Adaptability Evaluation of Polymer Flooding for Zahra Oil Field

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Abstract: Viscosity-concentration and temperature performance are the prerequisite constraint factor of the application of polymer flooding in the oilfield. The static and dynamic adsorption of the polymer in the core can affect the performance of polymer flooding. Based on the viscosity-concentration, temperature and the static, dynamic adsorption results of six kinds of polymers, DQ3500 is chosen as the most suitable polymer for Zahra oilfield. Its affects show that oil recovery is increased by 7% and water cut is reduced by 20%.

Keyword: Enhanced oil recovery, Polymer viscosity-concentration, Static dynamic adsorption, Temperature performance, Water cut.

1. INTRODUCTION

Viscosity-concentration, temperature performance are the prerequisite constraint for polymer flooding in an oilfield [1] .Static adsorption and dynamic adsorption of the polymer not only can restrict the dissemination properties of polymers directly [2-5], but also can affect the economic effects of polymer flooding in a specific reservoir. In this paper, adaptability of polymer flooding of 6 kinds of polymers in Zahra oil field is researched. Based on the viscosity-concentration, temperature relationship and the static, dynamic adsorption results of the 6 kinds of polymers, the polymer DQ3500 is selected as the most suitable polymer for polymer flooding in Zahra oil field. Its effects on enhancing oil recovery are analyzed.

2. EXPERIMENTAL APPARATUS AND MATERIALS

2.1. Experimental Apparatus

The apparatus include DMA 45 densitometer, Ultraviolet spectrophotometer, MCR301 viscometer, displacement equipment(pressure gage, thermostat, core gripper), PH meter, etc.

2.2. Experimental Materials

The chemicals applied in the experiments, such as NaOH (≥99.5%), Na_2CO_3(≥99.5%), NaCl(>99.5%), $CaCl_2$(>96%) and $MgCl_2 \cdot 6H_2O$(>99%) are provided by Beijing Modern East Fine Chemical Co.. Zahra dewatered oil（T=72℃, η=7.46mPas, ρ=0.8290g/cm^3） Polymer MO4000, FP3640s, FP6040s, DQ3500, KYPAM-2 and KYPAM-5.

3. EVALUATION OF POLYMER FLOODING IN ZAHRA FIELD

3.1. Formation Brine in Zahra field

The composition of formation brine in Zahra field is shown as in Table **1**. In the artificial simulation, the water based on the composition of the formation brine in Zahra field is prepared and used for preparing chemical solution in this research.

There are 6 polymers have been selected in the evaluation of polymer flooding for Zahra crude oil. The parameters of M_w, hydrolyzing degree, filtration factor, water insoluble matters, dissolving time and solid content of the 6 polymers are selected and listed in Table **2**. From Table **2**, it can be found that the content of all four polymers is higher than 86.5%. The dissolving time of all four polymers is less than 2 hours. The results show that all of the polymers selected can meet the polymer flooding standard.

Table.1. Ion composition of formation brine in Zahra field.

Ions	Na^+	K^+	Ca^{2+}	Mg^{2+}	Cl^-	SO_4^{2-}	HCO_3^-	CO_3^{2-}	Total	pH at 25 °C
C(mg/L)	3820	86	105	34	5250	645	485	NIL	10425	7.85

3.2. Relationships between the Apparent Viscosity and Polymer Concentration

The relationship between the apparent viscosity and the polymer concentration of polymer solution for the six kinds of polymers with formation brine are examined. The shear rate is 7.34 s^{-1} and the results are as shown in Table **3**. From Table **3**, it can be seen that the viscosity of polymer solution

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Table 2. Parameters of polymers selected for the evaluation of polymer flooding.

Polymer	MO4000	FP3640s	FP6040s	DQ3500	KYPAM-2	KYPAM-5
Manufacture	Misubishi.	SNF	SNF	DQ	Hengju Co.	Hengju Co.
Country	Japan	France	France	China	China	China
M_w ($\times 10^4$)	2400	2000	2500	1900	2447	1950
Hydrolyzing degree mol/%	22.46	31.80	24.60	37.41	21.50	25.06
Filtration factor	1.04	1.0	1.2	1.36	1.06	1.10
Water insoluble matter/%	0.018	0.19	0.062	0.163	0.071	0.079
Dissolving time/h	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0
Solid content/%	91.78	88.17	89.29	86.54	89.32	88.48

Table 3. Relationship between the apparent viscosity (mPa·s) and the polymer concentration (mg/L) (T=72°C shear rate :7.34s^{-1}).

