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Evaluation of the Gel Profile Control Agent Polyacrylamide in Enhanced Oil Recovery

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Abstract

Based on the system of anionic delayed cross-link polymer gel type deep profile control agent, experiments are conducted to evaluate the performance of long-term thermal stability, shearing resistance, and compatibility with natural debris of profile control agent and compatibility with ASP compound system. Besides, experiments are completed to simulate core displacement profile controlling and evaluate effect of oil displacement. Formula of anionic delayed cross-link polymer gel profile control agent with ideal long-term stability is confirmed. Profile control effect referred to core with diverse permeability and influence law of different injection time and injection rate on effect of oil displacement. Following conclusions are made according to the research. Long-term thermal stability, shearing resistance, and compatibility with natural debris of profile control agent and compatibility of ASP compound system of anionic delayed cross-link polymer gel profile control agent all have good performance, as well as core plugging effect and resistance to erosion. Displacing effect varies with the profile control agent injecting time, which shows, injection before polymer displacing proves the best, injection during polymer displacing the second, and injection after polymer displacing the worst. At the same time, the value of enhanced oil recovery increases with the injection rate of profile control agent increasing, however, when the rate comes to the point of 0.1 pv, the increasing extent begins to slow down.

Key Words: Profile control agent; Anionic; Delayed cross-link

INTRODUCTION

Since the polymer displacement technology was promoted in a large scale in 1996, Daqing Oilfield has been exploring the exploiting effect of improving polymer displacing and enhanced oil recovery that deep profile control achieves. There are already 450 well units have been profile controlled by the end of 2012, which most are compound ion profile control agent prepared with clear water. At present, many domestic scholars are studying profile control mechanism, performance, formula and other aspects of the anionic delayed cross-link polymer gel profile control agent system (Wei *et al*., 2000; Kan *et al*., 2001; Lei *et al*., 2001; Li *et al*., 2002; Lu *et al*., 2003; Zhao *et al*., 2003; Guo, 2005; Li *et al*., 2005; Lv, 2009; Zhang and Yao, 2010; Moradi-Araghi, 2000; Hutchins and Dovan, 1996). However, according to Daqing Oilfield requirements for developing of reducing sewerage discharge and saving clear water resources, most of the polymer injection stations have switched to polymer mother solution diluted by sewerage. Considering the oilfield's developing trends and cost control requirements, it is necessary to make further research on various kinds of chemical sewerage formula.

Based on the previous research achievements, this paper systematically and deeply conducts experiments to evaluate the performance of long-term thermal stability, shearing resistance, and compatibility with natural debris of anionic delayed cross-link polymer gel type deep profile control agent system prepared with oilfield's sewerage and compatibility of ASP compound system, as well as experiments to simulate indoor profile control in the way of core displacement and evaluate effect of oil displacement. This helps to lay theoretical foundation for making experiment schemes and taking it into action according to anionic delayed cross-link polymer gel type deep profile control agent system prepared with oilfield's sewerage.

1. BEHAVIOR EVALUATION OF PROFILE CONTROL AGENT

1.1 Thermal Stability of Profile Control Agent

Anionic delayed cross-link polymer gel profile control agent is one modified kind of compound ion profile control agent, which the main agent compound ion polymer is displaced with anionic polyacrylamide on the condition of cross-link system unchanged. Four different types of profile control agent have been prepared with oilfield's sewerage and clear water, specific formula as is shown in Table 1. The two types of profile control agent A-2-1 and A-2-2 are prepared with the sewerage containing oil of the West Fault Block of North No.1 Zone, while A-2-3 and A-2-4 are prepared with clear water. After completing the sample preparation, they all will be put into a thermo tank to observe gelation of the samples and then used to perform gel viscosity and long-term thermal stability experiments. Initial viscosity and gelation viscosity are both detected by DV-II viscometer produced by the United States.

