Study on Mathematical Characterization and Numerical Simulation Method of Heavy Oil Chemical Combination Flooding Mechanism

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Abstract. Due to the difficulty in the exploitation of heavy oil, chemical flooding as a technology to enhance oil recovery has received extensive attention from the petroleum industry. In view of actual engineering needs, taking Jin 8 block as an example, the single variable method is used to optimize the injection-production parameters affecting heavy oil chemical combination flooding. The results show that the injection concentration is 0.6%, the slug ratio is 3:2, and the injection section. When the plug volume is 0.35PV, the development effect is better, which can provide theoretical guidance for the actual production of heavy oil reservoirs.

1. Introduction
The recovery rate of heavy oil is low, generally about 10% of the original geological reserves. Due to the high viscosity of heavy oil, the water phase is easy to burst along the high permeability layer, and the water cut rises quickly. Therefore, for heavy oil reservoirs, improving the water-to-oil mobility ratio, increasing the sweep coefficient and the oil washing efficiency are the keys to enhancing the recovery factor.

Because the research at the laboratory scale cannot simulate the actual situation of the entire reservoir block, the author uses numerical simulation methods to study the synergy mechanism of chemical combination flooding in heavy oil reservoirs. For this reason, the study is based on the Jin 8 block of Shengli Oilfield Object, perform injection parameter optimization analysis, so as to achieve the purpose of improving productivity and recovery efficiency.

2. Study on Chemical Compound Cold Production of Heavy Oil

2.1. Chemical combination flooding mechanism
Polymer flooding increases the viscosity of the water phase and reduces the permeability of the water phase. The polymer is injected into the high-permeability small layer, which greatly reduces the flow rate of water in it, increases the injection pressure in the low-permeability small layer, and increases the speed of water displacement. To a certain extent, improve the water-oil mobility ratio, improve the heterogeneity of the formation, increase the sweep coefficient, and improve the water drive development effect. Surfactants can further reduce the oil-water interfacial tension, improve the water wetting properties of the rock particle surface, make it easier for heavy oil to flow in the porous media of the
formation, and can clean off the crude oil covering the rock surface in the form of a thin film, causing these oil films to rupture and was washed out.

Figure 1. Chemical combination flooding mechanism diagram.

2.2. Mathematical characterization of chemical flooding

2.2.1. Inaccessible pore volume. The inaccessible pore volume is the part of the pore volume that chemical agents cannot enter in the rock pores.

\[ IPV = \frac{\phi - \phi_p}{\phi} \]  

(1)

2.2.2. Adsorption. The interaction between polymer molecules and the pores of the oil layer makes part of the polymer molecules stay in the pores and on the surface of the pores. Langmuir adsorption occurs mainly on the rock surface, and its expression is:

\[ c = a \frac{bc_p}{1 + bc_p} \]  

(2)

2.2.3. Residual resistance factor. The residual resistance coefficient describes the ability of the chemical agent to reduce the water permeability, and is characterized by the ratio of the water permeability of the rock before and after chemical flooding.

\[ RRF = \frac{K_{wb}}{K_{wa}} \]  

(3)

3. Numerical simulation study of chemical flooding

Based on the structural interpretation and comprehensive geological research understanding of the upper part of the third member of the Jin 8 block, the drilling, logging and production performance data of the comprehensive test area, and the application of the reservoir stochastic modeling method to establish a
three-dimensional fine geological model of the Jin 8 block test well group to conduct heavy oil Research on optimization of injection-production parameters of chemical combination flooding system.

3.1. Geological model overview

Table 1. Basic parameter table of block gold 8 oil reservoir.

| Attribute parameter                  | Parameter value   |
|--------------------------------------|-------------------|
| Average porosity                     | 36.5%             |
| Penetration rate                      | 1764mD            |
| Mud content                           | 16.8%             |
| Surface crude oil density             | 955 kg/m³         |
| Surface crude oil viscosity           | 900 mPa·s         |
| Underground crude oil viscosity       | 98~180mPa·s       |
| Original oil pressure                 | 8.0 MPa           |
| Pressure coefficient                  | 0.967             |
| Original oil layer temperature        | 42°C              |
| Geothermal gradient                   | 3.53°C/100m       |
| Oil-bearing area                      | 1.27 km²          |

Figure 2. Geological model of the target block reservoir.

