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Abstract. The complexities of inter-layer heterogeneity conditions of low permeability reservoirs in china lead to non-applicability of conventional evaluation criteria and methods of profile control effect. This paper rebuilds a new precise division of methods to define the effectiveness of profile control which considered field data and characteristics of low permeability reservoir. The establishment of dynamic evaluation index system and methods of development effectiveness for low permeability reservoir on the basis of comprehensive consideration of the effect method sensitivity to dynamic parameters and the correlation of dynamic index system between oil well, water well and well group make the evaluation of profile control effect of single well and overall reservoir possible and has great practical significance in directing the implementation of profile control of low permeability reservoirs in china.

1. Introduction

The inter-layer heterogeneity conditions of (ultra) low permeability reservoirs in China are complex, and there are great differences compared with the conditions of medium and high permeability reservoirs. The dynamic characteristics are complex after the profile control measures are implemented. It is often difficult to judge the profile control effect according to the effective evaluation criteria of medium and high permeability reservoirs [1-6]. In many cases, the profile control operation cannot be effectively guided.

Based on a large number of production practices of profile control and water shutoff in domestic (ultra) low-permeability reservoirs for, analyzes and summarizes the effective characteristics and effective rules of oil well, water well and well group after the profile control and water shutoff measures, then re-divided the effect modes of the profile control well group (including effective and ineffective).Fully consider the sensitivity of different effective profile control methods to the dynamic parameters and the correlation between various dynamic indexes, then establish a comprehensive dynamic evaluation index system and dynamic effect evaluation method.

2. Dynamic evaluation index system

2.1. Classifications of effective mode

According to the geological characteristics of China's (ultra) low-permeability reservoirs and the comprehensive analysis of production dynamics of the profile control well group, the effective

characteristics of oil wells after the profile control measures mainly include four categories: oil increase, water decrease, liquid increase, and dynamic liquid level rise.

Based on the classifications of traditional effective mode, the effective mode of profile control well group in the low permeability reservoirs is subdivided into the following seven categories:

(1) Has not been effective;

(2) The amount of liquid oil increases, the water content increases steadily (Class A);

(3) The amount of liquid oil increases, the water content decreases (Class B);

(4)The liquid content is stable, the oil content increases, the water content decreases (Class C);

(5) The oil content is stable; the water content decreases (Class D);

(6) The liquid content increases (Class E);

(7) The dynamic liquid level rises (Class F).

2.2. The establishment of dynamic evaluation index system

Establish a dynamic evaluation index system for oil wells, including six items: effective period of profile control, responding time, water reduction amplitude, liquid increment, oil increment, and dynamic liquid level rises.

In general, the evaluation indicators of water well include oil pressure and daily water injection indicators. After subdividing the effective mode, a dynamic evaluation index system for water wells is established, including four items: oil pressure after profile control, pressure drop curve, water injection rate, and injection profile.

Using the well group as the unit to establish the dynamic evaluation index system of the well group, including three items: the effective rate of the well in the well group, the oil increment in the well group, and the effective period of the well group.

Dynamic effect evaluation method

2.3. Calculation of oil well dynamic evaluation index

According to the difference of the calculation methods, dividing the evaluation methods of six categories oil well dynamic evaluation index into two categories: the first type of indicators include the effective period of profile control and the responding time; the second type of indicators include water reduction amplitude, liquid increment, oil increment, and dynamic liquid level rises these four items.

The calculation methods and steps of the first type of evaluation indicators are as follows:

(1) According to the valid period and the time to responding time of the profile control, dividing into several time intervals, and the oil wells which in the same time interval are classified according to the effective type;

(2) Calculating the effective rate, water reduction amplitude and oil increment corresponding to each type of effective type in each time interval;

(3) Calculating the effective rate score, water reduction amplitude score and oil increment score corresponding to each type of effective type, formula 1~3;

(4) Calculating the geometrical mean of the effective rate score, water reduction amplitude score, and oil increment score corresponding to each effect type in the same time interval;

(5) Adding the geometrical mean values corresponding to the effective types in the same time interval to get the single group total score in the same time interval;

(6) Normalizing the single group total score in each time interval by being divided by the maximum value, get the converted total score corresponding to each time interval, formula 4;

(7) The converted total score of each factor is multiplied by the index weight, and get the final score of each factor.

