A novel optimization method considering fluid production rate and division time for 2D reservoir

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Abstract. The adjustment and control of the fluid production rates is one of the primary methods to increase the cumulative oil production for water flooding reservoir. In this article, the oil production optimization problem of two-dimensional water-flooding reservoir under the condition of fixed total fluid production rate is studied. The production process is divided into several segments. The relevance between the division time and the fluid production rate is considered. A novel optimization method considering both segmented time and fluid production rate is proposed. The stimulating effect on oil production of this method is tested by a realistic 2 dimensional oil reservoir in China. Compared with other conventional strategies and optimization schemes, this optimization method gains higher cumulative oil production, with the better water sweeping efficiency. For engineering practice, the proposed method may bring more economic benefits.

1. Introduction

With the development of the technology for the digital and intelligent oilfield, the optimization methods for improving the recovery efficiency receive much attention [1, 2]. The regulation of the production well’s rates is one of the most important techniques to increase the cumulative oil production and bring economic benefits. In 1980’s, this optimization problem of fluid production rate was studied without dividing the production procedure to segments [3]. The rate of each production well would not be adjusted during the whole production procedure. Gradient method was employed to calculate the optimal fluid production rates for different production wells. Obviously, it can be concluded that this optimal method has low efficiency on stimulating oil production due to the lack of dividing the production procedure. Some researches indicate that water phase does not move uniformly towards the production well in certain dead oil zones, the residual oil will not be fully displaced, which will cause poor sweeping efficiency and low oil recovery factor [4].

During the past 20 years, many researchers studied on dividing the production process into several independent segments. Zakirov divided the production procedure equally according to the total mining time and proposed the optimization method, where the cumulative oil production in each period was selected as the objective function [5]. The results calculated by numerical simulation showed that the...
optimization method with dividing the production procedure bring the higher oil recovery factor than the optimal method without segmentation. Aziz selected the cumulative oil production in a complete producing cycle as the objective function and numerically showed that the overall optimization technique has a good stimulation effect on oil production [6]. In Hasan’s study, the on-off state and operating time of the wells are adjusted and optimized. So that the breakthrough time of the water-flood front can be delayed and a higher displacement efficiency can be achieved [7].

However, there is not an optimization method considering not only the fluid production rate of each well, but also the time of procedure division. This article is organized as follows. In section 2, the mathematical expression for this novel optimization method is presented, along with comparison conventional adjustment and optimization schemes. In section 3, a realistic 2 dimensional reservoir case in China is performed to test the efficiency on stimulating oil production of the proposed method. Conclusions are given in section 4.

2. The novel optimization method and comparison schemes

2.1. Optimization method considering fluid production rate and division time

Divide the production process into segments with the length of time \( t_j \) (1 \( \leq j \leq n \)). Select the cumulative oil production \( Q_o = \sum_{j=1}^{n} Q_o^j \) as the objective function. Let \( Q_o^j \) denote the oil production in the segment \( j \) (1 \( \leq j \leq n \)) and \( q_i^j \) denote the fluid production rate of the production well \( i \) (1 \( \leq i \leq m \)) in the segment \( j \), where \( m \) is the number of wells. \( Q_{total} \) represents the total fluid production rate and \( T_{total} \) represents the total production time. The expression of the optimization problem and constraint condition is shown in eq.1.

\[
\begin{align*}
\text{maximize} & \quad \sum_{j=1}^{n} Q_o^j \\
\text{subject to:} & \quad \sum_{i=1}^{m} q_i^j = Q_{total}, \quad q_i^j \geq 0 \\
& \quad \sum_{j=1}^{n} q_j = T_{total}, \quad t_j \geq 0
\end{align*}
\]

The elimination method and steepest descent method is used to solve the constrained optimization problem. The commercial software ECLIPSE is employed for realistic reservoir calculation.

2.2. Comparison adjustment strategies and optimization methods

1. Average fluid production: The production process is not divided and the total fluid production rate is assigned to each well equally. The fluid production rate of each well is fixed during the whole production procedure.

2. Fluid production rate optimization: The production process is not divided and optimize fluid production rates of each wells. The fluid production rate of each well is fixed with the optimized value in whole production procedure.

