Study on the Development Effect Standard of Classified Well Groups for Polymer Flooding in Class II Reservoirs

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Abstract. Because of the development characteristics of the second type reservoir, the heterogeneity of the reservoir is obvious, and the development effect of polymer flooding in different well groups is quite different, which is not conducive to the adjustment and evaluation of later development. Therefore, it is necessary to classify the polymer flooding well groups in the second type reservoir according to the dynamic and static physical parameters, and evaluate the development effect of different types of polymer flooding well groups on this basis. By analyzing the dynamic and static data of polymer flooding blocks in type II reservoirs, this paper determines the influencing factors of well group classification evaluation, establishes the method of well group classification combined with grey correlation method and mathematical statistics analysis, uses reservoir numerical simulation technology to predict the development effect of polymer flooding for different types of well groups, gives the development effect standards of polymer flooding for different types of well groups, and plays a certain role in adjusting the development effect of polymer flooding in oilfields.

1. Introduction
The polymer flooding block of the second type reservoir in the Sazhong development area is located in the eastern anticline of the Saertu reservoir. The five-point well pattern is adopted. The spacing of the injection-production well is between 145-201m, the average injection-production well spacing is 175m, and the effective permeability is $241 \times 10^{-3}$ μm$^2$. The second type reservoir is mainly composed of inner and outer front facies of delta, and its development type is positive rhythm and compound rhythm oil reservoir. The reservoir can be divided into 8 sedimentary units longitudinally. According to the development form of underwater distributary channel sand body and various sand bodies, it is mainly divided into branch delta sand body of inner front facies, lump delta sand body of inner front facies and Class III sand body of outer front facies. Currently, there are five sets of well patterns for mining. The basic well pattern was put into development in 1966, and the second type reservoir will be injected and developed and produced in 2018. With the deepening of polymer flooding in Daqing Oilfield, the polymer injection block has developed from the first type reservoir to the second type reservoir. The second type reservoir is characterized by thin and thick sand, low permeability, many well sections, poor continuity of sand body and strong differential homogeneity. Because of the great difference in the development of the second type reservoir, the development effect characteristics of the polymer flooding well group are quite different, which has a great influence on the adjustment of the later polymer flooding development. Therefore, it is necessary to classify the second types of well groups, give the development effect standards of different well groups, treat them by classification, and improve the development effect of polymer flooding between different well groups.
2. Study on the classification method of polymer flooding well group

There are many factors to evaluate the development effect of polymer flooding well group. There are many factors that affect the effect of well cluster flooding development (recovery degree), so it is necessary to select the parameters that have significant influence on recovery degree and are easy to obtain and quantify. Because there are many factors affecting the recovery degree of each stage, it is necessary to conduct mathematical analysis on the geological and development data of each single well, and analyze the influencing factors of the recovery degree of each stage to find out the main influencing factors[1-3].

2.1. Determine the main influencing factors of well group classification and evaluation

The classification of well groups is mainly from the geological (static) and development (dynamic) factors related to each other, select the well groups with similar physical parameters. Therefore, the correlation between each factor and polymer flooding development effect (recovery degree in polymer flooding stage) is determined firstly. In this paper, the method of grey relation analysis is used to evaluate the similarity between each factor and development effect. Taking the data of related factors of cohesive flooding in a block as an example, the steps of grey correlation analysis are as follows.

(1) Determine the reference sequence (evaluation object) and comparison sequence (evaluation index)

The reference sequence is the sequence composed of the object to be evaluated, the sequence composed of the recovery degree of polymer flooding is the reference sequence, and the comparison sequence is the sequence composed of the influencing factors.

(2) Normalization of original data

The original data dimension of each index is different, and the quantity level difference is also great. In order to eliminate the dimension of each original data, merge the quantity level and make it comparable, the original data should be normalized first (Table 1).

For production related indicators:

\[
\frac{x_{ij}}{x_{j_{max}}} = X_{ij}
\]

Table 1. Normalization results of reference sequence and comparison sequence

| Dimensionless | Reference sequence X0(n) | Comparative sequence X1 | X2 | ...... | X7  | X8   | X9   |
|---------------|--------------------------|--------------------------|----|--------|-----|------|------|
|               | Recovery degree          | effective thickness      | permeability | ...... | Pre-polymerization water saturation | Degree of control | initial water content |
| N1            | 0.0817                   | 0.3619                   | 0.4291       | ...... | 0.9105 | 0.8533 | 0.9026 |
| N2            | 0.0836                   | 0.2269                   | 0.3346       | ...... | 0.8973 | 0.8166 | 0.9722 |
| ......         | ......                    | ......                    | ......        | ...... | ......  | ......  | ...... |
| N243          | 0.1434                   | 0.4539                   | 0.4632       | ...... | 0.9515 | 0.8129 | 0.7493 |

(3) Calculate the absolute value of the difference between the reference sequence and each comparison sequence

\[
\Delta_{0i} = |X_0 - X_i|
\]

