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Research on the Formulation System of Weak Gel and the Influencing Factors of Gel Formation after Polymer Flooding in Y1 Block

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Abstract: After long-term polymer flooding, water channeling, and ineffective water circulation occur in oil wells, which seriously affect polymer flooding efficiency and oilfield recovery. The weak gel system has the property of delaying cross-linking. After the weak gel system enters the deep formation, the cross-linking reaction is carried out, which can achieve the purpose of deep regulation and flooding. In this paper, according to the formation characteristics of high temperature, high permeability, and large pores in Y1 block (a block in the Daqing Yushulin Oilfield), the formulation of weak gel system was developed. The optimal formulation was determined by parameters such as gel-forming properties, stability, viscoelasticity, and rheology. Finally, the best formulation for the Y1 block is that containing 0.22% of polyacrylamide (HPAM) and 0.15% of chromium (III) acetate system. The gel-forming time of the formulation is 8 h, and the viscosity can be maintained at 15,000–24,000 mPa·s. Next, this paper studied the factors that affect the gelation of formulations, mainly including dissolved oxygen content, bacterial content, insoluble suspended solids content, and metal ions in the formulation water. The results show that the critical point of the worst effect is the oxygen content close to 1.5 mg/L, and the optimal critical point of oxygen content of the gel system is 7 mg/L. The bacteria in the prepared water degrade the weak gel solution. The more bacteria, the more serious the degradation of the weak gel. A small amount of insoluble suspended solids will greatly increase the viscosity of the weak gel solution, but will accelerate the gel-breaking time. When the content of insoluble suspended solids is high, more than 1000 mg/L, a precipitate will be formed at the bottom of the solution, and the difference in the content of insoluble suspended solids in this interval has little effect on weak gels. The metal ion that mainly affects the gelation effect is Fe^{2+}. With the increase of Fe^{2+} mass concentration, the viscosity of weak gel decreases sharply.

Keywords: weak gel; cross-linking agent; oxygen content; bacterial content; insoluble suspended solids; metal ions

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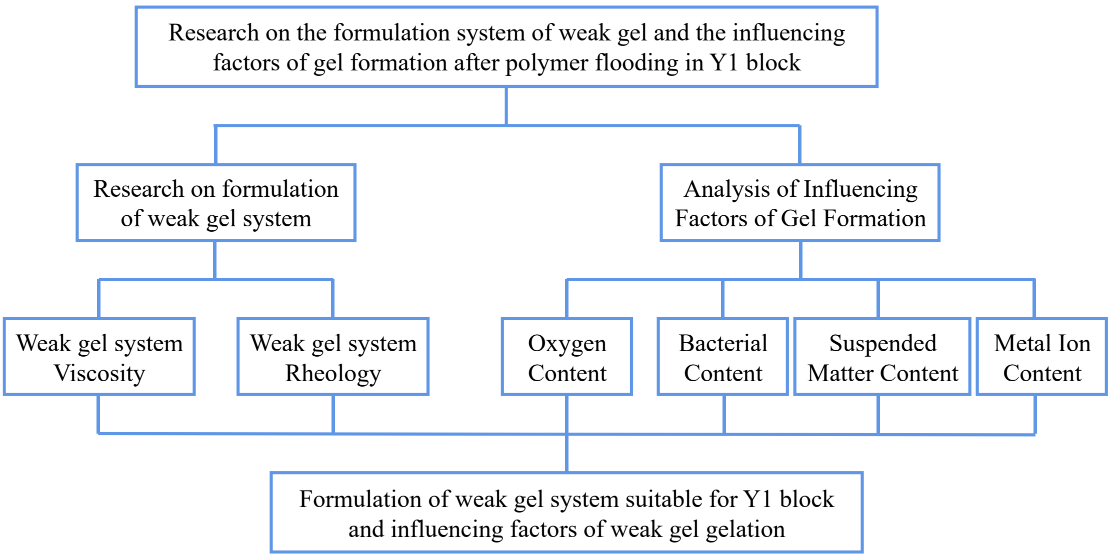
1. Introduction

At present, the development efficiency of water flooding in most oilfields in China has decreased, and major oilfields have entered the stage of tertiary oil recovery, and polymer flooding is the main method in this stage [1]. In Daqing, Liaohe, Shengli, Jilin, and other oilfields, large-scale industrial experiments have been carried out, and the application of polymer control and flooding technology in oilfields has achieved good EOR effects [2]. After years of development and combined with the development of deep reservoir control and flooding, polymer flooding technology has gradually evolved into weak gel control and flooding technology and has been widely used as a new type of tertiary oil recovery technology [3]. Compared with the original polymer flooding technology, the effect of weak gel flooding technology has been significantly improved. For the weak gel system used in the controlled flooding, the concentration of crosslinking agent and polymer in the preparation solution is relatively low [4]. Through the cross-linking between molecules and the internal cross-linking of molecules, a weakly cross-linked three-dimensional network system is formed [5]. The weak gel system has the property of delaying crosslinking, and the crosslinking time can be adjusted to 72–120 h. This technology enables the weak gel system to carry out crosslinking reaction after entering the deep formation to achieve the purpose of deep regulation and flooding [6]. After crosslinking, the system has low strength and viscoelasticity, and can flow in the formation. Due to the network three-dimensional structure formed by cross-linking, it can play a large flow resistance to subsequent water flooding. The system has both profile control and flooding: the combined effect of oil [7].

