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Experimental Study on High Temperature-resistant Gel for Profile Control

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Abstract: In order to control water and increase oil recovery in reservoir of high temperature (120℃), experiments were carried out to study the impacts of dosage of HPAM, crosslinking agent, delayed crosslinking agent and heat stabilizer on the properties of gel system, and a high temperature-resistant movable weak gel profile control system was presented, whose formula is 2.0g/L HPAM + 0.2% (volume fraction) crosslinking agent + 0.1g/L delayed crosslinking agent + 0.1g/L heat stabilizer. This gel system has good thermal stability at 120℃. It has good flow properties before gelation, and can effectively enter larger pores. After gelation, its viscosity increases so significantly that it can be stranded and the larger pores can be plugged. The plugging rate can be over 93%. Thus, subsequent fluid injection can be redirected into the low-permeability layers, effectively improving the reservoir water absorption profile and oil recovery.

Keywords high temperature-resistant gel system; profile control; experimental study

INTRODUCTION

Movable weak gel flooding technology is an extension of the polymer flooding technology, which is the combination of both near-well injection profile adjustment technology and the polymer flooding technology. The significance of movable weak gel flooding technology lies in the adjustment of injection profile and the increase of oil displacement recovery [1]. Movable weak gel is generated by the reaction of polymer and crosslinking agent. It plays the dual role in profile control and oil displacement [2].

In recent years, it becomes a problem to control water and increase oil recovery in part of the high temperature(120℃) reservoir. Facing this problem, a movable weak gel profile control system composed mainly by partially hydrolyzed polyacrylamide and water-soluble phenolic resin crosslinking agent was developed and evaluated.

DEVELOPMENT OF PROFILE CONTROL AGENT

Setup and materials

1) Setup

Non-isothermal steam flooding experiment device: ZJ-II type, 0-300 ℃.

Electronic balance: JA2003N type, the maximum range 210g, accurate to10-3g.

Electric mixer: JJ -1 type, speed range 0 - 3000 r/min.

Hydrothermal synthesis reaction kettle: 0-300℃, maximum capacity 50 ml.

Rotational rheometer: Haake RS6000 type.

2) Materials

Anionic partially hydrolyzed polyacrylamide: Molecular weight 26-30 million, the degree of hydrolysis 25%, Daqing Refining & Chemical Company;

Crosslinking agent: phenolic resin, prepared;

Delayed crosslinker: content is 50%, prepared;

Heat stabilizer: content is 99%, Tianjin Dengfeng chemical reagent factory.

Formulation optimization

The impacts of the different dosage of anionic polyacrylamide, delayed crosslinking agent and heat stabilizer on the properties of the gel were investigated through gelling experiments with deionized water at 120℃.

1) Optimal concentration of partially hydrolyzed polyacrylamide

Under the conditions of crosslinking agent volume fraction 0.2%, heat stabilizer concentration 0.1 g/L and delayed crosslinking agent concentration 0.1 g/L, the effect of HPAM concentration, from 1000 mg/L to 3000 mg/L, on strength and gelation time of the movable weak gel is shown in figure 1.

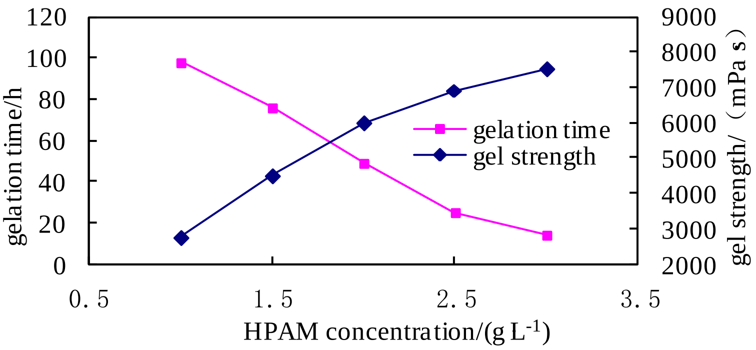

Figure 1 Relationship between the HPAM concentration and the gel strength and gelation time

At 120 ℃, as the increase of the concentration of HPAM, both the gelation rate and the gelling viscosity of the system increase, but the gelation time becomes shorter. When HPAM was over 2000 mg/L, the trend of viscosity increasing slowed down, so 2000 mg/L is the optimal concentration for HPAM.

2) Optimal concentration of crosslinking agent

The concentration of crosslinking agent not only determines whether the system can gel or not, but also greatly influences the gelation speed, the gel strength and the thermal stability of the system [3]. With the concentrations at HPAM 2000 mg/L, heat stabilizer 0.1 g/L and delayed crosslinker 0.1 g/L, the crosslinking agent was varied in the range of 0.1% to 0.3% by volume. The relationship between the crosslinking agent volume fraction and the gel strength and gelation time is shown in figure 2.

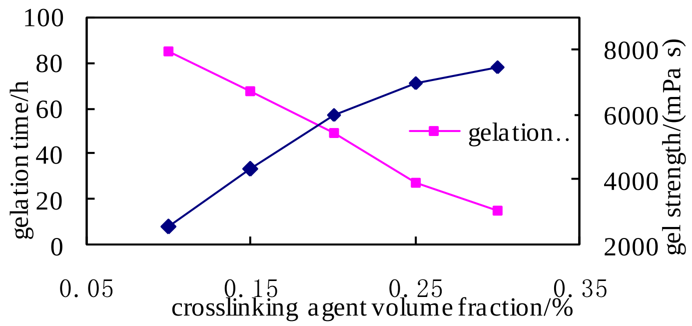

Figure 2 Relationship between the crosslinking agent volume fraction and the gel strength and gelation time

As the increase of the concentration of the crosslinking agent, the gelation time of the system becomes shorter, but the strength is improved greatly. When the volume fraction of the crosslinking agent is 0.2%, the gelation time can meet the engineering requirement, and the gel strength is appropriate.

