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Research on Adjustment of the Injection-Production Structure of Reservoir under Differential Fluid Flow Control

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Abstract

K oilfield has been in extra-high water cut period, and its degree of reserve recovery is 42.3%. In order to further improve the effect of water flooding development, in this paper, by establishing a streamline model based on the complex function, drawing a streamline diagram, and counting the number of streamlines per unit area, the dominant channels in the K oilfield are divided into three grades based on the cumulative frequency distribution of 25% and 75%, including 10 main dominant channels, 14 sub-dominant channels, and 7 non-dominant channels. Differential control of fluid production and water injection is carried out for different levels of dominant channels. Through the adjustment of oil well fluid production and water injection well water injection, the streamlines of the oilfield are redistributed. The practice of K Oilfield proves that 8 wells increase the liquid production rate by 40% - 107%; 1 well reduces the liquid production rate by 34%; 3 wells increase the water injection rate by 17% - 19%; 2 wells reduced the water injection rate by 12% - 32%; the average daily oil production of the oilfield increased by 40 m^3/d, and the average water cut decreased by 0.7%.

Keywords

Complex Function, Differential Control, Dominant Channel, Streamline Distribution, Injection Production Structure

1. Introduction

K oilfield is a structural layered oil and gas reservoir with an average porosity of 30% and an average permeability of 1200 mD, which is a typical high porosity and high permeability. At present, water injection is used for development. In the middle and high water cut stage, the core of the work is to increase the swept volume of water flooding. Through the adjustment of well pattern and separate flood, the development situation is good. At present, the K oilfield has a water cut of 94.4% and a recovery rate of 42.3%, which is in the development stage of "double extra high". As the oilfield enters the later stage of development, the number of oil wells with higher water cut is increasing. At present, the proportion of wells with water cut greater than 90% is 93%, and the proportion of high water cut wells with water cut greater than 95% is 53%. The difference in moisture content between the main layers is only 6.6%. According to development experience, it is difficult to adjust the injection-production structure by relying on the difference in water content between layers to tap the potential. Therefore, in view of the development contradiction in this ultra-high water-cut period, it is urgent to carry out rapid quantitative evaluation of the dominant channels and carry out targeted adjustment of injection-production structure. For the identification method of dominant channels in water drive reservoirs, domestic scholars have gradually developed various methods and theories. It mainly includes the following methods: ① Well testing monitoring method, which needs to collect pressure and production data, and establish a well testing interpretation model to identify dominant channels; ② Production dynamic data method. This method selects dynamic characterization parameters of dominant channels such as oil-water phase effective permeability, liquid production index, water absorption index. ③ Tracer test method. This method calculates the propulsion speed of the tracer according to the time when the tracer is seen in each well, and qualitatively evaluates whether the dominant channel exists. It is generally believed that there are dominant channels between injection and production wells with sharp and steep tracer production curves, and there are no dominant channels in flat ones; ④ Comprehensive fuzzy evaluation method, based on a comprehensive analysis of various factors affecting large pores, use the fuzzy evaluation method to comprehensively deal with various dynamic and static factor indicators, establish a high capacity channel identification expert system, and judge the existence and development status of large-scale pores in the reservoir through the comprehensive judgment value of large-scale pores [1]-[4]. The research method is to determine the streamline distribution based on the complex function according to the liquid production rate of the oil well and the water injection rate of the water injection well. Through the correction of the water content, the streamline distribution under the heterogeneous condition is determined, and then according to the density of the streamline in the unit area, the dominant channel is quantitatively described. According to the comprehensive analysis of the current water-cut stage of the oilfield and the actual water-cut rising speed of the oilfield, the seepage channel levels are divided according to the cumulative frequency distribution of 25% and 75% [5]-[8].

2. Method Derivation

Under the homogeneous conditions, the flow function method can be used to find the flow line distribution, the direction of the liquid flow, and the flow distribution of each well, so as to obtain the law of the fluid in the entire flow field.