Since the 1980s, a lot of research and applications have been carried out on the application of weak gels for deep control and flooding at home and abroad, and good EOR effects have been achieved [8]. Zhang et al. [9] developed a new type of high-strength gel ABP system for the characteristics of low temperature, high salinity, and low permeability reservoirs with large pores and large fractures. The temperature and salt resistance of the gel system, plugging characteristics, and enhanced oil recovery were studied. The results show that the delayed crosslinking shortens the time of the system and increases the gel strength when the temperature is increased. Wang et al. [10] The regulation and oil displacement performance of weak gel were evaluated by seepage behavior experiments and parallel core flooding experiments. Weak gels have more retention and greater strength in porous media. The profile control and flooding performance of weak gel is much better than that of polymer. The field test of weak gel flooding was successfully carried out in the LD10-1 oilfield. Cui et al. [11] studied the mechanism of ultra-high molecular weight HPAM/water-soluble phenol weak gel formulation and the optimization of deep profile control parameters in low-permeability reservoirs. The crosslinking kinetics of the ultra-high molecular weight HPAM/water-soluble phenolic weak gel system was studied by the viscosity method, and it was proved that the ultra-high molecular weight HPAM/water-soluble phenolic weak gel flooding profile control system can effectively improve the oil recovery in low permeability oilfields. Wang et al. [12] studied the flow mechanism and effect of a widely used weak gel of acrylamide-based polymers cross-linked with chromium (III) in porous media from macroscopic and microscopic scales. The research results show that the main effect of weak gel is oil displacement, and the secondary effect of profile control is temporary. Yang et al. [13] studied three kinds of polymer gel profile control agents with different strengths in view of the characteristics of high temperature salinity and severe heterogeneity in Bohai Oilfield. The strength of the polymer gel was evaluated using the storage modulus. Liu et al. [14] studied a kind of deep profile control agent using urotropine instead of formaldehyde, which not only delayed the gel time, but also avoided pollution. Orthogonal experiments were designed to optimize traditional organic HPAM-phenolic weak gels. The optimized weak gel has better stability, longer gel time, better salt tolerance, and environmental friendliness. It can better meet the needs of deep profile control in oilfields. Rydzek. G et al. [15] prepared dense polyelectrolyte complexes (COPECs) representing a new class of materials with high fracture strain and self-healing properties. Sciortino, F et al. [16] elucidated the tendency of salt plastic materials to exchange and concentrate ions by studying the effect of sodium ions on copper ion exchange within COPEC assembled from poly (methacrylic acid) (PMAA) and poly (allylamine hydrochloride) (PAH). The above scholars have carried out in-depth research on weak gel formulations under different formation conditions, but the formulations developed above are not suitable for high temperature, high permeability, and large pore formations. In addition, there is a lack of research on the factors affecting the gelation of weak gel systems.

It is necessary to apply weak gel control flooding technology in oilfields after polymer flooding through the above research. In this paper, according to the mining characteristics of high temperature, high permeability, large pore formation, and ineffective injection water circulation in the Y1 block, the formulation of the weak gel system applied in the Y1 block was studied, and the performance of the formulation was evaluated through the indoor displacement experiment. The influencing factors of weak gel formation were also studied. The weak gel system proposed in previous studies is only applicable to conventional reservoirs. This study focuses on high temperature, high permeability, and large pore reservoirs, and proposes a clearly targeted formulation, which provides some guidance for the development of other fields with similar types of post-polymer drive. The overall research scheme (Scheme 1) is shown in the figure below.



Scheme 1. The overall process of this research.

2. Experimental Part

2.1. Experimental Materials

Polyacrylamide (HPAM), degree of hydrolys is 25%, 25 $\times$ 10^6 Mw. The dispersion index (PDI) is 1.17. Chromium (III) acetate. Phenolic resin. KCl (analytical pure), NaCl (analytical pure), Na_2SO_4 (analytical pure), $MgCl_2$ (analytical pure), $NaHCO_3$ (analytical pure), $CaCl_2$ (analytical pure), Na_2CO_3 (analytical pure). Oxygen scavenger Na_2SO_3 (analytical pure), simulated sewage (divided into ordinary sewage, advanced treatment sewage), kaolin (particle size 0.5–2 μm), ferrous sulfate (analytical pure), ferric chloride (analytical pure). The above drugs are provided by Tianjin Yongda Chemical Reagent Co.

The simulated water of the sewage used for liquid preparation has a salinity of 3441.1 mg/L. The water quality analysis and the chemicals required for the preparation of the simulated water are shown in Table 1 below.

Table 1. Water quality analysis and chemicals required for the preparation of simulated water.

Formation Water Ionic Composition	Ion Concentration, mg/L	Chemical Name	Chemical Quality, mg/L
$Na^+ + K^+$	676.8	NaCl	501.189
Ca^{2+}	9.6	KCl	11.7
Mg^{2+}	14.2	$MgCl_2 6H_2O$	168.21
Cl^-	274.8	Na_2SO_4	90.6327
$SO_4{}^{2-}$	42.7	$CaCl_2$	36.725
$HCO_3{}^-$	1228.3	$NaHCO_3$	2219.24
$CO_3{}^{2-}$	56	Na_2CO_3	158.641

2.2. Formulation of Weak Gels

Two liters of simulated groundwater was formulated according to the groundwater formula; 200 mL of simulated groundwater was removed with a beaker, placed in constant water temperature and maintained at 50 °C, and stirred with a stirrer. A certain mass of polymer was added slowly to disperse it uniformly. Corresponding crosslinkers were added sequentially to the polymer solution. The prepared gel solution was left at room temperature for 2 h; its viscosity was measured and recorded. Next, the gels were placed in a 50 °C incubator, where they were observed to form and their viscosity was measured periodically until they broke.

