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Research Article

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The feasibility study for polymer flooding in heavy oil recovery based on block X

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ABSTRACT

Block X is located in No. 9 Production Plant in Daqing, which began to implement hot water flooding after 7 years of water flooding, but due to the low recovery degree and high energy-wasting, it limited the increase of the economic returns. In order to enhance oil recovery further and reduce the cost of extraction, it is urgent to adopt effective method to enhance recovery degree. By looking through the advantages of polymer flooding for heavy oil and comparing these with physical property in block X, it is feasible to implement polymer flooding in block X. Basing on liquidity experiments that different molecular weight was measured and resistance factor and residual resistance factor produced by polymer flooding with different concentrations when liquids flowed through the core, and displacing experiments that series of experiments including water flooding before polymer flooding, polymer flooding and water flooding after polymer flooding was simulated, It is further verified that it is feasible to implement polymer flooding in block X and reach an optimal project for implementing polymer flooding in block X, which included that the concentration, molecular weight and pore volume injected are respectively 2000 mg/L, 25 million Daltons and 0.4PV. This optimal project could improve 9.94% of the oil recovery for polymer flooding and water flooding after water flooding compared with water flooding alone.

Key words: High-viscous heavy oil; Polymer flooding; The feasibility study; Enhanced oil recovery.

INTRODUCTION

Heavy oil is the crude oil that its viscosity is greater than 50mPa•s at the oilfield conditions. With the higher heavy components, higher average molecular weight, more impurity atoms, constitutes and structures of heavy oil are more complicated. The fractions of it divided into four main fractions (SARA) which are saturated hydrocarbon, aromatic hydrocarbon, resin and asphaltene. Heavy oil is called as viscous heavy oil in China, which is divided into general heavy oil (the viscosity of it range from 50 mPa·s to 10000 mPa·s), extra heavy oil (the viscosity of it range from 10000 mPa·s to 50000 mPa·s) and super heavy oil (the viscosity of it is greater than 50000 mPa·s). At present, the recoverable reserve of heavy oil, extra heavy oil and super heavy oil that have been found in the world have surpassed general oil, and the development of the heavy oil is more and more valued with the progressive decrease in the production of general oil developed relatively easy. There are wealthy heavy oil resources in China. So it has important practical significance and long-term strategic significance to develop heavy oil well. There have been two common methods in the development of heavy oil[1,2]: one is steam flooding after huff and puff, another is the conventional water flooding. There are some questions such as low uptake for injected water and low recovery in water flooding[3-6]. The recovery of the huff and puff is low and is rarely more than 20%. However, some heavy oil reservoirs in China hardly been developed by steam flooding when considering the factors of technologies and economy, due to the complexity of the reservoir conditions, such as active edge water, no depressurization, deeply buried reservoir, Even though some heavy oil reservoirs were developed by steam flooding, because of great heat loss in the well, high pressure in the reservoir, small size for steam, severe gravity override and steam channeling for the steam, all of which reduce the sweep efficiency of the injected steam and lead to adverse effects for the recovery and economy of the steam flooding.

However, chemical flooding is the vital method for enhancing oil recovery in China. Chemical flooding refers to a method which is favorable to produce oil by adding certain chemical substance into the injected water to change the nature of the displacing fluid and the interfacial properties between displacing fluid and oil. The technologies of the chemical flooding include polymer flooding, caustic flooding, surfactant flooding, Binary system flooding and ASP flooding. Caustic flooding and surfactant flooding are primarily used in ASP flooding, while they are rarely used alone[7]. Polymer flooding is the main method for enhancing oil recovery among all the methods mentioned above.

MECHANISM OF POLYMER FLOODING

Polyacrylamide (it shorts for PAM) is the name for homopolymer and copolymer of the acrylamide (AM) or its derivatives. PAM is high polymer compound polymerized with monomer AM. Due to contain two functional groups that is $-CONH_2$ and the double bond, they enable AM to have the characteristic of amide and unsaturated alkene. PAM in industry refers to the polymer of monomer AM including the greater than or equal to 50%. PAM used in the process of oil production is HPAM which shorts for PAM here[8,9].

The fundamental mechanism of polymer flooding refers to enhance the viscosity injected liquid， adjust the mobility ratio for oil-water two-phase in reservoir to achieve the goal that expands the sweep volume[10].

