Research and application of polymer-surfactant binary combination flooding numerical simulation

Yanyu Zhang¹, Zhaowen Luo¹*, Mengke Xie², Zhiyi Teng¹, Yue Wang¹

¹School of Petroleum Engineering in China University of Petroleum, Qingdao, China
²Southwest Oil & Gas Field Company, PetroChina, Chengdu, Sichuan, China
*ţlw15845857442@163.com

Abstract—At present, many oilfields in China have entered the stage of high water cut development, and the research on the methods of improving oil recovery has been paid more and more attention. Among them, the application of binary combination flooding is more and more extensive. In view of the target area, based on the fine geological modelling, this paper establishes a binary combination flooding model considering the influence of surfactant on oil-water interfacial tension, the adsorption of surfactant by rock, the shear and degradation of polymer, and the adsorption of polymer by rock. Based on the matching of reserves and production history, the development schemes under different development methods are designed and the development effect is predicted and evaluated, the influence of development mode, injection time and injection-production speed on development effect is also studied. The results show that the development effect of binary combination flooding is the best, which provides a theoretical basis for the subsequent efficient and reasonable development of the block.

1. Introduction
Chemical flooding is a kind of oil displacement method that improves the swept volume of injected water and oil displacement efficiency by injecting specific chemical agent solution into the formation, so as to further improve the recovery[1-3]. Chemical flooding mainly includes polymer flooding, surfactant flooding, alkali flooding, foam flooding and binary combination flooding. However, compared with conventional oil displacement methods, chemical oil displacement is a kind of oil displacement method with high risk and high production cost, which requires more appropriate oil displacement technology and development scheme in the development process.

The polymer-surfactant binary combination flooding technology is a new oil displacement technology developed by removing alkali on the basis of the traditional ASP flooding. This combination flooding technology has developed into one of the key technologies of chemical flooding to further improve oil recovery[4,5]. In this paper, Petrel software is used for geological modeling for the target block. The binary combination flooding model is established by STARS module of CMG reservoir numerical simulation software. Based on the matching of reserves and production history, the development effect of binary combination flooding is predicted, which provides a theoretical basis for the subsequent efficient and reasonable development of the block.
2. Numerical Simulation of Polymer-Surface Binary Combination Flooding

2.1. Establishment of reservoir numerical simulation mode

3D reservoir geological modeling is through the limited observation points, the integrated use of geological, seismic, logging and reservoir test data, the unknown reservoir between wells multidisciplinary, integrated, three-dimensional quantitative prediction. Based on the whole reservoir, the Petrel fine geological model is established. There are 31 layers in the model longitudinally. The data of block grid, well location and saturation are extracted from Petrel geological model and imported into STARS module of CMG reservoir numerical simulation software, as shown in Fig.1.

![Structural model](image1)
![Permeability](image2)
![Porosity](image3)
![Oil saturation](image4)

Fig.1 Block Numerical Simulation Model

In order to simulate the dual compound flooding process, four components of water, oil, TA2 and VES were set up in the STARS module of CMG reservoir numerical simulation software. The model not only considers the physical properties of oil and water, but also considers the specific properties of surfactants and polymers, such as the effect of VES on oil-water interfacial tension and the shear and degradation of TA2. The physical parameters of each component in the model are shown in Table 1.

| Parameter name                        | Parameter value | Parameter name                        | Parameter value |
|---------------------------------------|-----------------|---------------------------------------|-----------------|
| Oil density, g/cm³                    | 0.9             | VES density ,g/cm³                    | 3.791           |
| Oil viscosity, mPa·s                  | 8.5             | VES viscosity ,mPa·s                  | 1.5             |
| Oil volume factor                     | 1.052           | TA2 density ,g/cm³                    | 0.76            |
| Oil compressibility factor, 1/kPa     | 9.15E-07        | TA2 viscosity ,mPa·s                  | 27.9            |

Table 1. Table of physical parameters
2.2. Research on reserves and historical matching

In order to ensure that the established reservoir numerical simulation model can fully reflect the real reservoir development situation, it is necessary to match the reserves and production history of the model that is, to adjust the relevant parameters according to the actual geological data and development data of the reservoir within a certain range. After repeated comparison, the historical dynamic simulated by the model is closest to the actual dynamic to the maximum extent.