Precautions in the preparation process: (1) the stirrer rpm should not be too high; too intense stirring will lead to the dissector being not easy to gel or not of high strength after gel formation; the gel-forming-agent component should ensure full dissolution, otherwise the dissector is not easy to gel. (2) After adding the crosslinking agent, it must be mixed well, but it should not be stirred for too long; otherwise the stability of the weak gel will be affected by water loss. (3) After the weak gel solution is prepared, the weak gel, which is sticky and transparent and entangled in the stirrer, has influence on the strength of the gel; if it is discarded, the strength of the gel will be reduced, so it should be scraped off and put into the solution with a glass rod frequently during the stirring process.

2.3. Weak Gel Performance Evaluation Experiment

By adjusting the concentrations of polymer and crosslinking agent, weak gel formulations that meet the requirements can be obtained. The prepared solution samples were placed in an incubator simulating the formation temperature, taken out periodically, and the viscosity was measured with a rotational viscometer. Record the change of the viscosity of the weak gel, from low to high and finally to a stable process, the changing viscosity value, and the elapsed time. Each sample was measured three times in parallel; the relative error of the reaction time of each corresponding sample was about 10%, and the results were recorded.

2.4. Experiment on Influencing Factors of Weak Gel Formation

2.4.1. Dissolved Oxygen Content Influence Analysis Experiment

The initial oxygen content of the simulated bottom water was measured; the oxygen content of the solution after adding the de-aerating agent (Na_2SO_3) to the simulated bottom water was recorded; the weak gels with different oxygen contents were prepared according to the experimental procedure of preparing weak gels, and the initial viscosity was measured and recorded with a rotational viscometer, and the viscosity was measured and recorded at room temperature for 2 h. Then the gels were placed in a 50 °C thermostat to observe the gelling condition, and the viscosity was measured and recorded periodically until the gels were broken.

2.4.2. Bacterial Content Influence Analysis Experiment

By culturing the bacteria in the sewage and diluting it with sterile distilled water, the bacterial content of the prepared water is changed. After preparing weak gels with different bacterial contents according to the experimental procedure for preparing weak gels, measure their viscosity regularly and observe their gel formation. The steps are the same as those in the first subsection. Attention should be paid to the preparation process: (1) the prepared bacterial solution must be used within 15 min; (2) the number of revolutions of the agitator should not be too high. Too-intense stirring will make the profile control agent difficult to form a gel or the strength after gelation is not high; the components of the gel former must be fully dissolved, otherwise the profile control agent will not be easy to form a gel. (3) After adding the cross-linking agent, it must be mixed evenly, but the stirring time should not be too long; otherwise the stability of the weak gel will be affected by water loss.

2.4.3. Insoluble Suspended Solids Content Influence Analysis Experiment

Put the kaolin particles into the simulated bottom water and shake with a shaker for 20 min to completely suspend the kaolin particles in the water. After preparing weak gels with different contents of insoluble suspended solids according to the experimental procedure for preparing weak gels, measure their viscosity regularly and observe their gel formation. The steps are the same as those in the first subsection.

2.4.4. Metal Ion Content Influence Analysis Experiment

The experiment was divided into two parts: first for the 10–50 mg/L of Fe^{3+} content interval, starting from 10 mg/L, with a separate sample at 10 mg/L intervals. The second part is the 5–30 mg/L of Fe^{2+} content interval, starting from 5 mg/L, with a separate sample at the 5 mg/L interval. The specific steps of the experiment are to put the $FeCl_3$/$FeSO_4$ into the simulated bottom water, and shake it with a shaker for 20 min so that the iron ions are completely dissolved in the water. After preparing weak gels with different metal ion contents according to the experimental procedure for preparing weak gels, measure the viscosity regularly and observe the gel formation. The steps are the same as those in the first subsection.

3. Results and Discussions

3.1. Weak Gel Flood Control System Formulation

According to the formation characteristics of the Y1 block, the weak gel formulations developed for high temperature, high porosity, and high permeability reservoirs are selected from the following formulations for screening, as shown in Table 2 (# representing different groups) below.

Table 2. Design of primary selection formulation.

Number	Polymer + Crosslinker	
	Type	Concentration
1 #	HPAM + chromium (III) acetate	0.25% + 0.18%
2 #	HPAM + chromium (III) acetate	0.22% + 0.15%
3 #	HPAM + chromium (III) acetate	0.19% + 0.12%
4 #	HPAM + chromium (III) acetate	0.16% + 0.09%
5 #	HPAM + chromium (III) acetate	0.13% + 0.06%
6 #	HPAM + Phenolic	0.24% + 0.18%
7 #	HPAM + Phenolic	0.2% + 0.15%

Through the determination of the initial viscosity, gel forming time, and gel strength of the above formulation, the specific experimental results are shown in Figure 1.