The formula for calculating effective rate score is:

$$\text{effective rate score} = \begin{cases} \gamma\left(\gamma \neq 0\right) \\ 0.001\left(\gamma = 0\right) \end{cases} \tag{1}$$

$$\text{water reduction amplitude score} = \begin{cases} \dfrac{\Delta f_w}{100}\left(\Delta f_w \neq 0\right) \\ 0.005\left(\Delta f_w = 0\right) \end{cases} \tag{2}$$

In the formula, γ is effective rate, f and Δfw is the water reduction amplitude, Δfw=0~100. The formula 2is used for calculating the water reduction amplitude score

The formula for calculating the oil increment score is:

$$\text{oil increment score} = \begin{cases} \dfrac{\Delta q_o}{1000}\left(\Delta q_o \neq 0\right) \\ 0.001\left(\Delta q_o = 0\right) \end{cases} \tag{3}$$

$$A_1' = \frac{A_1}{\max\left(A_1, A_2, \ldots\ldots A_n\right)} \tag{4}$$

In the formula 3, Δqo is oil increment, t. The formula 4 is used to calculate the converted total score and A1' is the converted total score in the first time interval; Ai is the single group total score in the number i time interval; i = 1, 2,... n; n is the number of time intervals.

The calculation methods and steps of the second type of evaluation indicators are as follows:

(1) Calculating the water reduction amplitude, liquid increment, oil increment, and dynamic liquid level raises data of each oil well;

(2) Assigning the values to each factor according to the actual data interval (the assignment interval is 0~1), and get the water reduction amplitude score, liquid increment score, oil increment score, and dynamic liquid level rise score ,formula 5~formula 8;

(3) Each factor score is multiplied by the index weight and the final score of each factor is achieved.

The formula for calculating the water reduction amplitude score is:

$$\text{water reduction amplitude score} = \begin{cases} 0.005\left(\Delta f_w = 0\right) \\ 0.1\left(0 < \Delta f_w \leq 0.1\right) \\ 0.2\left(0.1 < \Delta f_w \leq 0.2\right) \\ 0.3\left(0.2 < \Delta f_w \leq 0.3\right) \\ 0.4\left(0.3 < \Delta f_w \leq 0.4\right) \end{cases} and \begin{cases} 0.6\left(0.4 < \Delta f_w \leq 0.5\right) \\ 0.7\left(0.5 < \Delta f_w \leq 0.6\right) \\ 0.8\left(0.6 < \Delta f_w \leq 0.7\right) \\ 0.9\left(0.7 < \Delta f_w \leq 0.8\right) \\ 1\left(\Delta f_w > 0.8\right) \end{cases} \tag{5}$$

In the formula, Δfw is the water reduction amplitude, Δfw=0~1.

The formula for calculating the liquid increment score is:

$$\text{liquid increment score} = \begin{cases} 0.001\left(\Delta q_l = 0\right) \\ 0.01\left(0 < \Delta q_l \leq 100t\right) \\ 0.1\left(100t < \Delta q_l \leq 300t\right) \\ 0.2\left(300t < \Delta q_l \leq 500t\right) \\ 0.3\left(500t < \Delta q_l \leq 600t\right) \\ 0.4\left(600t < \Delta q_l \leq 700t\right) \end{cases} and \begin{cases} 0.5\left(700t < \Delta q_l \leq 800t\right) \\ 0.6\left(800t < \Delta q_l \leq 1000t\right) \\ 0.7\left(1000t < \Delta q_l \leq 1300t\right) \\ 0.8\left(1300t < \Delta q_l \leq 1600t\right) \\ 0.9\left(1600t < \Delta q_l \leq 2000t\right) \\ 1\left(\Delta q_l > 2000t\right) \end{cases} \tag{6}$$

In the formula, Δql is the liquid increment, t.