SUMMARY OF BLOCK X

X block located in the Ninth Factory of Daqing oilfield is typical homogeneous heavy oil reservoir of the continental deposit. The reservoir is single layer. The mid-point of pay-zone is 780m. The oil saturation is 65%. The effective thickness is 3m. The primitive reservoir temperature is 35.6℃. The porosity is 31.4%. The air permeability is 1415 mD. The shale content is 6.5%. The primitive formation pressure is 8.16 MPa. The oil density is 926 kg/m^3. The oil viscosity under the formation temperature and pressure is 541 mPa·s. The salinity of the formation water is up to 8115 mg/L. The primitive development in block X using water flooding had developed 7 years since 2004. Produced oil was 5 t/d at the beginning of the exploitation. The accumulated oils were 9712 t. Numerical simulation forecasted the indexes for the next 10 years, they found the recovery degree using water flooding is low, less than 3.83% for the recovery degree using hot water flooding and loss of 3.25×10^4t oil produced. Using hot water flooding in the end of 2011, the injected water for this block was $30m^3/d$. The accumulated water was $6226m^3$. The produced oils were 31.4t/d. The integrate water cut was 58.9%. The accumulated oil was 2.1287×10^4t. The recovery degree was 2.51%. Because of low recovery degree, the petroleum engineers of the Ninth Factory have been seeking the effective methods all the time to enhance the recovery degree in block X, to reduce the economic costs.

Basing on the geology and development of block X, it is feasible to implement polymer flooding through preliminary analysis.

RESEARCH ON LIQUIDITY EXPERIMENTS

Experiment equipment and materials

Constant temperature box, constant-flux pump, core gripper, Brookfield viscometer，hand ring pump, oil-water separator, vacuum pump, electronic balance, mechanical agitator, pistons containers, pressure gauges, 6-way valve, valves, artificial columned cores (the length is 10cm and the diameter is 2.5cm), dead crude and produced water provided in block X, partially hydrolyzed PAM with 25% ~ 30% of degree of hydrolysis (The molecular weights are 25 million Daltons, 19 million Daltons and 14million Daltons, respectively), some certain chemicals (see the following table), tubes, beakers, distilled water and so on.

Table 1 Chemicals required in experiments

Medicine name	Specification	Content (%)
$MgCl_2$	Analyze plain	98
$NaHCO_3$	Analyze plain	99.8
KCl	Analyze plain	99.8
NaCl	Analyze plain	99.5
Anhydrous $CaCl_2$	Specific	96
Anhydrous Na_2SO_4	Analyze plain	99
Anhydrous Na_2CO_3	Analyze plain	99.8

EXPERIMENTAL SECTION

Dispense simulated oil, simulated formation water, polymer solutions with different concentrations and molecular weight. Basing on using each of these polymer solutions flow through different columned core and measuring resistance factor and residual resistance factor, choose the optimal polymer concentration and molecular weight to make displacement experiment. Verify whether the optimal polymer solution is applied in block X based on this displacement experiment.

Experimental methods

(1) After the dead crude provided in block X is dehydrated with oil-water separator, in 35.6℃ constant temperature box, it is filtered out impurities with one dry columned core.
(2) Dispense simulated oil. It is compounded by using the oil filtered and kerosene with a ratio of about 8 to 1.
(3) Dispense simulated formation water. Dispense it with distilled water and some certain chemicals. The formula of it is shown as table 2.
(4) Dispense different polymer solutions with the different molecular weights and concentrations. Using the produced water provided on site to dispense polymer solutions with different molecular weights and concentrations. The molecular weights and concentrations of the polymer solutions are shown as figure1.
(5) At room temperatures, vacuum all columned core and saturate simulated formation water then calculate pore volume.
(6) After columned core saturated water is put into the core gripper and plus ring crush with 3MPa, which is put in 35.6℃ constant temperature box, carry on the displacement with simulated formation water at the speed of 0.1 ml/min; When the pressure is stable, carry on the displacement with ready-prepared polymer solution at the speed of 0.1 ml/min; When the pressure is stable again, carry on the displacement with simulated formation water at the speed of 0.15ml/min. Record stable pressure value of every stage. A series of experiments mentioned above is one group experiment.
(7) Calculate resistance factor and residual resistance factor of every group experiment, according to the results, primary choose the optimal polymer solution had the optimal concentration and molecular weight.
(8) In 35.6℃ constant temperature box, put one columned core (as number 120805B-24) saturated oil into the core gripper (plus ring crush with 3MPa), carry on the displacement with simulated formation water at the speed of 0.3 ml/min (this process is called as water flooding before polymer flooding); When the pressure is stable, carry on the displacement with the optimal polymer solution at the speed of 0.5ml/min (this process is called as polymer flooding); When the pressure is stable again, carry on the displacement with simulation formation water at the speed of 0.5ml/min(this process is called as water flooding after polymer flooding). After the pressure is stable, the displacement is over. Record the stable pressure value of every stage.
(9) If the pressure of every phase for step 8 is available, carry on the displacement experiment next; If not unavailable, choose the smaller molecular weight or concentration than this optimal polymer solution to repeat step 8, until the polymer solution chosen meets the pressure condition for this step.