Polymer \ Concentration	500	750	1000	1500	2000	2500
MO4000	3.1	5.0	6.7	14.2	25.6	38.5
FP3640s	1.9	3.0	4.4	8.2	14.8	24.2
FP6040s	5.2	8.8	14.0	28.0	49.0	75.6
DQ3500	6.9	11.7	21.0	39.0	66.5	102.5
KYPAM-2	4.9	8.5	12.5	29.7	52.0	83.4
KYPAM-5	4.4	7.3	11.6	23.4	41.8	64.7

is increased with the increasing of polymer concentration. The viscosity of polymer solution for polymer FP6040s, DQ3500 and KYPAM- 2 are larger than the others. Under the shear rate of 7.34 s^{-1}, the apparent viscosity of 1500mg/L polymer solution for polymer FP6040s, DQ3500 and KYPAM-2 are 28.0, 39.0 and 29.7 mPa·s at temperature of 72°C. From the perspective of the relationship between the apparent viscosity and the polymer concentration of polymer solution, polymer FP6040s, DQ3500, and KYPAM-2 are suitable for polymer flooding in Zahra's oil field.

3.3. Relationship between the Apparent Viscosity and Temperature

The relationship between the apparent viscosity and the temperature of polymer solution for the six kinds of polymers with formation brine is examined. The concentration of polymer solution is 1500mg/L and the shear rate is 7.34 s^{-1}. The results are as shown in Table **4**. From Table **4**, it can be seen that the viscosity of polymer solution is decreased with the increasing of temperature. Under the shear rate of 7.34 s^{-1}, the apparent viscosity of 1500mg/L polymer solution for polymer FP6040s, DQ3500 and KYPAM-2 are 25.2, 33.0, 23.8mPa·s at temperature of 85°C. The viscosity of polymer solution for polymer FP6040s, DQ 3500 and KYPAM-2 are larger than the others. From the perspective of the relationship between the apparent viscosity and the temperature, polymer FP6040s, DQ 3500, and KYPAM-2 are suitable for polymer flooding in Zahra's oil field.

3.4. Thermo-stability Characteristics of Polymer Solution

Fig. (**1**) is apparent viscosity changing of the polymers with thermal aging time, with the polymer concentration of 1500 mg/L in anaerobic condition at temperature of 72ºC. It can be seen from Fig. (**1**) that the apparent viscosity of polymer solution is basically remained unchanged. The polymers solution has long time thermo-stability.

3.5. Transmission Performance of Polymer in Cores

The static and dynamic adsorption of the polymer in core can affect the performance of the polymer flooding. Flow properties of the three kinds of polymer DQ3500, FP6040s and KYPAM-2 in the reservoir rocks are investigated through core flow test.

(1). Polymer of FP6040s

Fig. (**2**) is the pressure curve of four different measuring points in a core when 1500 mg/L FP6040s polymer solution flows through the core. The core permeability is 73.0 mD. From Fig. (**2**), it can be seen that the pressure at different position in the core is raised slowly when polymer solution is

Table 4. Relationship between the apparent viscosity（mPa·s）and the temperature(ºC) (c=1500mg/L，shear rate 7.34s^{-1}）.

Polymer \ Temperature (ºC)	45	55	65	70	75	85
MO4000	18.9	16.3	14.3	14.	13.5	12.1
FP3640s	12.5	11.3	9.5	8.9	8.2	7.8
FP6040s	34.5	32.2	29.9	28.7	27.4	25.2
DQ3500	48.6	44.5	41.0	39.0	37.8	33.0
KYPAM-2	36.0	30.8	29.3	26.3	24.8	23.8
KYPAM-5	30.7	27.9	25.2	23.5	22.7	19.9

Table 5. Parameter of core.

