Study on Influence Factors and Governance Countermeasures of Movable Gel Prepared with Backfilling Waste Water

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Abstract: Movable gel as profile control and flooding is one of the main measures in tertiary oil recovery in Huabei Oilfield. Many blocks have tight fresh water supplies, but produced waste water can not be discharged. Therefore, preparing movable gel with backfilling waste water has become an inevitable development trend of profile control and flooding. Three different quality of sewage water named SW, YW and ZW were used to prepare gel and then compared with gel prepared clean water. The results showed that the gel viscosity prepared with clean water was 1.5-5.6 times of sewage water at the same formula concentration. For this reason, the effect of Na⁺, Ca²⁺, Fe²⁺ on the gel performance were analyzed. The above ions lead to a decrease in the gel viscosity and poor stability, which can not even be crosslinked. According to the sewage water characteristics, corresponding treatment measures were developed respectively. The best treatment of SW and ZW was increasing polymer concentration followed by the addition of thiourea. The best treatment of YW was also increasing polymer concentration followed by stirring and aeration. The gel viscosity reached to 1800-2500 mPa·s and maintained at 800-1200 mPa·s after 90 days at formation temperature. It showed that the treatment can effectively improve the gel viscosity and stability prepared with sewage water. The results provide valuable experiences for the preparation of movable gel with different quality waste water.

1. Introduction

As a new technology of deep profile control, movable gel mainly solves the problem of uneven water absorption caused by vertical and in layer heterogeneity. The mechanism includes physical plugging effect, adsorption, collection, flow diversion and improved mobility ratio[1,2]. Clean water was generally used to prepare movable gel in order to ensure gel properties. However, many areas in Huabei Oilfield have a shortage of clean water in recent years. In contrast a lot of produced sewage can not be discharged. Therefore, the preparation of movable gel with sewage can solve the above two problems at the same time. It is an inevitable development trend of deep profile control technology.

In this paper, three different salinity of water from different temperatures of blocks were used to prepare movable gel. The gel properties were compared with the gel prepared with clean water. Based on this analysis, the main factors that affect the gel performance and the governance strategy were...
researched. Gel properties and stability were effectively improved after the sewage was dealt with appropriate measures.

2. The experiment

2.1 Experimental equipments and materials

2.1.1 Experimental equipments: constant temperature oven, analytical balance, HAAKE MARS rheometer.

2.1.2 Experimental materials. Polymer: temperature and salt-resistant polymer KY-2, molecular weight of 25 million, the degree of hydrolysis of 20% to 25% produced by Beijing Heng Ju Chemical Industry Group Co., Ltd.. Crosslinking agents: high temperature and medium temperature phenolic resin crosslinking agent produced by Beijing Jie Bot energy technology Co., Ltd.. water analysis reagents: AgNO₃, diluted HNO₃, potassium chromate indicator, standard solution of EDTA, etc. Lab-made. NaCl, CaCl₂, FeSO₄, analysis pure. Waste water: come from different injection plant named SW, YW, ZW.

2.2 Experimental method

Sewage water quality analysis references the standard of oilfield water analysis method(SY/T 5523-2006). Determination of gel properties such as cross-linking time, viscosity and stability references the standard of movable gel evaluation method for oilfields(Q/SY HB 0167-2013).

3. Experimental results and discussion

3.1 Water quality analysis

Quality of SW, YW, ZW sewage and clear water were analized separately. The results showed that the content of each ion in the wastewater was much higher than that in the fresh water. The salinity of ZW wastewater was the highest and the content of Ca²⁺ + Mg²⁺ was higher. The salinity of SW and YW sewage was close. Fe²⁺ was only detected in YW wastewater. The differences in the quality of the sewage can have different effects on the gel properties.

| Sample number | Salinity (mg/L) | Cl⁻ | HCO₃⁻ | Mg²⁺ | Ca²⁺ | SO₄²⁻ | Na⁺ | Fe³⁺ | Total Fe | PH | Water type |
|---------------|----------------|-----|--------|------|------|--------|-----|------|----------|----|------------|
| SW            | 11341.3        | 6425.3 | 579.7  | 21.3 | 205.4 | 0      | 4109.5 | 0    | 0       | 8.0  | CaCl₂      |
| YW            | 10156.8        | 6026.5 | 503.4  | 18.2 | 175.4 | 48.0   | 3385.3 | 0.1  | 0.2     | 9.0  | CaCl₂      |
| ZW            | 18459.7        | 10369 | 640.7  | 85.1 | 541.1 | 432.3  | 6391.2 | 0    | 0       | 7.5  | CaCl₂      |
| Clear water   | 472.7          | 56.9  | 192.5  | 9.1  | 25.1  | 100.4  | 88.7  | 0    | 0       | 7.7  | NaSO₄      |