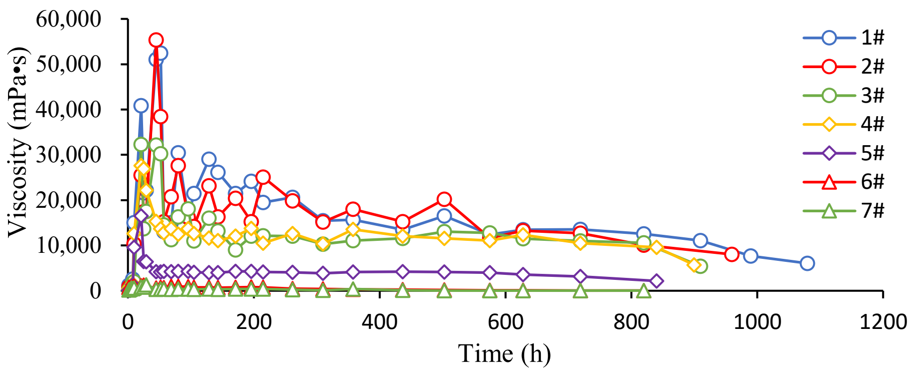


Figure 1. Viscosity versus time curve.

From the experimental results (Figure 1), it can be seen that: after formulations 1, 2, and 4 were crosslinked, they were put into a 50 °C incubator for 8 h to start to form gel. The gel-forming time of formulations 3 and 5 was 10 h, and formulations 6 and 7 could not be effectively crosslinked. The viscosity of formulation 1 reaches a maximum value of 51,000 mPa·s when placed at a constant temperature of 50 °C for 52 h, after 360 h, the strength of the profile control agent tends to be stable, and the viscosity remains at 15,000 mPa·s. The viscosity of formulation 2 reaches the maximum value of 54,000 mPa·s after being placed for 45 h, after 90 h, the strength of the profile control agent tends to be stable, and the viscosity remains at 15,000–24,000 mPa·s. The viscosity of formulation 3 reached the maximum value of 32,000 mPa.s after 21 h, and showed a downward trend, and the viscosity increased to 32,000 mPa·s in 45 h. After 190 h, the strength of the profile control agent tends to be stable, and the viscosity remains at 10,000–13,000 mPa·s. The viscosity of formulation 4 reaches the maximum value of 25,000 mPa·s after 21 h. After 48 h, the strength of the profile control agent tends to be stable, and the viscosity remains at 11,000–13,000 mPa·s. The viscosity of formulation 5 reaches the maximum value of 16,500 mPa·s after 21 h. After 48 h, the strength of the profile control agent tends to be stable, and the viscosity remains at 3000–5000 mPa·s. With the increase of temperature, the gel-forming time of weak gel gradually shortened, the gel-forming strength first increased to a certain peak, then leveled off, and finally showed a downward trend until the gel broke. The gel-breaking times of formulations 1–5 are 1000, 960, 900, 840, and 840 h in sequence, all of which can meet the requirements of Y1 block after polymer flooding.

The rheology of weak gel is an important factor affecting the recovery factor. Therefore, the rheological properties of formulations 1–5 are measured, and the parameters characterizing the fluid rheological properties are the elastic modulus G′ reflecting fluid elasticity and the loss modulus G″ reflecting fluid viscosity. The measurement results are shown in Figure 2.

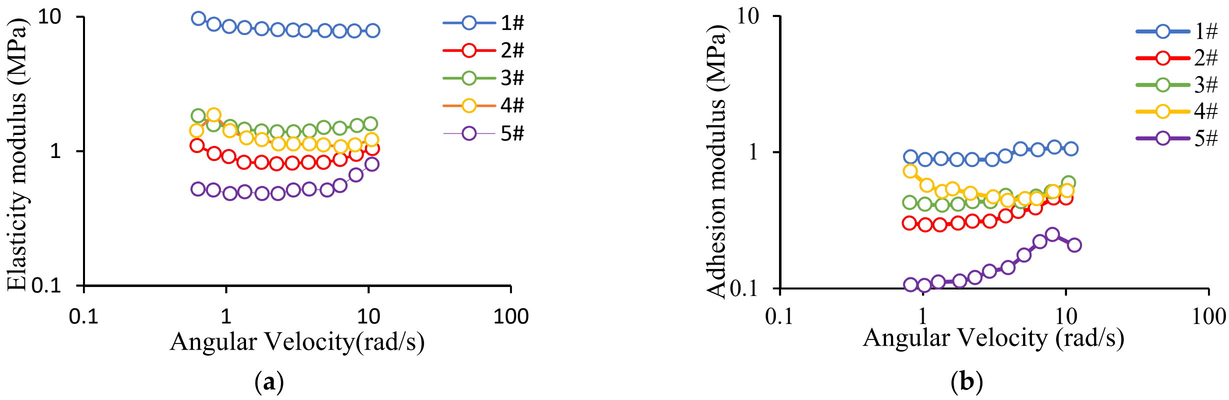


Figure 2. Rheological measurement results. (**a**) The relationship between elastic modulus and angular velocity. (**b**) The relationship between viscous modulus and angular velocity.

Based on the above experimental results (Figures 1 and 2), the phenolic system has poor crosslinking with the polymer, and it is difficult to form a stable gel, so it is not suitable for the application of the Y1 block. Chromium (III) acetate system has good gel stability, high gel strength, and long gel break cycle under high temperature conditions. The gel time of formulation 2 is 8 h, and the viscosity can be stably maintained at 15,000–24,000 mPa·s, which is suitable for the application of Y1 block. At the same time, the elastic modulus and viscous modulus are moderate, the friction between the molecules will not be too large during the gel movement, the transition speed of the molecular segments is normal, and the energy storage during the solution deformation process is good. Therefore, the optimal formulation selected is: 0.22% HPAM + 0.15% chromium (III) acetate system.

3.2. Analysis of Influencing Factors of Weak Gel Formation

3.2.1. Effect of Dissolved Oxygen Content on Gelling Properties of Weak Gel

In this paper, the effect of different dissolved oxygen content on the gelation of weak gels was investigated. The experiment is divided into two parts: the dissolved oxygen content is in the range of 0–3 mg/L, the dissolved oxygen content is in the range of 4–10 mg/L, and the experimental temperature is 50 °C. The experimental results are shown in Figure 3.