Table 2 Formula of simulated formation water per liter

Medicine name	Na_2CO_3	$NaHCO_3$	NaCl	Na_2SO_4	$MgCl_2$	KCl	$CaCl_2$
Content(g)	0.106	2.195	5.189	0.34	0.311	0.039	0.11

Table 3 Polymer solutions with configured with different concentrations and molecular weight

Molecular weight	14 million Daltons	19 million Daltons	25 million Daltons
Concentration	1000mg/L	1000mg/L	1000mg/L
	1500mg/L	1500mg/L	1500mg/L
	2000mg/L	2000mg/L	2000mg/L

Analysis for experimental results

(1) At 35.6℃, the viscosity for simulated oil configured was 541 mPa·s.
(2) The volumes of artificial columned cores saturated formation water were shown as the following table.
(3) The resistance factor and residual resistance factor produced by polymer solutions with different concentrations and molecular weights were shown as table5.

Based on the table 5, the resistance factor and the residual resistance factor produced by polymer solution with 25 million Daltons of molecular weight and 2000mg/L of concentration were 23.89 and 16.67, respectively.

Table 4 Volumes of artificial columned cores saturated formation water

Core number	Core dry weight (g)	Core wet weight (g)	Saturated water volume (ml)	Porosity (%)
120805B-5	83.5	97.9	14.4	29.33%
120805B-12	84.1	98.5	14.4	29.33%
120805B-14	84.1	98.4	14.3	29.12%
120805B-15	84.1	98.6	14.5	29.53%
120805B-23	83.6	97.9	14.3	29.12%
120805B-24	84.3	99.26	14.96	30.47%
120805B-27	84.8	99	14.2	28.92%
120805B-28	84.7	99	14.3	29.12%
120805B-29	84.7	98.7	14	28.51%
120805B-30	84.4	98.7	14.3	29.12%

(4) In the process of step 8 using polymer solution with 25 million Daltons of molecular weight and 2000 mg/L of concentration, the pressure continuously increased and decreased, and the core couldnot be fractured. The stable pressures for water flooding before polymer flooding, polymer flooding and water flooding after polymer flooding were respectively 0.22, 0.64 and 0.27. Some things were found in the whole displacement process， when the pressure of water flooding before polymer flooding was stable, there were hardly oils produced, then started to carry on polymer flooding, when the pressure was stable, there are some oils could be produced.

(5) Based on step 8, some oils could be produced by polymer flooding.

Table 5 Resistance factor and residual resistance factor produced by polymer solutions with different concentrations and molecular weights

Core number	Polymer	Stable pressure			Resistance factor	Residual resistance factor
		Water flooding(MPa)	Polymer flooding(MPa)	Water flooding after polymer flooding(MPa)		
120805B-15	1400 million Daltons, 2000mg/L	0.009	0.11	0.057	12.22	6.33
120805B-27	1900 million Daltons, 2000mg/L	0.01	0.165	0.095	16.50	9.50
120805B-23	2500 million Daltons, 2000mg/L	0.009	0.215	0.15	23.89	16.67
120805B-14	1400 million Daltons, 1500mg/L	0.009	0.092	0.038	10.22	4.22
120805B-28	1900 million Daltons, 1500mg/L	0.009	0.15	0.038	16.67	4.22
120805B-30	2500 million Daltons, 1500mg/L	0.009	0.22	0.062	24.44	6.89
120805B-29	1400 million Daltons, 1000mg/L	0.009	0.05	0.032	5.56	3.56
120805B-12	1900 million Daltons, 1000mg/L	0.01	0.072	0.03	7.20	3.00
120805B-5	2500 million Daltons, 1000mg/L	0.01	0.151	0.075	15.10	7.50