The formula for calculating the oil increment score is:

$$\text{oil increment score} = \begin{cases} 0.001\left(\Delta q_o = 0\right) \\ 0.08\left(0 < \Delta q_o \le 100t\right) \\ 0.2\left(100t < \Delta q_o \le 300t\right) \\ 0.3\left(300 < \Delta q_o \le 400t\right) \\ 0.4\left(400t < \Delta q_o \le 500t\right) \\ 0.5\left(500t < \Delta q_o \le 600t\right) \end{cases} and \begin{cases} 0.6\left(600t < \Delta q_o \le 700t\right) \\ 0.7\left(700t < \Delta q_o \le 800t\right) \\ 0.8\left(800t < \Delta q_o \le 1000t\right) \\ 0.9\left(1000t < \Delta q_o \le 1600t\right) \\ 1\left(\Delta q_o > 1600t\right) \end{cases} \tag{7}$$

In the formula, Δqo is oil increment, t.

The formula for calculating the dynamic liquid level rise score is:

$$\text{dynamic liquid level rise score} = \begin{cases} 0.001\left(\mathrm{L} = 0\right) \\ 0.1\left(0 < \mathrm{L} \le 200\mathrm{m}\right) \\ 0.2\left(200\mathrm{m} < \mathrm{L} \le 300m\right) \\ 0.3\left(300m < L \le 400m\right) \\ 0.4\left(400m < L \le 500m\right) \\ 0.5\left(500m < L \le 600m\right) \end{cases} and \begin{cases} 0.6\left(600m < L \le 700m\right) \\ 0.7\left(700m < L \le 900m\right) \\ 0.8\left(700m < L \le 1100m\right) \\ 0.9\left(1100m < L \le 1300m\right) \\ 1\left(L > 1300m\right) \end{cases} \tag{8}$$

In the formula, L is oil increment, m.

2.4. Calculation of water well dynamic evaluation index

The four items dynamic indicators in the water well dynamic evaluation index system are calculated by a similar method of the second type of dynamic evaluation index of the oil well are as follows:

(1) Dividing a number of amplitude intervals according to the numerical value of each factor, and classifying the oil wells in the same amplitude range according to the effective type;

(2) Counting the corresponding effective rate, water reduction amplitude and oil increment corresponding to each effective type in each amplitude interval;

(3) Using formula 1 ~ formula 3, calculating the effective rate score, water reduction amplitude score and oil increment score corresponding to each effective type;

(4) Calculating the geometrical mean of the effective rate score, water reduction amplitude score and oil increment score corresponding to each effective type within the same amplitude range;

(5) Adding the geometrical mean corresponding to the each effective type in the same amplitude range to get a single group total score within the same amplitude range;

(6) Using formula 4, normalizing the single group total score in each amplitude interval by the maximum value, and get the converted total score corresponding to each amplitude interval;

(7) The converted total score of each factor is multiplied by the index weight, and get the final score of each factor.

2.5. Calculation of well group dynamic evaluation index

The calculation methods and steps of the well group dynamic evaluation index are as follows:

(1) Calculating the data of the oil well effective rate, well group oil increment and the effective period of well group these three items of the well group;

(2) Assigning values to various factors according to the actual data interval (the assignment interval is 0~1), and get the oil well effective rate score, well group oil increment score and the effective period of well group score, formula 9 ~ formula 11;

(3) Normalizing the scores of each factor by the maximum value, and get the converted scores of each factor;

(4) The converted score of each factor is multiplied by the index weight, and get the final score of each factor.

The formula for calculating the oil well effective rate score of the well group is:

$$\text{oil well effective rate score of the well group} = \begin{cases} \eta\left(\eta \neq 0\right) \\ 0.001\left(\eta = 0\right) \end{cases} \tag{9}$$

In the formula, η is the oil well effective rate of the well group, f.