3.2 Gel performance comparison of sewage and clear water

The corresponding reservoir temperature is 95 °C for SW and YW wastewater, and 70 °C for ZW wastewater. The gel was prepared with sewage and clear water separately according to the formula of high temperature[3] and medium temperature[4]. The gel formula and corresponding performance are showed in Table 2. It can be seen that when the polymer concentration was less than 1000mg/L, the gel cannot crosslink prepared with SW and YW wastewater. Under the same formulation conditions, the viscosity of clear water gel was 1.5-5.6 times that of sewage. While due to ZW wastewater had the highest salinity, the polymer concentration required to reach 1200mg/L or more in order to gel. Under the same conditions, the gel viscosity prepared with clear water was 2.5 times that of the sewage. The gel prepared with waste water was gelout and had water separation when being placed in the formation...
temperature for 15-30 days. This showed that the sewage will seriously affect the gel performance and stability.

### 3.3 Study on influencing factors of gel prepared by sewage

#### 3.3.1 Effect of Na\(^+\) on gel properties

Different concentrations of NaCl were added into fresh water to prepare movable gel. The polymer concentration was 1500 mg/L and the crosslinker concentration was 1800 mg/L.

The experimental results indicated that with the increase of Na\(^+\) the gel viscosity decreased rapidly. When the concentration of Na\(^+\) reached 5000 mg/L, the stability of the gel became worse. This is because Na\(^+\) will make the sodium carboxyl of the polyacrylamide molecule electrical shielding. This will lead the molecular chain rolling. Therefore, the reaction chance of polyacrylamide and crosslinker molecules was reduced and the gel viscosity decreased\[5\]. The higher degree of hydrolysis, the crimp of polyacrylamide molecules will be more serious and the gel viscosity will be lower. Na\(^+\) concentrations of SW, YW, ZW sewage are close to 5000 mg/L, so the gel performance was poor when prepared with the original formula.

#### 3.3.2 Effect of Ca\(^{2+}\) on gel properties

Different concentrations of CaCl\(_2\) were added into clear water to prepare movable gel. The polymer concentration was 1500 mg/L and the crosslinker concentration was 1800 mg/L. The experimental results were shown in Figure 2.

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**Table 2 gel properties of sewage and clear water**

| Water quality | Formula concentration, mg/L | Crosslinking time, h | Viscosity after 5d, mPa·s | Viscosity after 90d, mPa·s |
|---------------|---------------------------|----------------------|--------------------------|-------------------------|
|               | polymer | Crosslinking agent A | Crosslinking agent B | Sewage | Clear water | Sewage | Clear water | Sewage | Clear water |
| SW            | 1000    | 1200                | 800                  | Not gel | 50          | 581    | 1475        | /          | 878        |
|               | 1200    | 1500                | 1000                 | 74      | 48          | 924    | 1750        | Gelout    | 1072       |
| YW            | 800     | 1000                | 1000                 | Not gel | 55          | 214    | 1200        | /          | 578        |
|               | 1000    | 1200                | 1200                 | Not gel | 50          | 483    | 1866        | /          | 1199       |
|               | 1500    | 1800                | 1800                 | 66      | 40          | 1708   | 2473        | Gelout    | 1792       |
| ZW            | 1000    | 1100                | 500                  | Not gel | 33          | 105    | 1291        | /          | 876        |
|               | 1200    | 1300                | 700                  | Not gel | 30          | 211    | 1923        | /          | 1354       |
|               | 1500    | 1700                | 900                  | 66      | 30          | 1101   | 2115        | Gelout    | 1514       |
The experimental results showed that with the increase of Ca$^{2+}$ concentration, the gel viscosity decreased. When Ca$^{2+}$ concentration reached 200mg/L, the phenomenon of water separation appeared after 20 days. This is due to the combination of polyacrylamide molecules and Ca$^{2+}$+Mg$^{2+}$, flocculation and precipitation occurred. In addition, Ca$^{2+}$+Mg$^{2+}$ will make the phenolic resin self-polymerization reducing its effective concentration. Ca$^{2+}$+Mg$^{2+}$ concentration of ZW wastewater was up to 626.2mg/L which had a great impact on gel properties.