Core	Length/mm	Diameter/mm	Pore volume/ml	Porosity/ %	Permeability of air /mD	Permeability of water/mD
1#	281.60	25.00	38.43	27.8	247	73.0

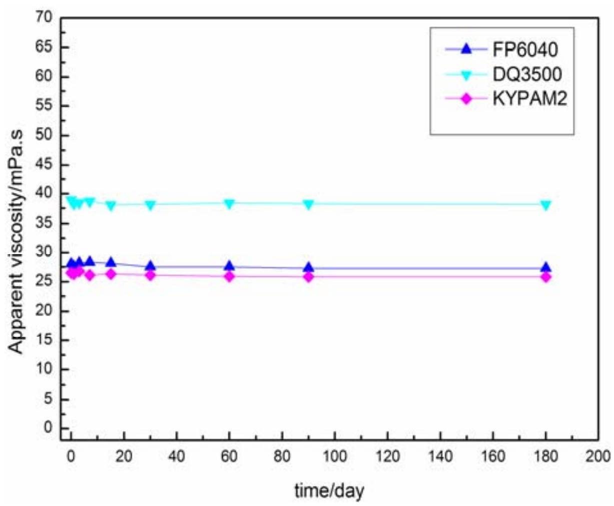


Fig. (1). Relationship between the viscosity of polymer solution and aging time.（anaerobic condition at 72 ºC, concentration: 1500mg/L，shear rate :7.34s^{-1}）

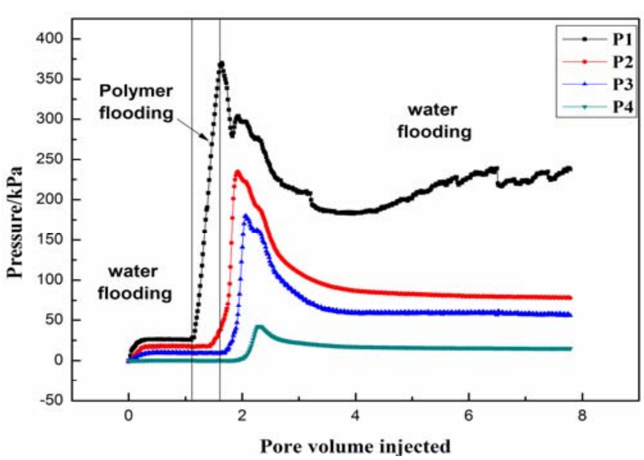


Fig. (2). 1500 mg/L FP6040s solution injection performance in a core.

injected into the core. And then water replaced the polymer solution when the polymer solution injection volume reached 0.5 PV (pore volume). The pressure at different position in the core rose slowly, but along with the water injection, the pressure at different position in the core is declined slowly and then to be stability. The dramatic change of pressure is not appeared.

(2). Polymer of KYPAM-2

Fig. (**3**) is the pressure curve of four different measuring points in a core when 1500 mg/L KYPAM-2 polymer solution flows through the core. The core permeability is 82.6 mD. It can be seen from Fig. (**3**) that the pressure at different position in the core is raised slowly when polymer solution is injected into the core. And then water replaces the polymer solution when the polymer solution injection volume reaches 0.5 PV (pore volume). The pressure at different position in the core rose slowly along with the water injection, the pressure at different position in the core is declined slowly and then to be in stability state. The dramatic change of pressure is also not appeared.

(3). Polymer DQ3500

Fig. (**4**) is the pressure curve of four different measuring points in a core when 1500 mg/L DQ3500 polymer solution flows through the core. The core permeability is 59.3 mD. It can be seen from Fig. (**4**) that the pressure at different position in the core is raised slowly when polymer solution is injected into the core. And then water replaces the polymer solution when the polymer solution injection volume reaches 0.5 PV (pore volume). The pressure at different position in the core is also risen slowly. But along with the water injection, the pressure at different position in the core is declined slowly and then to be in stability stat. The pressure does not present dramatic changes.

Table 6. Parameter of core.

Core	Lenth/mm	Diameter/mm	Pore volume/ml	Porosity/%	Permeability of air/mD	Permeability of water/mD
2#	284.12	25.00	31.07	22.3	167	82.6

Table 7. Parameter of core.

Core	Lenth/mm	Diameter/mm	Pore volume/	Porosity %	Permeability of air/mD	Permeability of water/mD
3#	283.78	25.00	30.00	21.5	158	59.3

Table 8. Adsorption of t polymers with different concentration on natural rock particles (μg/g).