2.1. Using Flow Function to Obtain Streamline Distribution

As shown in **Figure 1**, if there are n point sources (sinks) at the same time, and they are respectively located at points a_1, a_2, a_3, ..., a_n on the complex plane Z, then the complex potential at any point M on the plane, The principle of superposition can be used to get [9] [10]:

$$W(Z)=\sum_{j=1}^{n}\left[\pm\frac{q_{hj}}{2\pi}\ln\left(Z-a_j\right)+C_j\right] \tag{1}$$

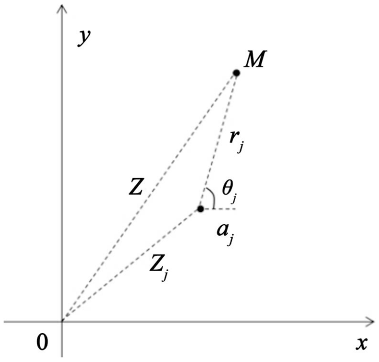

Figure 1. Complex plane schematic.

At this point, the potential function is:

$$\phi=\sum_{j=1}^{n}\phi_j=\sum_{j=1}^{n}\left[\pm\frac{q_j}{2\pi}\ln\left(r_j\right)+C_{j1}\right] \tag{2}$$

The flow function is:

$$\psi=\sum_{j=1}^{n}\psi_j=\sum_{j=1}^{n}\left[\pm\frac{q_j}{2\pi}\ln\left(\theta_j\right)+C_{j2}\right] \tag{3}$$

2.2. Derive the Relationship between Water Cut and Well Position on the Streamline

The flow function calculation in Equations (1)-(3) above is applicable to homogeneous isotropic models. Considering the heterogeneity of actual oil reservoirs, the streamline distribution calculated by homogeneous isotropy should be corrected. Given that there is a monotonic relationship between water cut, a certain position x on the streamline, and water saturation, a relationship between water cut and a certain position x can be established. This article uses a complex potential function to solve the streamline distribution of the entire oil reservoir under the assumption of homogeneity; Further derivation of the oil-water two-phase flow theory yields the corresponding relationship between water cut and the position within the flow line. By substituting the water cut, the sequential positions of each well point in the flow line are obtained, thereby correcting the distribution of the flow line under homogeneous conditions [11] [12].

Based on the one -dimensional water -removing model, ignore the capacity and gravity of the capacity, and use the reciprocating function to solve the streamline distribution of the entire oil under the hypothesis; further derives the theory of two-phase infiltration theory of oil and water The corresponding relationship of the inner location, through the substitution of the water cut, obtains the sequence of each well in the streamline. Thus correcting the streamline distribution under homogeneous conditions. The water cut value adopted here is the measured dynamic water cut during production. The simplification process is as follows: For a given time and injection volume, the Buckley-Leverett equation provides the saturation profile. This profile is highly nonlinear. At each point on the saturation profile, there is a corresponding saturation. Substituting this saturation into the diversion equation allows the calculation of the instantaneous water cut at that point. Therefore, the relationship between water cut and position is a composite function.

The specific research process is as follows:

The formula for moving the isosaturation surface is:

$$x - x_0 = \frac{f_w'(S_w)}{\phi A}\int_0^t Q dt \tag{4}$$

Establish the relationship between a certain position x in the streamline and the water cut at that position. You can calculate f_w' by giving x in Equation (4) [13] [14], and then find the corresponding S_{wf} from the diversion function and its derivative function graph. Since f_w' has two monotone intervals, S_{wf} has a double solution. In applied mathematics, it is unique to use the starting point of the monotone function as the tangent line. For the monotonically increasing function f_w, use S_{wi} as the f_w tangent line, and the tangent point is located on the right side of the peak value of the derivative curve, To determine the unique solution of S_{wf}, the corresponding relationship between water cut f_w and a certain position x on the streamline can be obtained through the f_w curve, where f_w is monotonic with respect to x; The area where the current edge has not reached, $f_w = 0$ (**Figure 2**, **Figure 3**).

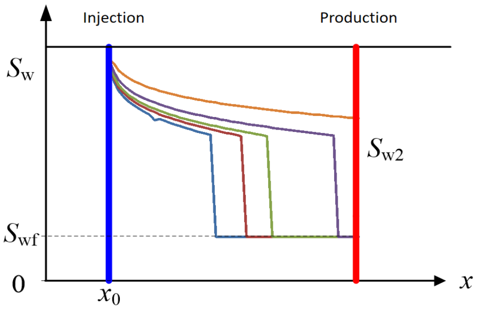

Figure 2. Water saturation distribution in streamline at different times.