3.3.3 Effect of Fe$^{2+}$ on gel properties. In order to investigate the effect of Fe$^{2+}$ on the gel, FeSO$_4$ and oxygen scavenger were added to the formulation. The experimental results were shown in Figure 3.

The experimental results showed that the gel viscosity decreased by 12.5% when Fe$^{2+}$ concentration was 0.5mg/L. The gel stability decreased with Fe$^{2+}$ concentration of 2mg/L. The reason is that, at a certain temperature, Fe$^{2+}$ is very easily oxidized to Fe$^{3+}$ by the carboxymethyl in the phenolic resin crosslinking agent. This will cause the carboxymethyl derivative gradually losing activity. When Fe$^{2+}$ concentration increased to a certain extent, there will be no gel[6]. Although the water quality analysis showed that only YW wastewater contained Fe$^{2+}$, the SW and ZW wastewater may contain a certain amount of Fe$^{3+}$ and Fe$^{2+}$ due to the influence of pipeline corrosion products. Except Na$^+$, Ca$^{2+}$, Fe$^{2+}$, S$^{2-}$, bacteria and various water treatment agents in sewage can also affect the gel performance. However, the influence degree was smaller relative to Na$^+$, Ca$^{2+}$, Fe$^{2+}$.

3.4 Treatment measure studies of movable gel prepared by sewage
In order to improve the performance of the mobile gel prepared by sewage, based on the results of literature research, four different measures is proposed to shield or reduce the impact of Na$^+$, Ca$^{2+}$ and Fe$^{2+}$.

The first solution: Increase the polymer concentration. Considering the high concentration, the difficulty in precipitation, as well as the difficulty shielding of other substances of Na$^+$ salts, the simplest method is to increase the concentration of the polymer to reduce the influence of Na$^+$. In addition, the polymer can also adsorb and encapsulate Ca$^{2+}$ and Mg$^{2+}$ in sewage.

The second solution: Add thiourea. The addition of thiourea (50mg/L~100mg/L) to sewage can complex Ca$^{2+}$ and Mg$^{2+}$ to improve the stability of mobile gel.
The third solution: Stirring aeration. Since the content of Fe$^{2+}$ in SW, YW, and ZW sewages was low, taking the measure of mixing and exposuring oxygen to change Fe$^{2+}$ into Fe$^{3+}$, which could greatly reduced the impact of Fe$^{2+}$ on the gel performance[7].

The fourth solution: Adjust the pH value to neutral. The hydrolysis of polymer is an important factor affecting the performance of sewage with plasticizer. In general, the hydrolysis rate of polymer molecules is slow under the neutral condition, while its hydrolysis rate is obviously accelerated under the acid, the alkali or the high temperature condition[8]. Since the pH values of three kinds of sewage are all alkaline, the measure of adjusting the pH value to neutral can be used to improve the performance of the gel.

Based on all the above, considering the quality characteristics of SW, YW, and ZW sewage water, the corresponding management strategies were developed, which was shown in Table 3.

| sewage | quality characteristics | management strategies |
|--------|-------------------------|-----------------------|
| SW     | the high concentration of Na$^+$, Ca$^{2+}$+Mg$^{2+}$ weak alkaline | increase the polymer concentration, add thiourea, stirring | adjust the pH value |
| YW     | a certain Fe$^+$ a high pH | 1500~3000mg/L, 100mg/L, 2h | use HCl solution adjusting pH to 7 |
| ZW     | a high concentration of Ca$^{2+}$+Mg$^{2+}$ a high salinity | 2000~3000mg/L, 100mg/L, 2h | use HCl solution adjusting pH to 7 |

4. Application effect

4.1 Formula optimization of SW sewage

On the basis of the original formula, the following four measures were taken: increasing the polymer concentration to 1500mg/L~3000mg/L, adding thiourea of the concentration of 100mg/L, mixing aeration, as well as adjusting the pH value. The results were respectively shown in the following figure4.

