Flooding Control Mechanism of Waterflooding Sweep Control Technology

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\textbf{Abstract.} In view of the problems of high permeability, high water cut and high recovery in offshore heterogeneous oil fields, the system including cross-linked polymer gel and flexible microgel gel was prepared indoors, which was used in the experiments of classified combination of waterflooding sweep control technology. The SMG microscopic oil displacement experiment shows that after the SMG system is injected into the model, the speed of the displacement fluid in the large pores decreases and the speed of the small pores increases, thereby effectively improving the oil recovery in the small pores. The long core experiment with multiple pressure points proves that the driving method of that cross-linked polymer gel and flexible microgel gel are alternately injected into core, which can block the dominant channel step by step and start. Then the low permeability area was displaced and the displacement fluid continuously diverted in the core, thus maximizing the purpose of oil recovery. The classification and grading water flooding control technology method provides effective technical support for the optimization of process parameters of offshore oilfield.

\section{Introduction}

The main Bohai Oilfields are all continental sandstone oil fields, and the heterogeneity of the reservoir is relatively serious. Because of water injection for a long time, the heterogeneity of the reservoir was continuously aggravated. That eventually led to excessively high water cut of the produced fluid and had a serious impact on production effect\cite{1,2}. In response to this technical problem, conventional profile control agents such as high-viscosity Bulk gel were often used on site to improve the water injection profile of water injection wells. However, due to the high viscosity, the blocking ability was too strong and the chemical agents were difficult to enter the deep part of the reservoir and cannot solve the problem of the bypass of the injected water in the deep part of the formation\cite{3}. In addition, the traditional polymer flooding was usually used to control technology of the flow distribution between injection and production\cite{4,5}, but some problems happened including resistance poor salt capacity, fear of shearing, high polymer concentration of the produced fluid, and waste of resources etc.\cite{6,7}. The water flooding sweep control technology was proposed by the team of Academician Han Dakuang of China Petroleum Exploration and Development Research Institute\cite{4,8}, the specific technical connotation includes (1)A type of granular water-dispersible chemical agent (Soft microgel)
is used as the displacement phase. It can adjust the heterogeneity difference and improve oil recovery through the microscopic "division and cooperation" mechanism of water and SMG, plugging-adjusting-flooding synchronously dynamically. (2) Classify and grading of the advantageous flow channels. A variety of plugging agents and displacement control agents are combined and applied and the system scheme is designed for different heterogeneous reservoir. (3) Water flooding and sweep control chemical products are research and develop to realize deformation migration and form dynamic temporary blockage along the superior channel of the formation, that support the efficient development of different types of high water-cut oil fields.

Other paragraphs are indented (BodytextIndented style). This paper takes the actual oil reservoir in a block of Bohai Oilfield as the research object. Aiming at the problem of high water cut during the development of the reservoir. Oil displacement experiments of the microscopic model and long core are carried out to provide technical support for the oil field.

2. Experiment

2.1 Experimental material and setups
In the experiment sub-millimeter we use SMG dispersion agent, which is researched and developed independently by Research Institute of Petroleum Exploration & Development. The experiment water is simulated formation water with salinity 9000 mg/L, and the experiment oil is the simulated oil that crude oil and kerosene are configured according to 2:1. The experiment temperature is 60 ℃. Two models are used in the experiment, one of which is the microscopic model is engraving and etching the real field core (the real core photoetching mode) and the other is a three-layer heterogeneous artificial core with the permeability of 900, 1500 and 3000. The experimental setups mainly include Master size 2000 Laser Particle Sizer (Malvern, UK), Microflow injection pump, Displacement pump, Core holder, Intermediate container, Microscope, Pressure sensor and so on.

2.2 Preparation of cross-linked polymer gel
1.5g (0.3%) of polymer was prepared added to a beaker (500mL) placed in a 60 ℃ water bath under stirring conditions. After the polymer is fully dissolved, we slowly added 1.0g (0.2%) crosslinking agent and 0.15g (0.03%) auxiliary agent to the beaker under stirring conditions. Stir for about one hour to fully dissolve the cross-linking agent and auxiliary agent.

2.3 SMG hydration swelling experiment
The mother liquor of SMG is stirred to make it evenly dispersed. The SMG concentration of 0.3% in simulated water is prepared by using a dropper. We divide the prepared solution into two groups and place them in an oven at room temperature (25°C) and 60°C. Samples were taken out on days 1, 3, 5, 10, 15, 20, and 30, and the median particle size was measured with Master size 2000 Laser Particle Sizer to calculate the expansion ratio.