Summary

There were some conclusions found in liquidity experiment. Polymer solutions with 25 million Daltons of molecular weight and 2500 mg/L of concentration could flow through the core and produce some oils and couldnot make the core fractured. This polymer solution was optimal got by the liquidity experiment, but how many polymer solutions needed to inject was the best for block X that how much the recovery extent it could enhance were unknown. So in the following experiment, I would carry on displacement experiments by injecting polymer solutions with different quantities for pore volume, compared the displaced effects among these experiments so that I chose the optimal project for the quantities of polymer. However, as the bigger quantities of polymer solutions is injected, the more seriously emulsification occurs in produced liquids for the later stage of polymer flooding and water flooding after polymer flooding. Emulsification can have effects on the accuracy for reading the volume of produced liquids. Hence, I chose the injected quantities of polymer solutions are 0.2, 0.3 and 0.4 of pore volume, respectively.

RESEARCH ON DISPLACEMENT EXPERIMENTS

Experiment equipments and materials

Constant temperature box, constant-flux pump, hand ring pump, vacuum pump, electronic balance, mechanical agitator, pistons containers, pressure gauges, 6-way valve, valves, homogeneous core models (the shape sizes are shown as 4.5cm×4.5cm×30cm) for about 1400 of gas permeability, simulated formation water and oil, partially hydrolyzed PAM solution with 25 million Daltons of molecular weight and 2000 mg/L of concentration, tubes, breakers and so on.

Experimental scheme

Based on some series of displacement experiment shown as the following: after water cut is more than 98% (even no oil is produced) for water flooding before polymer flooding, carry on polymer flooding using polymer solutions of different quantities (which are 0.2, 0.3 and 0.4, respectively) with 25 million Daltons of molecular weight and 2000 mg/L of concentration, when the injected quantities meet requirement, carry on water flooding again, when water cut is more than 98% again, one experiment is over. By comparing how much recovery extent for polymer flooding using polymers with different quantities and water flooding after polymer flooding for every group, choose the optimal project for the quantities of polymer.

Experimental methods

(1) At room temperature, after the core model is vacuumed, saturate simulated formation water with hand ring pump. The pressure does not decrease after a time when the pressure is up to 0.2MPa, the process of saturation is over.

(2) At 36.5℃ constant temperature box, saturate simulated oil after saturating simulated formation water. When oil produced is up to 30ml, this process is over.

(3) Carry on 3 groups of displacement experiments. The process of the first one is shown as the following: at 36.5℃ constant temperature box, carry on water flooding with simulated formation water at the speed of 0.3 ml/min, when water cut is more than 98% (even no oil is produced), carry on polymer flooding with 0.2PV of the quantities of the polymer mentioned above at the speed of 0.5 ml/min, finally, carry on water flooding after polymer flooding with simulated formation water at the speed of 0.5ml/min, when water is more than 98% again, this process is over. All the stages for the second and the third are the same as the first one besides respectively using 0.3PV and0.4PV of the quantities of polymer at the stage of polymer flooding.

Table 6 Volumes of saturated water and oil and the injected quantities of polymer for every model

Core number	Specification (mm^2)	Saturated water volume (ml)	Saturated oil volume(ml)	Permeability (mD)	Oil saturation	Inject polymer needed (ml)
131219C-3	45*45*300	148	107	1400	72.30%	29.6
131219C-2	45*45*300	149.5	113	1419	75.59%	44.85
131219C-4	45*45*300	149	108	1423	72.48%	59.6

Table 7 Testing data of the injecting pressure, water cut and recovery for number131219C-3

Displacement method	PV value injected	Pressure (MPa)	Water cut (%)	Recovery (%)
Water flooding	0.03	0.47	0	4.11
	0.08	0.47	0	11.59
	0.13	0.47	0	17.85
	0.17	0.47	22.58	22.43
	0.22	0.46	28.57	27.29
	0.26	0.4	48.39	30.75
	0.3	0.36	58.06	33.08
	0.35	0.3	74.19	35.05
	0.39	0.26	81.82	36.45
	0.44	0.25	83.37	37.01
	0.48	0.25	96.77	37.29
	0.52	0.25	87.5	37.85
	0.57	0.25	91.43	38.5
	0.63	0.22	91.43	38.97
	0.67	0.21	96.77	39.16
	0.72	0.2	90.63	39.53
	0.78	0.2	100	39.72
polymer flooding	0.79	0.13	100	39.72
	0.83	0.18	100	39.72
	0.88	0.26	100	39.72
	0.93	0.33	88	40.28
	0.98	0.46	73.91	41.96
Water flooding after polymer flooding	0.99	0.31	73.91	42.52
	1.04	0.25	84.62	44.21
	1.07	0.21	95.83	44.39
	1.12	0.21	98.53	44.49
	1.17	0.21	98.63	44.58

Analysis for experimental results

(1) For every core model, the volumes of saturated water and oil and the injected quantities of polymer used for the experiments were shown as the following table6.