3.2. Injection parameter optimization

3.2.1. Injection concentration optimization. The concentration of the chemical agent determines whether the chemical agent can play an effective role in the oil layer, thereby affecting the production effect. When the slug size is determined to be 0.3PV, the polymer to surfactant slug ratio is 1:1, and the injection speed is 200m³/d, the chemical injection concentration is 0.1%, 0.2%, 0.4%, 0.6 %, 0.8%, 1% are simulated and calculated, and the added value of the recovery factor is used as the evaluation standard.
Figure 3. Increased value of oil recovery under different injection concentrations

The polymer in the formation can increase the viscosity of the displacement fluid, improve the water-oil mobility ratio, and improve the sweeping technology: surfactants can make it easier to peel from the rock surface, and the two complement each other to increase the recovery rate. As shown in Figure 2, as the injection concentration increases, the recovery factor of the chemical system gradually increases, but this increase effect becomes smaller when the injection concentration reaches 0.6%. This is because after the injection concentration reaches 0.6%, the affected surface gradually tends to be flat, and a larger concentration cannot effectively improve the oil recovery. Therefore, considering the cost and economic factors and the adsorption loss of the chemical agent in the formation, the injection concentration should be selected as 0.6%.

3.2.2. Injection slug ratio optimization. When the slug size is determined to be 0.3PV, the injection speed is 200m³/d, and the injection concentration is 0.6%, the injection ratio of polymer to surfactant slug is 1:1, 1:2, 2:1, 1:3, 2:3, 3:2 are simulated and calculated, and the increase in recovery factor is used as the evaluation standard.

Figure 4. Different injection slug ratios increase the value of recovery

As can be clearly seen in Figure 3, when the injected polymer to surfactant slug ratio is 3:2, the highest enhanced oil recovery range can be achieved; when the injected polymer to surfactant slug ratio
is 1:3, The extent of improving oil recovery is the smallest. This is because while the surfactant reduces
the viscosity of crude oil, the polymer content is too low to effectively increase the viscosity of the water
phase, so that the displacement fluid reaches the production well earlier along the high-permeability
channel during the displacement phase, affecting production Effect. The high polymer content increases
the ability to reduce the effective permeability of the water phase, better improves the seepage resistance
of the water phase fluid, reduces the water cut of the production well, and thus has a better oil
displacement effect. Therefore, it is considered that the injection slug ratio of 3:2 is the optimal value.

3.2.3. Injection volume optimization. When the injection speed is 200m$^3$/d, the injection concentration
is 0.6%, and the slug ratio is 3:2, the slug injection volume is 0.1PV, 0.15PV, 0.2PV, 0.25PV, 0.3PV,
0.35PV, 0.4PV, 0.45 PV are simulated and calculated, and the added value of recovery factor is used as
the evaluation standard.

![Figure 5. Different injection volumes increase the value of recovery](image)

As shown in Figure 4, when the injection volume is 0.1-0.2PV, the increase in oil recovery is more
obvious. When the injection volume is 0.2-0.35PV, the increase in oil recovery is linear, and then
gradually flattened to improve the recovery. The increase was significantly weakened. It is not that
more the injection volume, the more effective it is. Therefore, it is considered that the injection volume
is the best 0.35PV.

4. Conclusion
Numerical simulation is used to fit the indoor core displacement experiment, and on this basis, the
feasibility of numerical simulation application is verified. In addition, numerical simulation methods are
used to analyze the main influencing factors of heavy oil chemical combination flooding, and provide
theoretical support for the formulation of strategies for enhancing oil recovery of heavy oil reservoirs.

(1) Based on the characteristics of heavy oil reservoirs and the clear chemical flooding mechanism,
the mathematical characterization mechanism of chemical combination flooding with different
influencing factors is carried out.

(2) According to actual engineering needs, a single variable method is used to optimize the injection-
production parameters that affect heavy oil chemical combination flooding. The results show that when
the injection concentration is 0.6%, the slug ratio is 3:2, and the injection slug volume is 0.35PV. The
development effect is good, which can provide theoretical guidance for the actual production of heavy
oil reservoirs.
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