According to the reliability of the data obtained, the model saturation, effective thickness, relative permeability curve, rock compression coefficient and other parameters are properly adjusted, and the geological reserves are determined to be 1.67402 million tons after repeated fitting. According to the volume method in the reservoir engineering method, the geological reserves of the well group are calculated to be 1.5767 million tons. By comparing the two methods, the geological reserve error is 6.1 %, which proves the reliability of the geological model after fitting.

Well group production history is 18 years, using water flooding development. The whole block and single well production history are fitted with the main index parameters of cumulative oil production, cumulative water production and water content in the block and single well. According to the reliability of the data, the parameters such as permeability, relative permeability curve and rock compression coefficient in the model are appropriately adjusted. After repeated fitting, the historical fitting results are shown in Fig.2. It can be seen that the simulation results are in good agreement with the actual results, which provides a reliable reservoir numerical simulation model for the subsequent program prediction research and economic evaluation research.

3. Development scheme design and prediction

According to the laboratory experiment and field production, four kinds of development schemes are designed, including water flooding, surfactant flooding, binary compound flooding, polymer flooding and surfactant flooding. The influence of development mode, chemical agent injection time, injection speed and liquid production speed on the development effect is studied.

3.1. Prediction and results of water flooding scheme

The simulation time of water flooding scheme is 15 years, and the injection rate of well group injection well and the liquid production rate of production well are designed to be 0.7 times, 1 times and 1.3 times of the monthly speed at the end of the production history. The specific scheme design and simulation results are shown in Table 2.

Fig.2 Historical matching results of whole area
Table 2. Water flooding scheme design and simulation results

| Scheme number | Simulation time / year | Injection rate multiple | Recovery rate multiple | Cumulative oil production /m³ |
|---------------|------------------------|-------------------------|------------------------|-------------------------------|
| 1             | 0.7                    | 0.7                     | 130569                 |
| 2             | 15                     | 1                       | 146046                 |
| 3             | 1.3                    | 1.3                     | 163987                 |

From Table 2, it can be seen that the injection-production speed has obvious influence on the oil production results of the whole block. With the increase of injection-production speed, the cumulative oil production of the block increases gradually, while the overall water content changes little. The low speed of water flooding injection and production leads to low recovery degree, which greatly increases the cost of site facilities, and the high speed of water flooding injection and production is easy to increase fingering phenomenon, advance water breakthrough time, resulting in a large number of residual oil. Therefore, increasing injection-production rate appropriately within the allowable range of conditions is conducive to efficient exploitation of reservoirs.

3.2. Prediction and results of surfactant flooding scheme

The concentration of VES in surfactant flooding scheme is 0.5%, the injection time of VES is 1, 3 and 5 years, and the remaining time is for subsequent water flooding. The specific scheme design and simulation results are shown in Table 3 and Fig.3.

Table 3 VES flooding scheme design and simulation results

| Scheme number | VES injection time / year | Injection rate multiple | Recovery rate multiple | Cumulative oil production /m³ | Incremental oil production /m³ |
|---------------|--------------------------|-------------------------|------------------------|-------------------------------|-----------------------------|
| 4             | 1                        | 1                       | 1                      | 146702                        | 656                         |
| 5             | 3                        | 1                       | 1                      | 147049                        | 1003                        |
| 6             | 5                        | 1                       | 1                      | 147125                        | 1079                        |
| 7             | 5                        | 0.7                     | 0.7                    | 131078                        | 792                         |
| 8             | 5                        | 1.3                     | 1.3                    | 166071                        | 2084                        |

The table shows that the oil production increases with the increase of VES injection time and injection-production speed. Surfactant flooding has fast effect and long duration. The daily oil production in the whole area began to increase significantly in 2019, and the water content decreased slightly. The surfactant flooding effect is better than water flooding.

Fig.3 Simulation results of VES flooding whole area and typical wells
3.3. Prediction and results of binary combination flooding scheme

In the binary combination flooding scheme, the concentration of VES is 0.1 %, the concentration of TA2 is 0.05 %, the injection time of binary combination flooding is 1, 3, 5 years. The specific scheme design and simulation results are shown in Table 4 and Fig.4.

| Scheme number | Injection time / year | Injection rate multiple | Recovery rate multiple | Cumulative oil production /m³ | Incremental oil production /m³ |
|---------------|-----------------------|-------------------------|------------------------|-----------------------------|-------------------------------|
| 9             | 1                     | 1                       | 1                      | 147623                      | 1577                          |
| 10            | 3                     | 1                       | 1                      | 148577                      | 2531                          |
| 11            | 5                     | 1                       | 1                      | 149180                      | 3134                          |
| 12            | 5                     | 0.7                     | 0.7                    | 132347                      | 1778                          |
| 13            | 5                     | 1.3                     | 1.3                    | 167784                      | 3797                          |

It can be seen from the table that the increase of oil production increases with the increase of chemical injection time and injection-production speed. Binary combination flooding began to take effect in 2020, with daily oil production significantly increased and water content decreased. The longer the injection time of binary combination flooding is, the slower the daily oil production decreases, the slower the water content increases, and the higher the cumulative oil production is.

