Study on the Standard Boundary of Subdivision Water Injection in Extra High Water Cut Period

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Abstract. In order to improve the overall utilization degree of oil reservoirs in the late stage of oilfield flooding development [1], reduce the difference of interlayer utilization [2], expand the water injection coefficient, and improve the potential of residual oil development efficiency [3]. We establish a comprehensive water injection well subdivision standard system based on the analysis of the factors affecting the oil layer utilization [4]. Through the application of dynamic monitoring data, the relationship between the stratification index and the utilization status of the injection well is established [5], and the main factors affecting the utilization degree of the oil layer are determined. For the original subdivision water injection standard, only the vertical index is considered, the comprehensive and scientific problems are lacked, and the planar evaluation index is introduced innovatively. According to the relationship between the planar index and the utilization degree, the subdivision standard of the water injection well is optimized. Daqing Oilfield uses a model based on different reservoir properties to develop well patterns [3]. The physical properties of the reservoirs in the wells are quite different, which further refine the layered water injection standards of each well's network, making the stratification standards more scientific and reasonable, more targeted and practical. It meets the actual needs of precise development of oilfields with high water cut period and effectively improves the efficiency of oilfield development.

Keywords: Utilization status · Planar indicator · Subdivision standard · Precise development

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1 Introduction

In the late stage of development of ultra-high water cut, with the continuous improvement of technical adjustment methods, the overall utilization degree of oil layers has gradually increased, and the cumulative utilization degree has reached more than 80%. However, due to the influence of longitudinal heterogeneity, some well-developed layers are continuously used to form dominant seepage channels [6], while some of the poorly developed oil layers are used poorly or even unutilized. The degree of utilization of off-balance reservoirs is only about 60%. The difference in the use of oil layers leads to a more scattered distribution of remaining oil and more difficulties in tapping potential. In order to improve the oilfield oil utilization situation and improve the water injection efficiency [7], the main factors affecting the oil layer utilization degree must be clearly defined. In this paper, aiming at improving the utilization degree of the whole oil layer and reducing the difference in interlayer utilization, the influencing factors of the utilization degree of an oil field are analyzed, and the main influencing factors are determined.

An oilfield belongs to a sandstone oilfield with multiple reservoir development, and the factors affecting the effect of water injection development are complex [1]. It is mainly embodies in two aspects: one is the vertical heterogeneity caused by the large number of reservoir layers in the vertical direction and the large difference in the physical properties of the interlayer reservoirs; the other is the planar heterogeneity caused by the difference in physical properties between different sand bodies and different parts in the plane [8].

The relationship between various indicators and the degree of oil layer utilization was established, and the correlation between interval division, interlayer difference, oil layer development, water injection pressure, number of connected wells, connectivity ratio and oil layer utilization degree were evaluated [5]. The "666" subdivision water injection standard with the number of single-layer layers, single-card sandstone thickness and interval permeability coefficient is formed [5]. The standard guides the implementation of targeted program adjustments in the oilfield, and good results have been achieved. However, the standard focuses on the impact of vertical heterogeneity, does not consider the impact of the planar indicators, which lacks certain scientificity [9]. Based on the consideration of vertical influence factors, this paper further studies the influence of planar factors on the effect of water injection development [10], and finally determines five evaluating indicators, the number of single-layer oil layers in the interval, the thickness of single-card sandstone, and the coefficient of variation of interval permeability, planar deposition face contact coefficient and planar permeability breakthrough coefficient.

2 Analysis of Relationship Between Planar Index and Oil Layer Utilization Status

2.1 Planar Sedimentary Face Contact Coefficient

On the macro level, the more connected oil and water wells, the higher the degree of water flood control, and the better the water injection effect. However, considering only the number of oil-water well connections in each layer can not truly reflect the actual connectivity. Therefore, the contact and connectivity modes of sedimentary facies are studied, and the oil-water well connectivity that takes into account the distribution trend of the sedimentary facies in each layer of oil and water wells is proposed, Coefficient algorithm.

Planarly, the sedimentary facies type determines the spreading trend, and the oil and water wells correspond to the type of sedimentary facies, which determines the connectivity of the two wells in this horizon. However, in the actual operation process, the sedimentary facies encountered by oil-water wells in various small layers are usually described as: underwater distributary channel, main thin layer sand, non-body thin layer sand, off-surface sand body and Off-surface sand. In geological modeling, in order to facilitate computer recognition, the software usually uses the numbers 0, 1, 2, 3, 4 to characterize, but number can not accurately describe the degree of superiority of the sedimentary faces of the planar connection. Therefore, the analytic hierarchy method is used to quantify the qualitative description.

