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Numerical Simulation of High Concentration Polymer Flooding in Oilfield Development

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Abstract

The field test of high concentration polymer flooding has the characteristics of high cost, long cycle and irreversibility of the reservoir development process. In order to ensure the best development effect of the development block, this paper simulated and calculated the high concentration polymer flooding development case of the polymer flooding pilot test area through numerical simulation research, and selected the best case through the comparison of various development indicators. The simulation results showed that the larger the polymer dosage and the higher the concentration, the better the oil displacement effect. The best injection method in the construction process was the overall injection of high concentration polymer. The test area should implement high concentration polymer oil displacement as soon as possible. The research results provided theoretical guidance for the future development and management of the pilot area.

Keywords

Polymer Flooding, Numerical Simulation, Reservoir Development, Recovery Ratio

1. Introduction

With the deepening of oilfield development, polymer flooding and other measures to further enhance oil recovery have entered the stage of industrial application [1]. Because of its high cost and high risk, it is necessary to reasonably optimize the cases under different polymer concentrations, dosage, injection methods and other conditions before field construction to achieve the best development effect [2] [3]. At the same time, the rise of multi-disciplinary research technology in reservoir development and the rapid development of software technology have extended computer simulation technology to the field of reservoir development. Because the computer reservoir numerical simulation technology has many advantages, such as a complete theoretical basis, short running time, low cost, and so on, it is increasingly favored by oilfield development workers [4]. The numerical simulation technology of polymer flooding is the most mature in the aspect of enhancing oil recovery [5] [6].

In order to increase the output of crude oil, the study of residual oil is an indispensable part. There has been a great breakthrough in the relevant technology in this field. Since then, the Committee on Residual Oil Saturation was established in the United States in 1975. In 1984, Tumkur *et al.* used qualitative analysis to explain the possible role of surface viscoelasticity in the process of remaining oil trap and displacement, indicating that when the interfacial tension is less than the critical value, the displacement rate of remaining oil increases with the decrease of surface viscoelasticity [7]. In 2011, Jamaloei *et al.* studied the change in the detailed microstructure of residual high viscosity oil trapped in porous media with the change of wettability. In 2016, Kar *et al.* studied the accuracy of two common solvent extraction methods for determining residual oil saturation extracted from steam assisted gravity drainage and solvent waste rock samples. In 2018, Koh *et al.* studied how to better understand and predict the behavior of HPAM polymer and its impact on residual oil saturation, so as to improve the ability to optimize oilfield design and performance [8] [9] [10].

As for polymer flooding technology, it has become an important method to further improve oil recovery after water flooding, and has achieved remarkable results in major oilfields, and its research will be more and more in the future. When selecting the polymer injection method, the traditional method used in the past is single molecular weight and single concentration polymer slug injection. However, with the prolongation of the development time of polymer flooding, the development effect of this injection method in some blocks or oilfields with relatively serious heterogeneity is greatly limited, which is manifested by the polymer solution protrusion phenomenon in the high permeability layer, the low degree of production in the low permeability layer, the relatively difficult injection, the reverse of the liquid absorption profile and the low efficiency of a single oil well. The occurrence of these problems has seriously affected the development effect of polymer flooding, and caused the waste of polymer, which has greatly limited the large-scale application of polymer flooding technology in the field. The resulting impact is that the remaining underground oil cannot be fully exploited, resulting in the reduction of crude oil production and economic benefits of the oilfield.

In this paper, the numerical simulation technology was applied to simulate and calculate the high concentration polymer flooding case in the pilot polymer flooding pilot area, compare the obtained development technical indicators and select the best case, so as to guide the future development and adjustment of the pilot area.

2. Numerical Simulation Model

The mathematical model of reservoir numerical simulation is to describe the real physical process of the reservoir under certain assumptions through a set of equations.

For the system with N_p phase N_c component, its material balance system can be expressed as:

$$\nabla\cdot\left[\sum_{j=1}^{N_p}\left(S_j\varphi \underline{D_{eij}}\nabla C_{ij}\right)\right]-\vec{u}_t\cdot\nabla\sum_{j=1}^{N_p}f_jC_{ij}=\varphi\frac{\partial C_i}{\partial t}+\left(1-\varphi\right)\rho_r\frac{\partial C_{ri}}{\partial t}$$

If the number of basic equations is the same as the number of basic variables, the system can be solved. In order to solve the system, it is necessary to supplement the description relationship of relevant physical and chemical parameters.