Polymers \ Concentration (mg/L)	400	800	1000	1500
FP6040	1276	1396	1464	1492
DQ3500	1012	1060	992	876
KYPAM-2	1280	1104	1496	1172

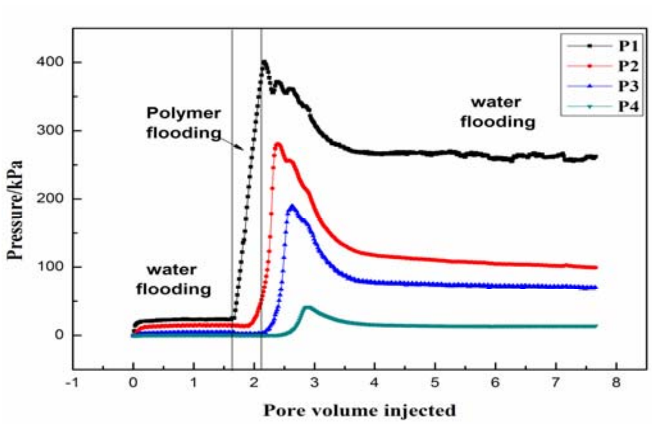


Fig. (3). 1500 mg/L KYPAM-2solution injection performance in a core.

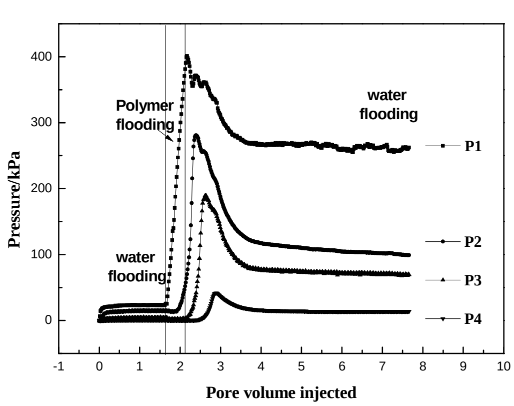


Fig. (4). 1500 mg/L DQ3500 solution injection performance in a core.

3.6. Static Adsorption of the Polymer on Natural Rock Particles

Static adsorption of the polymer FP6040s, DQ3500 and KYPAM-2 on the surface of the natural rock particles (100 mesh) is examined [5] at 72 ºC. The experimental results are shown in Table **8**. It can be seen from Table **8** that static adsorption of the polymer FP6040s, DQ3500 and KYPAM - 2 do not change a lot with the increasing of concentration of polymer solution. Static adsorption amount of polymer FP6040s, DQ3500, KYPAM - 2 is approximately 1000 mg/g, especially the static adsorption amount of DQ3500 is the smallest.

3.7. Dynamic Adsorption of Polymer on Surface of Natural Core

Dynamic adsorption of polymer FP6040s, DQ3500, KYPAM-2 with a concentration of 1500 mg/L on the surface of the natural rock is measured by core flow test at 72 ºC. Parameters of cores are shown as in Table **9**. The results are shown in Table **10**. It can be seen from Table **10** that dynamic adsorption of polymer FP6040s, DQ3500, KYPAM–2 on the surface of the core are 196, 125 and 159 mg/L, respectively. The dynamic adsorption of the polymer DQ3500 is the smallest.

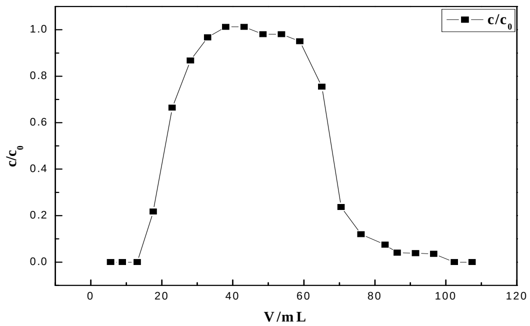
It can be seen from the static and dynamic adsorption results that DQ3500 adsorption is significantly smaller than the other two polymers. In practical application of polymer solution flooding the reducing of the polymer adsorption can reduce the amount of injection volume which is helpful to displacement efficient. So DQ3500 is chosen as the most suitable polymer for polymer solution flooding in Zahra oilfield.

