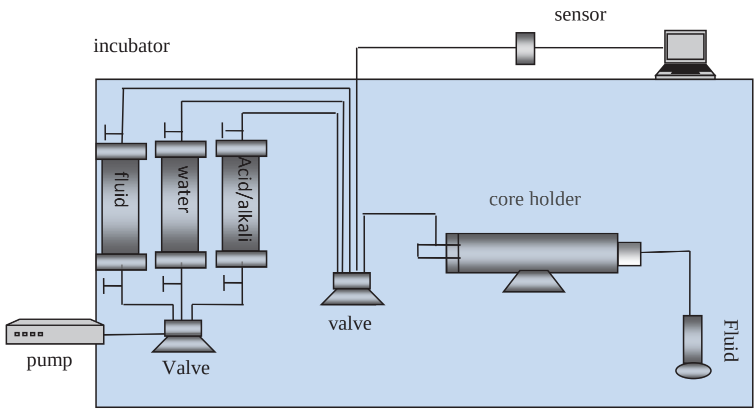


Figure 1: Schematic of Experimental apparatus.

3 Result and discussion

3.1 Velocity sensitive

Velocity sensitivity is refers to the fluid flowed in the oil and gas layer, which cause particle migration, throat clogging and permeability decline. In this experiment, two coring rock sample were selected before and after ASP flooding, and the core permeability was measured under different injection speed to study speed??-sensitive. The results are shown in Fig. 2.

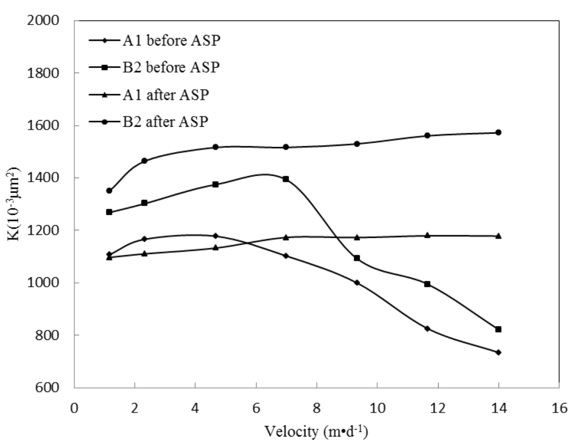


Figure 2: The permeability of core at different inject velocity before and after ASP flooding.

As can be seen from the Fig.2, before ASP flooding, the core sample permeability decreased with the fluid injection rate increase. At the critical velocity, about 5∼6m/d, the permeability drops sharply. After ASP flooding, the permeability of rock samples did not have critical velocity. With the injection rate increased, the permeability increased too. According to the calculation formula of permeability damage rate[SY / T 5358(2002)], the permeability damage degree was researched.

$$D_{k1}=\frac{\bar{K}_{w1}-K_{\min}}{\bar{K}_{w1}}\times 100\% \tag{1}$$

where:

D_{k1} is damage rate of permeability caused by velocity-sensitive.

$\bar{K}_{w1}$ is average of the permeability before the critical velocity, $10^{-3}\mu m^2$.

$K_{\min}$ is the minimum value of permeability after the critical velocity, $10^{-3}\mu m^2$.

And the relationship between damage rate and Permeability damage are as follows:

Table 1: Permeability damage rate of velocity-sensitive.

Permeability damage rate(%)	Permeability damage
$D_{k1} \leq 5$	Not exist
$5<D_{k1} \leq 30$	Weak
$30<D_{k1} \leq 50$	Weak to medium
$50<D_{k1} \leq 70$	Strong to medium
$70<D_{k1}$	Strong

As Tab.1 shows, the core sample before ASP flooding is existing weak to medium speed-sensitive. The main reason for the speed-sensitive is the presence of kaolinite in the core of clay minerals [Chen Zhong (1996), Yan Jianping (2002)]. After the ASP flooding, there is no speed-sensitive phenomenon anymore.

