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Oil Displacement Efficiency and Performance Evaluation of Composite Ion Profile Control Agents Prepared with Oilfield Sewage

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Abstract

According to the demand of development in Daqing oil field, in order to reduce sewage discharge and save clean water, most of the polymer injection stations have switched to polymer solution diluted by sewage. Considering the present development trend of the oil field and requirement in terms of cost control, we should further deepen the research of formulas for all kinds of chemical sewage. Performance evaluating experiments on the long-term stability, the anti-shear property, the compatibility with initial rock debris and alkali ternary combination system of profile control agents, as well as the test for the efficiency of core displacement physical simulation of profile control and oil displacement evaluation are carried in this paper, which are intended for the composite ion profile control system that are prepared with oilfield sewage. In this paper, the long-term stable composite ion profile control agents formular prepared with oilfield sewage have been determined; the profile control effect of composite ion profile control agents prepared with sewage for cores with different permeability have been presented, and the rules of composite ion profile control agents prepared with sewage on oil displacement effect at different injection time and injection rate have been studied.

Research shows that the long-term heat stability, anti-shear property, compatibility with initial rock debris and alkali ternary combination system of composite ion profile control agents prepared with sewage are well, as well as the core plugging effect and anti-corrosion performance. Oil displacement results are obviously different when profile control agents are injected at different time. Injecting profile control agents before polymer flooding works best, medium term secondly, and late stage thirdly. At the same time, the enhanced recovery rate increases with increased profile control agents injection. While the increase of enhanced oil recovery rate becomes slower when the profile control agents injection reach 0.1 PV. After profile control measures are taken, the average injection pressure and starting pressure has risen respectively by 2.7 Mpa and 2.6 Mpa; the water absorbing capacity of high permeable formation has been under control; the water absorbing capacity of low permeable formation has been strengthened; the absorbing water thickness of all wells have been increased; the breakthrough of flooded fluid in certain direction have been solved, which leads to more even polymer forward.

Key words: Oil displacement effect evaluation; Performance evaluation; Composite ion profile control agents; Oil produced water preparing polymer

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FOREWORD

Composite ion profile control agents have been widely used in Daqing oilfield for many years[1-2]. Composite ion profile control agents prepared with clean water have always been the molding formula[3]. Since the large-scale promotion and application of polymer flooding in 1996, Daqing oilfield has began to explore the deep profile control technique in order to improve the development effect of the polymer flooding and enhanced oil recovery rate[4]. By the end of 2009, the number of profile control wells was more than 150, 60.8% of which were injected with composite ion profile control agents, most of which prepared by water[5-6]. According to the demand of development in Daqing oil field, in order to reduce sewage discharge and save clean water, most of the polymer injection stations have switched to polymer solution diluted by sewage[7]. Considering the present development trend of the oil field and requirement in terms of cost control, we should further deepen the research of formula for all kinds of chemical sewage.

Performance evaluating experiments on the long-term stability, the anti-shear property, the compatibility with initial rock debris and alkali ternary combination system of profile control agents, as well as the test for the efficiency of core displacement physical simulation of profile control and oil displacement evaluation are carried in this paper, which are intended for the composite ion profile control system that are prepared with oilfield sewage. All of these studies have provided theoretical basis for the implementation and drafting procedures of testing schemes to prepare composite ion profile control agent system.

1. THE PERFORMANCE EVALUATION OF PROFILE CONTROL AGENTS

1.1 The Heat Stability of Profile Control Agents

Three different kinds of profile control agents which are prepared respectively with sewage and clean water have been used. The specific formula is shown in Table 1. B-1 and B-2 profile control agents are prepared with ordinary oily sewage in western faults of block Beiyi, and B-3 control profile agents are prepared with clean water. After preparation, we put the samples in an incubator chamber at 45 degrees Celsius to observe the gelation situation, and then carry out experiment on the long-term heat stability and gelling viscosity. The initial viscosity and gel viscosity are measures by DV-II viscometer which was made in America.

Table 1 shows the initial viscosity and gel time of three formulas. Figure 1 shows the heat stability curve of three formulas. As shown in table 1, the initial viscosity of B-1 and B-2 composite ion profile control agents is 80~90 mPa·s; while the initial viscosity of B-3 compound ion profile control agents which are prepared with clean water is around 800 mPa·s, so it is difficult for workers on the site to inject them. Under the condition of 45 degrees, it takes 3 days for B-1 and B-2 to become gel, and the viscosity can reach up to 20000 mPa·s. It takes 6 days for B-3 to become gel, and the viscosity can reach around 15000 mPa·s, which is significantly less than B-1 and B-2. From Figure 1, we can see the heat stability of B-1 is better than B-2 and B-3, and the viscosity of B-1 can still remain above 20000 mPa·s by the 225th day, while the viscosity of B-2 and B-3 have obviously decreased by the 120th day, and nearly fail by the 225th day. The next experiment on performance evaluation is for B-1.

