Performance Evaluation of Polymer Gel Composite Resin Coated Sand Water Shutoff System

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Abstract. Aiming at the problems of low plugging strength and short plugging time of Polymer gel in fractured ultra-low permeability reservoirs, a composite plugging process of Polymer gel and resin coated sand is proposed. This paper evaluates the rheological properties of Polymer gel and the consolidation performance of resin coated sand through laboratory tests. Furthermore, the sand-packed tube was used to compare and evaluate the water blocking ability of Polymer gel and resin coated sand alone and the combined water blocking ability of the two. The results show that the initial viscosity of Polymer gel is very low (20-30cp), the strength after gelation is high (>40000cp), it has certain temperature and salt resistance, and it can still maintain high gel strength after shearing. However, after long-term water flooding, its plugging strength gradually decreases, and its plugging validity period is shorter. The selected resin coated sand has better consolidation effect at reservoir temperature and good plugging ability. After combining the polymer gel with the selected resin coated sand, the plugging strength and validity period of the system have been greatly improved. The research results in this paper can provide new exploration ideas for chemical water shutoff in fractured ultra-low permeability reservoirs.

1. Introduction

In recent years, ultra-low permeability reservoirs have become the main source of onshore oil and gas resources in my country [1]. The matrix of this type of reservoir is tight, and production wells usually use hydraulic fracturing for reservoir reconstruction to obtain better oil and gas productivity. At the same time, due to the serious heterogeneity of oil reservoirs and the existence of natural fractures, water channeling and premature flooding of oil wells are prone to occur during the secondary oil recovery process, resulting in low recovery and severely restricting the development of oilfields.

As a result, various water shutoff measures for oil wells have appeared and developed to reduce the water production [2,3]. Those measures can be roughly divided into two categories: mechanical water shutoff and chemical water shutoff. Mechanical water shutoff uses mechanical equipment to seal the water outlet position in the wellbore to control excessive water production in the oil well. But mechanical water shutoff method cannot fundamentally solve the problem of water production in the oil layer, and it not practical for high-temperature and high-salt reservoirs. The chemical water shutoff is to inject water shutoff agents, including inorganic particles, gels, foams, etc., into the reservoir or even the
deep part of the formation to block the channel of water channeling, so that the water will divert inside the other area of the formation that water unreached[4]. Among many chemical water shutoff methods, polymer gels are widely used in profile control and water shutoff measures for fractured ultra-low permeability reservoirs due to their excellent water control and oil enhancement performance, as well as economy and easy to get [5-8].

The Ordos Basin is one of the main areas of ultra-low permeability oil reservoirs in our country, and its main layer of ultra-low permeability oil reservoirs is the Yanchang Formation. As of the end of 2019, more than 19,000 wells had opened in this area, with an average single well production of less than 1.2t/d, and an average water cut of more than 60%. More than 150 reservoirs have entered the medium and high water cut stage. The reserves of these oil reservoirs account for about 96% of the total geological reserves and about 97% of the total production. At present, the geological recovery of ultra-low permeability reservoirs is less than 10%, and a large amount of crude oil can’t be recovered. Field monitor and production evaluation show that the main types of water breakthrough in the ultra-low permeability reservoirs in the Ordos Basin are mainly pore-fracture types. In recent years, with the goal of improving the recovery factor, these oil fields have implemented polymer gel chemical water plugging, temporary plugging and fracturing, and other measures to control water production, which have achieved a certain increase in production [9,10]. However, the valid period of these measures is relatively short, and after multiple rounds of application, the effect gradually becomes worse. Therefore, there is an urgent need for a more efficient and durable chemical water control system.

Resin coated sand is a new type of solid particle developed in recent years for plugging drilling fluid loss during drilling and as a water control proppant during hydraulic fracturing[11]. Coating modification is to change the surface properties of the particles through the adsorption or chemical reaction of the functional groups in the organic surface modifier molecules on the particle surface, so that the surface properties of the solid particles can meet specific engineering requirements while still maintaining their own hardness. For example, as a water-control proppant in the fracturing process, a super-hydrophobic coating is processed on the surface of the proppant, resulting in the formation of fracturing fractures that naturally have a certain water-control ability. As the best of my knowledge, there is no report about combining resin coated sand and Polymer gel for chemical water plugging in old production wells.

