Research on Identification Method of the Inefficient and Ineffective Circulation Well Layer in Tracer Flow Simulation

Wang Jia
The First Oil Production Plant of Daqing Oilfield Corp. Ltd., Daqing, Heilongjiang, China, 163000

Abstract: The development of old Daqing Oilfield has entered the late stage of extra-high water cut, and the situation of inefficient and ineffective circulation is serious. Based only on the static and dynamic geological parameters, it is far from satisfying the requirement of analysis and judgement in the case of that the current well pattern, well spacing and dynamic state have all changed greatly, so the difficulty of development and adjustment is increasing. In this paper, tracer numerical simulation method is used to quantitatively study the directional injection-production rate of injection-production well layers, and the chart of the relationship between liquid production and water cut under different oil prices is established. The benefit types of production layers in production wells are classified and quantitatively evaluated, and then the inefficient and ineffective layers of production wells and their main inflow direction are accurately identified, which provides a basis for water control and efficiency improvement of inefficient and ineffective circulation well layers.

1. Introduction
Daqing Oilfield belongs to continental river-delta deposit with serious heterogeneity. After long-term development of water flooding and polymer flooding, Daqing placanticline has entered the stage of extra-high water cut development, with a comprehensive water cut of about 95%. Because of serious heterogeneity of the reservoir, under the long-term scouring of injectants, the seepage capability of the reservoir with relatively superior geological conditions is constantly strengthened, resulting in inefficient or ineffective circulation of injected water or other displacement agents in the production layer and extremely uneven utilization in the layer, resulting in waste of injected solution and poor development effect. How to effectively identify and control the inefficient and ineffective underground circulation layers and improve the efficiency of oilfield development has become an urgent problem to be solved.

2. Research status in China and abroad
At home and abroad, a lot of technical explorations and breakthroughs have been carried out for the identification of inefficient and ineffective circulation layer, and a variety of identification methods have been formed, which can be summarized as static data identification method, test monitoring identification method and dynamic comprehensive identification method. Static data identification method mainly uses static data such as logging data [1], coring well data, and so on. It qualitatively identifies inefficient and ineffective circulation layers according to the characteristics of logging curves, core direct observation and permeability change analysis. The method is simple and direct, but it is difficult to popularize in a large area...
due to the limitation of data quantity and timeliness. Test monitoring identification method mainly uses pressure drawdown well testing [2], interference well testing [3], tracer monitoring [4] and other means to identify inefficient and ineffective circulation layers by monitoring injection-production well pressure, production change and tracer appearance time and direction. However, this method has high cost, large workload and requires well shut-down in which production will be affected. Dynamic comprehensive identification method mainly deals with all kinds of dynamic and static factors. Through grey correlation analysis, fuzzy comprehensive evaluation, cluster analysis and other methods, it can identify inefficient and ineffective circulation layer comprehensively. This method has many factors and complex operation, and there are some differences in the results of selecting different indicators.

In this paper, tracer numerical simulation method is used to quantitatively study the directional injection-production rate of injection-production well layers, and the chart of the relationship between liquid production and water cut under different oil prices is established. The benefit types of production layers in production wells are classified and quantitatively evaluated, and then the inefficient and ineffective layers of production wells and their main inflow direction are accurately identified, which provides a basis for water control and efficiency improvement of inefficient and ineffective circulation well layers.

3. Tracer Flow Simulation
The essence of tracer flow simulation is to quantitatively describe the characteristics of oil-water movement in stratum by using pseudo-tracer technology in numerical simulation method on the basis of fine multi-disciplinary oil reservoir research. The main methods are as follows: on the basis of accurate geological model, it is assumed that different tracers are injected into each well of a certain well group, and the tracer does not diffuse in the fluid. It moves along the same trajectory as the injected water or the original fluid in stratum [7]; when the tracer moves through the reservoir, there is no loss or separation with the fluid. By studying the production characteristics of tracers in each production well, the direction of water inflow and the injection volume in this direction can be determined.

On the basis of Brigham-Smith model, the relationship between the ratio of water inflow in different directions on the plane and the peak concentration and peak time of tracer and well spacing can be deduced [8]:

\[ \alpha_1 = \frac{Q_{w1}}{Q_{w1} + Q_{w2} + \cdots + Q_{WN}} \]

where: \( \alpha_1 \) is the ratio of water inflow of well \( w_i \) to total water inflow of oil wells; \( Q_{w1} \) is the fluid production of well \( w_i \), m\(^3\)/d; \( L \) is injection-production well spacing, m; \( C_p \) is the peak concentration of tracer, mg/L; \( T \) is the peak time of tracer, d.

The quantitative description results can be used to quantitatively identify the main inflow direction and quantity in each direction according to the output ratio of different pseudo-tracers at the end of the oil well (Fig. 1), so as to effectively guide the identification of inefficient and ineffective circulation layers.
4. Identification of inefficient and ineffective well layer based on economic benefit evaluation

After the injection-production changes of single well and single layer in the stratum are quantitatively analyzed by using the tracer flow simulation method, the inefficient and ineffective well layers should be identified. In the past, the multi-factor comprehensive analysis method was mainly used for identification. This method has many factors and complex operation, and the results of different identification parameters will be different. Considering the dynamic significance of inefficient and ineffective circulation layers, which is that reservoirs with high injection displacement dose and low crude oil production volume result in serious increase of oilfield development cost and decrease of benefit, economic benefit is chosen as the only criterion to identify inefficient and ineffective circulation layers.

