Sensitivity Analysis on Key Parameters of ASP Flooding Numerical Simulation

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Abstract. ASP Flooding has been realized industrial application in the development area. In the process of optimizing the injection plan of ASP Flooding, the sensitivity and reasonable range of the simulation parameters have great influence on the prediction accuracy. According to the mechanism of ASP Flooding, Key Parameters of ASP Flooding mainly include rheological property, interfacial tension and chemical adsorption. According to the achievement of the fine reservoir description, the physical parameters of target layer are acquired in the research area. By establishing conceptual model of the study area and designing simulation comparison scheme, we can analyze the rheological property, interfacial tension, adsorption parameters of ASP Flooding. By history matching of typical well groups of ASP flooding, we can verify the sensitivity of Key Parameters and to acquire the reasonable range of parameters. The research results can effectively guide ASP Flooding injection scheme optimization.

1. Sensitivity analysis on key parameters of ASP flooding
According to the achievement of the fine reservoir description of research area, various physical parameters of the target layers of the research area are obtained and conceptual model is established. The planar grid step length is 12.5 meters. The number of grids is 66978 in total and the dimension of grid is 61 * 61 * 18. It consists of 25 wells, 9 injection wells and 16 production wells. 125 meters well spacing and five-spot pattern. The initial water content of ASP flooding is 95 % and the injection speed is 0.23 PV/a. According to the ASP Flooding mechanism, the rheological property, interfacial tension and adsorption parameters of ASP Flooding are the key parameters.

1.1. Rheological sensitivity analysis
Polymer as a typical non-Newtonian fluid, its viscosity is not constant at different shear rates. According to research of the relevant scholars on polymer shear-thinning behavior or viscosity reduction, coefficient of shear ranges from 0.3 to 0.7 in general. The development results of five schemes of different coefficient of shear are predicted respectively. Increment values of recovery ratio of schemes are shown in table 1.

| Scheme 1 | Scheme 2 | Scheme 3 | Scheme 4 | Scheme 5 |
|----------|----------|----------|----------|----------|
| Coefficient of shear | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 |
| Increment value of recovery (%) | 20.16 | 19.60 | 18.78 | 17.69 | 16.31 |
The simulation results show that with the increase of the coefficient of shear, the shear action can reduce the recovery rate of the ASP composite system. As the coefficient of shear increases from 0.3 to 0.7, the recovery ratio decreases by 3.85%. The recovery ratio decreases by the maximum of 1.38% when the coefficient of shear increases by 0.1. The minimum reduction of recovery ratio is 0.56% and the average reduction of recovery ratio is 0.96%. This shear effect can not be avoided. However, complex polymeric systems with different properties and structures can be optimized to reduce this effect.

In order to determine the reasonable range of coefficient of shear of the ASP flooding systems in the research area, we select the ASP flooding test area with similar physical properties and carry out history matching of typical well groups of ASP flooding. The reasonable range of coefficient of shear is determined based on the results of history matching. Three typical well groups with good, medium and poor displacement effect are selected from test area. By changing the value of coefficient of shear, we carry out the history matching of the typical well groups respectively. From the history matching results of the three typical well groups, we can see that the reasonable coefficient of shear of the well group with good development results is 0.4 to 0.5, the reasonable coefficient of shear of the well group with medium development results is 0.5 and the reasonable coefficient of shear of the well group with poor development results is 0.6. So reasonable range of coefficient of shear in the research area is 0.4 ~ 0.6.

1.2. Sensitivity analysis of oil and water interfacial tension

According to ASP flooding mechanism, the oil droplets are easily deformed when the interfacial tension of oil and water is reduced and the resistance is reduced when it passes through the porosity and throat. The microscopic oil displacement efficiency is improved. With the other parameters unchanged, the development effect of ASP flooding under different oil and water interfacial tension is predicted respectively. The Increment values of recovery ratio of ASP flooding under different oil and water interfacial tension are shown in table 2.

Table 2. Sensitivity analysis of oil and water interfacial tension.

| Scheme  | Interfacial tension(mN/m) | Increment value of recovery (%) |
|---------|---------------------------|---------------------------------|
| 1       | $1 \times 10^{-4}$       | 19.28                           |
| 2       | $1 \times 10^{-3}$       | 18.78                           |
| 3       | $1 \times 10^{-2}$       | 14.33                           |
| 4       | $1 \times 10^{-1}$       | 12.32                           |
| 5       | 1                         | 11.20                           |

The simulation results show that with the decrease of oil and water interfacial tension, the oil displacement efficiency of ASP flooding is improved and the recovery ratio is increased. The recovery ratio decreases by 8.08% when the interfacial tension increases from $1 \times 10^{-4}$mN/m to 1 mN/m. The interfacial tension has a great influence on the recovery ratio, when the interfacial tension is greater than $1 \times 10^{-3}$mN/m. The interfacial tension has less effect on the recovery ratio, when the interfacial tension is less than $1 \times 10^{-3}$mN/m. As the interfacial tension increases by an order of magnitude, the recovery ratio is only reduced by 0.5%. It can be seen that the oil displacement efficiency can be greatly improved, when the ASP composite system forms $10^{-3}$mN/m ultra-low interface tension. In order to achieve better oil displacement characteristics, we should ensure that the oil and water interfacial tension reaches $10^{-3}$ order of magnitude.

