Numerical simulation of factors affecting water flooding efficiency

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Abstract. Numerical simulation method is used to study the influence of reservoir physical properties and development mode on oil displacement efficiency, and the factors affecting oil displacement efficiency are qualitatively described. The core factor affecting oil displacement efficiency is water injection multiple. When the water injection multiple reaches a certain value, the increase of oil displacement efficiency is very small; when the reservoir rock wettability is neutral and weak, the oil displacement efficiency is higher than that of strong water wettability.

Key words: Numerical Simulation; Oil displacement efficiency; Water injection multiple; Wettability; Reservoir heterogeneity.

1. Introduction
At present, water flooding is still the most important method of oilfield development [1]. The recovery factor of water flooding oilfield is the product of injected water wave and its coefficient and displacement efficiency. For a specific oilfield or reservoir [2-3], the geological reserve No is a fixed value. In order to maximize the ultimate oil production, it is necessary to maximize the macro sweep efficiency and micro displacement efficiency of the reservoir. Oil displacement efficiency has always been a concern of people. It is an important parameter to determine the water flooded condition, evaluate the oilfield development effect and predict the ultimate oil recovery. The oil displacement efficiency directly affects the oil recovery. Therefore, it is of great significance to study the displacement efficiency and its influencing factors in the process of water flooding development. Taking the main reservoir of A Oilfield as the research object, the relationship between oil displacement efficiency and water injection multiple, reservoir wettability and reservoir heterogeneity is explored by using numerical simulation method.

2. Effect of water injection multiple on oil displacement efficiency
2.1. The establishment of the model
Taking the fluid properties and reservoir parameters of A Oilfield as basic data, a five point well pattern is constructed. The basic parameters of the model are shown in Table 1, and the grid model is shown in Figure 1.
Table 1. Basic data

| Parameter name                     | Value       | Parameter name                      | Value       |
|------------------------------------|-------------|-------------------------------------|-------------|
| Reservoir depth (m)                | 1000        | Viscosity of water (mPa·s)          | 0.4         |
| Number of nodes 20×20×3            | 1200        | Initial viscosity of oil (mPa·s)    | 1.95        |
| Grid size dx=dy (m)                | 30          | Irreducible water saturation S_{WC} | 0.30        |
| Grid size dz (m)                   | 10          | Initial oil saturation              | 0.70        |
| Porosity (%)                       | 0.2798      | Initial reservoir pressure (Mpa)    | 25.3        |
| Plane permeability (μm²)           | 0.1         | Bubble point pressure (Mpa)         | 10.00       |
| Vertical permeability (μm²)        | 2.55        |                                     |             |

Fig. 1 Grid model

2.2. Analysis of simulation results

It can be seen from Fig. 2 that with the increase of the pore volume multiple of injected water, the recovery degree increases rapidly; when the water cut reaches more than 98% and the pore volume multiple of injected water is greater than 5, the oil displacement efficiency increases slowly and almost no longer increases.

Fig. 2 Relation curve between water injection multiple and water cut, recovery degree

3. Influence of wettability on oil displacement efficiency

In order to study the influence of wettability transformation of reservoir rock from lipophilic to hydrophilic on development effect, the prediction results of numerical simulation technology (Figure 1 for geological model) were applied to compare the water cut rising law and the influence on recovery degree of lipophilic reservoir, weak hydrophilic to strong hydrophilic reservoir (reservoir with wettability change caused by development factors) and hydrophilic reservoir. The relative permeability curves of the three types of reservoirs are shown in Table 2.
Table 2. Relative permeability of three types of reservoirs