Minerals and clays of core are analyzed with the method of X-ray diffraction [Liao Libing (1995)]. The results are illustrated in Table 2, the composition of sandstone is quartz, K-feldspar and plagioclase. There are large number of kaolinite in clay mineral (about 80%), the content of illite is from 4% to 10%, without considering the smectite and chlorite, the illite/smectite(I/S) mixed layer is only 3% -4% .

Comparing the data in Tab.2 with Tab.3, the types of minerals have a little change after ASP flooding. The total amount of quartz, K-feldspar, plagioclase, calcite, clay minerals remain basically unchanged. But ASP flooding has some impact on the type of clay, such as the content of illite / smectite and chlorite increasing, while

Table 2: The composition of natural core minerals and clay.

NO.	Contents of clay minerals (%)						species and content of mineral (%)				Clay minerals (%)
	S	I/S	I	K	C	C/S	quartz	potash feldspar	plagioclase	calcite	
1	/	3	6	91	/	/	42.9	20.7	28.3	/	8.1
2	/	3	4	93	/	/	47.5	26.1	22.6	/	3.8
3	/	4	7	89	/	/	44.2	17.7	34.4	/	3.7
4	/	4	12	84	/	/	58.3	12.3	25.4	/	4
5	/	4	16	80	/	/	51.1	9.8	33.6	/	5.5
6	/	3	10	87	/	/	50.2	21.9	22.1	/	5.8
7	/	3	6	91	/	/	40.1	17.8	34.8	/	7.3
8	/	3	10	87	/	/	49	21.4	22.8	/	6.8
9	/	3	9	88	/	/	49.5	15.4	26.1	/	8.5
10	/	1	4	95	/	/	49.8	18.4	26.8	/	5
11	/	1	4	95	/	/	51.1	14.7	28.3	/	5.9

Table 3: The composition of natural core minerals and clay after ASP flooding.

NO.	Contents of clay minerals (%)						species and content of mineral (%)				Clay minerals (%)
	S	I/S	I	K	C	C/S	quartz	potash feldspar	plagioclase	calcite	
G1	/	43	8	28	21	/	48.6	9.3	33.2	/	8.9
G2	/	54	7	18	21	/	36.1	13.6	30.8	/	19.5
G3	/	19	6	55	20	/	46.8	11.9	34.1	/	7.2
G4	/	17	7	61	15	/	53.9	10.0	32.1	/	4.0
G5	/	24	6	47	23	/	48.8	8.3	33.4	/	9.5
G6	/	16	5	68	11	/	46.8	21.8	24.3	/	7.1
G7	/	26	5	40	29	/	40.7	12.7	39.7	/	6.9
G8	/	17	3	54	26	/	50.4	10.1	32.2	/	7.3
G9	/	32	4	50	14	/	41.6	14.2	33.9	/	10.3
G10	/	55	6	17	22	/	34.2	8.9	36.1	/	20.8
G11	/	26	6	46	22	/	44.1	16.8	35.5	/	3.6
Where, K is kaolinite; I is illite; S is smectite; C is chlorite; I/S is illite/smectite mixed layer; C/S is chlorite/ smectite mixed layer.											

the kaolinite declining. And the chlorite (C) barely exists firstly, while it can reach 20-30 percent of the clay minerals after ASP flooding.

According to the X-ray diffraction analysis, the content of kaolinite decreases significantly, because of the alkali corrosion. See Fig.3. It may be related to the schistose structure of the kaolinite. The crystal structure of kaolinite is composited

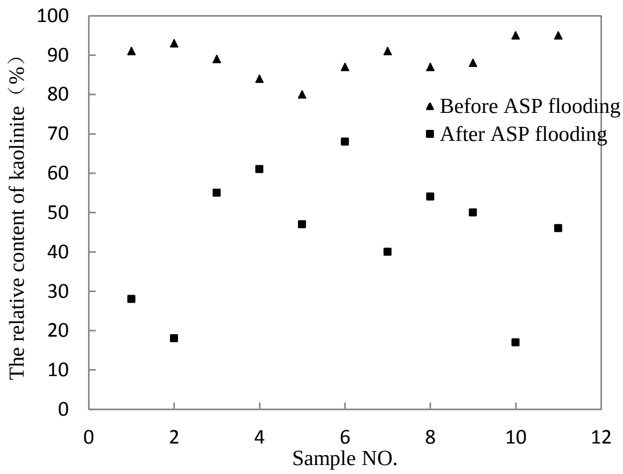


Figure 3: The content of kaolinite of the Clay minerals before and after ASP flooding.