3) Optimization of the delayed crosslinking concentration

Delayed crosslinker affects seriously the gelation time of the gel system. With the concentrations at HPAM 2000mg/L, crosslinking agent 0.2%, heat stabilizer 0.1g/L, The relationship between the delayed crosslinker concentration, 0 to 0.2g/L, and the gel strength and gelation time is shown in figure 3.

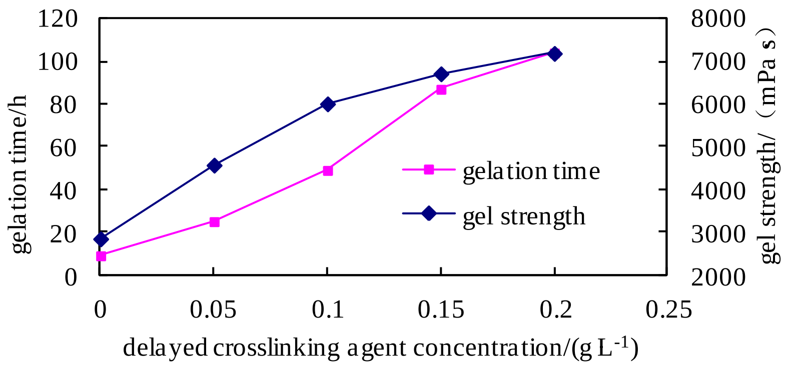

Figure 3 Relationship between the delayed crosslinker concentration and the gel strength and gelation time

With the increase of delayed crosslinker concentration, the gelation time increased significantly, and the system strength also increase. When the delayed crosslinker concentration is up to 0.1 g/L, the increase of gel strength slowed down, and the gelation time was greatly extended, so 0.1g/L is the optimal concentration for delayed crosslinker.

4) Optimization of the concentration of heat stabilizer

Heat stabilizer is one of the factors affecting the heat resistance performance of gel system. The heat stabilizer concentration is varied from 0 to 0.2 g/L in experiments with the HPAM concentration at 2000 mg/L, crosslinking agent at 0.2%, delayed crosslinker at 0.1 g/L. The relationship between the heat stabilizer concentration and the gel strength and gelation time is shown in figure 4.

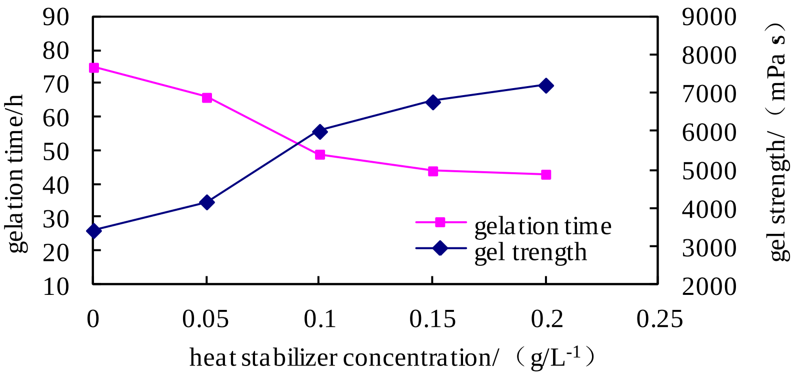

Figure 4 Relationship between the heat stabilizer concentration and the gel strength and gelation time

It showed that with the increase of the concentration of heat stabilizer, the strength of gel system increased greatly while the gelation time becomes shorter. Obviously, the gel time of the system has little change after the heat stabilizer concentration reached 0.1 g/L. Therefore, heat stabilizer concentration should be 0.1 g/L considering the economic purpose.

FLOW PROPERTIES AND PLUGGING PERFORMANCE OF THE PROFILE CONTROL SYSTEM

Flow properties

The viscosity of profile control agent is 221mPa s before gelation at 20℃. After gelation at 120℃, its viscosity is 6009mPa s. So this gel has good flow properties before gelation, and it can enter effectively into larger pores. With the significant increase of viscosity after gelation, the gel retention can plug the larger pores.

Plugging performance

According to the features of ISMR, inspired by the metasynthesis, the ways and means of achieving comprehensive and integrated are concluded as follow.

The plugging ability of the gel system changes with the variation of core permeability. In order to evaluate the plugging effect of gel system, parallel sand packs were used in displacement experiments [4].

The permeability of 1# and 2# sand pack, k1, were measured respectively with water. Then the gel system was injected and the sand packs were placed at 120℃ for 72 hours. The permeability of the two packs, k2, were measured again with water respectively and the plugging ratio η were calculated. The data is shown in table 1.

Table 2 the plugging experiment data of parallel sand packs

Sand pack	K_1/mD	K_2/mD	η	Breakthrough pressure /MPa
1#	3100	198	93.61%	1.76
2#	1600	969	39.43%	0.034

Table 2 shows that the breakthrough pressure of high permeability sand pack is 51.76 times of the low permeability sand pack after gel injection and gelation. Therefore, the gel system can enter preferentially into the high-permeability layers and form blockage, increasing the breakthrough pressure and diverting the liquid flow into the low-permeability layers, thus to improve the reservoir water absorption profile effectively and enhance the oil recovery.

CONCLUSIONS

1) The formula for high temperature-resistant gel for profile control is 2.0g/L HPAM + 0.2% (volume fraction) crosslinking agent + 0.1g/L delayed crosslinker + 0.1g/L heat stabilizer. The system has good thermal stability at 120℃.

2) This gel system has lower viscosity before gelation. It can enter preferentially into the high

permeable formation and can reduce its permeability with a plugging rate of over 93%.

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