Based on this, the effect of combining resin coated sand and Polymer gel for water shutoff in oil wells was studied through laboratory experiments in this paper. The rheological properties of the polymer gel are evaluated at the reservoir condition, and the solid resin coated sand with the best consolidation performance was selected, and the water plugging ability of the polymer gel, solid resin coated sand and the composite of the two agents were evaluated by using the sand-packed tube and the fracture core model. The experimental results show that compared with the single polymer gel or resin coated sand, the composite plugging of solid resin coated sand and polymer gel makes the water plugging strength significantly improved and the plugging valid period is significantly prolonged. The results of the thesis can provide a reference for further research on ways to improve the effectiveness of chemical water shutoff in ultra-low permeability reservoirs.

2. Experimental Methods

2.1. Materials:
Polyacrylamide, crosslinking agent, accelerator, curing agent, resin coated sand, formation water, red ink

2.2. Equipment and methods
The polymer gel viscosity was tested using Brookfield DVT-3; the experimental temperature was maintained at 50°C reservoir temperature, and the formation water salinity was 80,000 mg/L.
**Polymer gel preparation:**
Take 1000ml formation water, stir at 400r/min, and slowly add 2.0g polyacrylamide to the water, and stir until the polyacrylamide is completely dissolved, ageing for 24h. Add 2.5g cross-linking agent to the polymer solution, stir for 15 minutes until uniform, then add 1.2 g accelerator, and stir for 10 minutes until uniform, then add 2.0 g curing agent, and stir for 10 minutes until uniform, and put it in the temperate box 50°C for observation.

**Consolidation of Resin coated sand:**
Seal the bottom of a 2.5cm diameter glass tube with a rubber, weigh amount of resin coated sand, and put it into tube, smooth the upper interface of the resin coated sand. And fill it with formation water until it is well over the upper surface of the resin coated sand (Fig 1), and then sealed the upper end of the tube. Put the tube into thermostat at 50°C for consolidation. Using glass rod to pick up the upper surface of resin coated sand in the glass tube regularly to observe the consolidation. After consolidation, the compressive strength were tested at 40MPa.

![Resin coated sand in the glass tube](image1)

**Figure 1.** Consolidation of Resin coated sand

**Plugging experiment with sand-packed tube core model:**
Water flooding sand-packed tube core models at different rates (Table 1 for parameters), and record the water flooding pressure. Then use polymer gel, resin coated sand, and the composite of those agents is injected in the reverse direction from the outlet end. Water flooding experiment is conducted and the water flooding pressure is recorded in the positive and reverse directions after gelation or consolidation.

| Serial number | Sand core specifications | Permeability \((\times 10^{-3}\mu m^2)\) | Plugging method         |
|---------------|-------------------------|--------------------------------------|-------------------------|
| 1             | φ2.5×30cm               | 30.45                                | Polymer gel             |
| 2             | φ2.5×30cm               | 27.31                                | resin coated sand       |
| 3             | φ2.5×30cm               | 31.26                                | resin coated sand+ Polymer gel |

**Plugging experiment with fracture core model:**
The parameters of the fracture core model are 60×4.5×4.5cm, the opening of fracture is 2mm, and the density of sand filling in the fracture is 50kg/m². Water flooding the fracture core models with different rates in positive direction, and record the water flooding pressure; then use polymer gel, and the composite of them to inject in the reverse direction from the outlet end. Water flooding experiment is conducted after gelation or consolidation, and the water flooding pressure is recorded.
3. Results and discussion:

3.1. Rheology of polymer gels

Using Brookfield DVT-3 rotational viscometer, 64# rotor, continuously tested the change of polymer gel viscosity with time at a rate of 6r/min, as shown in Figure 2. The initial solution viscosity of the polymer gel is about 20-60cp, and the viscosity after being completely gelled exceeds 45000cp, and the gelling time is greater than 30h. The smaller initial viscosity and longer gelling time can ensure a smooth pumping process, and promote the polymer gel to enter the formation further.

![Figure 2. Curve of polymer gel viscosity versus time](image)

Testing the gel-forming ability of the polymer gel under the conditions of different temperature, different pH, and different salt content of formation water. Figures 3, 4, and Table 2. The results show that the polymer gel can maintain a good gel strength 70°C. The salt content of more than 200,000mg/L will result in a significant decrease in the polymer gel strength, and a good gel strength can be ensured when the pH is 6-9.