The analytic hierarchy process is to give the degree of superiority each type of sedimentary facies in the actual connection process through empirical methods, and quantify the qualitative language and participate in the whole calculation process. In contrast, the analytic hierarchy process is based on the expression of subjective judgments in quantitative form, and uses mathematical methods to test the reliability and correctness of people's subjective judgments.

According to the principle of analytic hierarchy process, in the process of connectivity comparison, the two types of sedimentary facies can use the qualitative language of "equivalent", "slightly important" and "significantly important" to indicate the importance of one type to the other type. These qualitative languages are quantified and a function $f(x, y)$ is introduced to represent the importance scale of factors x to factors y for the population as a whole. Compare all the factors in the factor concentration to establish a judgment matrix (Table 1).

Table 1. Analytic hierarchy method 1–9 ratio

Factor x, y comparison	$f(x, y)$	$f(y, x)$
x is as important as y	1	1
x is slightly more important than y	3	1/3
x is significantly more important than y	5	1/5
x is obviously more important than y	7	1/7
x is extremely important than y	9	1/9
x is y between the above two adjacent judgments	2 4 6 8	1/2 1/4 1/6 1/8

$$A = (a_{ij})_{m \times m}, \text{ In the formula, } a_{ij} = f(x, y) \tag{1}$$

$$A = (a_{ij})_{m \times m} = \begin{bmatrix} a_{11} & \cdots & a_{1m} \\ \vdots & \ddots & \vdots \\ a_{m1} & \cdots & a_{mm} \end{bmatrix} \tag{2}$$

After the judgment matrix A is established, the eigenvector $W = (\omega_{1,}\omega_{2,\cdots,}\omega_m)$ corresponding to the maximum eigenvalue of the judgment matrix A and $\lambda_{\max}$ is obtained by using the "sum method" or the "root method", and the feature vector is normalized to obtain the weight set $X = (\mu_1, \mu_{2,} \cdots, \mu_m)$. The feature vector is calculated by the sum method, that is, each column of the judgment matrix A is first normalized to obtain a matrix $B = (b_{ij})_{m \times m}$, and then summed by the row of B.

$$\mathrm{b}_{ij} = a_{ij} / \sum_{k=1}^{m} a_{kj}, i, j = 1, 2, \cdots, m \tag{3}$$

$$\omega_i = \sum_{j=1}^{m} b_{ij}, i = 1, 2, \cdots m \tag{4}$$

$$\mu_i = \omega_i / \sum_{k=1}^{m} \omega_k \tag{5}$$

Considering the degree of superiority of each type of sedimentary facies in connectivity, the comparative quantitative values of each sedimentary facies type are given in combination with the analytic hierarchy method (Table 2).

Table 2. Comparison of sedimentary phase types and quantitative values

Sedimentary microfacies	Underwater diversion channel/River sand	Thin layer of sand/Abandoned river	Non-main body thin layer sand/Inter-sand	Off-surface sand
Underwater diversion channel/River sand	1.00	2.00	3.00	4.00
Thin layer of sand/Abandoned river	0.50	1.00	1.50	2.00
Non-main body thin layer sand/Inter-sand	0.33	0.67	1.00	1.33
Off-surface sand	0.25	0.50	0.75	1.00

Judging matrix A is established by comparing the sedimentary face type comparison quantization table:

$$A = \begin{vmatrix} 1.00 & 2.00 & 3.00 & 4.00 \\ 0.50 & 1.00 & 1.50 & 2.00 \\ 0.33 & 0.67 & 1.00 & 1.33 \\ 0.25 & 0.50 & 0.75 & 1.00 \end{vmatrix}$$

Apply the “sum method” to solve the judgment matrix A, and calculate the solution vector, that is, the degree of superiority of each type of sedimentary facies in connectivity.

$$X = (0.48, 0.24, 0.16, 0.12)$$

According to the quantitative results, the face value of the river sand plane is determined to be 0.48, the face value of the main thin layer sand plane is 0.24, the non-body thin layer sand planar face value is 0.16, and the off-surface sand body planar face value is 0.12. Calculate the single-layer planar face contact coefficient based on the planar face values of various sand bodies:

$$A = \sum_{i=1}^{n} b_i \tag{6}$$

In the formula, A – single layer planar deposition face contact coefficient, b_i – connected oil wells single layer planar deposition contact face value.