(2) Experiment results for every group were shown as table 7, 8 and 9 as well as figure 2,3 and 4.

Table 8 Testing data of the injecting pressure, water cut and recovery for number131219C-2

Displacement method	PV value injected	Pressure (MPa)	Water cut (%)	Recovery (%)
Water flooding	0.03	0.58	0	3.63
	0.08	0.58	0	10.71
	0.12	0.58	0	16.02
	0.16	0.58	24.14	20.35
	0.21	0.52	28.57	24.69
	0.25	0.45	46.88	27.96
	0.29	0.41	58.06	30.27
	0.34	0.36	74.19	32.72
	0.38	0.32	72.73	33.81
	0.43	0.3	87.5	34.6
	0.47	0.26	83.87	35.4
	0.51	0.25	87.5	36.02
	0.55	0.23	93.94	36.55
	0.59	0.22	92.31	37.43
	0.64	0.21	94.44	37.43
	0.68	0.18	96.88	37.88
	0.72	0.18	92.86	38.32
	0.77	0.18	100	38.32
polymer flooding	0.79	0.23	100	38.32
	0.83	0.24	100	38.32
	0.88	0.32	100	38.32
	0.92	0.43	84.21	38.94
	0.96	0.52	82.61	40
	1	0.57	89.66	40.53
	1.05	0.65	61.54	42.12
	1.08	0.72	65.22	43.45
Water flooding after polymer flooding	1.09	0.33	73.91	43.98
	1.14	0.3	86.96	44.96
	1.19	0.23	93.48	45.66
	1.25	0.21	98.04	45.84
	1.3	0.21	98.67	45.93

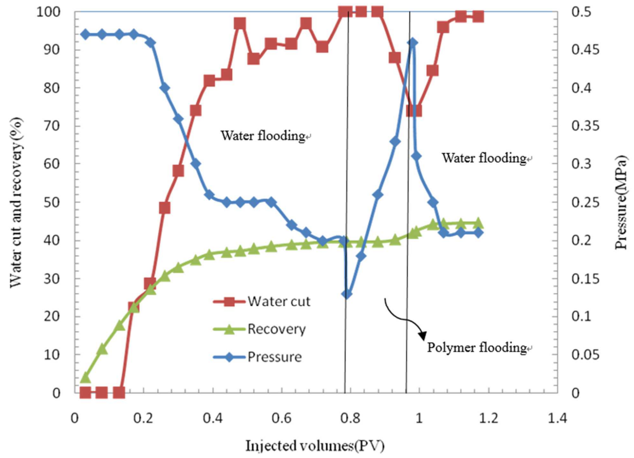

Fig. 2 Relationship curve for water cut, recovery and pressure with injected volume for number 131219C-3

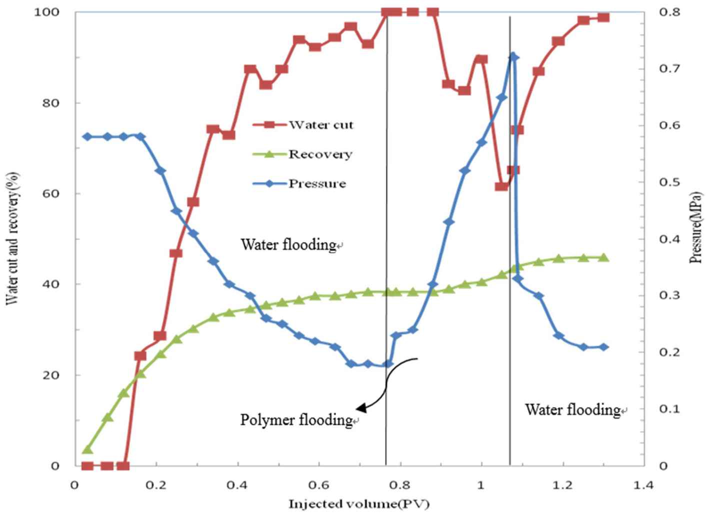

Fig. 3 Relationship curve for water cut, recovery and pressure with injected volume for number 131219C-2

Table 9 Testing data of the injecting pressure, water cut and recovery for number131219C-4