Table 1
The Formula and Gel Time of Different Compound Ion Profile Control Agents

Formular code	Preparation water	Main agent concentration (mg/L)	Cross-linking agent concentration (mg/L)	Initial viscosity (mPa.s)	Gel time (day)	Gel viscosity (mPa.s)
B-1	Sewage	3000	1000	90.0	3	21800
B-2	Sewage	2500	1000	83.0	3	20700
B-3	Clean water	3500	900	808.8	6	15670

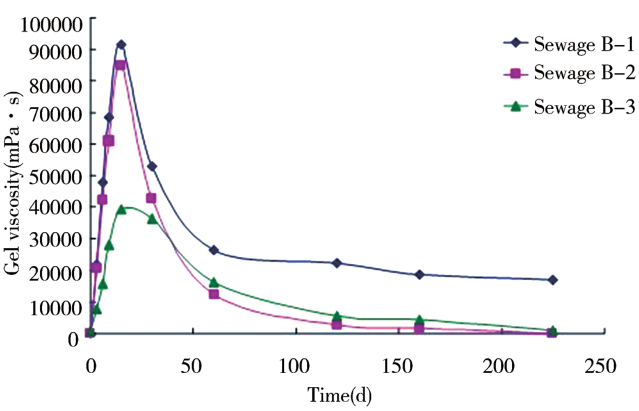


Figure 1
The Heat Stability of Different Compound Ion Profile Control Agents

1.2 The Anti-Shear Property of Profile Control Agents

In the next test B-1 profile control agents are sheared. After shearing test, the solution viscosity is 80% of its initial viscosity. Next, the heat stability experiments are carried on. The results are shown in Figure 2. We can see that the anti-shear property of B-1 is well. After shearing, the gel strength and heat stability of the new solution show little change compared with the initial solution, so it shows just a decreased molecular weight occurs after B-1 composite ion profile control system have been sheared. Due to the presence of cross-linking agents, the system can still go on cross-linking reaction and the viscosity of the system will gradually restore at a certain temperature.

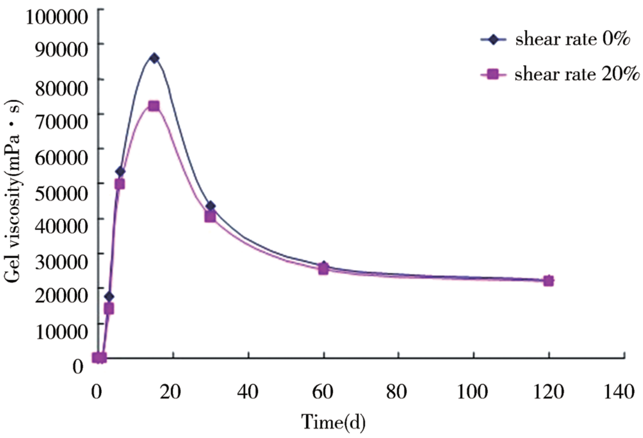


Figure 2
The Heat Stability Curve of B-1 After Shearing

1.3 The Compatibility with Initial Rock Debris of Profile Control Agents

Mix rock debris of 60 mesh (oil content is 17000 mg/L) with B-1 with a ratio of 2:3, then observe the compatibility of profile control agents with initial rock debris, as shown in Figure 3. Lab studies show that the compatibility of B-1 with natural debris is well, and no floc produces, just with long gel time, about 60 days. Debris binds together and stops flowing when inclined.

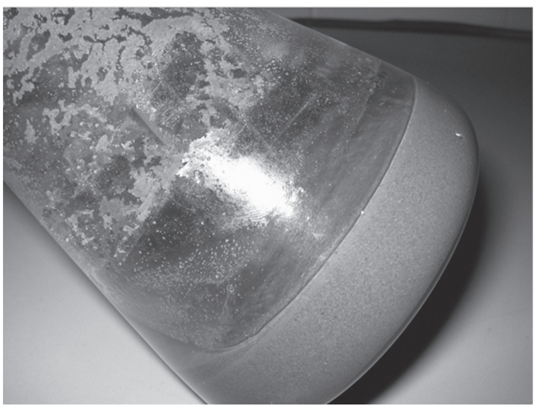
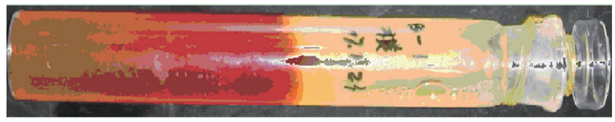