3.8. Flooding Effect on Natural Core

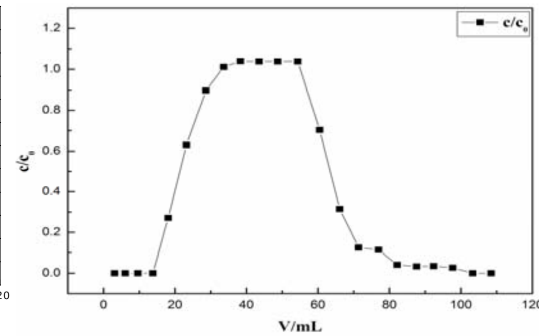
Polymer solution flooding effect is evaluated by displacement experiment in natural core. Fig. (**6**) is the

Table 9. Parameter of cores.

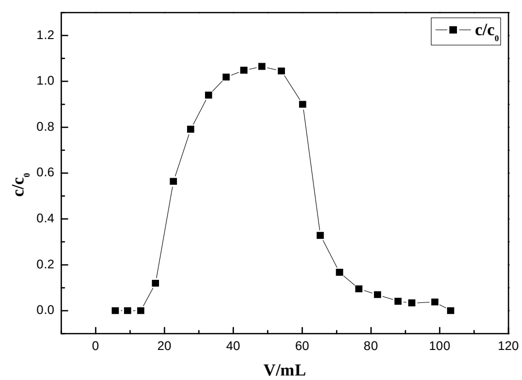
Core	Length of core/mm	Diameterof core/mm	Pore Volume/ml	Porosity/%	Kg/mD	K_W/mD
4#	287.60	25.00	34.16	24.2	173	66.3
5#	286.00	25.00	33.35	23.8	184	50.4
6#	286.34	25.00	32.78	23.3	182	49.1



(**a**). Polymer DQ3500

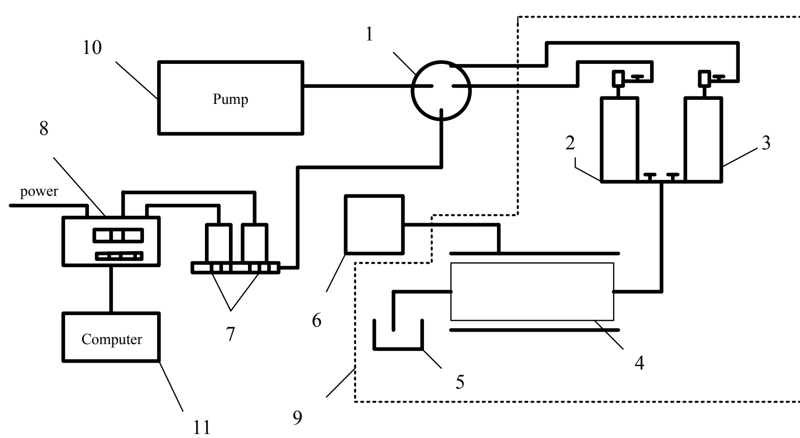


(**b**). Polymer KYPAM-2



(**c**).Polymer FP6040s

Fig. (5). Dynamic adsorption of polymer on cores.



1. Valve 2. Tank of water 3. Tank of polymer solution 4. Core holder 5. Beaker 6. Pump 7. Pressure tranformer 8. Pressure meter 9. Heating box 10. Pump 11 Computer

Fig. (6). Schematic diagram of polymer flooding for Zahra crude oil apparatus used in experiment

schematic diagram of polymer flooding for Zahra crude oil apparatus used in displacement experiment.

Displacement experiment results of polymer solution of DQ3500 with 1500 mg/L in 25 cm long and permeability of

Table 10. Dynamic adsorption of polymers in core.

Polymer	FP6040	DQ3500	KYPAM-2
Adsorption amount（μg/g）	196	125	159

Concentration of polymer solution: 1500mg/L

Table 11. Parameter of cores.

Core	Length of core / mm	Diameter of core/mm	Pore Volume / ml	Porosity / %	Kg /mD	K_W /mD
7#	277.58	25.00	24.11	17.8	114.8	26.4
8#	260.22	25.00	26.43	20.7	1800	237.3

Table 12. Displacement performance of 1500mg/L polymer solution of DQ 3500.