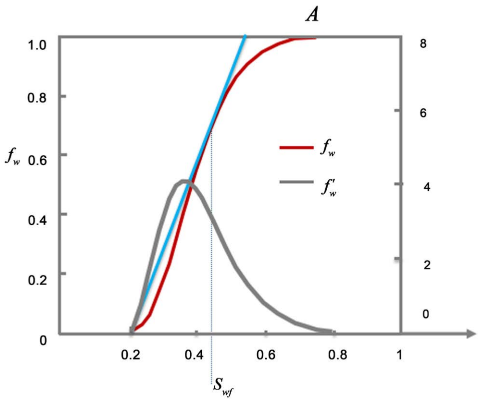

Figure 3. Factional flow curve analysis chart.

2.3. Quantitative Characterization of Seepage Channels

Based on complex function and oil-water two-phase seepage theory, a new streamline model is established, and a new method of seepage channel identification is proposed. That is, by drawing a streamline diagram, the number of flow pipes in a unit area is counted. Taking the number of streamlines per unit area as the variable and using the quartile system for classification, this method is stable and practical. The seepage channel levels are divided according to the cumulative frequency distribution of 25% and 75%.

Through the new method of seepage channel identification, the dominant channels are divided into three levels: major dominant channels, secondary dominant channels, and non-dominant channels. Among them, there are 10 major dominant channels in the K Oilfield, 14 secondary dominant channels, and 7 non-dominant channels (as shown in **Table 1** and **Figure 4**).

Table 1. The result of seepage channel judgment.

injection well	production well	Number of Streamline	channel level	injection well	production well	Number of Streamline	channel level
W7	X1	15	main	W18	X17	2	Non
	X2	8	Sub		X23	3	Non
	X8	12	main		X24	6	Sub
	X13	6	Sub	W19	X13	10	main
	X14	1	Non		X14	8	Non
	X26	3	Non		X20	9	Sub
	X27	8	Sub		X26	8	Sub
W9	X2	12	main	W21	X14	5	Sub
	X3	13	main		X15	12	main
	X4	5	Sub		X20	15	main
	X8	10	main		X22	8	Sub
	X10	7	Sub	W16	X10	10	main

Continued

	X14	6	Sub	X15	9	Sub
	X15	4	Non	X17	6	Sub
W11	X4	10	main	X22	7	Sub
	X5	11	main	X23	2	Non

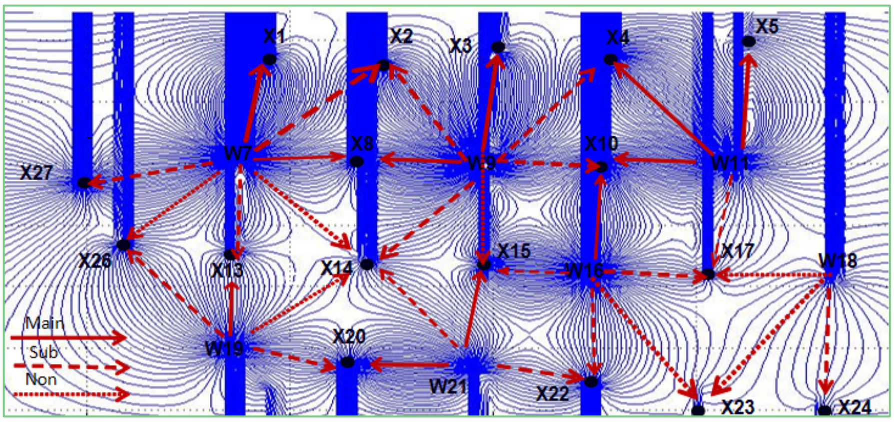

Figure 4. Streamline of K oil field.

Explanation: Blue represents the water injection rate of the water injection well and the liquid production rate of the oil well. When substituted into the complex function, the water injection rate is a negative value, and the liquid production rate is a positive value.

