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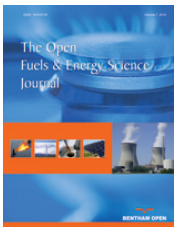

RESEARCH ARTICLE

Preparation and Performance Evaluation of Alkali-resistant Gel-type Deep Profile Agent

Yazhou Zhou* and Daiyin Yin

College of Petroleum Engineering, Northeast Petroleum University, Daqing 163318, China

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Abstract: Currently, most profile control agents would be degraded in strong alkaline condition. They could not be applied in ASP (alkaline, surfactant and partially hydrolyzed polyacrylamide) flooding. To solve this problem, a new kind of alkali-resistant gel for deep profile has been studied. Based on the profile control mechanism of profile agent and the crosslinking mechanism of the polymer, the selection of the chemical agent with different type and concentration was carried out in strong alkaline (pH=12), using ordinary polymer as the main agent, organic and inorganic chemical crosslinking agent. The performance evaluation, residual resistance factor and displacement experiment for the prepared profile agent were carried out. The results show that the profile agent weakly affected the interfacial tension of the ASP flooding. The gelation time could be tuned by adjusting the concentration of the delayed coagulant. The alkali-resistant profile agent with good plugging performance was suitable for deep profile control. When this profile agent was applied in the process of ASP flooding, it could adjust the liquid producing profile and improve the oil displacement efficiency, the recovery ratio was about 4% higher than ASP flooding. The field test of alkali-resistant gel-type profile agent shows that, this alkali-resistant profile agent can achieve good effect, it can enhance oil recovery by 3%.

Keywords: Alkali resistant, ASP Flooding, Deep profile control, Gel, Polymer.

1. INTRODUCTION

The ASP flooding technology is about to enter the promotion stage of industrialization in Daqing sandstone reservoir. Some test sites were quite successful. Comparing with water flooding, the oil recovery of ASP flooding technology could increase by more than 20% [1 - 3]. For the reservoirs with high heterogeneity and thick main reservoir, the injected chemical liquid in the late ASP flooding seriously flow along the high permeable layer [4], leading to the futile circulation of chemical agents. The deep profile control technology could be applied in ASP flooding, which could significantly reduce the futile cycle of the ASP liquid in the high permeable layer, and increase the oil displacement efficiency of ASP flooding [5 - 9]. Presently, profile agents, such as HPAM/Cr^{3+}, HPAM/Al^{3+} and HPAM/organic phenol, have poor stability due to the higher pH value, molecular shape could be easily changed in high pH, leading to the low gel strength in the reservoir [10 - 12]. Despite the polymeric particles have good alkali resistant, they could not well match the oil layer. At present, there is no successful experience to use for reference in alkali profile control system. Therefore, it is of great significance to research the alkali-resistant profile agent for improving oil recovery under condition of high pH value and the development effectiveness of ASP flooding [13 - 16].

In this paper, based on the actual reservoir and development situation in ASP flooding testing area, Daqing x oilfield, the alkali-resistant profile agent was developed, using polymer as the main agent, and organic and inorganic chemical crosslinking agent, together with stabilizer. The performance evaluation, core liquidity experiment and displacement experiment for the prepared profile agents were carried out, and the profile control agent application has been given in field test.

* Address correspondence to this author at the College of Petroleum Engineering, Northeast Petroleum University, Daqing 163318, Heilongjiang, China; Tel: 0459-6503654; E-mail: zhouyazhou720@163.com

2. EXPERIMENTAL INSTRUMENTS AND REAGENTS

2.1. Main Agents

Partially hydrolyzed polyacrylamide, NaOH and surfactants were taken from x block in Daqing oilfield. Metallic crosslinking agent was chromium acetate, organic crosslinking agents were phenol and methyl aldehyde. The salinity of simulated injection water and formation water were 5216.04 mg/L and 729.3 mg/L, respectively.

2.2. Experimental Cores

The cores were designed according to the PI1~3 oil layer of x oilfield. It has three layers, the size was 30cm×30cm×4.5cm, the permeability was about 300×10^{-3} μm^2, 500×10^{-3} μm^2, and 800×10^{-3} μm^2, respectively. The well net was five point well pattern with four injection wells and one production well.