Core	Oil Saturation/%	Oil Recovery by Water/%	Ultimate Recovery/%	Enhanced Oil Recovery/%	Resistance Factor/%	Residual Resistance Factor/%
7#	56.4	43.44	50.53	7.09	4.47	1.35
8#	58.8	29.77	36.87	7.1	5.32	2.36

20-240 mD natural cores at 72 ºC are shown from Fig. (**7**) to Fig. (**10**) and Table **12**, respectively. The oil used in displacement experiment is the dewatered Zahra crude oil. The displacement procedure was as follows [6,7]:

1. The core is saturated with water in a vacuum state. So the pore volume is calculated by the water volume.

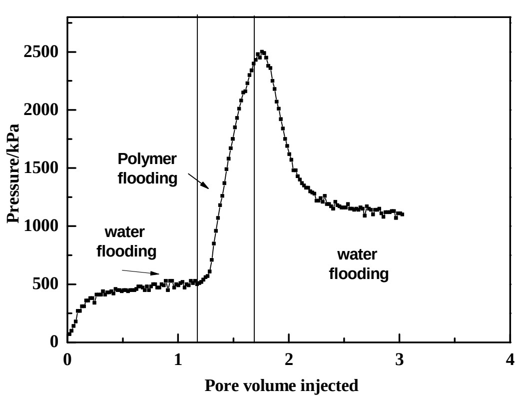


Fig. (7). Pressure in displacement experiment in core 7#.

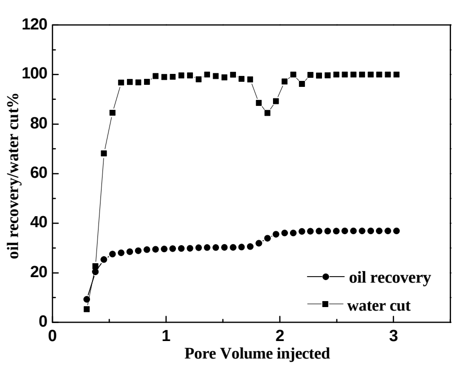


Fig. (8). Water cut /oil recovery in displacement experiment in core 7#.

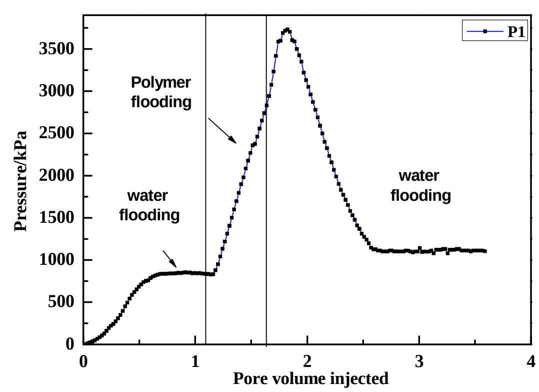


Fig. (9). Pressure in displacement experiment in core 8#.

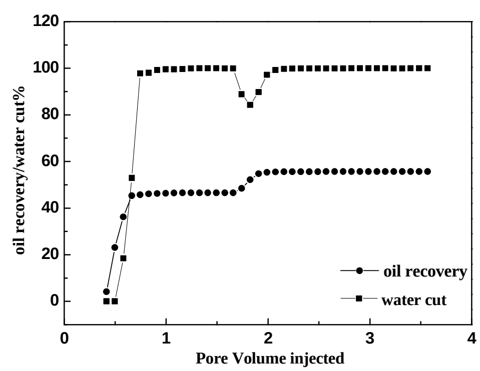


Fig. (10). Water cut /oil recovery in displacement experiment in core 8#.

2. The core is flooded with the dewatered Zahra crude oil until no more water could be displaced. The oil saturation is calculated by the ratio of saturation oil volume to the saturation water volume in step 1.
3. The core is water flooded at a rate of 0.1ml/min. When water cut reaches 98%, the core is flooded by of polymer solution of DQ3500.When the injected polymer solution volume reaches 0.5 PV, the core is flooded by water again until no more oil could be displaced.

The cores used in the displacement experiment are shown in Table **11** and the results of the displacement experiment are shown in Table **12**.

It can be seen from Table **12** that enhanced oil recovery by polymer solution of DQ3500 in natural core is about 7% and the water cut is significantly decreased about 20%.

4. CONCLUSION

1. From the view of viscosity-concentration/temperature performance and the static/dynamic adsorption of the polymer in core, DQ3500 is chosen as the most suitable polymer for Zahra oilfield flooding.
2. Enhanced oil recovery by polymer solution of Qaqing 3500 in natural core is about 7% and the water cut is significantly decreased about 20%.

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