The formula for calculating the oil increment score of the well group is:

$$\text{oil increment score of the well group} = \begin{cases} \dfrac{\Delta Q_o}{2000}\left(\Delta \mathrm{Q_o} \neq 0\right) \\ 0.001\left(\Delta \mathrm{Q_o} = 0\right) \end{cases} \tag{10}$$

In the formula, ΔQo is the oil increment of the well group, t.

The formula for calculating the effective period of the well group is:

$$\text{effective period of the well group} = \begin{cases} \dfrac{\mathrm{T}}{720}\left(T \neq 0\right) \\ 0.001\left(\mathrm{T} = 0\right) \end{cases} \tag{11}$$

In the formula, T is the effective period of the well group, d.

3. Field application

The A oil field is a lithological oil pool with poor reservoir physical properties. According to the core analysis: the average effective porosity is 10.14%, and the average air permeability is 3.81×10-3μm2. The difference of permeability on the plane is large, the heterogeneity is strong, the coefficient of variation is 0.72, and the coefficient of penetration is 3.39.

According to the dynamic index evaluation method which established in this paper, evaluating the 74 well groups that have been profile controlled in A oil field, first scoring separately according to the evaluation index system of oil well, water well and well group level, and then sorting by the block effect whole well group evaluation method, and get the overall sorting results of the profile control effects of all well groups in the whole oil field.

Among them, Table 1 is the weight of each index involved in the dynamic effect evaluation method; Table 2 is the dynamic evaluation result of the profile control effect of 74 well groups that have been profile controlled in the A oil field.

4. Conclusion

Through the analysis of dynamic evaluation index and its evaluation methods, we may conclude as follows.

(1) Based on the characteristics of (ultra) low permeability reservoirs and the system analysis of development data, the effective profile control mode of well group was re-divided. Among them, the effective mode is subdivided into six types: A, B, C, D, E, and F.

(2) Referring to the domestic profile control evaluation index system, combined with the dynamic correlation and dynamic law characteristics between oil well, water well and well group, a dynamic evaluation index system which is suitable for the effectiveness evaluation of profile control in China's (ultra) low permeability reservoirs is proposed, including oil well dynamic evaluation index, water well dynamic evaluation index and well group dynamic evaluation index.

(3) Fully considering the sensitivity of different effective methods to dynamic parameters and the correlation between various dynamic indicators, establishing a dynamic effect evaluation method based on reservoir dynamic comprehensive analysis. The local or individual evaluation of the oil well, water well and well group and the comprehensive evaluation of the overall profile control effect of the whole well group in the block are realized.

Table 1. The weight values of indicators

Level	Primary Weight	Dynamic Evaluation Indicator	Secondary Weight	Total Weight
oil well	0.5	profile control effective period	0.12	0.06
		responding time	0.08	0.04
		water reduction amplitude	0.2	0.1
		liquid increment	0.08	0.04
		oil increment	0.5	0.25
		dynamic liquid level rises	0.02	0.01
water well	0.2	oil pressure after profile control	1	0.2
		pressure drop curve	—	—
		water injection rate	—	—
		injection profile	—	—
well group	0.3	effective rate of the oil well in the well group	0.1	0.03
		oil increment in the well group	0.65	0.195
		effective period of the well group	0.25	0.075

Table 2. Dynamic evaluation results of all well groups profile control effect

The well group	Oil well total score	Water well total score	Well group total score	Comprehensive score	Sorting result
A1	0.551	0.135	0.078	0.764	1
A2	0.443	0.139	0.144	0.726	2
⋮	⋮	⋮	⋮	⋮	⋮
A36	0.370	0.159	0.042	0.571	36
⋮	⋮	⋮	⋮	⋮	⋮
A73	0.279	0.157	0.054	0.490	73
A74	0.262	0.145	0.081	0.488	74

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