Table 1 gives gelation time and situation of gelation viscosity of the four kinds of profile control agent, and Figure 1 shows their thermal stability curves. It can be seen from Table 1 and Figure 1, the increasing extent of formula viscosity of A-2-2 prepared with sewerage is not large, the value drops to below 300 mPa.s, which receives poor effect; the rest three types of formula gel between 3 to 7 days except this one type above, but initial formula viscosity of A-2-2 reaches as high as 268.4mPa.s, and the increasing extent is not large enough along with time going, which the highest value only rises to 8198 mPa. s, and then down to the point of 1900 mPa.s after 110 days, indicating that this type of formula is not applicable as well; comparing A-2-1 with A-2-3, though the concentration of polymer is low (1000 mg/L) and which is prepared with produced sewerage, its gelation viscosity value is higher and thermal stability performs better than A-2-3(gelation viscosity value drops to 600 mPa.s after 110 days), whose viscosity value remains 26000mPa. s after 110 days. Thus, we can conclude that formula of type A-2-1 achieves the best effect of the four types of formula. Type A-2-1 anionic delayed cross-link polymer gel profile control agent will be the object in the following performance evaluation experiments.

Table 1
Different Formulas and Gelation Time of Anionic Delayed Cross-Link Polymer Gel Profile Control Agent

Formulas of profile control agent	Water type	Concentration of main agent(mg/L)	Concentration of cross-link agent(mg/L)	Gelation time(d)	Initial viscosity(mPa·s)	Gelation viscosity(mPa·s)
A-2-1	Water from the West Fault Block	2000	1000	3	68.0	28294
A-2-2	Water from the West Fault Block	1500	1000	7	47.0	3499
A-2-3	Clear water	3000	600	7	38.0	2000
A-2-4	Clear water	5000	500	4	268.4	2899

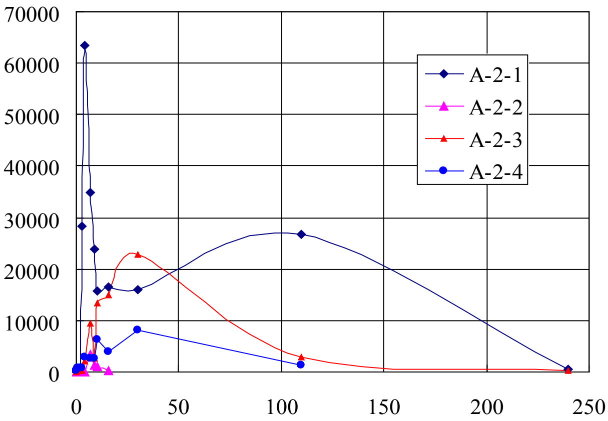

Figure 1
Thermal Stability of Different Types of Anionic Delayed Cross-Link Polymer Gel Profile Control Agent Formula

1.2 Shearing Resistance of Profile Control Agent

Shearing the system of anionic delayed cross-link polymer gel profile control agent prepared with formula of type A-2-1, the solution viscosity after shearing accounts for 20%~50% of the solution viscosity before shearing, and then performing thermal stability experiment according to the system of anionic delayed cross-link polymer gel profile control agent prepared with formula of type A-2-1 after shearing, results are shown in Figure 2. A-2-1 still can gel after mechanical shearing to the degree between 20%~50%, which gelation time is the same as the time before shearing, but gelation viscosity is lower, and with the degree of shearing increasing, gelation viscosity reduces, while overall changing trends basically correspond with each other.