1.3. Absorption loss of chemical agents

In the process of flowing through porous media, the adsorption phenomenon is caused by surface adsorption, mechanical capture and interaction between the molecules of various chemical agents. The adsorption of chemical agents on the surface of rock particles causes the adsorption loss of chemical agents. The concentration of alkali, surfactant and polymer in the ASP solution is reduced. This phenomenon leads to poor displacement effect. Refer to the research results of related scholars on the adsorption data of various chemical agents in the ASP flooding, we can determine the parameters of alkali, surfactant and polymer adsorption of main plug and auxiliary plug of ASP composite system.
Under the condition that the adsorption coefficient of the other two chemicals is fixed, the adsorption coefficient of one chemical agent is changed respectively. The development effect of ASP flooding with different chemical agent adsorption coefficient is predicted. Increment values of recovery ratio of schemes with different chemical agent adsorption coefficient are shown in Table 3.

Table 3. Adsorption sensitivity analysis of chemical agents.

| Scheme  | Scheme 2 | Scheme 3 | Scheme 4 | Scheme 5 |
|---------|---------|---------|---------|---------|
| Adsorption coefficient | 0.5 | 1 | 1.5 | 3 | 5 |
| A Increment value of recovery (%) | 20.12 | 18.78 | 18.28 | 17.45 | 16.83 |
| S Increment value of recovery (%) | 20.63 | 18.78 | 17.74 | 16.60 | 15.86 |
| P Increment value of recovery (%) | 21.51 | 18.78 | 17.15 | 14.26 | 12.32 |

The simulation results show that with the increase of adsorption coefficient, the loss of chemical agent increases and the effect of oil displacement becomes worse. The increment value of the recovery ratio varies, when the adsorption coefficient of different components changes by the same multiples. As the adsorption coefficient of the alkali is doubled, the recovery ratio is reduced by 0.733 % on average. As the adsorption coefficient of surfactant is doubled, the average recovery ratio is reduced by 1.06 %. As the adsorption coefficient of the polymer is doubled, the average recovery ratio is reduced by 2.04 %. It can be seen that the adsorption of polymer has the greatest effect, followed by surfactant and alkali. Therefore, the adsorption of chemical agents, especially polymer, should be reduced in the concrete implementation of ASP flooding.

In order to determine the reasonable range of adsorption coefficient of chemical agents of the ASP flooding systems in the research area, we select the ASP flooding test area with similar physical properties and carry out history matching of typical well groups of ASP flooding. A well with good displacement effect is selected from the ASP flooding test area. Under the condition that the adsorption coefficient of the other two chemicals is kept at 1, the adsorption coefficient of one chemical agent is changed respectively. According to the results of history matching for typical well under different adsorption coefficients, the reasonable range of adsorption coefficient of ASP flooding systems is 0.5 to 1.5.

2. Application effect

Because the sensitivity and reasonable range of ASP flooding simulation parameters are not clear at the beginning, the prediction curve of the development effect is quite different from the actual production curve, when the 0.101PV of ASP flooding systems is injected into the second-class oil layers. The results of sensitivity analysis are applied to guide history matching and prediction of the development effect of the study area. Compared with the prediction results in the previous period, the reliability of the prediction is significantly improved. At present, the injected pore volume of the ASP composite system is 0.431PV. The actual water cut is 1.83 percentage points lower than that predicted by numerical simulation and the recovery ratio is 0.53 percentage points higher than that predicted by numerical simulation.

3. Conclusion

(1) Shearing action reduces the recovery ratio of the ASP composite flooding system and the decline of recovery ratio gradually becomes larger with the increase of the coefficient of shear.

(2) With the decrease of oil and water interfacial tension, the oil displacement efficiency of ASP flooding is improved and the recovery ratio is increased. The interfacial tension has a great influence on the recovery ratio, when the interfacial tension is greater than 1×10⁻³mN/m. The interfacial tension has less effect on the recovery ratio, when the interfacial tension is less than 1×10⁻³mN/m.

(3) With the increase of adsorption coefficient, the loss of chemical agent increases and the effect of oil displacement becomes worse. The adsorption of polymer has the greatest effect, followed by surfactant and alkali.
(4) The parameters of the ASP composite flooding system in the research area are determined. The reasonable range of coefficient of shear is 0.4 to 0.6, the oil and water interfacial tension should reach $10^{-3}$ order of magnitude and the reasonable adsorption coefficient of the chemical agent is 0.5 to 1.5.

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