![Figure 3. The influence of temperature on the gel forming process of polymer gel](image)

![Figure 4. The influence of salinity on the gelation effect of polymer gel](image)
Table 2. The influence of pH on the gel strength of polymer gel

| PH  | 4   | 5   | 6   | 7   | 8   | 9   | 10  | 11  |
|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Viscosity /cp | No gel formed | 4560 | 36800 | 47360 | 37460 | 37140 | 2830 | No gel formed |

In order to consider the impact of the shearing action of pumps, pipes and porous media on the strength of the polymer gel, we simulated shearing it with a stirrer for 4 hours, and then test its gelation process, Figure 5. The results show that the shearing effect of less than 3000r/min has little effect on the gelation process of the polymer gel. We also tested the long-term stability of the polymer gel at 50°C, Figure 5 shows that the polymer gel can maintain a strength higher than 40,000 cp for more than 100 days, and has good long-term stability. This brings us doubts, why the polymer gel can maintain the strength for such a long time in the laboratory experiment, but fail prematurely during the field application. Therefore, in subsequent experimental studies, we used sand-packed core tube and fractured cores to simulate the water plugging process of oil wells to find the reasons for the short valid period of polymer gel water plugging and try to improve it.

![Figure 5. The effect of shear on polymer gel](image1)

![Figure 6. Polymer gel Polymer gel long-term stability test](image2)

3.2. Consolidation of resin coated sand

We have selected 4 most widely used resin coated sands based on their consolidation capacity and water blocking capacity, SD-2 and BJS have better consolidation ability and high compressive strength after consolidation. We used the sand-packed core pipe to evaluate the water-flooding breakthrough pressure and stable water-flooding pressure after plugging to study the water plugging capacity of 4 resin coated sands. The results show that SD-2 has the highest water flooding breakthrough pressure (2.93 MPa) and stable water flooding pressure (2.5 MPa) after consolidation in the sand-packed tube. Therefore, we select SD-2 to study the possibility of resin coated sand to improve water plugging strength and validity period of polymer gel.
Table 3. Resin coated sand water plugging strength test results

| plugging agent | QXD-1 | QXD-2 | STBJS | BJKL |
|----------------|-------|-------|-------|------|
| Break through the pressure/MPa | 0.6   | 2.93  | 1.03  | 0.54 |
| Steady pressure/MPa       | 0.32  | 2.5   | 0.89  | 0.38 |

3.3. Plugging experiment with sand-packed tube core model

After the polymer gel was used to plug the sand-packed tube, the corresponding stable pressure results at different water flooding rates are shown in Table 4. The positive direction water flooding breakthrough pressure reached 2.24MPa at a flow rate of 3 mL/min, and the stable pressure was 2.04MPa. Water flooding pressure rises proportionally with water flooding rate, the stable pressure reached 6.12MPa at a flow rate of 7mL/min. Converted to reverse displacement, the breakthrough pressure reached 4.21MPa at a flow rate of 3mL/min, but the steady pressure gradient was only 0.17MPa, the stable pressure only 0.19MPa at 7mL/min. And after continuous water flooding at 7mL/min for more than 0.5h, the liquid at the outlet showed obvious viscosity and wire drawing, indicating that the polymer gel has been damaged and washed out by the water flow, so the plugging strength was seriously reduced.

Generally, oil wells that require water shutoff measures have strong water production capacity and fast fluid velocity near the well. It is easier to damage the polymer gel and wash it out of the formation. This is one of the important reasons for the short valid period of polymer gel used in oil wells.

Table 4. Polymer gel plugging and filling sandstone core tube experiment results

| Water flooding rate/mL·min⁻¹ | Break through the pressure/MPa | Steady pressure/MPa | Water flooding |
|-----------------------------|--------------------------------|-------------------|---------------|
| 3                           | 2.24                           | 2.04              | Positive direction |
| 5                           | /                              | 4.44              |               |
| 7                           | /                              | 6.12              |               |
| 3                           | 4.21                           | 0.17              | Reverse direction |
| 5                           | /                              | 0.21              |               |
| 7                           | /                              | 0.19              |               |

In the polymer and resin coated sand composite plugging sand-packed core model experiment, the polymer gel is injected from the outlet first, and then the resin coated sand with continuous stirring is injected to ensure that the particles do not settle in the pipeline. After consolidation, the water flooding experiment was started, water injected from the inlet and the experimental results are shown in Table 5. The combination of resin coated sand and polymer gel significantly increases the breakthrough pressure and stable pressure of water flooding, and the difference between the breakthrough pressure and stable pressure of positive water flooding and reverse water flooding is very small, and the liquid flowing out of the outlet with no polymer gel.