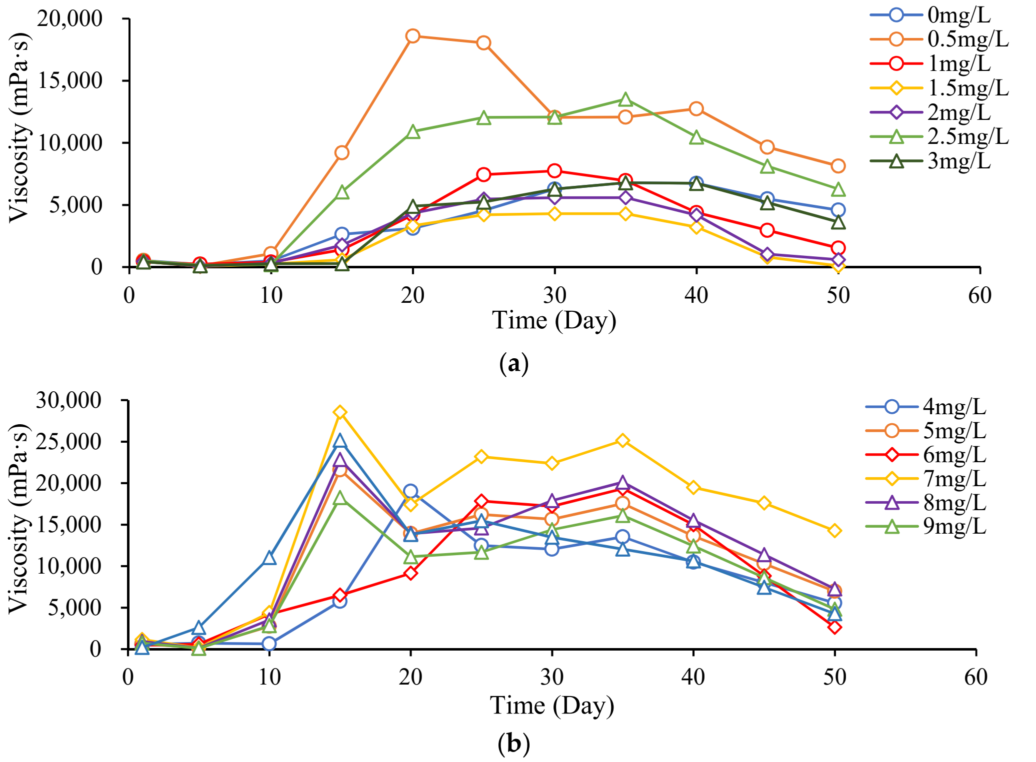


Figure 3. Effect of dissolved oxygen content on the gel strength of weak gels. (**a**) 0–3 mg/L Dissolved oxygen content. (**b**) 4–10 mg/L Dissolved oxygen content.

It can be seen from the experimental results (Figure 3) that in the range of 0–3 mg/L, the weak gel solution viscosity is relatively low and the gel formation time is long. Under the oxygen content of 4–10 mg/L, the gelling strength and gelling time of weak gel solution are ideal. The weak gel with an oxygen concentration of 1.5 mg/L has a longer gel-forming time of 400 h, a low gel-forming strength, a peak viscosity of 4210 mPa·s, and a gel breaking trend at 210 h. The weak gel solution with 1.5 mg/L oxygen content is the sample in the experimental interval that the oxygen content has a serious influence on the weak gel system, which is the critical value of the influence of the dissolved oxygen content in the water on the weak gel. The system has poor effect in the process of oil adjustment and displacement. The weak gel system with an oxygen concentration of 7 mg/L has the best effect in the range of 4–10 mg/L. After being placed in an incubator for 140 h, the gel starts to form. The maximum value is 28,544 mPa·s, showing a tendency to break the gel at 960 h. This concentration of oxygen content prepares a weak gel with a reasonable speed of gel formation. After gelation, the strength and stability are relatively high. the best cut-off value. It is determined that the dissolved oxygen content is the main reason for the fluctuation of gel formation and the deterioration of the gel formation rate. When the dissolved oxygen content in the preparation water is close to that of the 1.5 mg/L weak gel solution, the gel formation effect is poor, the strength is low, and the gel breaking time is fast. When the dissolved oxygen content is 7 mg/L, the weak gel control and flooding system has good temperature resistance, reasonable gel forming speed and high gel strength. The viscosity after gel forming can reach more than 20,000 mPa·s.

3.2.2. Effects of Bacteria on the Gel-Forming Properties of Weak Gels

In this paper, the effect of different numbers of bacteria on the gel strength of weak gel was studied. The experimental temperature was 50 °C, and the number of bacteria was adjusted by diluting sewage with sterile distilled water. The experiment was divided into two groups, one for advanced treatment sewage of the weak gel solution of 100/mL, 300/mL, and 500/mL, and the second group was the weak gel solution prepared from ordinary sewage, and the bacteria contents were 1000/mL, 2000/mL, and 3000/mL.