(4) Calculate the correlation coefficient between the parent sequence and each subsequence by the following formula:

...
\[ L_{oi} = \frac{\Delta_{\text{min}} + 0.5\Delta_{\text{max}}}{\Delta_{\text{oi}} + 0.5\Delta_{\text{max}}} \]  

(3)

(5) Calculate the correlation degree, that is, calculate the average value of the correlation coefficient, and sort the evaluation indexes according to the magnitude of the correlation degree.

\[ r_{oi} = \frac{1}{n} \sum_{j=1}^{n} L_{oi} \]  

(4)

In the formula: \( x_{ij} \)-value of row \( i \) and column \( j \); \( x'_{ij} \)-normalized dimension value; \( \Delta_{oi} \)-difference sequence value; \( \Delta_{\text{max}} \)-difference sequence maximum value; \( \Delta_{\text{min}} \)-difference sequence minimum value; \( L_{oi} \)-gray correlation coefficient; \( \gamma_{oi} \)-gray correlation degree.

The correlation degree of each influencing factor parameter is calculated as shown in Table 2:

**Table 2. Correlation degree table of recovery degree and influencing factors in polymer flooding stage**

| Factor                      | effective thickness | Degree of control | Pre-coalescence saturation | Recovery degree before coalescence | permeability |
|-----------------------------|---------------------|-------------------|----------------------------|-----------------------------------|--------------|
| Correlation degree          | 0.8521              | 0.9371            | 0.8280                     | 0.8169                            | 0.8067       |
| Factor                      | permeability ratio  | Geological reserves | Single layer burst coefficient | Initial water content of polymer flooding |
| Correlation degree          | 0.7829              | 0.6747            | 0.6893                     | 0.7225                            |

Generally, the grey correlation degree is 0.75 as the critical point, and the correlation degree greater than 0.75 indicates that the correlation between influencing factors and reference factors is good. The main factors were identified as pre-polymerization recovery degree, permeability, effective thickness, control degree, pre-polymerization water saturation and permeability ratio.

2.2. **determine well group classification standard**

After determining the main factors of well group classification, the comprehensive evaluation method of fuzzy mathematics is used to classify the well group of polymer flooding. There are three steps in the comprehensive evaluation method of the fuzzy comprehensive analysis method: ① normalize the influencing factors; ② calculate the evaluation matrix; ③ calculate the evaluation results and get the comprehensive evaluation.

(1) Normalization of influencing factors

According to the parameters of each well group, the interval value of each influencing factor is determined. The parameter index value is expressed as \( B_i \in [A_i, C_i] \) within the value range of the influencing factor index. There is a formula for normalizing the larger the better index:

\[ x_i = \frac{B_i - A_i}{C_i - A_i} \]  

(5)

There is a formula for normalizing the smaller the better index:

\[ x_i = 1 - \frac{B_i - A_i}{C_i - A_i} \]  

(6)

In the formula: \( i \) is the number of indicators, \( I = 1,2, \ldots, n \). The parameters of each well group in the block in this paper include permeability, effective thickness, permeability range, recovery degree before polymerization, control degree, and water saturation before polymerization. So in this paper, \( n \) is equal to 6.

For the influencing factors of each well group in the block, the larger the data, the more favorable
the parameters are: permeability, effective thickness, and control degree; the smaller the data, the more favorable the parameters are pre-polymerization water saturation, permeability range, and pre-polymerization recovery degree.

(2) Calculate evaluation matrix

Calculate the evaluation level vector (V):

\[ V = [v_1, v_2, v_3, \ldots, v_m]^T \]

\[ v_i = y_i + \frac{z_i - y_i}{2} \]  \hspace{1cm} (7)

In the formula: \( j \) is the number of evaluation levels, \( j = 1, 2, \ldots, m \). In this paper, the interval is divided into four levels, so \( m = 4 \).

Calculation of evaluation matrix (R)

\[ R = \begin{bmatrix}
    r_{11} & \cdots & r_{1m} \\
    \vdots & \ddots & \vdots \\
    r_{n1} & \cdots & r_{nm}
\end{bmatrix} \]

In the formula: \( r_{ij} \) is the possibility of evaluating factors only in terms of index \( i \), and the factor belongs to grade \( j \).

\[ r_{ij} = 1 - |x_i - v_j| \]  \hspace{1cm} (8)

\( i \) is the number of indicators, \( i = 1, 2, \ldots, n \); \( j \) is the number of evaluation levels, \( j = 1, 2, \ldots, m \), \( m = 4 \) in this paper.

(3) Comprehensive evaluation of influencing factors

Evaluation vector \( S \) is obtained:

\[ S = R = [s_1, s_2, s_3, \ldots, s_m]^T \]

\[ s_j = \sum_{i=1}^{n} r_{ij} \]  \hspace{1cm} (9)

\( s_j \) is the evaluation vector, \( i = 1, j = 1, 2, \ldots, m \). According to the evaluation level vector \( V \) and evaluation matrix \( R \), the evaluation vector \( S = [s_1, s_2, s_3, \ldots, s_m]^T \) can be obtained.

