Study on Polymer Flooding Profile Control and Antimony Technology

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Abstract. In view of the problems of polymer flooding in wells with high concentration and severe coalescence, a polymer flooding profile control and anti-sludging efficiency enhancement technique was proposed. By adjusting the formulation of the gel system, profile control systems with different gel strengths were constructed. The pre-shearing experiment of the gelation liquid showed that the shearing effect severely affected the long-term stability and gel strength of the gel for the same formulation system with the same initial gel strength, and the addition of nanoparticles could effectively reduce the shear effect on the long-term stability of the gel. Impact. On this basis, the strength of the gel profile modification system was optimized through physical simulation. The results show that for GD polymer flooding reservoirs, only H-strength gel systems can effectively seal the high-permeability layers. Therefore, the optimized formulation for the formation of the solitary polydisperse reservoirs is 0.5% polymer N632+ 0.4% organic chromium crosslinker + 0.3% nanoparticle stabilizer.

Keywords: polymer flooding, organic chromium gel, shear effect, nanoparticle; plugging efficiency, long-term stability.

1. Introduction

Polymer flooding is a relatively mature tertiary oil recovery technology. Zhao Fulin et al. believe that this technology can increase the recovery rate by 8%-15% [1]. However, it has a problem: In oil reservoirs with severe heterogeneity, especially in the formations with high-permeability channels and large pore channels, high concentrations of polycondensation and serious segregation would occur in the wells, resulting in a large amount of waste of polymer and a poor polymer flooding effect. In order to solve the problem for polymer flooding, ensure that the polymer is uniformly promoted in the formation and maximize the Swept volume, a polymer flooding control technology is proposed.

At present, there are relatively few researches on the profile adjustment of polymer flooding reservoirs, and they mainly draw lessons from the experience of water flooding profile control. Compared with the water flooding reservoir profile control, polymer flooding reservoir profile control has the following two difficulties. First, the polymer system used in polymer flooding has a higher viscosity than water, and the displacement pressure is much higher than that of water flooding. To seal the polymer flooding layer effectively and improve the liquid flow steering capability of polymer system, it is necessary use a profile control agent system with high-strength and viscoelasticity to prevent profile control agents from being washed away or broken due to excessive flooding pressure, resulting in seal failure. Secondly, the polymer flooding fluid would be diluted, results in a significant decrease in the gel strength and long-term stability of the gel and even the absence of gelation. In view of the above complicated conditions, a gel system suitable for the formation conditions was constructed according to the existing formulation, and the long-term stability evaluation of the gel system was performed. The experiment was carried out by the model displacement of the laboratory to simulate the on-site conditions and the strength of the gel was optimized. The research provides theoretical guidance for the design of subsequent polymer-driven segmented plugs.

2. Experimental Part

2.1 Experimental Drugs, Materials and Instruments

2.1.1 Experimental Drugs, Materials

Partially hydrolyzed polyacrylamide (N632), industrial product (Anhui Jucheng Fine Chemical Co., Ltd.); GD formation water (see Table 1 for ion concentration); organic chromium cross-linking agent; nanoparticle stabilizer.

Table 1.GD formation water ion mass concentration

Ionic composition	Na+	Ca2+	Mg2+	Cl-	SO42-
Concentration (mg/L)	8353.7	750.7	539.5	9556.9	69.1

2.1.2 Experimental Instruments

Electronic analytical balance (accuracy 0.001g and 0.0001g, respectively); Ampoule bottle; JJ-1 precision force electric mixer; WARING high-speed stirrer; viscometer (BROOKFIELD viscometer); constant temperature water bath; alcohol torch; advection pump; Precision pressure gauge (0 ~ 0.1Mpa and 0 ~ 3Mpa); six-way valve; intermediate container; constant temperature oven; sand filling tube (L: 19.6cm, Φ: 2.5cm).

2.2 Experimental Methods

2.2.1 Preparation of Adhesive

The polymer is configured to a certain concentration of the mother liquor, the crosslinker and the stabilizer are dissolved with GD formation water according to a certain ratio, and then a certain proportion of the polymer mother liquor is added to the solution of the crosslinking agent, stirred uniformly with a stirrer. 20g of the gelatinized liquid was weighed and injected into the ampoule bottle, and the ampoule bottle was sealed with an alcohol torch. Finally, the ampoule was placed in a constant temperature water bath to examine the strength and dehydration rate of the gel.

2.2.2 Test Methods for Long-term Stability of Gel

The WARING high-speed stirrer was adjusted to 3000 rpm in a simulated high-speed shearing process. Four identical polymer solution samples were placed in a stirrer for 1 min, 3 min, 5 min, and 10 min respectively, and the viscosities of the five gel samples were measured. According to a certain proportion, the cross-linking agent and stabilizer (or no stabilizer) are dissolved in GD formation water. The above polymer solution was added to the crosslinker solution to form a gel. The resulting gel was sealed in an ampule and placed in a constant temperature water bath at 70°C to age for 30 days. The gel strength, water loss rate at 3 days and 30 days were observed, and the elastic modulus of 5 samples was measured using a rheometer.