It can be seen from the experimental results (Figure 4) that in the advanced treated sewage samples, with the increase of the number of bacteria, the viscosity of the weak gel solution decreases accordingly. When the bacterial content was 100/mL, the solution viscosity decreased by about 2% relative to the sterile sample. When the bacterial content was 300/mL, the viscosity of the solution decreased by about 5% relative to the sterile sample. When the bacterial content was 500/mL, the viscosity of the solution decreased by about 7% relative to the sterile sample. It can be seen that the weak gel solution will be degraded when bacteria are present in the preparation water. In ordinary sewage samples, as the number of bacteria increases, the viscosity of weak gel solution decreases accordingly. When the bacterial content was 1000/mL, the solution viscosity decreased by about 15% relative to the sterile sample. When the bacterial content was 2000/mL, the viscosity of the solution decreased by about 30% relative to the sterile sample. When the bacterial content was 3000/mL, the solution viscosity decreased by about 45% relative to the sterile sample. It can be seen that bacteria will seriously degrade the weak gel solution, and the ordinary sewage collected on site cannot be directly used to prepare weak gel.

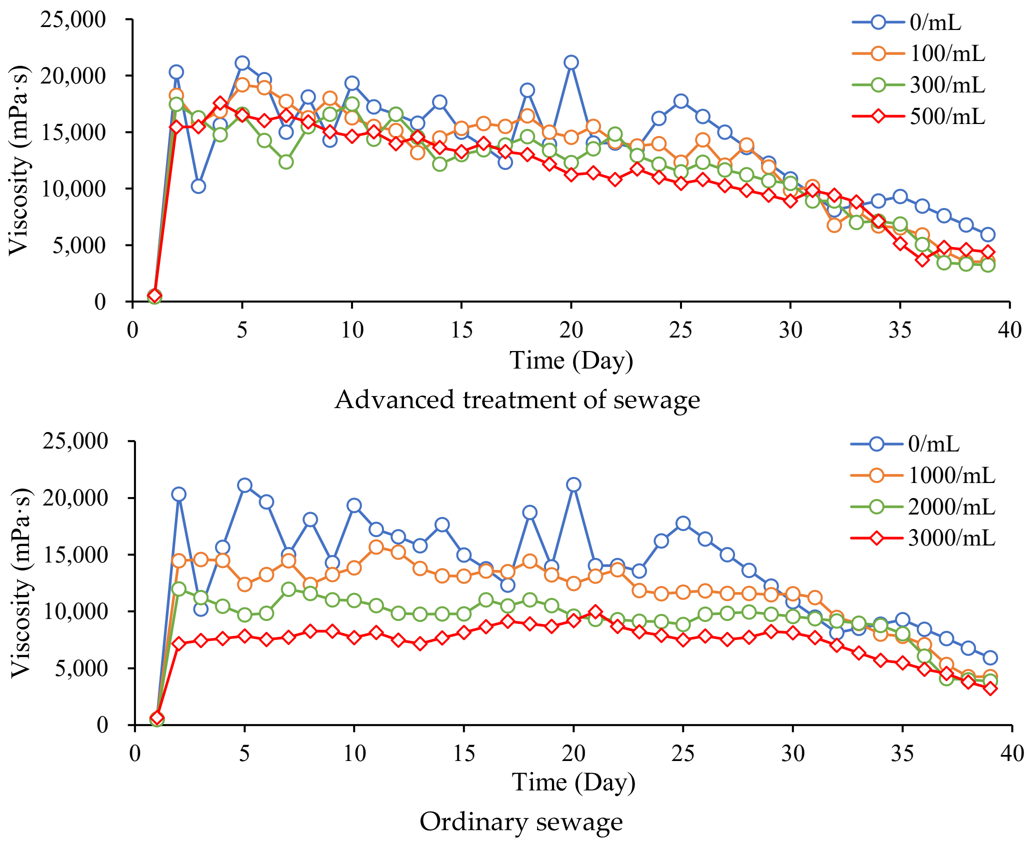


Figure 4. The effect of bacterial content on the gelation of weak gels.

3.2.3. Effect of Insoluble Suspended Solids on Gelling Properties of Weak Gel

The oilfield production practice shows that the content of insoluble suspended solids in water has a serious impact on the weak gel flood control system. In view of this problem, by analyzing the degradation mechanism of insoluble suspended matter on weak gel, according to the actual situation of weak gel flood control in Y1 block, the insoluble kaolin content in the range of 20–100 mg/L and 1000–10,000 mg/L was determined. The effect of suspended solids content on the gel-forming properties of weak gel systems.

From the experimental results (Figure 5), it can be seen that a small amount of insoluble suspended solids will greatly increase the viscosity of the weak gel solution, but it will accelerate the gel breaking time. When the content of insoluble suspended solids is 20 mg/L, the maximum viscosity can rise to 85,000 mPa·s, which is four times that when no insoluble suspended solids are added, but the prepared solution only lasts for 240 h from successful crosslinking to gel breaking; 60 mg/L has the greatest impact on the solution, the solution has been completely broken within 140 h of preparation, and the highest viscosity is only 16,190 mPa·s. It can be concluded that the insoluble suspended matter has a greater influence on the formation of weak gels. When the polyacrylamide molecules in the weak gel system are dissolved in water and ionized, the carboxyl groups will be negatively charged to form negatively charged polyions, which may be adsorbed on the mineral surface because of electrostatic interaction, which will make the polymer. When the crosslinking agent interacts, a gel core is formed to increase the viscosity. When the content of insoluble suspended solids is high, more than 1000 mg/L, a precipitate will be formed at the bottom of the solution, and it is difficult to completely suspend it in the solution. When the insoluble suspended solids are not added as a whole, the viscosity will increase as a whole, and the gel breaking time will be accelerated accordingly.