![Fig.4 Daily oil production and water cut of typical wells with different injection times](image)

3.4. Prediction and results of polymer flooding and surfactant flooding

The polymer flooding and surfactant flooding scheme first carried out TA2 flooding with 0.05 % concentration, and then carried out VES flooding with 0.1 % concentration. The injection time of TA2 is the same as that of VES, which is 1, 3 and 5 years. The specific scheme design and simulation results are shown in Table 5 and Fig.5.

| Scheme number | Injection time / year | Injection rate multiple | Recovery rate multiple | Cumulative oil production /m³ | Incremental oil production /m³ |
|---------------|-----------------------|-------------------------|------------------------|-----------------------------|-------------------------------|
| 14            | 1                     | 1                       | 1                      | 146888                      | 842                           |
| 15            | 3                     | 1                       | 1                      | 148147                      | 2101                          |
| 16            | 5                     | 1                       | 1                      | 147928                      | 1882                          |
| 17            | 5                     | 0.7                     | 0.7                    | 131856                      | 1287                          |
| 18            | 5                     | 1.3                     | 1.3                    | 166649                      | 2662                          |

It can be seen from table that the increase in oil production is the highest when the injection time is three years. With the increase of injection-production speed, cumulative oil production gradually increased. Fig.5 shows the daily oil production and water content of typical wells in polymer flooding.
and surfactant flooding at different injection times. After polymer flooding and surfactant flooding, the daily oil production gradually increases, and the water content gradually decreases. The effect in single well is obvious.

Fig.5 Daily oil production and water cut of typical wells with different injection times

However, compared with binary combination flooding, the increased oil production of polymer flooding and surfactant flooding is lower. It shows that the effect of binary compound flooding is the best.

4. Conclusion
Based on the establishment of three-dimensional fine geological model, the reservoir numerical simulation model is established through CMG. The matching of reserves and production history proves the reliability of the established model, which lays the foundation for subsequent program prediction and economic evaluation. Considering the special properties of surfactant and polymer, a numerical simulation model of binary compound flooding is established, which can accurately simulate the binary compound flooding scheme.

According to the actual situation, four development schemes of water flooding, surfactant flooding, binary compound flooding, polymer flooding and surfactant flooding are designed, and the influence of development mode, injection time and injection-production speed on the development effect is studied. The results show that under whatever injection time and injection-production rate, the increase in oil production of binary combination flooding is the highest, and the increase in oil production of the optimal scheme increases by 3797 m³. In this paper, the optimal development scheme is proposed for the target block, and the development effect is predicted, which provides a theoretical basis for the subsequent efficient and reasonable development of the block.

References
[1] Shiran B S , Skauge A . Enhanced Oil Recovery (EOR) by Combined Low Salinity Water/Polymer Flooding[J]. Energy & Fuels, 2013, 27(mar.-apr.):1223-1235.
[2] Cristian S. Loaiza, Juan F. Patiño, Juan M. Mejía. Numerical evaluation of a combined chemical enhanced oil recovery process with polymer and nanoparticles based on experimental observations[J]. Journal of Petroleum Science and Engineering, 2020, 191
[3] Longde SUN, Xiaolin WU, Wanfu ZHOU, et al. Technologies of enhancing oil recovery by chemical flooding in Daqing Oilfield, NE China[J]. Petroleum Exploration and Development Online, 2018, 45(4):673-684.
[4] WANG Yefei, ZHAO Fulin, BAI Baojun, et al. Optimized surfactant IFT and polymer viscosity for surfactant-polymer flooding in heterogeneous formations. SPE 127391, 2010.
[5] Wei Y , Liu J , Luo L , et al. Performance of Polymer/Surfactant Binary Flooding in Enlarging Swept Volumes[J]. Journal of Southwest Petroleum University(Science & Technology Edition), 2018.