4.1 Classification of benefit types

Twenty-one kinds of costs are mentioned in single well benefit evaluation, which can be classified into four kinds of cost items, namely, the lowest cost, operation cost, production cost and running cost. Among them, the lowest cost includes 11 kinds of costs, such as direct material cost, direct fuel cost, direct power cost, direct personnel cost and displacement agent injection cost; operation cost adds 7 kinds of costs on the basis of the lowest cost, such as downhole operation cost, well logging test cost, maintenance and repair cost; production cost adds depreciation cost on the basis of operation cost; running cost adds exploration costs and period costs on the basis of production cost. According to the current financial system and the composition of the project, based on the results of benefit evaluation, oil and gas wells can be divided into type 1 benefit wells, type 2 benefit wells, type 3 benefit wells, marginal benefit wells and non-benefit wells (Table 1).

| Type  | Classification standard                                      |
|-------|-------------------------------------------------------------|
| Type 1| Annual after-tax income of oil and gas production and       |
| | associated products > Running cost                         |
| Type 2| Production cost < Annual after-tax income of oil and gas    |
| | production and associated products ≤ Running cost          |
| Type 3| Operation cost < Annual after-tax income of oil and gas     |
| | production and associated products ≤ Production cost       |
Marginal benefit  The lowest cost < Annual after-tax income of oil and gas production and associated products ≤ Operation cost
Non-benefit  Annual after-tax income of oil and gas production and associated products ≤ The lowest cost

4.2 Establishment of relationship curve between liquid production and water cut based on economic benefit evaluation
In order to establish the relationship between economic indicators and production dynamic indicators, according to the characteristics of cost allocation, 21 kinds of costs used in single well benefit evaluation are divided into four types, namely, average well cost, average oil cost, average water cost and average liquid cost. Based on the profit and loss balance principle commonly used in economics, i.e. the balance of input and output, the water cut and liquid production formulas of different oil prices under economic benefits are derived:

\[
f_w = 1 + \frac{\sum_{i=1}^{n} C_{Li} + \sum_{i=1}^{m} C_{Oi}}{\sum_{i=1}^{n} C_{Oi} - I \times (P - R_t - S)}
\]

where: \(f_w\) is the water cut, \%; \(C_L\) is the average liquid cost, yuan; \(C_J\) is the average well cost, yuan; \(C_O\) is the average oil cost, yuan; \(I\) is the commodity rate of crude oil; \(P\) is the price of crude, dollar/barrel; \(R_t\) is the oil tax per ton, yuan; \(S\) is the special oil gain levy, yuan.

4.3 Identification of inefficient and ineffective circulation well layer
Based on the results of single well benefit evaluation, the average well cost, average oil cost, average water cost and average liquid cost corresponding to different cost items are sorted out, and the water cut and liquid production formulas corresponding to four kinds of cost for oil and gas well benefit evaluation are calculated respectively, and the economic benefit evaluation chart of ineffective circulation identification is established.

![Water cut and daily liquid production chart of different benefit layers at oil price of $50 per barrel](image-url)
According to the economic benefit evaluation chart of ineffective circulation identification, the benefit types of single well under different fluid production and water cut levels can be identified. Taking oil price of $50 per barrel as an example (Fig. 2), when the daily production of oil wells is 60 tons, wells with water cut greater than 99.27% will be non-benefit. Similarly, the daily liquid production of single layer can be calculated according to the ratio of liquid production intensity of single layer to liquid production intensity of single well, and the benefit type of single layer can be evaluated when it corresponds to water cut of single layer.

5. The application situation
Well M1 was put into operation in 2010. G reservoir was exploited by water flooding. The perforation sandstone thickness was 32.1 meters and effective perforation thickness was 5.8 meters. “Five-point” well pattern was adopted. The well connects four water injection wells, and the injection-production well spacing is 106 meters. As of June 2017, it has produced 110 tons of liquid per day, 1.9 tons of oil per day and 98.31% of water cut. The tracer flow simulation method is applied to identify inefficient and ineffective circulation layer in this well. It is found that G35 layer is non-benefit layer, and the fluid production accounts for 38% of the total well. The main inflow direction of G35 layer is well W1 and well W2 (Fig. 3).

Fig. 3 Tracer flow profile of M1 well group

At the end of July 2017, restricted water injection was implemented in the G35 layer of Well W1 and Well W2. After injection restriction, the daily liquid production of M1 well decreases greatly, the daily oil production decreases slightly, and the water cut decreases steadily and slightly (Fig. 4).

Fig. 4 Comprehensive production curve of well M1

With this method, a total of 57 water injection wells were adjusted, the daily water injection volume was reduced by 288 cubic meters, the daily fluid production of 87 oil wells connected with each other was reduced by 211 tons, and the comprehensive water cut was reduced by 0.1%. Good results have been achieved.
6. Conclusion
(1) Tracer flow simulation technology can simulate and trace the characteristics of oil and water movement in stratum, and can quantitatively describe the water inflow in all directions of oil production wells, and then identify the main inflow direction.

(2) The identification method of inefficient and ineffective well layer based on economic benefit evaluation can adjust the identification chart timely according to the change of oil price, and can accurately identify the inefficient and ineffective well layer under the oil price at that time.

(3) Compared with other identification methods, the identification method of inefficient and ineffective circulation well layer in tracer flow simulation has the advantages of low cost, comprehensive consideration and strong operability, which can be popularized.

About the authors: Wang Jia(1985-),Male, Engineer, Master, Oilfield Development, The First Oil Production Plant of Daqing Oilfield Corp. Ltd., ( tel ) 0459-5815547,(E-mail)wangjia1985@petrochina.com.cn

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