Figure 3
The Gel Situation of B-1 Composite Ion Profile Control Agents Mixed with Initial Rock Debris

1.4 The Compatibility of Profile Control Agents with Ternary System

In order to study the stability of B-1 in ternary compound system, we put about 25 ml of the well-prepared ternary compound system (the mass fraction of surfactant is 0.3%; the mass fraction of sodium hydroxide is 1.2%; the concentration of Partially Hydrolyzed Polyacrylamide is 2000 mg/L; the molecular weight is 25 million; and the degree of hydrolysis is 25%) into a 50 ml scale pipe with stopper, then put the gelling composite ion profile control agents in 50 ml scale tube with stopper, and then observe the stability of composite ion profile control agents in the ternary compound system after sealed. Experimental results show that the stability of composite ion profile control agents in ternary system is well. Only a small part of agents break down by the 65th day. Therefore, when profile control is taken before the ASP flooding, if composite ion profile control agents are used, we suggest sealing with the high-strength anti-alkali profile control agents or to make a polymer protection slug, then inject ternary compound system.



The First Day

B.The Third Day

C.The 65th Day

Figure 4
The Changes After Mixing

2. THE PERFORMANCE EVALUATION OF CORE DISPLACEMENT SIMULATION OF PROFILE CONTROL

2.1 The Plugging Experiment of Profile Control Agents

Displacement experiment on the plugging rate, residual resistance coefficient and scouring resistance of profile control agents in cores with different permeability (as shown Table 2) are carried. The measurement results are shown in Table 3. We can see that the composite ion profile control agents have good plugging effect for cores with different permeability, and core plugging rates can reach up to 96.5% when the water phase permeability ranges from 0.06~0.75 mD. The higher the permeability is, the better plugging effect will be, and the larger the residual resistance coefficient will be. After washing with 10 PV water, the core plugging rate can still reach up to 95.7%, which indicates that the composite ion profile control agents have good scouring resistance.

2.2 The Shunt Rate Experiment of Profile Control Agents

Connect two pieces of cores (permeability are 0.5107 mD and 0.3836 mD) in parallel, then perform the shunt rate experiment of profile control agents. Table 4 shows the experimental results. We can see that the shunt rate has a great change after profile control. The shunt rate of high permeability core decreases from 57.43% to 24.94%, and the shunt rate of low permeability core increased from 42.57% to 75.06%, which suggests that the profile control agents play a role in plugging high permeable zone, and the suction profile has got obvious improvement.

Table 2
The Basic Data of Core

Core number	Length (cm)	Diameter (cm)	Pore volume (mL)	Porosity(%)	Permeability(mD)
070321A-7	9.42	2.52	15.5	33.0	0.06064
070304-7	9.40	2.52	15.6	33.2	0.1573
070321C-9	9.35	2.52	15.8	33.9	0.6158
070321C-1	9.38	2.50	15.8	34.3	0.7453

Table 3
The Measurement Results of the Profile Control Agents

Core number	Permeability before profile control (mD)	Subsequent washing 1PV			Subsequent washing 10PV		
		Permeability after profile control(mD)	Plugging rate (%)	Residual resistance coefficient	Permeability after profile control (mD)	Plugging rate (%)	Residual resistance coefficient
070321A-7	0.06064	0.0021	96.54	29	0.0026	95.71	23
070304-7	0.1573	0.0023	98.54	68	0.0035	97.77	45
070321C-9	0.6158	0.0034	99.43	175	0.0055	99.08	108
070321C-1	0.7453	0.0036	99.52	207	0.0056	99.25	133

Table 4
The Experimental Determination Results of Shunt Rate

Displacement process	The flow of high Permeable core(mL)	The flow of low Permeable core(mL)	The shunt rate(%)	
			High permeable core	Lower permeable core
Water flooding	13.68	10.14	57.43	42.57
Profile control agents	7.92	6	56.9	43.10
Subsequent water flooding	5.82	17.52	24.94	75.06