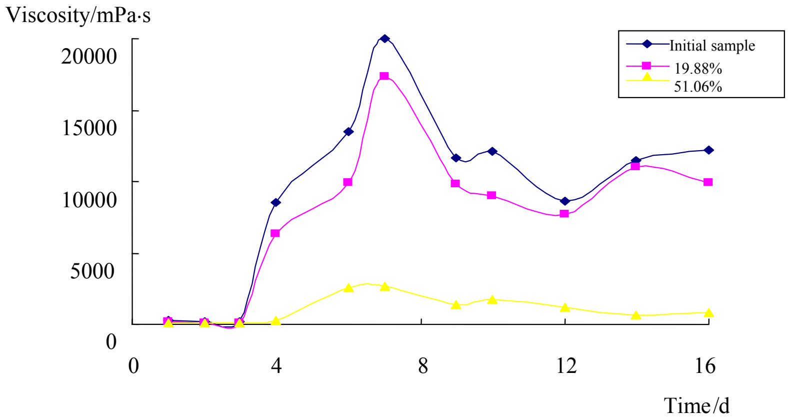

Figure 2
Thermal Stability Curves After Shearing of Anionic Delayed Cross-Link Polymer Gel Profile Control Agent

1.3 Compatibility with Natural Debris of Profile Control Agent

After mixing 60 meshes natural debris (oil content for 17000 mg/L) with type A-2-1 anionic delayed cross-link polymer gel profile control agent in the ratio of 2:3, observing its compatibility with natural debris. As is shown in Figure 3, A-2-1 type profile control agent gets desired compatibility with natural debris with no floc generating, cementing with debris after gelling about 60 days, and it will no longer flow while inclining.

Figure 3
Gelation Situation After Anionic Delayed Cross-Link Polymer Gel Profile Control Agent Mixing with Natural Debris

1.4 Compatibility with ASP System of Profile Control Agent

In order to test the stability while type A-2-1 anionic delayed cross-link polymer gel profile control agent blending in ASP compound system, putting ASP compound system (mass fraction of surface acting agent and sodium hydrate is 0.3 % and 1.2 % respectively, part of hydrolyzed polyacrylamide concentration is 2000 mg/L, molecular weight is 25 million and degree of hydrolysis is 25%) that has been prepared into 50mL centrifugal tube with stopper to the height of 25mL or so together with gelatinized A-2-1 type profile control agent, then sealing and observing the situation of stability while A-2-1 type profile control agent blending in ASP compound system. Experimental results show that anionic delayed cross-link polymer gel profile control agent performs poor stability while blending in ASP system, gel breaking phenomenon occurs on the third day, gel has been broken completely on the 65th day. So we can conclude that anionic delayed cross-link polymer gel profile control agent does not apply to profile control before ASP displacement.

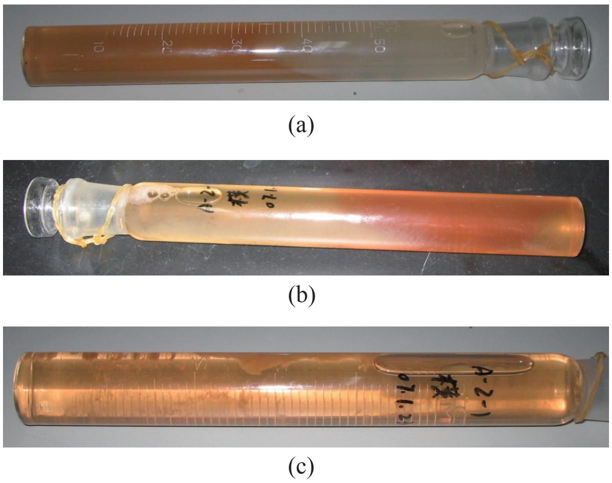

Figure 4
(a) Gelatinized Profile Control Agent Blends with ASP System; (b) Changes After Blending on the Third Day; (c) Changes After Blending on the 65th Day

2. EFFECT EVALUATION OF CORE DISPLACEMENT STIMULATING PROFILE CONTROL

2.1 Plugging Experiment of Profile Control Agent

Conducting displacement experiments of plugging rate, residual resistance factor and resistance to erosion using core having various permeability respectively, the results are shown in Table 3. We can see through it that anionic delayed cross-link polymer gel profile control agent has satisfying plugging effect on low permeability core, plugging rate reaches as high as 98.54% with permeability being 0.1573 μm², and residual resistance factor is also relatively high, plugging rate can also reach 97.77% as well as residual resistance factor reaches 45 after being eroded by large amounts of 10 PV water. It is concluded that anionic delayed cross-link polymer gel profile control agent has good performance in resistance to erosion and is applicable in low permeability reservoirs.