2.3. Experimental Oil

The oil was prepared by wellhead crude oil and aviation kerosene, its viscosity was 6.84 mPa•s.

3. SELECTION OF PROFILE AGENTS

In this paper, the alkali-resistant gel-type profile agent was studied by blending the polymer solution, metal crosslinking agent, and organic crosslinking agent to prepare profile agents. Under the action of the crosslinking agents, the constitutional units of polymer could be crosslinked, forming the spatial lattice structures with the resin filler from the organic crosslinking agent, which has high strength and alkali resistance.

Through optimizing polymer concentration and molecular weight, organic crosslinking agent type and concentration, metallic crosslinking agent type and concentration, stabilizer concentration, the alkali-resistant profile agent formulation has been determined. Taking the optimization of polymer concentration for example, the experimental result is shown in Fig.(**1**), the formative gel picture of different polymer concentrations is shown in Fig. (**2**).

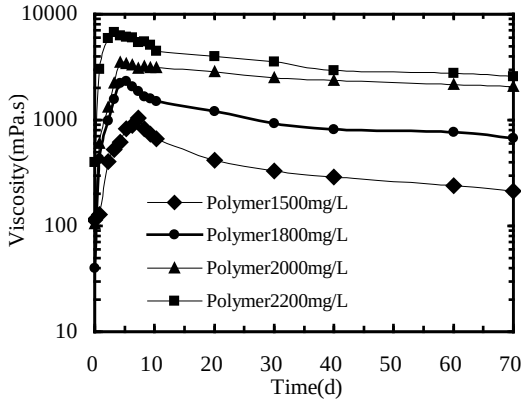

Fig.(1). The gel viscosity of different polymer concentrations.

1500mg/L 1800mg/L 2000mg/L 2200mg/L

Fig.(2). The formative gel picture of different polymer concentrations.

With the increasing polymer concentration, the viscosity of gel system is increased, gelation time is shorten. This is because under certain conditions, the hydraulic radius of polymer molecule is curtained. As concentration of polymer increasing, the chance of the collision and winding of polymer molecules is large, the polymer molecules react with crosslinking agent is much, which increasing the force among the polymer molecules, and the viscosity of gel system increased.

According to experimental result, the composition of the alkali-resistant profile agent was as follows: partially hydrolyzed polyacrylamide: Mw=25000000, 1800~2000 mg/L; metallic crosslinking agent: 0.15% chromium acetate; organic crosslinking agents: 0.1% phenol and 0.08% methyl aldehyde; 0.2% NaCl. The gelation time of profile agent was 4~5 days and the viscosity of the gel was 2320~3510 mPa•s, the stabilization time was more than 60d, it can meet the deep profile requirements in the process of ASP flooding.

4. PERFORMANCE EVALUATIONS OF THE PROFILE AGENTS

4.1. Influence of the Profile Agent on the Interfacial Tension of ASP System

The preferred profile agent was added in to the ASP liquid (1.2% NaOH + 0.3% surfactant + 2000 mg/L polymer) and then the interfacial tension of the composite system was measured, the contrast of interfacial tension between ASP system and compound system was shown in Table **1**.

Table 1. The contrast of interfacial tension between ASP system and compound system.

Time(d)	1	3	5	10
Interfacial tension of ASP system($\times10^{-3}$mN/m)	3.42	4.25	4.83	5.12
Interfacial tension of compound system($\times10^{-3}$mN/m)	3.64	4.87	5.37	6.02

From the interfacial tension comparison of the ASP liquid and the composite systems after adding the profile agent, it could be seen that the profile agent had little effect on interfacial tension of the ASP system.

4.2. Influence of the Delayed Coagulant Concentration on the Gelation Time of the Profile Agent

If the gelation time of the alkali-resistant profile agent could be well controlled, the profile agent could be better applied in the oilfield practice [17, 18]. Gelatigenous performance in different delayed coagulant concentration was shown in Fig.(**3**).