3. THE CORE FLOODING EFFECT EVALUATION OF POLYMER FLOODING PROFILE CONTROL AGENTS

3.1 Experiment Introduction

We use quartz sand to epoxy artificial cores, then choose three cores whose water phase permeability is respectively 200 mD, 500 mD and 800 mD, and arranged them according to positive rhythm. Its model specification is 30 cm×4.5 cm×4.5 cm. The oil prepared for the experiment is simulated oil which is prepared with crude oil from the first oil production plant of Daqing oil field and kerosene, and its viscosity is 10 mPa·s at 45 degrees Celsius. The water prepared for the experiment is the sewage from the station 603 in the first oil production plant of Daqing oil field. The polymer is anionic polyacrylamide produced in Daqing Refining & Chemical, and its relative molecular mass is between 1200~1600 million. Profile control agents are B-1 composite ion profile control agents prepared with oilfield sewage. Specific experiment scheme is as follows:

(1) The Simulation Experiment on Polymer Flooding

The sample A is saturated by oil, then it is waterflooded until its water saturation is 98%; and then it is injected with 0.69 PV middle MW(molecular weight) polymer(1500 mg/L); subsequently, it is waterflooded until its water saturation is 98%. The sample B is saturated by oil, then it is waterflooded until its water saturation is 98%; and then it is injected with 0.74 PV middle MW polymer (1500 mg/L); subsequently, it is waterflooded until its water saturation is 98%. The sample C is saturated by oil, then it is waterflooded until its water saturation is 98%; and then it is injected with 0.84 PV middle MW polymer(1500 mg/L); subsequently, it is waterflooded until its water saturation is 98%.

(2) The Simulation Experiment on Profile Control Displacement Before Polymer Flooding

The sample A is saturated by oil, then it is waterflooded until its water saturation is 98%; and then it is injected with 0.05 PV profile control agents; then it is injected with 0.64 PV middle MW polymer(1500 mg/L); subsequently, it is waterflooded until its water saturation is 98%. The sample B is saturated by oil, then it is waterflooded until its water saturation is 98%; and then it is injected with 0.10 PV profile control agents; then it is injected with 0.64 PV middle MW polymer (1500 mg/L); subsequently, it is waterflooded until its water saturation is 98%. The sample C is saturated by oil, then it is waterflooded until its water saturation is 98%; and then it is injected with 0.20 PV profile control agents; then it is injected with 0.64 PV middle MW polymer (1500 mg/L); subsequently, it is waterflooded until its water saturation is 98%.

(3) The Simulation Experiment on Profile Control Displacement in the Course of Polymer Flooding

The sample A is saturated by oil, then it is waterflooded until its water saturation is 98%; and then it is injected with 0.10 PV middle MW polymer (1500 mg/L), then it is injected with 0.10 PV profile control agents; then it is injected with 0.54 PV middle MW polymer (1500 mg/L); subsequently, it is waterflooded until its water saturation is 98%. The sample B is saturated by oil, then it is waterflooded until its water saturation is 98%; and then it is injected with 0.20 PV middle MW polymer (1500 mg/L), then it is injected with 0.10 PV profile control agents; then it is injected with 0.44 PV middle MW polymer (1500 mg/L); subsequently, it is waterflooded until its water saturation is 98%. The sample C is saturated by oil, then it is waterflooded until its water saturation is 98%; and then it is injected with 0.30 PV middle MW polymer (1500 mg/L), then it is injected with 0.10 PV profile control agents; then it is injected with 0.34 PV middle MW polymer (1500 mg/L); subsequently, it is waterflooded until its water saturation is 98%.

(4) The Simulation Experiment of Polymer Flooding After Profile Control Displacement

The sample A is saturated by oil, then it is waterflooded until its water saturation is 98%; and then it is injected with 0.64 PV middle MW polymer(1500 mg/L), then it is injected with 0.05 PV profile control agents; subsequently, it is waterflooded until its water saturation is 98%. The sample B is saturated by oil, then it is waterflooded until its water saturation is 98%; and then it is injected with 0.64 PV middle MW polymer (1500 mg/L), then it is injected with 0.10 PV profile control agents; subsequently, it is waterflooded until its water saturation is 98%. The sample C is saturated by oil, then it is waterflooded until its water saturation is 98%; and then it is injected with 0.64 PV middle MW polymer (1500 mg/L), then it is injected with 0.20 PV profile control agents; subsequently, it is waterflooded until its water saturation is 98%.