2.4 SMG microscopic displacement experiment
The SMG microscopic displacement experiment was designed with a real core photoetching model. This type of model has good light transmittance and can obtain clear image photos. It is suitable for observing various interface phenomena and studying various multiphase seepage processes and their physical and chemical effects. The specific experimental operation steps are as follows:

(1) Vacuum the model and then saturate it with water at room temperature;
(2) Then use simulated oil to displace water to establish irreducible water;
(3) Displace the simulated oil in the pore medium with injected water until residual oil is formed;
(4) Carry out SMG flooding experiment, and observe the entire displacement process, use microscopy video and photomicrography to record the flow process and various phenomena in the experiment for analysis and research. Computer software is used to calculate the microscopic oil displacement efficiency of SMG.
2.5 Waterflooding Sweep Control Classification and Grading Profile Control and Flooding Mechanism experiment

The heterogeneous long core model in size of 4.5 cm×4.5 cm×320 cm was designed and made by ourselves for core flooding experiment. The chemical flooding process adopts a combination of cross-linked polymer gel and SMG to control flooding. The core model is evenly distributed with 6 pressure measuring points numbered sequentially from the entrance of the core, which is shown in Figure 1. In the process of injecting the SMG agent, the migration law of the SMG dispersion agent in the deep location of the heterogeneous reservoir was studied by recording the water cut and recovery factor, as well as the pressure along the way with the injection volume. The core parameters of the long core model are shown in Table 1.

![Figure 1. The plan and profile schematic model diagram of the long core](image)

### Table 1 Table of core parameters

| Core type | Gas permeability/ mD | Liquid permeability/ mD | Porosity/% | Oil saturation/% |
|-----------|----------------------|-------------------------|------------|-----------------|
| Long core | 900/1500/3000        | 1450                    | 25.9       | 69.1            |

3. Results and Discussions

3.1 Experimental material and setups

The change of the expansion ratio of the SMG dispersion agent with time is shown in Figure 2. It can be seen from Figure 2 that with the increase of the swelling time, the particle size of SMG continues to increase, and the expansion speed becomes slower and slower. When the swelling time is 5 days, the particle size basically stabilizes. At the same time, with the increase of temperature, the expansion ratio of SMG increases, so the SMG dispersion agent after swelling for 5 days is selected as the deep profile control and displacement agent.

![Figure 2. Relationship between SMG expansion ratio and swelling time at different temperature](image)

3.2 Microscopic oil displacement experiment

**Figure 3** shows the corresponding model pictures of different displacement stages in the microscopic oil displacement experiment. Using this model to simulate the experiment, the computer calculated
that the waterflooding recovery factor was 35.2%, and the SMG injection increased the recovery factor by 12.7%. Microscopic oil displacement experiments show that the SMG system has a good oil displacement effect. In the experiment, we observed SMG dispersion agent can play a role in peeling and entrainment to the oil. As long as the consistency is large enough, small oil droplets can be taken away. In the expansion and contraction pores, the remaining oil in the small pores is less than that in the large pores, indicating that the SMG system serves the purpose of liquid flow diversion.

Figure 3. The photos of microscopic oil displacement effect

3.3 Research on Classification and Grading Control and Flooding Mechanism

The dynamic characteristic curve in the long core flooding experiment with multiple pressure measuring points is shown in Figure 4. The experimental results show that the injection pressure of the six pressure measurement points increases with the increase of the injection volume in the long core water flooding process. The closer to the injection side, the higher the injection pressure is. In the chemical flooding phase, once the gel is injected, the pressure at the pressure measurement point 1 rises sharply, while the pressure measurement points 2 and 3 rise slightly, and there is no obvious change in the subsequent pressure measurement points. After the SMG agent is injected, the pressure at the pressure measurement point 1 rises slowly, at the same time, the follow-up pressure at the pressure measurement point began to rise significantly, the water content of the injected produced fluid decreased, and the recovery factor gradually increased. After the subsequent water flooding, the pressure at the pressure measurement point 1 first decreased and then stabilized. The injection pressure at the subsequent five pressure measurement points still showed an upward trend, and the recovery rate increased slowly. In the end, after the long core has been profiled and flooded, the recovery rate has increased by 17.6%. The analysis shows that in the chemical flooding stage, because the cross-linked polymer gel effectively seals the high-permeability area, most of the injected SMG system is transferred to the low-permeability area and stays in the pore throat. With the continuous injection of SMG particles, the internal pressure gradient of the core increases, and the SMG particles squeeze out of the pore throat, and when they continue to block the next pore throat, the continuous temporary plugging-deformation-migration-temporary plugging again. During the process, the deep part of the core continuously produces liquid flow diversion, which improves the recovery rate in the low permeability area[8,9].
4. Conclusion and Suggestion
The coordinated Classification and Grading Control and Flooding technique of continuous phase cross-linked polymer gel and dispersed phase SMG can improve the recovery rate of heterogeneous cores to a limited extent. The field performance of the oil reservoir is that the cross-linked polymer gel fully adjusts the profile in the near-well area, and SMG continues to move to the deep well area with high oil saturation to displace oil.

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