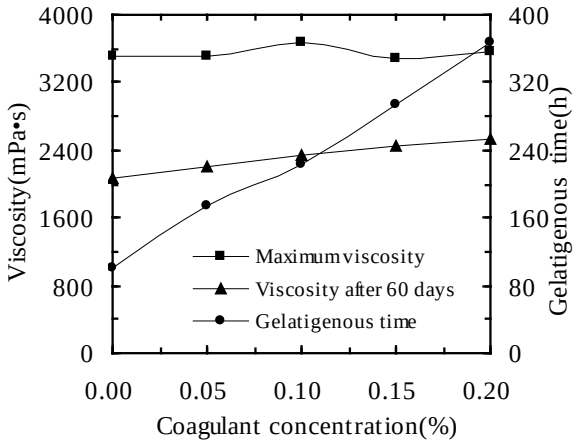

Fig.(3). Gelatigenous performance in different delayed coagulant concentration.

It could be seen from the experimental results that the gelation time prolonged with the increasing of the delayed coagulant concentration. When the delayed coagulant concentration of 0.2%, the gelation time was 366h (15 days). As the delayed coagulant had little effect on the viscosity of the profile agent after gelation, the gelation time could be prolonged by adjusting the concentration of delayed coagulant.

5. THE CORE FLOODING EXPERIMENT FOR ALKALI-RESISTANT PROFILE AGENT

5.1. The Core Flow Experiments

The results of core flow experiments was shown in Table **2**.

Table 2. The result of plugging experiment.

Core number	Permeability ($\times10^{-3}\mu m^2$)	Permeability after plugging ($\times10^{-3}\mu m^2$)	Resistance factor	Residual resistance factor
W-30	800.74	14.4	50	56
W-31	507.46	5.84	95	99
Y-6	314.56	2.36	113	133
Y-7	109.84	0.48	125	149

It could be seen in Table **3** that the residual resistance factor greater than 50 under the pH value of 12 by core flooding experiment for the profile agent, which could meet the requirements of deep profile control for the ASP flooding.

5.2. Oil Displacement Experiment

Scheme 1: water flooding to 98% water cut;

Scheme 2: water flooding to 95% water cut + ASP system 0.4 PV + subsequent water flooding into 98%water cut;

Scheme 3: water flooding into 95% water cut + ASP system 0.15 PV + profile agent 0.035 PV + ASP system 0.25 PV + subsequent water flooding into 98% water cut. The formula of ASP system was 2000 mg/L polymer, 1.2% surfactant and 0.3% alkali. The results of oil displacement experiment were shown in Table **3**.

Table 3. Oil displacement efficiency of three schemes.

Scheme	Core	Minimum value of water cut (%)	Recovery Factor (%)
Scheme 1	#1	/	47.60
Scheme 2	#2	52.6	65.54
Scheme 3	#3	46.5	69.84
	#4	47.5	69.31
	#5	43.7	69.66

It could be seen that the recovery ratio of ASP flooding with alkali-resistant profile agent enhanced by about 4% comparing with that of the ASP flooding. Therefore, the development effect of ASP flooding could be improved by using alkali-resistant profile agent in the process of ASP flooding.

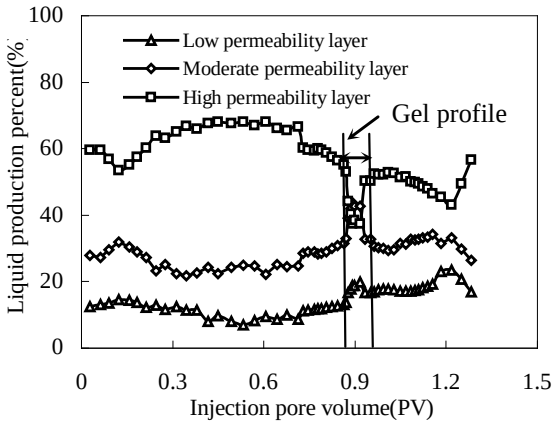

Fig.(4). The produced fluid proportions of different permeable layers.