Table 5. Experimental results of core plugging of sand-packed pipe with the combination of resin coated sand and Polymer gel

| Water flooding rate/mL/min | Break through the pressure/MPa | Steady pressure/MPa | Water flooding |
|----------------------------|--------------------------------|-------------------|---------------|
| 3                          | 4.06                           | 3.59              | Positive flooding |
| 5                          | /                              | 5.94              |               |
| 7                          | /                              | 7.73              |               |
| 3                          | 4                              | 3.44              | Reverse flooding |
| 5                          | /                              | 5.85              |               |
| 7                          | /                              | 7.64              |               |
Further, reverse water flooding was performed respectively on the sand-packed tube core plugged by polymer gel alone and polymer gel combined with resin coated sand at a rate of 7ml/min. and the water flooding pressure is recorded, Figure 7. It’s clearly, the water flooding pressure of the sand-packed tube core model plugged by the polymer gel alone continues to drop, and has dropped from 6 MPa to 0.19 MPa in 24 hours. While the water-flooding pressure of the polymer gel combined with resin coated sand can be stabilized by about approx. 7.7 MPa, and the water flooding pressure dropped only slightly after 24 hours. This proves that the polymer gel combined with resin coated sand for water plugging can significantly improve the overall plugging strength, and at the same time, it can greatly extend the valid period of plugging.

![Figure 7](image)

**Figure 7.** Test results of erosion resistance of different plugging methods

3.4. Fracture core plugging experiment

![Figure 8](image)

**Figure 8.** Fractured core and lithology holder

| Table 6 Experimental results of plugging fracture cores |
|-------------------------------------------------------|
| **Polymer gel (0.6PV)** | Water flooding rate/mL/min | Confining pressure/MPa | Break through pressure/MPa | Steady pressure/MPa | Remarks |
|--------------------------|----------------------------|------------------------|----------------------------|---------------------|---------|
|                          | 3                          | 10                     | /                          | 3.61                | 3.33    |
|                          | 5                          | /                      | 3.28                       | 3.38                | Reverse water flooding after plugging |
|                          | 7                          | /                      | 3.42                       |                      |         |
| **Polymer gel (0.4PV)+Resin coated sand(0.2PV)** | Water flooding rate/mL/min | Confining pressure/MPa | Break through pressure/MPa | Steady pressure/MPa | Remarks |
|--------------------------|----------------------------|------------------------|----------------------------|---------------------|---------|
|                          | 3                          | 10                     | /                          | 5.21                | 5.09    |
|                          | 5                          | /                      | 5.42                       | 5.66                | Reverse water flooding after plugging |
|                          | 7                          | /                      | 5.66                       |                      |         |
In order to simulate the water plugging process of the oil well in the reservoir environment more realistically, we use the fracture sand filling model (Figure 8) to simulate the ultra-low-permeability reservoir environment. Compare the effect of polymer gel alone and Polymer gel combined with resin coated sand to plug fracture core, the results are shown in Table 6, Figure 9. Under the experimental conditions, the water flooding pressure increases by more than 3 MPa, when the polymer gel plugs the fractured core along. When the polymer combined with resin coated sand, the water flooding pressure increases by more than 5 MPa. In contrast to the polymer, gel plugging alone the plugging strength and effectiveness have been significantly improved, and it can still maintain a stable plugging strength under continuous water flooding. Meanwhile, at the outlet of the fracture core plugged by the polymer gel combined with resin coated sand, the red injected water cannot break through the end of the fracture, but can only penetrate from the edge of the fracture.

4. Conclusion
Through a series of laboratory study, this paper systematically evaluated the feasibility of combining resin coated sand and Polymer gel for chemical water shutoff in oil wells, and obtained the following conclusions:

Polymer gel can gel well under the salinity, temperature and injection rate of conventional oil reservoirs. And can keep more than 100 days without dehydration and decomposition. The main reason for the short time in the reservoir water shutoff measures is that the polymer gel is easily damaged and taken out of the formation after being washed by high-intensity water flooding near the wellbore.

Among the four resin coated sands selected in this paper, SD-2 has the strongest consolidation effect and water plugging ability after consolidation at reservoir temperature, and it has the ability to improve the chemical water plugging efficiency of oil wells combined with Polymer gel.

In the sand-packed core tube experiment, the combination of resin coated sand and Polymer gel increased the water flooding pressure by more than 1 MPa. In addition, the plugging strength did not drop significantly after long-term water flooding in the positive and reverse directions, and there was no longer any polymer gel in the outlet liquid. In the fracture core model experiment, there are few red traces of water flow at the ends of the fractures that Polymer gel and resin coated sand seal together.

The addition of resin coated sand significantly improves the water blocking capacity and validity period of the liquid Polymer gel. This is because the ability of consolidation and hydrophobicity of the surface coating of resin coated sand make it have a certain water blocking ability. At the same time, the consolidation of resin coated sand in the fractures or high-permeability channels effectively prevents the polymer gel from moving out of the formation, so that the polymer gel can maintain a good water cutting capacity for a long time.
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