|                | Lipophilic reservoir | Weak hydrophilic to strong hydrophilic reservoir | Hydrophilic reservoir |
|----------------|----------------------|------------------------------------------------------|----------------------|
| Sw            | Kro                  | Krw                                    | Sw                   | Kro                  | Krw                                    |
| 20.8          | 1                    | 0                                      | 29.71                | 1                    | 0                                      |
| 22.5          | 0.665                | 0.01                                   | 32.5                 | 0.76                 | 0.01                                   |
| 25            | 0.43                 | 0.02                                   | 35                   | 0.605                | 0.02                                   |
| 27.5          | 0.295                | 0.04                                   | 37.5                 | 0.475                | 0.03                                   |
| 30            | 0.2                  | 0.06                                   | 40                   | 0.365                | 0.045                                  |
| 32.5          | 0.14                 | 0.08                                   | 42.5                 | 0.28                 | 0.065                                  |
| 35            | 0.095                | 0.115                                  | 45                   | 0.215                | 0.09                                   |
| 37.5          | 0.065                | 0.145                                  | 47.5                 | 0.165                | 0.114                                  |
| 40            | 0.045                | 0.195                                  | 50                   | 0.125                | 0.145                                  |
| 42.5          | 0.03                 | 0.245                                  | 52.5                 | 0.09                 | 0.18                                   |
| 45            | 0.02                 | 0.3                                    | 55                   | 0.06                 | 0.215                                  |
| 47.5          | 0.013                | 0.355                                  | 57.5                 | 0.04                 | 0.245                                  |
| 50            | 0.006                | 0.415                                  | 60                   | 0.025                | 0.28                                   |
| 52.5          | 0.002                | 0.48                                   | 62.5                 | 0.01                 | 0.315                                  |
| 55.3          | 0                    | 0.545                                  | 65                   | 0.005                | 0.35                                   |
|               |                      |                                        | 67.5                 | 0.0025               | 0.385                                  |
|               |                      |                                        | 70                   | 0.002                | 0.422                                  |
|               |                      |                                        | 72.5                 | 0.001                | 0.46                                   |
|               |                      |                                        | 74.34                | 0                    | 0.49                                   |

Figure 3 shows that water breakthrough is the fastest in oleophilic reservoir, and water cut rises the fastest in the middle period; water breakthrough time is the slowest in strong hydrophilic reservoir, and water cut rises the slowest in the middle period; during the development process, the water cut rising law of reservoir transformed from weak hydrophilic to strong hydrophilic is between the former two, and the recovery degree is higher than that of hydrophilic reservoir. The ultimate recovery rates of the lipophilic reservoir, weak hydrophilic to strong hydrophilic conversion reservoir and hydrophilic reservoir are 32%, 47.97% and 37.51% respectively (Figure 4).
4. Influence of heterogeneity on oil displacement efficiency

In order to study the influence of reservoir heterogeneity (rhythm) on development effect in the process of development, the numerical simulation technology is applied to predict the results (Figure 1 for geological model), and the oil displacement efficiency of different rhythm reservoirs is compared, as shown in Figure 5.

The displacement efficiency of five types of reservoirs are 45.49, 50.06, 53.61, 54.12 and 58.13 respectively. It can be seen that the reverse rhythm reservoir has the highest oil displacement efficiency, while the positive rhythm reservoir has low oil displacement efficiency, but it is higher than the low mean value. The high permeability zone of high medium low medium high combination reservoir is in the upper part, and the reservoir is dominated by reverse rhythm, so the oil displacement efficiency is higher. The early appearance of strong water washing section at the bottom of positive rhythm reservoir and the preferential scouring of injected water make the lithology and physical properties of the strong water washing section change. All these changes improve the water displacement efficiency of the strong water washing section from the micro level, and aggravate the intraformational shield of positive rhythm reservoir from the macro level, which is not conducive to the improvement of water washing thickness and the expansion of water flooding swept volume in the vertical and horizontal levels. The washing thickness and strong washing thickness increase slowly with the increase of water injection multiple.
5. Conclusion
(1) The larger the volume ratio PV is, the higher the oil displacement efficiency is; when the water injection ratio exceeds a certain value, the oil displacement efficiency increases slowly.

(2) When the wettability of reservoir rock is neutral and weak water wettability, the displacement efficiency is higher than that of strong water wettability.

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