In order to accurately establish the relationship between the contact coefficient of the planar sedimentary facies and the degree of utilization, the difference analysis of the contact coefficients of the planar sedimentary facies is carried out based on the layer segments, and the following formula is used:

$$A_{\varsigma} = \frac{\sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(A_i - \overline{A}\right)}}{\overline{A}} \tag{7}$$

In the formula, A_{ς} – the difference coefficient of the contact coefficient of the layer planar deposition, n – the number of small layers in the interval, A_i – the contact coefficient of the sedimentary face of the layer i, $\overline{A}$ – the contact coefficient of the sedimentary face of each small layer in the interval average value.

The relationship between the difference coefficient of the contact coefficient of the planar deposition face and the thickness of the water absorption. It can be seen from the figure that with the decrease of the contact coefficient of the planar sedimentary facies, the contact relationship between the wells of the sedimentary units in the interval tends to be equal, the proportion of the water absorption thickness of the interval gradually increases, and the difference in the utilization condition of each layer gradually decreases. When the planar phase contact coefficient is less than 0.3, the oil layer utilization degree is greater than 50% (Fig. 1).

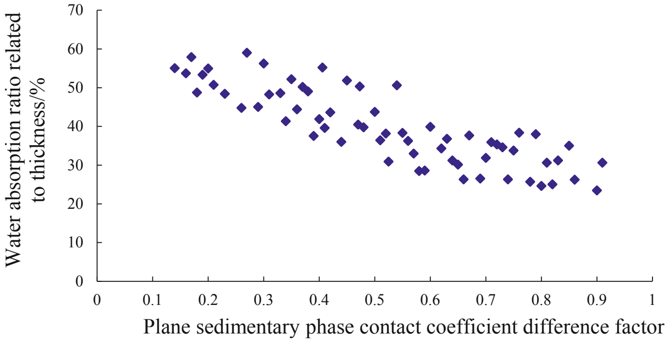

Fig. 1. The relationship between the difference coefficient of contact coefficient of planar sedimentary facies and the water absorption thickness of sandstone

2.2 Planar Permeability Breakthrough Parameter

The planar permeability breakthrough coefficient is the ratio of the permeability of a layer to the average permeability of all connected wells. The planar penetration rate breakthrough coefficient reflects the degree of the layer's dominant effect on the planar water injection, which reflects the favorable degree of the layer forming the dominant channel. The formula is as follows:

$$K_\varsigma = K_i/\overline{K} \tag{8}$$

In the formula: K_ς – Planar permeability breakthrough coefficient; K_i – Single layer permeability value; $\overline{K}$ – Average value of connected well permeability.

The permeability breakthrough coefficient is dimensionless according to the following formula, and the formula is as follows:

$$A_\varsigma = \frac{\sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(K_{\varsigma i} - \overline{K_\varsigma}\right)}}{\overline{K_\varsigma}} \tag{9}$$

In the formula, A_ς – the permeability factor of the penetration coefficient in the interval, n – number of layers in the interval, $K_{\varsigma i}$ – the value of the penetration coefficient of the i-th small plane, $\overline{K_\varsigma}$ – the average of the penetration coefficient of the planar permeability in the interval.

The relationship between the planar penetration rate and the water absorption thickness ratio, as the difference coefficient of the planar penetration rate is reduced, the planar spurt coefficients of the sedimentary units in the interval tend to be equal, and the proportion of the water absorption thickness of the layer gradually increases, when the planar penetration rate advances. When the coefficient difference factor is less than 0.5, the thickness utilization ratio is greater than 50% (Fig. 2).

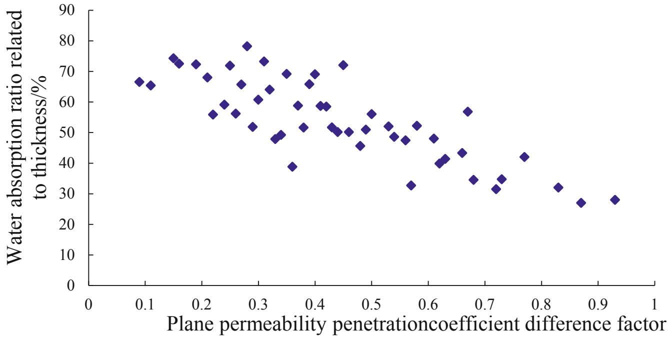

Fig. 2. The relationship between the difference factor of plane permeability penetration coefficient and the water absorption thickness of sandstone

3 Water Injection Standard Adaptability Evaluation

According to the different properties of the reservoirs, Daqing Oilfield is classified and mined by different well networks, and there are large differences in the physical properties of the oil layers in each network. The original subdivision water injection standard only quantifies the subdivision standard on the whole, but not refines to each well network. In order to meet the precise development needs, it is necessary to separately quantify the subdivision water injection standards of each well network.