3. Mathematical Description of Physicochemical Mechanism

The oil displacement mechanism of polymer is to increase the viscosity of water phase, reduce the permeability of water phase, improve the mobility ratio, increase the swept volume of oil layer, and then improve the oil recovery factor by injecting water-soluble polymer with high molecular weight.

3.1. Viscosity of Polymer Solution

The polymer solution is a non-Newtonian fluid, and its viscosity mainly changes with polymer concentration, salt content and shear rate:

$$\mu_p=\mu_w\left[1+\left(\frac{\gamma}{\gamma_{\min}}\right)^{n-1}\left(\frac{C}{C_{\min}}\right)^m\left(AP_1C_p+AP_2C_p^2+AP_3C_p^3\right)\right]$$

where, μ_p is the viscosity of polymer solution, μ_w is the viscosity of pure water, γ Is the shear rate, C is the water salinity, C_p is the polymer concentration, m is the salinity index, n is the shear rate index, and AP_1, AP_2, and AP_3 are the coefficients in the polymer viscosity equation.

3.2. Permeability Reduction Coefficient

The retention of polymer in the solution in the pore of rock causes the decrease of water phase permeability. The permeability reduction coefficient R_k is used to reflect this physical and chemical phenomenon:

$$R_k=1+\frac{\left(R_{k\max}-1\right)b_{rk}C_p}{1+b_{rk}C_p}$$

where, R_k is dimensionless and b_{rk} is constant.

3.3. Inaccessible Pore Volume Coefficient

When polymer solution flows through porous media, it can only pass through part of the pore volume [11]. The existence of inaccessible pore volume accelerates the flow of polymer solution.

$$\phi_D=\frac{\phi-\phi_p}{\phi}$$

where, Φ is the pore volume of the medium, Φ_P is the pore volume that the polymer can reach.

Based on the above numerical model, this paper will use the polymer flooding module of the numerical simulation software to simulate the polymer flooding process. The polymer flooding model option uses a fully implicit, five-component model to study various oil displacement mechanisms involved in the polymer flooding process.

4. Application Example of Polymer Flooding Numerical Simulation

The area of polymer pilot test area is 0.31 km^2, and the injection-production well spacing is 200 m. The five-point water injection method is adopted. The well location is shown in Figure 1. The test target layer is P21 - P33, with a total of four layers and a pore volume of 100.75×10^4 m^3, original geological reserves of the test area 61.2×10^4 t, the whole area has been put into production since 1968, and the current comprehensive water content is 95%.

4.1. Establishment of Geological Model

Before numerical simulation, the reservoir geological model should be established first, that is, the type, geometry, internal structure, reservoir parameters and fluid distribution of oil and gas reservoirs should be described by data volume [12]. According to the reservoir geological characteristics, fluid properties and seepage characteristics, this paper used the most popular facies-controlled reservoir modeling technology in the world to establish a three-dimensional geological model of the study area. The model plane adopts an equidistant corner coordinate grid, with 30 grids in the X direction, 30 grids in the Y direction, and 4 simulation layers in the longitudinal direction. The average width is about 35 m. The number of nodes in the simulation area is 3600, of which the number of effective grids is 2516. The geological model of the simulation area is shown in Figure 2.

4.2. History Fitting

In order to obtain accurate reservoir parameters (such as permeability, porosity, relative permeability, etc.), the established model is modified repeatedly until the historical performance calculated by the model simulation is consistent with the actual performance. The core of the historical fitting work is the water cut fitting. The actual comprehensive water cut of the fitting block is 95.78%, and the comprehensive water cut calculated by the mathematical model is 95.98%, with an absolute error of 0.2%. The fitting accuracy meets the field requirements, indicating that the established model is consistent with the actual reservoir and can be used for simulation prediction.