by both oxygen and hydrocarbon. Crystal layer is tightly connected by hydrogen bonds, so that the water is difficultly to access. However, owing to the larger contacting area of kaolinite with ASP flooding, the kaolinite is more easily eroded by alkali than that dense minerals, like quartz.

Kaolinite belongs to the non-swelling clay mineral, which is one of the most common authigenic clay minerals in sandstone reservoir. Kaolinite usually appears in the pore throats, which crystal is larger than chlorite. Kaolinite can be transformed into albite, the reaction equation is as follows:

$$Al_2[Si_2O_5](OH)_4 + 2Na^{+} + 2OH^{-} + 4Si(OH)_4 = 2NaAlSi_3O_3 + 11H_2O \tag{2}$$

The reaction equation of Kaolinite is dissolved by alkali is as follows:

$$Al_4[Si_4O_{10}](OH)_8 + 8OH^{-} = 4Al(OH)_3 \downarrow + 4SiO_3^{2-} + 2H_2O \tag{3}$$

After the ASP flooding, as velocity sensitive mineral kaolinite is dissolved by the alkali, the component of Silicon and aluminum transfers from the solid phase to formation water, so that the Velocity sensitivity disappears. Meanwhile, the increasing of flow rate makes the particle migrate in the Porous media, so the permeability of the core becomes slightly larger than the lower injecting speed.

3.2 Water sensitivity

Water sensitivity is refers to the permeability decline phenomenon in reservoir, which is caused by hydration expansion of clay minerals in the decreasing concentration of salt solution. In the water sensitive evaluation experiment, and the core permeability was measured under different salinity. Five different salinities of core fluids were measured. The results are shown in Fig.4.

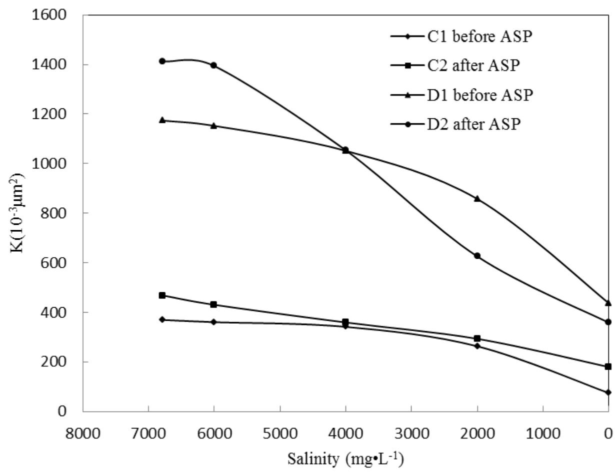


Figure 4: The permeability of core at different salinity before and after ASP flooding.

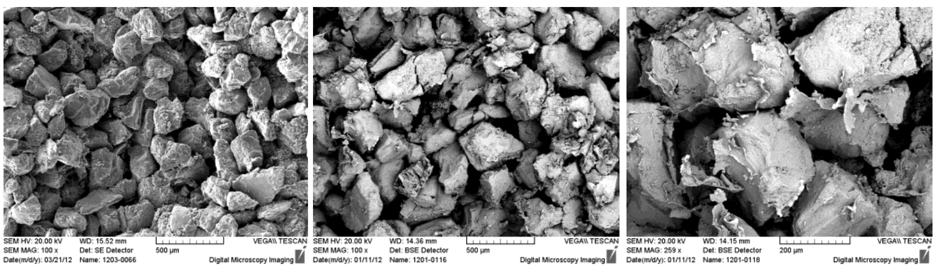
The permeability of the cores decreased with the reduction salinity of the formation water both before and after ASP flooding. Before the ASP flooding, when the salt concentration is 4000mg/L, the core permeability decreases significantly, which means the critical salinity is 4000mg/L. However, after the ASP flooding, the critical salinity is about 6000mg/L. According to the water sensitivity evaluation [SY / T 5358(2002)], the core water sensitivity results are as follows:

Table 4: Water sensitivity index (I_W).