![Figure 4. Comparison effects of SW sewage taken different measures](image)

It can be seen that the four measures taken by SW sewage had different effects. The measure of increasing the polymer concentration had the best effect on the gel forming, followed by the addition of thiourea(100 mg/L), and then, the stirring and the aeration, as well as adjusting the pH value, had no significant effects on the gel forming. Considering the properties of forming gel and the cost of flooding, the following measures were recommended: increasing the polymer concentration to 1500~2000 mg/L (the crosslinker A concentration 1800~2400 mg/L, the crosslinker B concentration 1500~2000 mg/L), as well as adding 100 mg/L thiourea to the SW sewage. After the above treatments, the viscosity of the gel increased to 1800~2500mPa·s, and the viscosity remained at 1000~1500mPa·s after 90 days.

4.2 Formula optimization of YW sewage
On the basis of the original formula, the four measures were taken as followed: increasing the polymer concentration to 2000mg/L~3000mg/L, stirring and aeration for 2 hours, adjusting the pH value to 7, as well as adding the thiourea of 50mg/L. The results were respectively shown in figure 5.

**Fig.5.** comparison effects of YW sewage taken different measures

The results showed that the four measures taken by YW sewage had different effects. The measure of increasing the polymer concentration had the best effect on the gel forming, followed by the measure of stirring and aeration for 2 hours. However, the addition of thiourea and the adjusting of pH value had no significant effects on the gel forming. Therefore, the following measures were recommended: increasing the polymer concentration to 1500–2000 mg/L (the crosslinker A concentration 1800–2400 mg/L, the crosslinker B concentration 1500–2000 mg/L), as well as stirring and aeration for 2 hours of YW sewage. After the above treatments, the viscosity of the gel increased to 1900–2200mPa·s, and the viscosity still remained at 900–1200mPa·s after 90 days, which could meet the requirement of the deep conditioning drive for the gel strength.

### 3.3 Formula optimization of ZW sewage

On the basis of the original formula, the three following measures were taken: increasing the polymer concentration to 2000mg/L~3000mg/L, adding the thiourea of 50mg/L, as well as stirring and aeration for 2 hours. The results were respectively shown in figure 6.

**Fig.6.** comparison effects of ZW sewage taken different measures

It can be seen that the measure of increasing the polymer concentration had the best effect on the gel forming used by ZW sewage, followed by the addition of thiourea, and then the measure of stirring and aeration for 2 hours. Besides, the last measure had little effect on the gel forming. According to the gel viscosity, the following measures were recommended: selecting the polymer concentration to 1800–2500 mg/L (the crosslinker A concentration 2200–2750 mg/L, the crosslinker B concentration 1200–1500 mg/L), as well as adding 100 mg/L thiourea. After the above treatments, the viscosity of the gel increased to 1800–2300mPa·s, and the viscosity still remained at 800–1200mPa·s after 90 days, which could meet the requirement of the deep conditioning drive for the gel strength.

From all the above results, it can be seen that the viscosity and stability of the gel all had been greatly improved, which indicated that the treatment measures could effectively stabilize the ions in the sewage.
5. Conclusions

i. Under the condition of the same formulation, the viscosity of the mobile gel prepared by fresh water was 1.5–5.6 times as large as the gel viscosity compounded by the sewage. Besides, the sewage gel could occur the phenomenon of separating out of water and breaking in the formation temperature last for 15–30 days. All the above indicated that the sewage would seriously affect the gel properties and stability.

ii. Na\(^{+}\), Ca\(^{2+}\), and Fe\(^{2+}\) in the sewage could reduce the viscosity of the gel and break the gel eventually, which attributed to the salt ions changed the molecule structure of the polyacrylamide, as well as merged the crosslinking agent of the phenolic resin. When the concentration of Na\(^{+}\) reached 5000mg/L or the concentration of Ca\(^{2+}\) reached 200mg/L, the gel broke lasting for 20 days. When the concentration of Fe\(^{2+}\) was only 2mg/L, the gel broke for 15 days.

iii. According to the characteristics of sewage quality, the corresponding treatment measures were formulated: the treatment measure of SW and ZW sewages were to improve the concentration of polymer, as well as the addition of thiourea; the treatment measures of YW sewage was to improve the polymer concentration, stir, as well as exposure oxygen of the sewage. After the above treatments, the viscosity of the gel reacheds 1800~2500 mPa·s, and the viscosity could maintain at 800~1200 mPa·s after 90 days. Besides, the viscoelasticity of the gel was good. All the above indicated that the treatment measures can effectively improve the performance and stability of the movable gel prepared by the sewage.

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