4.3. Development Effect Prediction

The ultimate purpose of reservoir numerical simulation is to predict the development effect of future reservoirs and provide theoretical basis for further

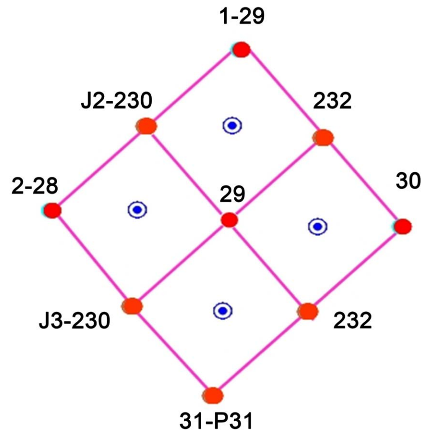

Figure 1. Well location of test area.

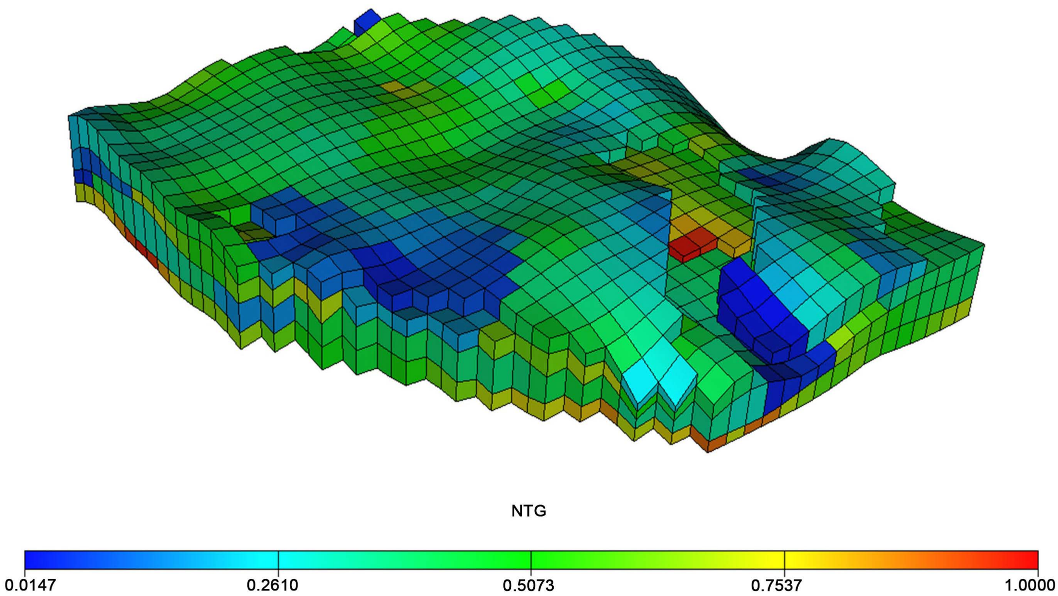

Figure 2. Geological model of the test area.

optimizing the reservoir working system and tapping the potential of remaining oil [13]. On the basis of satisfying the historical fitting accuracy of the model and taking the current well pattern and development layer series as the preconditions, the effect of high concentration polymer flooding is predicted with the current production system of oil and water wells unchanged.

According to the current development status and geological conditions of the test area, a reasonable development plan has been formulated, and polymer injection has been started since January 2023, with an injection rate of 0.1 PV/a. The molecular weight of the injected polymer is 35 million, and the injection time is designed to end in 1 year and 2 years respectively, followed by water flooding. The polymer concentration is designed to be 2000 mg/L and 2500 mg/L respectively, and the overall injection or alternate injection of high and low concentrations is adopted. A total of 6 cases are designed:

Case 1-1: polymer dosage 200 mg/L·PV, molecular weight 35 million, polymer injection concentration 2000 mg/L, overall injection.

Case 1-2: polymer dosage 250 mg/L·PV, molecular weight 35 million, polymer injection concentration 2500 mg/L, overall injection.

Case 2-1: polymer dosage: 400 mg/L·PV, molecular weight: 35 million, polymer injection concentration: 2000 mg/L, overall injection.

Case 2-2: polymer dosage 500 mg/L·PV, molecular weight 35 million, polymer injection concentration 2500 mg/L, overall injection.

Case 3-1: The polymer dosage is 225 mg/L·PV, the molecular weight is 35 million, the concentration is 2000 mg/L, 2500 mg/L slugs are injected alternately, and the alternate period is 3 months.

Case 3-2: The polymer dosage is 450 mg/L·PV, the molecular weight is 35 million, the concentration is 2000 mg/L, 2500 mg/L slugs are injected alternately, and the alternate period is 3 months.