Displacement method	PV value injected	Pressure (MPa)	Water cut (%)	Recovery (%)
Water flooding	0.02	0.59	0	2.13
	0.05	0.58	0	6.94
	0.09	0.58	0	12.87
	0.14	0.58	0	18.98
	0.18	0.58	24.14	23.33
	0.23	0.51	28.57	28.06
	0.27	0.45	46.88	31.48
	0.31	0.41	58.06	33.8
	0.35	0.36	74.19	35.56
	0.4	0.32	81.82	37.04
	0.44	0.3	88.57	37.5
	0.48	0.26	96.77	37.78
	0.53	0.25	87.5	38.33
	0.57	0.25	91.43	38.98
	0.61	0.22	96	39.17
	0.65	0.21	97.22	39.54
	0.7	0.21	96.88	39.72
	0.74	0.18	92.86	40.19
	0.78	0.18	100	40.19
polymer flooding	0.81	0.15	100	40.19
	0.87	0.28	100	40.19
	0.94	0.56	87.99	42.53
	1	0.7	82.49	43.83
	1.07	0.77	89.6	45.03
	1.14	0.82	88.76	45.59
	1.2	0.83	90.6	46.68
	1.27	0.83	93.96	47.31
Water flooding after polymer flooding	1.3	0.51	85.71	47.78
	1.36	0.35	89.61	48.92
	1.44	0.28	95.25	49.39
	1.64	0.23	97.89	49.94
	1.77	0.23	98.99	50.13

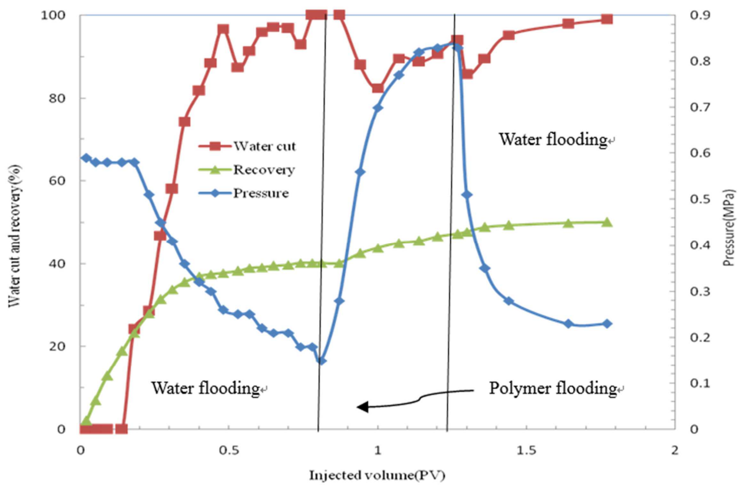

Fig. 4 Relationship curve for water cut, recovery and pressure with injected volume for number 131219C-4

(3) The average oil recovery for water flooding was 39.41%.
(4) In the process for every group of experiment, the pressure was first increased and then decreased for water flooding before polymer flooding, the pressure continued to rise in the stage of polymer flooding, the pressure fell suddenly when it began to enter into the stage of water flooding after polymer flooding. This fallen extent was dramatic. The stable pressure for water flooding after polymer flooding was more than it for water flooding before polymer flooding.
(5) Enhancing recovery extent by using polymer solution for 25 million Daltons of molecular weight and 2000 mg/L of concentration with 0.2PV, 0.3PV and 0.4PV were 4.76%, 7.61%, and 9.94%, respectively.

Summary
The experiment results showed that the average oil recovery for water flooding was up to 39.41%; it was effective to implement polymer flooding; as the quantity of polymer solution increased, oil recovery increased; enhancing recovery extent by using polymer solution for 25 million Daltons of molecular weight and 2000 mg/L of concentration with 0.4PV was the maximum which could be up to 9.94%; This experiment proved that it is feasible to implement polymer flooding for block X.

CONCLUSION

It is feasibility to implement polymer flooding in block X based on liquidity experiments and displacement experiments in laboratory.
(1) HPAM was chosen as the displacement agent， whose degree of hydrolysis is 25%~30%.
(2) The optimal molecular weight and concentration of polymer solution were 25 million Daltons and 2000 mg/L, respectively.
(3) The optimal injected quantity for polymer solution was 0.4PV.
(4) The project of polymer flooding was shown as the following: water flooding fist; carry on polymer flooding after arriving economic limit for water flooding; carry on water flooding after polymer flooding.
(5) Enhancing oil recovery extent for polymer flooding was9.94%.

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