Table 2
Basic Data of Core

Core number	Length of core (cm)	Diameter of core (cm)	Pore volume (mL)	Porosity (%)	Permeability (μm^2)
27C0506C−1	8.93	2.48	18.05	33.0	2.5801
070321C−5	9.02	2.50	17.10	33.2	1.7566
070321C−6	9.36	2.52	18.30	33.9	0.7087
E−2	9.38	2.52	15.5	33.1	0.1573

Table 3
Testing Results of Profile Control Agent Plugging Rate, Residual Resistance Factor and Resistance to Erosion

Core number	Permeability before profile control(μm^2)	Subsequent water erosion 1 PV			Subsequent water erosion 10 PV		
		Permeability after profile control(μm^2)	Plugging rate(%)	Residual resistance factor	Permeability after profile control(μm^2)	Plugging rate(%)	Residual resistance factor
27C0506C-1	2.5801	0.4859	81.17	5.31	/	/	/
070321C-5	1.7566	0.1591	90.94	11.04	/	/	/
070321C-6	0.7087	0.1170	83.49	6.06	/	/	/
E-2	0.1573	0.0023	98.54	68	0.0035	97.77	45

2.2 Shunt Rate Experiment of Profile Control Agent

Getting a couple of artificial core with different permeability to connect the process in parallel after pumping off the saturated water, displacing water subsequently, measuring displaced liquid every 10 minutes for at least 2PV. Displacing profile control agent valued 2PV after water displacing, then displacing water again at least 2PV after gelation. As is shown in Table 4, it can be seen that shunt rate of core changes dramatically after profile control, shunt rate in the high permeability tube drops to 24.94% after profile control from 57.43% before profile control, while shunt rate in the low permeability tube rises to 75.06% from 42.57%. It is concluded that profile control agent inside core takes effect on plugging high permeability zones for which the entry profile has been improved obviously.

Table 4
Testing Results of Shunt Rate

Displacing process	Rate of flow of high permeability core (mL)	Rate of flow of low permeability core (mL)	Shunt rate(%)	
			High permeability core	Low permeability core
Water displacement	13.68	10.14	57.43	42.57
Profile control agent displacement	7.92	6	56.9	43.10
Subsequent water displacement	5.82	17.52	24.94	75.06

Notes: Permeability of high permeability tube: 0.5107 μm², permeability of low permeability tube: 0.3836 μm²

3. EVALUATING EFFECT OF OIL DISPLACEMENT INSIDE CORE USING POLYMER PROFILE CONTROL AGENT

3.1 Introduction of the Experiment

Cementing artificial core with quartz sand epoxy, choosing three sticks of core with water phase permeability valued 200 mD, 500 mD and 800 mD to arrange in positive rhythm, which the model specification is 30 cm×4.5 cm×4.5 cm; the experimental oil is mixture of simulated oil prepared with crude oil from the First Production of Daqing Oilfield and kerosene, the viscosity reaches about 10 mPa.s under the condition of 45 degrees; the experimental water gets from sewerage of the First Production Station 603 of Daqing Oilfield; the experimental polymer is anionic polyacrylamide produced by Daqing Refining & Chemical Company, its relative molecular mass is in the range of 1200 to 16 million; the experimental profile control agent is type A-2-1 anionic delayed cross-link polymer gel profile control agent prepared with oilfield's sewerage. Specific experiment schemes are as follows:

3.1.1 Simulation Experiment of Displacing Oil Using Polymer

After saturating with oil: A. water displacing to water content of 98%+ 0.69PV 1500mg/L fractal polymer+ subsequent water displacing to water content of 98%; B. water displacing to water content of 98%+ 0.74PV 1500mg/L fractal polymer+ subsequent water displacing to water content of 98%; C. water displacing to water content of 98%+ 0.84PV 1500mg/L fractal polymer+ subsequent water displacing to water content of 98%.