2.2.3 Single Tube Model Displacement Experiment Method

A quartz sand (80-120 mesh) with a particle size range was used to fill a sand-filled pipe with a length of 19.6 cm and a cross-sectional area of 4.906 cm2. Permeabilities were measured by liquids, After injecting the polymer (the viscosity at the shear rate of 7.34 ¯S is 40 mPa.s) until the pressure is stable, the gels with different strengths (F, G, H) and different PV numbers (0.1, 0.3, 0.6) are injected, respectively. The gel was then placed in a constant temperature water bath to form a gel, then polymer was injected into the gel until the pressure was stable. The pressure of the injected polymer before and after the injection of different properties of the gel was recorded, and the blocking rate and the residual resistance coefficient were calculated. Among them, the plugging rate equation and residual resistance coefficient equation are:

$$R_{Plugging}=\left(1-\frac{Kw2}{Kw1}\right)\times 100\% \quad (1)$$

In the formula: Kw1 is the permeability before plugging; Kw2 is the permeability after plugging.

$$R_{ff}=\frac{Kw1}{Kw2} \quad (2)$$

In the formula: Kw1 is the permeability before plugging; Kw2 is the permeability after plugging.

3. Experimental Results

3.1 Construction and Performance Evaluation of the Gel System

3.1.1 The Optimization of the Gel System

According to the research of the organic chromium gel system, the gelling agent used N632 polymer (no shearing effect) in the experiment, the crosslinker was organic chromium (chromium acetate), the stabilizer was nanoparticle, and the gelation temperature was 70°C. The gel system with different gelation properties was constructed. The results are shown in Table 2.

Table 2. Construction of Different Gelling Performance Gel System

No.	Polymer /wt%	Crosslinker/wt%	Stabilizer /wt%	Gel strength	Stability
1	0.2	0.35	0.2	D	30 days without dehydration
2	0.3	0.35	0.2	F	30 days dehydration 1.7%
3	0.4	0.35	0.3	G	30 days dehydration 1%
4	0.5	0.4	0.3	H	30 days without dehydration
5	0.2	0.35	0	D	30 days dehydration 0.6%
6	0.3	0.35	0	F	30 days dehydration 2.2%
7	0.4	0.35	0	G	30 days dehydration 1.8%
8	0.5	0.4	0	H	30 days dehydration 1%

From Table 1, it can be seen that as the mass fraction of the polymer increases, the gelation time of the gel system gradually decreases from 12 hours at 0.2% to 4 hours at 0.5%, and the gel strength significantly increases from D at 2% to H at 0.5%, this is because the greater the mass fraction of the polymer, the more crosslinks it has with the crosslinker, the faster the reaction rate, the shorter the gelation time, and the formation of cross-linking reactions. The network structure will also be more dense, so that the strength of gel will also gradually increase. The addition of a stabilizer enhances the stability of the gel system. Therefore, a gel system with different gelation time, gel strength and stability can be obtained by adjusting the mass fraction of polymer, crosslinker and stabilizer. Constructing a gel system with strengths of F, G and H levels and good stability will lay the foundation for the subsequent study of the effects of different properties of gel on polymer blocking efficiency.

3.1.2 Shearing Effect on the Long-term Stability of Gel

Two gel formulations (with and without stabilizers) with H-grade gel strength were chosen to perform two groups of comparative experiments under the same conditions. Each group is divided into five groups, of which one group is not sheared. In the shear control group, the remaining 4 sets of the same polymer sample were placed in a 3000 rpm stirrer and shear for 1 min, 3 min, 5 min, and 10 min, respectively, and the viscosity of the gelation agent was measured at different shear times. The crosslinker and stabilizer (or no stabilizer) are dissolved in a certain proportion of GD formation water, and then the above polymer solution is added to the crosslinker solution to form a gel solution. The gel solution was placed in a constant temperature water bath at 70°C to age for 30 days, and the difference between gel strength and water loss rate at the 3rd and 30th days were observed. The rheometer was set at the oscillation mode, shear strain 1%, frequency 1HZ, to measure the elastic modulus of the gel at different shearing times, and compare the effect of different shearing time on the long-term stability of the gel, the results are shown in Figure 1, Figure 2 and Table 2.