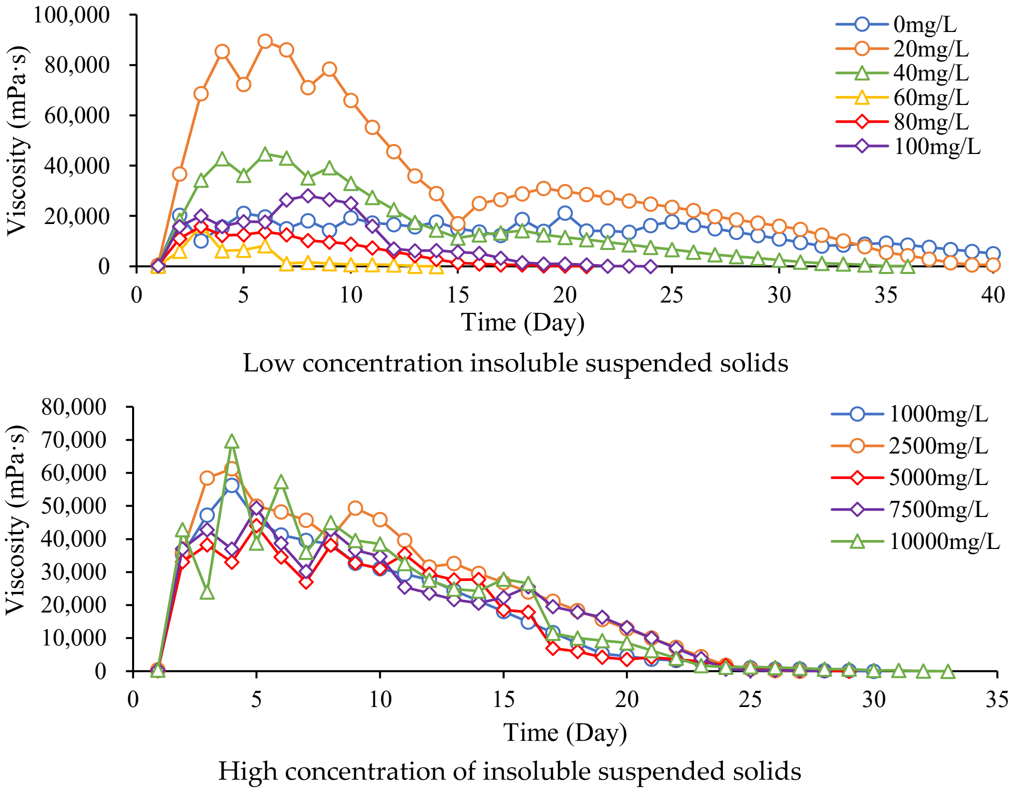


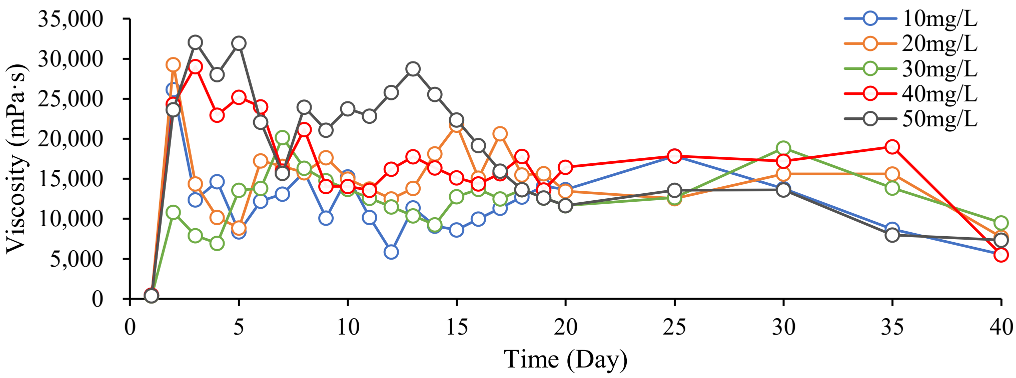
Figure 5. Influence of insoluble suspended matter on weak gel formation.

When the other indicators do not change and the content of suspended solids increases, the gelling time, gelling strength, and gelling stability of weak gels will change greatly. This shows that when the content of insoluble suspended solids is high, the polymer molecules will flocculate and settle because of the adsorption loss on the mineral surface, resulting in a decrease in the viscosity of the solution. Because clay minerals have permanent negative charges, most of them are distributed at the crystal layer level. On the other hand, when the polyacrylamide molecule in the weak gel system is dissolved in water and ionized, the carboxyl group will carry a negative charge to form a negatively charged polyion, which will cause adsorption on the surface of the mineral that is due to electrostatic action. The surface can undergo hydroxylation to generate hydroxyl groups, and the hydroxyl groups can be connected to the carboxylate group in HPAM through hydrogen bonds, or to the amide group in HPAM through hydrogen bonds, resulting in adsorption generated by hydrogen bonding. Therefore, it is believed that reducing the suspended solids content in sewage through advanced treatment can be accompanied by significant improvement of other water quality indicators, which is beneficial to improve the efficiency of weak gel use.

3.2.4. Effects of Metal Ions on the Gel-Forming Properties of Weak Gels

This section mainly studies the relationship between Fe^{2+} and Fe^{3+} on the apparent viscosity of weak gel solution, and then discusses the degradation mechanism of Fe^{2+} on weak gel.