NO.	C1	C2	D1	D2
I_W/%	57.2	77.1	62.8	74.5
Water sensitivity	Strong to medium	strong sensitivity	Strong to medium	strong sensitivity

The experimental results show that, before ASP flooding, the formation is strong to medium water sensitive. With the ASP flooding, the formation water sensitive becomes more serious, it is strong water sensitive. Researches show that the existing of illite and I/S is the main reason of the water sensitive [SUN Liyan (2008)]. The illite can absorb water and expand, which will cause the water sensitive.

The change of mineral particles in the Core pore was studied by the methods of scanning electronic microscope(SEM), the core is basically the same with the ASP flooding. The sample structure is loose, and antiparticle pore is about 50-150μm. But rock grain surface shows a lot of flocculent material, see c in Fig.5. According to the X-ray diffraction results (Fig. 6), the flocculent material should be illite-smectite (I/S) mixed layer.



a) SEM analysis before ASP b) SEM analysis after ASP c) Partial enlargement of (b)

Figure 5: SEM analysis before and after ASP flooding.

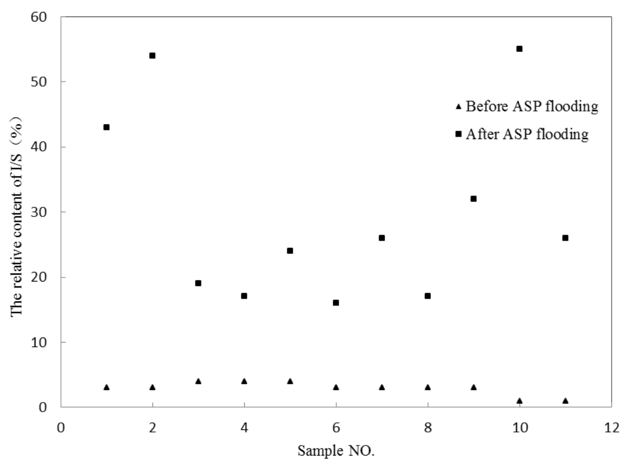


Figure 6: The compare of I/S before or after ASP flooding.

The I/S mixed layer has serious water sensitivity, especially sodium montmorillonite, it can be expansion for 6 to 10 times in water. The illite-smectite swells and decentralizes by absorbing water. So that water sensitive will be greatly enhanced. And the mixed layer has the difference electric, which is more easily dispersed, and more likely to swell. New minerals chlorite may make the porosity and permeability is reduced too. Silicon aluminum ions is dissolute by alkali in the flow process, leading to the change of silicon aluminum form, will also affect scaling type of change in the process of combination flooding at different stages in injection Wells.

3.3 Acid sensitivity

Reservoir acid sensitivity is that acidizing fluid flow into the reservoir and has a reaction with acid sensitivity mineral, then release precipitation or particulate, which reduces permeability. The acid sensitive experimental analysis is carried out before and after the ASP flooding, the result shows that:

Table 5: acid sensitivity experiment.

Sample NO.	Permeability before injecting acid	Permeability after injecting acid	Acid sensitive index
E1 before ASP	448.0	319.2	28.7
E2 after ASP	389	410.3	0
F1 before ASP	473.9	356.7	24.7
F2 after ASP	510	534	0

Depend on the acid-sensitive assessment indicator [SY / T 5358(2002)], data in the Tab.4 indicates that before ASP flooding, acid-sensitive indicator in the core is about 20%-30%, which belongs to strong to medium acid sensitive damage. Conducting experiments on cores after ASP flooding, from the change of permeability we can obtain that the permeability of cores increases a little after injecting acid, which obviously illustrates that the cores are not damaged by acid.