According to the principle of maximum membership, it refers to the set generation of evaluation grade corresponding to max \( s_j \) the largest evaluation index, as the final evaluation result.

2.3. Classification results of polymer flooding well groups

Calculate all the well groups in the block, and get the number of various well groups and the average value of the actual parameters of each well group calculated by statistics, as shown in Table 3:

| Counting number | Category | Effective thickness (m) | Permeability (mD) | Permeability ratio | Recovery before polymerization (%) | Pre-polymerization water saturation (%) | Degree of control (%) |
|-----------------|----------|------------------------|-------------------|-------------------|-----------------------------------|----------------------------------------|----------------------|
| 31              | Class I  | 9.45                   | 690.75            | 6.03              | 1.13                              | 45.61                                  | 80.13                |
| 119             | Class II | 7.65                   | 565.19            | 7.96              | 2.56                              | 48.00                                  | 74.50                |
| 75              | Class III| 5.86                   | 416.43            | 8.86              | 3.11                              | 50.64                                  | 68.32                |
| 18              | Class IV | 3.85                   | 244.29            | 9.40              | 4.08                              | 54.70                                  | 52.12                |

According to the analysis of classification results of polymer flooding well group, the second type reservoir is mainly composed of the second and third type well groups, accounting for 79.83% of the total wells. The physical properties, geological conditions and development effects of the reservoirs...
from one type to four types of polymer flooding well groups gradually become worse.

3. Research on development effect standard of various well groups by polymer flooding

Due to the different physical property conditions and development effects of various well groups, polymer flooding results in different injection effects of various well groups. In this paper, numerical simulation technology is used to study the optimal injection parameters of various types of polymer flooding well groups, and finally determine the development effect standard curve of various types of well groups, which provides theoretical basis for development adjustment of polymer flooding well groups. In this paper, using the results of well group classification, the corresponding polymer flooding wells are classified in numerical simulation, and various well groups are fitted finely[4-7].

3.1. Determine the standard curve of development effect of classified well groups of polymer flooding

In view of the effects of polymer flooding development in different well groups, the development effects of various well groups with different polymer concentrations and concentrations were predicted according to the well groups. The polymer concentrations selected for the physical properties of the two oil layers were 600mg/L, 800mg/L, 1000mg/L, 1200mg/L, 1400mg/L, 1600mg/L and 1800mg/L. Numerical simulation [8] was used to predict the development effect of a well group with different polymer concentrations, as shown in Figure 1.

![Figure 1 Development effect of polymer flooding in a well group](image)

From the analysis of numerical simulation results, it can be seen that cumulative oil production increases with the increase of concentration, but the increase decreases gradually; from the point of view of water content, with the increase of concentration, the decrease of water content also increases and decreases gradually. Considering the factors such as the accumulation of oil, the amplitude of enhanced recovery and the decrease of water cut, it is concluded that the polymer concentration of 1000mg/L-1400 mg/L is the best for a class 1 well group.

The standard curve of a well group with 1000mg/L-1400 mg/L concentration is obtained by area weighting method, and the standard curve is shown in Figure 2.

![Figure 2 Standard curve of aggregation amount and enhanced recovery rate of Class I wells](image)

By the same method, the labeled curves of polymer flooding development effect of Class II well group, Class III well group and Class IV well group are predicted by numerical simulation software, as shown in Figure 3:
3.2. Application of standard curve of development effect for classified well groups of polymer flooding

After determining the standard curves of the four types of polymer flooding well groups in the second type reservoir, the standard curves of each well group are compared to provide the basis for the adjustment of the development of polymer flooding in each type of well group. The comparison is shown in Figures 4-7:

The shape of the standard curve varies with different well groups due to different physical properties. Compared with the standard curve of the same kind of well group, the reason for the poor effect of the cluster flooding can be analyzed, and the dynamic measures can be adjusted.

4. Conclusion

Through the classification and evaluation of polymer flooding well groups in the second class reservoir, the standard curves of polymer flooding in different well groups are predicted and the adjustment scheme of polymer flooding measures is optimized by using numerical simulation technology.

(1) Through grey correlation method and single factor analysis method, the factors affecting the maximum degree of recovery at the stage are determined as follows: pre-polymer recovery degree, permeability ratio, permeability, effective thickness, control degree, pre-polymer water saturation; through fuzzy comprehensive evaluation method, the two types of reservoir polymer flooding well components are divided into four categories;

(2) Using numerical simulation technology to predict and analyze the effects of polymer flooding development of various well groups in type ii reservoirs, and determine the optimal injection parameters of polymer flooding of various well groups and the standard chart of development effects;

(3) Analyze and compare the actual development effect and the standard curve of the polymer flooding well group, and adjust the development measures of the polymer driving state for the well
group with poor effect of the polymer flooding.

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