From the experimental results (Figure 6), it can be seen that the content of Fe^{3+} has little effect on the viscosity, gel formation, and gel-breaking time of the weak gel, while a small amount of Fe^{2+} will have a serious degradation effect on the weak gel. The gel time is slow, the gel breaking time is accelerated and the apparent viscosity of the weak gel solution is greatly reduced. When Fe^{2+} is 5 mg/L, the viscosity loss rate of weak gel solution is about 5%. With the increase of Fe^{2+} concentration, the viscosity of weak gel decreases sharply. When Fe^{2+} is 15 mg/L, the viscosity loss rate of weak gel solution reaches 75%; when Fe^{2+} exceeds 20 mg/L, the viscosity loss rate of weak gel solution has exceeded 90%, and the presence of a small amount of Fe^{2+} will have a significant impact on the viscosity of weak gel solution. When Fe^{2+} reaches 30 mg/L, it begins to break the gel after 120 h, and the peak viscosity only reaches 4000 mPa·s. When Fe^{2+} is above 30 mg/L, the gel-breaking time is shorter, and the gel viscosity is also greatly reduced. It shows that Fe^{2+} has obvious influence on the stability of weak gel solution in aerobic environment. Due to the existence of Fe^{2+} in the solution, the repulsive force between weak gel molecules will be weakened, the molecular structure will change, and the viscosity of the weak gel solution will decrease from a macroscopic point of view. It can be seen that Fe^{2+} affects the weak gel. The sources of Fe^{2+} mainly include: the formation water contains a certain amount of Fe^{2+}, followed by the corrosion of pipeline equipment, the water contains corrosive gas CO_2, and, at the same time, there are solid substances such as sand in the water, which have a erosive effect on the pipeline wall under high-speed flow. The effluent contains a certain amount of Fe^{2+}.



Different density Fe^{3+}

Figure 6. *Cont.*

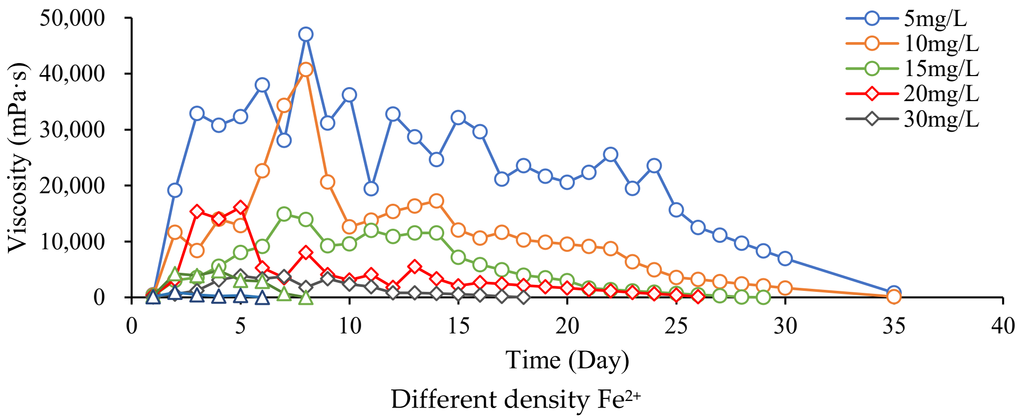


Figure 6. Effects of Fe^{2+} and Fe^{3+} on the gel-forming properties of weak gels.

4. Summary and Conclusions

In this paper, the following conclusions are obtained through the research on the formulation of the weak gel system suitable for the Y1 block and the influencing factors of weak gel gelation.

(1) The chromium (III) acetate system forms gel at high temperature and has good stability. The best formulation for the Y1 block is 0.22% of HPAM + 0.15% of chromium (III) acetate system. The elastic modulus and viscous modulus are moderate, the friction between the molecules during the gel movement is moderate, the transition speed of the molecular chain segment is normal, the energy storage during the solution deformation process is good, the gelation time is 8 h, and the viscosity is maintained at 15,000–24,000 mPa·s to meet the on-site application conditions of the Y1 block.

(2) Dissolved oxygen content, bacterial content, suspended solids content, and metal ion content are the main reasons for the fluctuation of gel formation and the deterioration of gel formation rate in a weak gel system. Oxygen content close to 1.5 mg/L is the critical point of the worst effect; the optimal oxygen content critical point of gel system is 7 mg/L. The bacteria in the water will degrade the weak gel solution. The more bacteria there are, the more serious the degradation of the weak gel will be. When the bacteria content is 3000/mL, the viscosity of the solution decreases by about 45% compared to the sterile sample. A small amount of insoluble suspended matter will greatly increase the viscosity of the weak gel solution, but it will speed up the gel-breaking time. When the content of insoluble suspended matter is 20 mg/L, the maximum viscosity can rise to 85,000 mPa·s, but from the successful crosslinking to breaking the gel only It lasted 240 h. When the content of insoluble suspended solids is high, more than 1000 mg/L, it has little effect on weak gel. The metal ion that mainly affects the gelation effect is Fe^{2+}. With the increase of Fe^{2+} mass concentration, the viscosity of weak gel drops sharply. When the Fe^{2+} concentration exceeds 20 mg/L, the viscosity loss rate of weak gel solution exceeds 90%.

(3) This study has certain guiding significance for the follow-up development of oilfields with water channeling and ineffective water circulation after polymer flooding, and experimental analysis of the factors affecting the gelation of weak gel systems has provided certain help for the subsequent field application of this technology. However, there are still some limitations in this paper. The weak gel system formulation proposed in this paper is not suitable for all oil fields. It is hoped that future researchers can further improve the weak gel system formulation and increase the field application scope of weak gel technology.

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