3.1.2 Simulation Experiment of Profile Control Displacement Before Polymer Displacing

After saturating with oil: A. water displacing to water content of 98%+ 0.05PV profile control agent+ 0.64PV 1500mg/L fractal polymer +subsequent water displacing to water content of 98%; B. water displacing to water content of 98%+ 0.10PV profile control agent+ 0.64PV 1500mg/L fractal polymer+ subsequent water displacing to water content of 98%; C. water displacing to water content of 98%+ 0.20PV profile control agent+ 0.64PV 1500mg/L fractal polymer+ subsequent water displacing to water content of 98%.

3.1.3 Simulation Experiment of Profile Control Displacement During Polymer Displacing

After saturating with oil: A. water displacing to water content of 98%+ 0.10PV 1500mg/L fractal polymer+ 0.10PV profile control agent+ 0.54PV 1500mg/L fractal polymer + subsequent water displacing to water content of 98%; B. water displacing to water content of 98%+ 0.20PV 1500mg/L fractal polymer + 0.10PV profile control agent+ 0.44PV 1500mg/L fractal polymer+ subsequent water displacing to water content of 98%; C. water displacing to water content of 98%+ 0.30PV 1500mg/L fractal polymer+ 0.10PV profile control agent+ 0.34PV 1500mg/L fractal polymer+ subsequent water displacing to water content of 98%.

3.1.4 Simulation Experiment of Profile Control Displacement After Polymer Displacing

After saturating with oil: A. water displacing to water content of 98%+ 0.64PV 1500mg/L fractal polymer+ 0.05PV profile control agent+ subsequent water displacing to water content of 98%; B. water displacing to water content of 98%+ 0.64PV 1500mg/L fractal polymer+ 0.10PV profile control agent+ subsequent water displacing to water content of 98%; C. water displacing to water content of 98%+ 0.64PV 1500mg/L fractal polymer+ 0.20PV profile control agent+ subsequent water displacing to water content of 98%.

3.2 Analysis of Experiment Results

Table 5 shows the relationship between different injection time or injection rate of type A-2-1 anionic delayed cross-link polymer gel profile control agent and enhanced oil recovery. It can be seen that effect of profile control becomes gradually worse along with the injection time of before, during and after polymer displacing, the average value of enhanced oil recovery is 2.91 %, 2.64 % and 2.03 % respectively; from the aspect of injection rate, the value of enhanced oil recovery becomes larger along with injection rate getting larger, but the increasing extent slows down after reaching the point of 0.1 PV. Considering cost will rise as increasing injection rate, it is recommended to adopt the way of profile control displacement before polymer displacing which 0.10 PV is the ideal injection rate.

Table 5
The Relationship Between Different Injection Time or Injection Rate and Enhanced Oil Recovery

Injection time	Water phase permeability of core	Enhanced oil recovery (%)					
		0.05PV	Average	0.1PV	Average	0.2PV	Average
Before polymer displacing	200md	0.75	0.49	2.05	1.83	1.66	1.95
	500md	0.40		1.70		1.96	
	800md	0.32		1.74		2.24	

To be continued

Continued

Injection time	Water phase permeability of core	Enhanced oil recovery (%)					
		0.05PV	Average	0.1PV	Average	0.2PV	Average
During polymer displacing	200md			1.43	1.59	3.04	1.61
	500md			1.58		1.09	
	800md			1.77		0.70	
After polymer displacing	200md	0.38	0.18	1.98	1.76	1.75	1.70
	500md	0.12		1.77		1.93	
	800md	0.05		1.53		1.42	

CONCLUSIONS

(1) Long-term thermal stability and shearing resistance of anionic delayed cross-link polymer gel profile control agent both have good performance, gelation viscosity remains 26000mPa.s after 110 days under the condition of 45 degrees, and still can gel after mechanical shearing to the degree between 20%~50%, which gelation time is the same as the time after shearing, but gelation viscosity is lower, and with the degree of shearing increasing, gelation viscosity reduces, while overall changing trends basically correspond with each other.