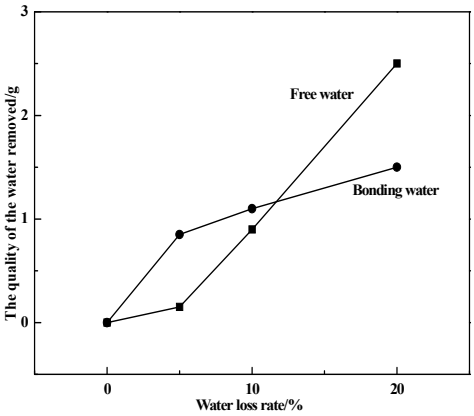

Fig 1. Effect of shearing time on the viscosity of gelation agent and the elastic modulus of the gel syste

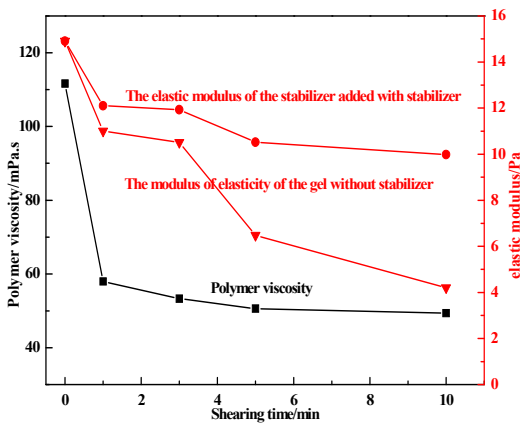

Fig 2.The quality of the dewatered water changes with dehydration rate

Table 3. Effect of shear time on the performance of the gel system

Cuttingtime/min	0		1		3		5		10	
	+	-	+	-	+	-	+	-	+	-
3daysgelstrength	H	H	H	H	H	H	H	G	H	G
3dayslossrate/%	0	0	0.6	2.8	0.7	3.1	0.9	3.4	1	3.9
30daysgelstrength	H	H	H	G	H	G	H	F	H	F
30dayslossrate/%	0	1	0.9	7.7	1.2	8.1	1.5	9.2	1.8	9.8

+:Add stabilizers; -: Do not add stabilizers

From Fig. 1 and Fig. 2, it can be seen that as the shear time of the polymer solution increases, the elastic modulus of the stabilizer-free gel system decreases significantly and the strength decreases; the elastic modulus of the stabilizer system does not change significantly, and the intensity is almost unchanged. The gel strength of the gel system without stabilizer was significantly reduced, and the water loss rate was significantly increased. The shear loss of polymers is a complex physical and chemical process. The molecular chain segments of polymer macromolecules are destroyed under shearing effect, which leads to a decrease in viscosity [2].

The dehydration phenomenon of gel after shearing occurs because the shearing effect degrades the HPAM molecules, leading to the increase of acrylamide derivatives containing hydrophobic groups (double bonds, epoxy groups, etc.), and the interaction between HPAM and water molecules weakens; The breakage of the molecular chain leads to the destruction of the "nano-pores" in the network structure of the polymer and the reduced water holding capacity [3]. The breaking of the HPAM molecular chain reduces the reaction between the cross-linking agent and the reactive groups on the polymer molecular segment, resulting in a decrease in the lattice density and a decrease in the strength of the gel [4].

As it can be seen from Table 3, compared with the gel system without stabilizer under the shearing effect, the gel strength of the gel with stabilizer significantly increased, the water loss rate significantly decreased, and the long-term stability was favorable [5]. This is because the addition of stabilizers will increase the water holding capacity of the gel, leading to an increase in the amount of bound water in the gel [6].

3.1.3 Evaluation of Plugging Performance of Gel Sealing

The experiment was divided into 3 groups, and the gel formulations with the gel strength of F, G and H were selected. Calculate the plugging rate and residual resistance coefficient and analyze the effect of different gel strength on the plugging efficiency of the polymer flooding reservoir. The results are shown in Table 4.

Table 4.Effect of Gel Strength on Plugging Efficiency

No.	Gel strength	Blocking rate/%	Residual resistance coefficient
1	F	23.4	1.3
2	G	52.4	2.1
3	H	73.9	3.5

From Table 4, it can be seen that as the strength of the gel increases, the plugging rate and the residual resistance coefficient increase to some extent. The blocking effect of the F-grade and G-grade gel on the polymer flooding reservoir layer is poor. Grade H gel could block effectively, and the plugging rate can reach 73.9%.

4. Conclusion

(1) By adjusting the formulation of the gel system, a profile control system with different gel strength was constructed. For the same formulation system with the same initial gel strength, the shearing effect seriously affects the long-term stability and gel strength. With the addition of nanoparticle stabilizer, the gel strength increased significantly and the water loss rate decreased evidently, which can effectively reduce the effect of shearing effect on the long-term stability of the gel.

(2) For polymer flooding reservoirs, only H-strength gel systems can effectively block high permeability layers. Therefore, the optimized formulation for the formation of GD polymer flooding reservoirs is 0.5% polymer N632 + 0.4% organic chromium crosslinking agent + 0.3% nanoparticle stabilizer. The gel time of organic chromium gel system is 2h, the gel strength can reach H level. After the shearing effect of the gelled liquid, the water loss rate in the constant temperature water bath at 70°C for 30 days remained at about 1.8%.

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