By establishing the relationship between the longitudinal index, the planar index and the degree of utilization of each well network, combined with the single-card condition of the current interval, the subdivision water injection standard of each well network is quantified, so that the subdivision adjustment of the injection well would be more eazily targeted (Table 3).

According to the stratification standards of each well net, the stratification of the injection wells in the whole plant was evaluated. There are 588 vertical indicators that do not meet the subdivision criteria, accounting for 16.74% of the total number of wells. There are 610 wells that do not meet the subdivision planar criteria, accounting for 17.37% of the total number of wells. While clarifying the potential for adjustment, it is necessary to increase the intensity of subdivision adjustment, promote the more uniform utilization of the oil layer, and effectively improve the quality of oilfield development (Table 4).

Table 3. Subdivision water injection standard limits for each well network

Well net	Vertical indicator			Planar indicator	
	Number of layers	Sandstone hickness/m	Permeability Coefficient of variation	Planar deposition facies Contact coefficient difference factor	Planar permeability Sudden coefficient difference factor
Basic well net	7	6.0	0.64	0.36	0.61
Initially encrypted well net	6	5.5	0.61	0.33	0.57
Secondarily encrypted well net	6	5.0	0.51	0.26	0.53
Tertiarily encrypted well net	5	4.0	0.43	0.22	0.49

Table 4. Evaluation of different well network subdivisions

Well net	Number of wells	Vertical indicator not matched		Planar indicator not matched	
		Number of wells	Proportion/%	Number of wells	Proportion/%
Basic well net	348	112	32.18	77	22.13
Initially encrypted well net	977	207	21.19	189	19.34
Secondarily encrypted well net	1153	193	16.74	212	18.39
Tertiarily encrypted well net	1034	76	7.35	132	12.77
Total	3512	588	16.74	610	17.37

4 Conclusions

1. The factors affecting the degree of utilization of oil layers are complex. Considering the influence of vertical indicators, it is also necessary to consider the factors affecting the plane. Two evaluation indexes of planar deposition facies contact coefficient and planar permeability breakthrough coefficient are introduced to make the injection well subdivision evaluation index more excellent;
2. By fitting the relationship between the planar index and the degree of oil layer utilization, determine the correlation between the two, and combine the vertical correlation indicators to quantify the subdivision water injection standards of different well networks;

3. Reasonably increase the number of submerged water injection intervals and reduce inter-layer interference, which can effectively improve the utilization degree of oil layers. It should increase the subdivision of single wells that do not meet the stratification standards, continuously improve the rationality of single-slot single-slots, and effectively improve the oilfield's development effect.

References

1. Zhao, Y., Hu, G.: Evaluation of reservoir utilization at different stages in Lamadian Oilfield. Daqing Pet. Geol. Dev. **25**(03), 54–55 (2006)
2. Wang, C.: Research and application of subdivision water injection technology in a oilfield. China Pet. Chem. Stand. Qual. (01), 79 (2013)
3. Li, H., Shan, L.: Effective improvement of oilfield development effect by subdivision water injection adjustment method. Inner Mongolia Petrochem. Ind. (12), 153–158 (2010)
4. Liu, X.: Research on technical limits of subdivision water injection in water flooding super high water cut period. New Technol. Prod. China **1**(19), 22–23 (2010)
5. Yang, D.: Study on the adaptability of "666" subdivision water injection standard in development zone. In: Technical Seminar on Improving Water Flooding and EOR (2011)
6. Xie, H., Wang, F.: Research on subdivision injection method. Oil Gas Field Surf. Eng. **26**(2), 8–9 (2007)
7. Tan, C.: Principles and potential of optimal segmentation of water injection wells. Inner Mongolia Petrochem. Ind. (11), 53–54 (2014)
8. Feng, Q., Wang, B., Wang, X.: Study on optimization method of subdivision injection interval combination in high water cut reservoir. J. Southwest Pet. Univ. (4–38), 103–108 (2016)
9. Liu, D.: Discussion on principle and application of fine layered water injection technology. Chem. Eng. Equip. (07), 134–135 s(2018)
10. Zhang, Z., Bai, M.: Study on adjustment of water well subdivision strata in high water cut period. Xinjiang Pet. Sci. Technol. (02), 26–29 (2017)