For acid-sensitive layers, the mineral deposition is mainly ferric hydroxide precipitation, which can plug pore throats. The mineral commonly includes ferrous ions, which convert into ferric ion in oxidizing conditions. When the PH value is low, precipitation plugs the pores. After ASP flooding, this kind of precipitation cannot generate in the long time of alkali environment. However, alkali scale would be generated after a long time alkali flooding. When acid was injecting, acid pickling increases the layer permeability [Tang and Meng (2002)].

3.4 Alkaline sensitivity

When high PH fluid is flew into the oil and gas layer, clay minerals and siliceous cement structure will be destroyed, resulting in the clogging of the oil and gas layer damage. Cores are selected to take an experiment before and after ASP flooding. The results are as follows:

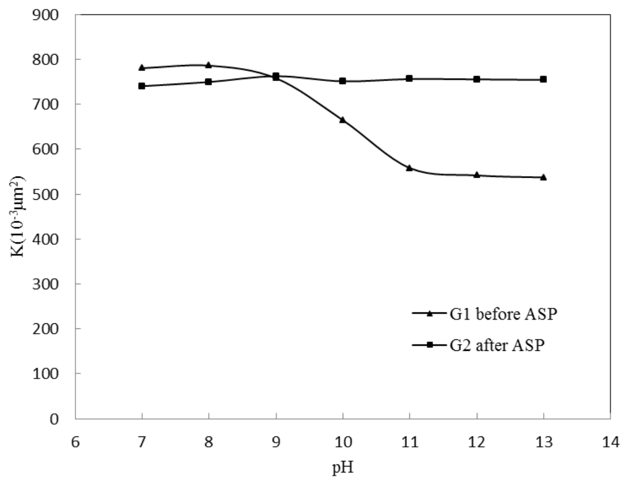


Figure 7: The change of permeability of alkali sensitivity.

The experimental data show that, before ASP flooding core permeability shows a flat trend after a rapid decline as the pH value increases. Alkali sensitivity critical PH is 9. According to the standard, the alkali sensitivity index is about 31.6%, which is weak to Medium alkali sensitive. But after ASP flooding, the permeability reduction is not so obvious. This proves that the core of the alkali-sensitive damage reduced.

The factor causing the alkali sensitivity damage is mainly that alkali combines with ions such as calcium and magnesium in clay minerals and hydroxide precipitations are produced. Because of the decrease of calcium coverage on surface, clays tend to expand or release from the gravel surface. When the temperature is high, alkali has the most distinct reaction with kaolinite and reaction products can jam formation. According to the clay mineral analysis result before and after, content of kaolinite decreases. At the same time, the alkali in the ASP flooding system has caused certain damage to the formation after long time of ASP flooding, which makes the core less sensitive to the alkali damage after ASP flooding [Jia Tongquan (2007)].

4 Conclusions

1. The Daqing oilfield reservoir formation has the weak velocity sensitivity, strong to medium water sensitivity, acid sensitivity and weak to medium alkali sensitivity before ASP flooding. However, after the ASP flooding, the sensitivity of formation is changed.

2. The velocity sensitivity disappears because of the decreasing of kaolinite, which is a Water sensitive mineral. The water sensitivity becomes more serious because of the increasing of illite/smectite layer, which have strong expansion ratio and cation exchange capacity.

3. After the long time reaction of the alkaline fluids with rocks, both the acid and the alkali sensitivity reduce relatively. Acid can dissolve the alkali scale generated in the ASP flooding, resulting in the increasing of reservoir permeability. Because the alkali in the ASP flooding has made some damage to formation, alkali sensitivity damage after the flooding is smaller than the original reservoir damage.

4. The components of reservoir stratum and clay mineral have been changed in the ASP flooding. Most of all, alkali corrosion and scale-forming lead to pore throat choke and reservoir permeability change.

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