In order to analyze profile control result of alkali resistance profile agent, parallel core which permeability was about 300×10^{-3} μm^2, 500×10^{-3} μm^2, and 800×10^{-3} μm^2 has been used to carry out displacement experiment. In the

experiment, the liquid production of different cores has been recorded, and the obtained produced fluid proportions in different stages were shown in Fig. (**4**).

From the produced fluid proportions of three different permeable layers, it could be seen that after adding the gel profile control system, the plugging capability of high permeable layer was enhanced. Based on ASP flooding, the produced fluid proportions of high permeable layer decreased about 18%; while moderateand and low permeable layers increased about 12% and 6%, respectively. So, the alkali resistance profile agent can improve liquid producing profile.

6. APPLICATION OF ALKALI-RESISTANT PROFILE AGENT

The average permeability of X block is 343×10^{-3} μm^2. It started to ASP flooding in March 2014, the injection rate is 0.2PV/a. The effect of some production well was bad, this type wells mainly focused on the water injection well of the basic well pattern. Inefficient and invalid cycle of injection liquid was serious, the relative imbibition of high permeable layer was up to 69.2%. X block is divided into 1# test area and 2# test area. The alkali resistance profile control agent was injected in 1# test area in September 2015, and the injection pore volume is 0.035PV, the water cut classification is shown in Table **4**, the water cut curves of two test area are shown in Fig. (**5**).

Table 4. Water cut classification in 1# test area.

Water cut classification (%)	Before injecting profile control agent			After injecting profile control agent		
	Well number	Ratio (%)	Oil production (t/d)	Well number	Ratio (%)	Oil production (t/d)
<80	19	28	341	22	33	433
80~85	15	22	111	19	28	141
85~90	12	18	61	13	19	70
90~95	13	19	46	12	18	43
>95	8	12	12	1	1	1
Total	67	100	572	67	100	686

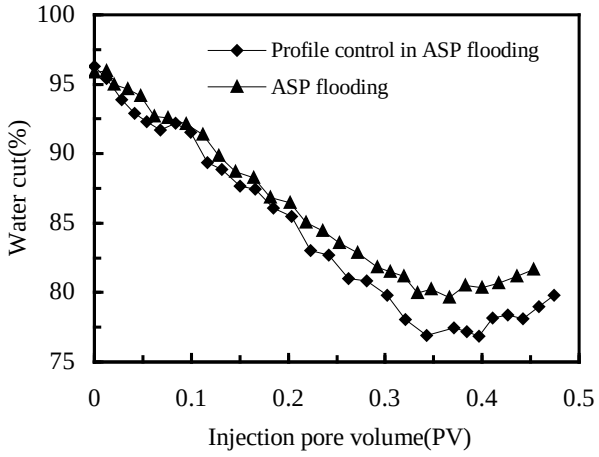

Fig.(5). Contrastion of water cut in 1#test area and 2#test area.

As is shown, after injecting alkali resistance profile control agent, the well number which water cut were less than 80% was from 19 up to 22, the number of wells which water cut were more than 90% was from 8 reduced to 1. The water cut of 1# test area is decreased greatly, the water cut is 4% less than 2# test area. So far, the recovery percent of 1# test area is 2.86% more than 2# test area.

CONCLUSION AND DISCUSSION

The composition of the alkali-resistant profile agent was as follows: polyacrylamide: Mw=25000000, 1800~2000 mg/L; metallic crosslinking agent: 0.15% chromium acetate; organic crosslinking agents: 0.1% phenol and 0.08% methyl aldehyde; 0.2% NaCl. The profile agent had little effect on the interfacial tension of ASP system, the gelation

time could be tuned by adjusting the concentration of delayed coagulant. From the results of core liquidity experiment, the alkali-resistant profile could be seen that the residual resistance factor of the profile agent is greater than 50 in pH=12. The results of oil displacement experiment show that the recovery ratio of ASP flooding with alkali-resistant profile agent enhanced by about 4% comparing with that of the ASP flooding. The development effect of x oilfield field shows that, this alkali-resistant profile agent can be applied in the process of ASP flooding, and it can achieve considerable effect, it can enhance oil recovery by 3%.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

ACKNOWLEDGEMENTS

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