The comparison of water cut and oil production in each case is shown in **Figure 3**. The comparison of the oil displacement effect and polymer dry powder consumption of each case is shown in **Table 1**. Case 2-2 has the best effect, with a 14708.15 t oil increase in the whole area, 70.39% final oil recovery, a 3.2 percentage points reduction in water content, and 486.24 tons of polymer dry powder consumption.

Under the same injection time, the recovery factor of the solution 1-2 and 2-2 with polymer injection concentration of 2500 mg/L is 0.23 and 0.34 percentage points higher than that of the solution 1-1 and 2-1 with injection concentration of 2000 mg/L, and the water cut decrease is 0.31 and 0.54 percentage points higher, respectively, indicating that the higher the polymer concentration of high concentration, the better the oil displacement effect.

It can also be found that under the same polymer concentration, the greater the injection volume, the higher the recovery degree and the greater the water cut reduction. For example, the recovery degree of Case 2-1 and Case 2-2 is 0.74 and 0.85 percentage points higher than that of Case 1-1 and Case 1-2 respectively, and the water cut decrease is 1.21 and 1.43 percentage points higher.

The high concentration polymer flooding case with the same polymer injection time has better continuous injection effect, while the alternating injection effect of high and low concentration polymer is not obvious. It is suggested that in the field construction process, on the premise of meeting the economic benefits, the case of high concentration, large dosage and continuous injection should be adopted as far as possible to achieve the best development effect.

5. Conclusions

1) The development case of the reservoir was optimized. The simulation results showed that case 2-2 had the best effect. It was estimated that 14708.15 t of oil can be increased in the whole area, the final recovery factor was 70.39%, and the water cut decrease was 3.2 percentage points.

2) In the process of high concentration polymer flooding, the higher the polymer dosage and concentration, the better the oil displacement effect.

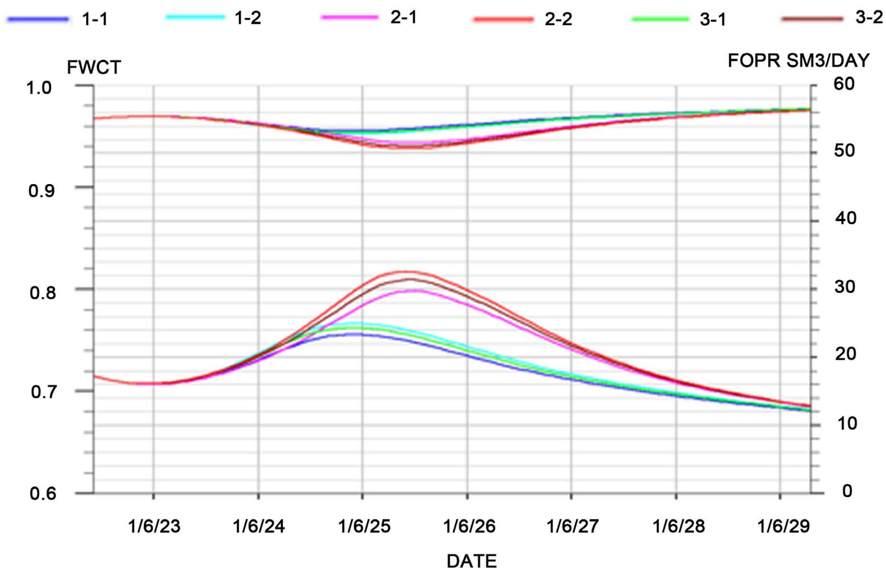

Figure 3. Comparison of water cut and oil production of each case.

Table 1. Comparison of oil increase effects of various cases.

Case	Recovery degree (%)	Final recovery factor (%)	Oil increase (t)	Polymer dry powder consumption (t)
Water drive	3.25	65.78	/	/
1-1	4.57	69.23	8104.05	194.49
1-2	4.8	69.46	9531.74	243.12
2-1	5.31	69.88	12628.81	388.99
2-2	5.65	70.39	14708.15	486.24
3-1	4.71	69.43	8962.54	218.81
3-2	5.50	70.11	13831.36	437.61

3) The development effect of alternative injection of high and low concentration polymer slugs was not obvious, so the injection method of the construction process was the overall injection of high concentration polymer.

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Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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