3. Numerical tests

In this section, we use 2-D realistic oil reservoir block to test proposed optimization method’s oil producing efficiency. For comparison purpose, the calculations of other conventional adjustment and optimization schemes, listed in section 2, are performed in this example. Consider reservoir block given in Figure 1, which is taken from one layer in Shengli Oil Field Xin-42 reservoir block in China. Two injection wells and five production wells are taken into consideration. Optimize five production wells’ fluid production rates and division time. The wells’ location and absolute permeability distribution are shown in Figure 1, along with reservoir’s relative permeability. The total production time is 2400 days and the total fluid production rate is fixed with 25 m\(^3\)/day. Other parameters are listed in Table 1. Commercial software ECLIPSE is used for calculation.
Figure 1. Wells’ location, absolute permeability distribution and relative permeability.

Table 1. XIN-42 reservoir block’s parameters.

| Parameter                  | Value       |
|----------------------------|-------------|
| Density of the cruel oil (kg/m³) | 882.9       |
| Formation water density (kg/m³)  | 1000.0      |
| Rock compressibility (1/bar)    | 8.0         |
| Irreducible water saturation   | 0.3         |
| Residual oil saturation        | 0.2         |
| PVDO Pressure (bar)            | 200 250 300 |
| Volume ratio                  | 1.13 1.123 1.116 |
| Viscosity of crude oil (mpa.s) | 16.5 17.2 18.0 |

The cumulative oil production of different adjustment schemes and optimized fluid producing rates of each production wells are presented in Table 2. Schemes numbers are corresponding to: 1. Average fluid production; 2. Fluid production rate optimization; 3. Novel optimization method considering fluid production rate and division time. Results show that the proposed scheme 3 achieves highest cumulative oil production. And the optimized rate distribution results indicate that larger fluid producing rates are necessary for No.1 and No.5 production wells, which are far away from injection wells (see Figure 1). Compared with the average fluid production method, the proposed optimization strategies with 2-segment division have 6.1% increase. In contrast, the scheme 2 only gains the improvement of about 5.4%.

Table 2. Cumulative oil production and optimization results of each scheme.

| Scheme number | Segment Time (days) | Fluid producing rates (m³/day) | Cumulative oil production (m³) | Improving Rate (%) |
|---------------|---------------------|--------------------------------|--------------------------------|--------------------|
| 1             | T=2400              | q₁=5.0 q₂=5.0 q₃=5.0 q₄=5.0 q₅=5.0 | 26364                         | —                  |
| 2             | T=2400              | q₁=12.2 q₂=0.1 q₃=0.1 q₄=0.1 q₅=12.5 | 27780                         | 5.4                |
| 3             | T₁=1365 T₂=1035     | q₁=19.4 q₂=0.1 q₃=0.1 q₄=0.1 q₅=23.2 | 27974                         | 6.1                |

The residual oil distribution are shown in Figure 2. It can be seen that the proposed method, which optimize fluid production rate and division time, leaves less oil all over the reservoir. Most crude oil, where distribute in the top and bottom of the block, are driven from dead oil zones into urban area. In that case, it is verified that the proposed method can produce higher cumulative oil production and has better water flooding efficiency. For engineering practice, the novel method can increase the cumulative oil production to some extent, compared with other conventional strategies and optimization methods.
4. Conclusion
In this article, under the condition of fixed total fluid production rate, the oil production optimization problem of 2D water-flooding reservoir is studied. By dividing the production process into several segments, a novel optimization method considering fluid production rate and division time is proposed. It is suggested that the relationships between each division’s time length and the fluid production rate be taken into account. A realistic reservoir case are performed to test the proposed optimization method’s stimulation effect on oil production. Results show that the proposed method gains higher cumulative oil production and better water sweeping efficiency, compared with other conventional adjustment strategies and optimization schemes. In practical engineering, the proposed optimization method may increase economic benefits by adjusting well’s fluid production rate and regulating its operating time.

Acknowledgments
This work was financially supported by National Science and Technology Major Project of China (No.2016ZX05011002).

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