3.2 The Analysis of the Experimental Results

Table 5 shows the enhanced oil recovery rate when the B-1 composite ion profile control agents prepared with oilfield sewage are injected at different time and with different volume. From table 5, we can see that the effect of profile control turns gradually worse before, during, and after polymer flooding. When the injection is 0.1 PV, the average enhanced oil recovery rate is respectively 2.91%, 2.64% and 2.03%. From the injection of profile control agents, the enhanced oil recovery rate is bigger with the increase of the injection of profile control agents, but the appreciation has slowed when the injection is up to 0.1 PV. Considering the cost increase as the consumption of profile control agents, we recommend profile control before polymer flooding, and the consumption of profile control agent is 0.10 PV.

Table 5
The Relation Between Enhanced Oil Recovery Rate and Different Injection Time & Volume

Injection time	Water phase permeability of core	Enhanced oil recovery (%)					
		0.05PV	Average	0.1PV	Average	0.2PV	Average
Before polymer flooding	200 mD	0.96	0.67	3.33	2.91	3.45	3.09
	500 mD	0.45		2.08		2.61	
	800 mD	0.65		3.33		3.22	
During polymer flooding	200 mD	0.79	0.58	3.23	2.64	3.77	2.86
	500 mD	0.43		2.12		2.18	
	800 mD	0.52		2.07		2.63	
After polymer flooding	200 mD	0.56	0.46	3.20	2.03	3.00	2.58
	500 mD	0.72		1.37		2.51	
	800 mD	0.11		1.53		2.22	

4. THE ANALYSIS OF APPLICATION EFFECT OF POLYMER FLOODING PROFILE CONTROL AGENT

According 95 wells of 10 blocks in Daqing oil field, we carry out the composite ion profile control technique prepared with oilfield sewage. 51 wells are profile controlled before polymer flooding, 38 wells during the polymer flooding, and 6 wells after the polymer flooding. These effectively improve the producing status of the reservoir and the utilization rate of the polymer. The wells, whose injection profile have been improved after profile control, account for about 88.5%, which indicates good results.

The average injection pressure rises 2.7 MPa after the profile control, and the starting pressure rises 2.6 MPa. The water absorbing capacity of high permeable formation is under control after the profile control, and the water absorbing capacity of low permeable formation is strengthened. As shown in the well DD2-P2, its water absorbing thickness increases from 6.8 m to 13.7 m after the profile control, 6.9 m increased. The absorbing ratio of high permeable zone drops from 84.7% to 57%. The water absorbing ratio of the originally bad layer increase considerably. According to the tracer production curves of well DD2-P4 group, the tracers advance mainly along the well DD2-P3 before injecting profile control agents. We can see the time and concentration of tracers are basically the same after injecting profile control agents in three directions, which explains the phenomenon of the breakthrough of flooded fluid in certain direction have disappeared and leads to more even polymer forward. After the profile control response was observed, water cut decreases greatly in a short period. Such as northern well 1-5-P46 well group, which reach the minimum water cut of 47.3% in 7 months, which has declined 44.8% compared with that before injecting profile control agents. The average monthly water cut has dropped by 7.5%, and the oil recovery rate has increased by 2.2%.

CONCLUSION

(1) The long-term heat stability and anti-shear properties of B-1 composite ion profile control agents prepared with oilfield sewage are well. Under the condition of 45 degrees Celsius, the viscosity can still reach up to 20000 mPa·s by the 225th day. When the initial viscosity of profile control agents is 80% of the original solution viscosity, the gel strength and heat stability of the new solution show little change with time.

(2) The compatibility of B-1 composite ion profile control agents with natural debris and the alkali ASP system is well. After 60 days of mixing, no flocs generate. Only a small part of composite ion profile control agents break down in 65 days.

(3) The plugging effect of core and resistance erosion performance of B-1 composite ion profile control agents are well. The water phase permeability lies between 0.06~0.75 mD, and the core plugging rate all can reach above 96.5%. After washing with 10 PV of water, the plugging rate can still reach up to 95.7%.

(4) It works the best to inject profile control agents before polymer flooding, the second in the medium term, and the worst after it. When the injection is 0.1 PV, the average enhanced oil recovery rates are 2.91%, 2.64% and 2.03% respectively. At the same time, with the injection of profile control agent increases, the enhanced oil recovery rate increases. When the injection is up to 0.1 PV, the appreciation becomes slower.

(5) The field application results indicate that the average injection pressure rises 2.7 MPa after the profile control, and the starting pressure rises 2.6 MPa. The water absorbing capacity of high permeable formation is under control after the profile control, and the water absorbing capacity of low permeable formation is strengthened. The water absorbing thickness of all well increases, the absorbing water thickness of all wells have been increased; the breakthrough of flooded fluid in certain direction have been solved, which leads to more even polymer forward.

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