(2) Anionic delayed cross-link polymer gel profile control agent gets desired compatibility with natural debris with no floc generating, cementing with debris after gelling about 60 days, and it will no longer flow while inclining; but it performs poor stability while blending in ASP system, Gel breaking phenomenon occurs on the third day, gel has been broken completely on the 65th day. So we can conclude that anionic delayed cross-link polymer gel profile control agent does not apply to profile control before ASP displacement.

(3) Anionic delayed cross-link polymer gel profile control agent has satisfying plugging effect on low permeability core, plugging rate reaches as high as 98.54% with permeability being 0.1573 μm^2, and residual resistance factor is also relatively high, plugging rate can also reach 97.77% as well as residual resistance factor reaches 45 after being eroded by large amounts of 10 PV water. It is concluded that anionic delayed cross-link polymer gel profile control agent has good performance in resistance to erosion and is applicable in low permeability reservoirs.

(4) Effect of profile control becomes gradually worse along with the injection time of before, during and after polymer displacing, the average value of enhanced oil recovery is 2.91 %, 2.64 % and 2.03 % respectively; the value of enhanced oil recovery becomes larger along with injection rate getting larger, but the increasing extent slows down after reaching the point of 0.1 PV.

REFERENCES

[1] Wei, X.M, Cao, M.J, *et al*. (2000). Application of Compound-Ion Profile-Modifying Agent. *Journal of Daqing Petroleum Institute*, *24*(2), 98-100.

[2] Kan, C.L, Yan, Y.R., *et al*. (2001). Compound Ion Depth Profile Control in SaZhong Area. *Petroleum Geology & Oilfield Development in Daqing*, *20*(2), 130-132.

[3] Lei, G.L, Chen, Y.M, *et al*. (2001). Research of Depth Profile Control Technology in Polymer Flooding. *Oil & Gas Recovery Technology*, *8*(3), 54-57.

[4] Li, A.F, Chen, Y.M., *et al*. (2002). The Mechanism of Profile Modification of Amphoteric Copolymer Modification Agent. *Journal of the University of Petroleum*, *26*(2), 47-49.

[5] Lu, X.G., Gao, Y.J., *et al*. (2003). Optimization Design Of Formulations For Compound Ionic Plugging Agent. *Journal of Daqing Petroleum Institute*, *27*(1), 85-87.

[6] Zhao, Q.P., Zhao, C.Y., *et al*. (2003). The Capability and Affecting Factors of Compound-Ion Profile Control Agent. *Petroleum Geology & Oilfield Development in Daqing*, *22*(3), 82-84.

[7] Guo, J.L. (2005). Research on Gelation Behavior Control Conditions of Compound Ion Profile Control Agent. *Oil-Gasfield Surface Engineering*, *24*(4), 13-15.

[8] Li, X., Li, Y., *et al*. (2005). Influencing Factors of Performance of Profile Modification System by Using Compound Ions Polymer. *Petroleum Geology & Oilfield Development in Daqing*, *24*(3), 90-92.

[9] Lv, C.S. (2009). Performance Evaluation Of Compound Ion Profile Control Agent. *Drilling & Production Technology*, *32*(1), 81-83.

[10] Zhang, R.M., & Yao, P.Y. (2010). Performance Evaluation Of Polymer Flooding Profile Control Agent Composite Ion YPY-1. *Petrochemical Industry Application*, *29*(1), 31-33.

[11] Moradi-Araghi, A. (2000). A Review of Thermally Stable Gels for Fluid Diversion in Petroleum Production. *J. Pet. Sci. Eng.*, *26*(1), 1-10.

[12] Hutchins, R.D., & Dovan, H.T. (1996). Field Application of High Temperature Organic Gels for Water Control. Paper SPE 35444 Presented at *the 1996 SPE/DOE Symposium on Improved Oil Recovery*, Tulsa, Oklahoma, 21-24 April.