2.4. Adjustment Strategy for Optimization of Water Injection and Liquid Production

According to the classification results of dominant channels, different governance methods are proposed for the three levels of dominant channels [15]. For the non-dominant passage area, the main well areas include the X14 and X26 wells in the W7 well area, the X15 well in the W9 well area, the X17 and X23 wells in the W11 well area, the X14 well in the W19 well area, and the X23 well in the W16 well area. The remaining oil is relatively rich. First, the flow of remaining oil is increased by oil well transfer, and second, the oil well is used to increase the liquid production and reduce the water cut of the oil well; for the main dominant passage area, The main well areas include the X1 and X8 wells in the W7 well area, the X2, X3 and X8 wells in the W9 well area, the X4 and X5 wells in the W11 well area, the X13 well in the W19 well area, the X15 and X20 wells in the W21 well area, and the X10 well in the W16 well area. The remaining oil is relatively small. Reduce the water injection rate of water injection wells, increase the water injection rate of adjacent water injection wells, and change the direction of the original streamline; for the secondary dominant seepage channel, The main well areas include the X2, X13 and X27 wells in the W7 well area, the X4, X10 and X14 wells in the W9 well area, the X24 well in the W18 well area, the X20 and X26 wells in the W19 well area, the X14 and X22 wells in the W21 well area, and the X15, X17 and X22 wells in the W16 well area. Increase the liquid production rate in the area with low streamline density, increase the streamline in the remaining oil-enriched area, Redistribute the streamlines in the well area.

3. Instance Application

Application of research methods in K Oilfield. Based on the classification of dominant channels in the K oilfield, the water injection rate and liquid production rate of the oilfield are adjusted according to the adjustment strategy of water injection rate and liquid production rate. In the K Oilfield, 1 oil well was switched to injection, 8 wells increased fluid production, 1 well decreased fluid production, 3 wells increased water injection, and 2 wells decreased water injection (as shown in **Table 2**). After the adjustment of water injection rate and liquid production rate, the streamline of K Oilfield changed (the adjusted streamline is shown in **Figure 5**). The average daily oil production of the oilfield increased by 40 m^3/d, and the average water cut decreased by 0.7% (**Figure 6**).

Table 2. Liquid-producing capacity of different well groups.

injection well	production well	Fluid production before adjustment (m^3/d)	Adjusted fluid production (m^3/d)	Water injection volume before adjustment (m^3/d)	Adjusted water injection volume (m^3/d)	injection well	production well	Fluid production before adjustment (m^3/d)	Adjusted fluid production (m^3/d)	Water injection volume before adjustment (m^3/d)	Adjusted water injection volume (m^3/d)
W7	X1	180	180	809	809	W9	X2	280	390	764	892
	X2	260	390				X3	180	180		
	X8	150	150				X4	220	370		
	X13	180	180				X8	150	150		
	X14	357	357				X10	170	280		
	X26	250	420				X14	357	357		
	X27	140	290				X15	150	150		
W19	X13	180	180	668	784	W21	X14	357	357	425	373
	X14	357	357				X15	150	150		
	X20	180	180				X20	130	130		
	X26	250	420				X22	200	320		
W23	X17	130	182	0	385	W11	X4	220	370	523	356
	X22	200	320				X5	264	173		
	X24	88	206				X10	170	280		
W18	X17	130	182	260	310		X17	130	182		

4. Applicability Suggestions

This method is based on oilfields with relatively complete injection and production well patterns, weak heterogeneity and no complex faults. For oilfields with the above conditions, further research is needed when applying this method.

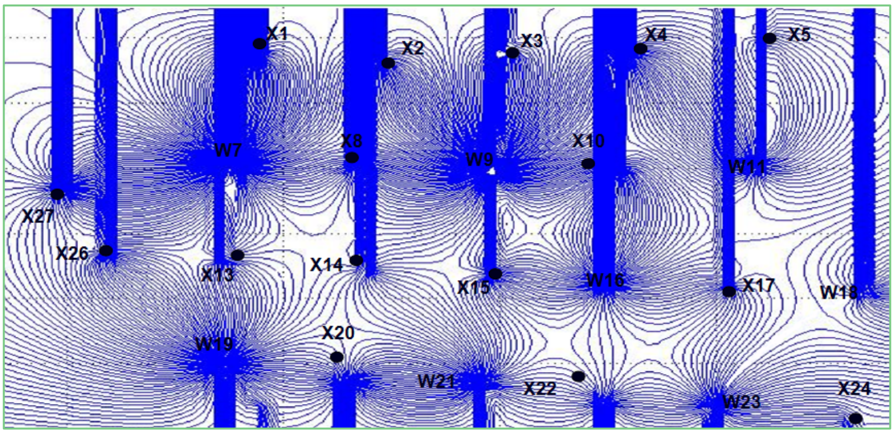

Figure 5. Streamline of K oil field (after adjustment).

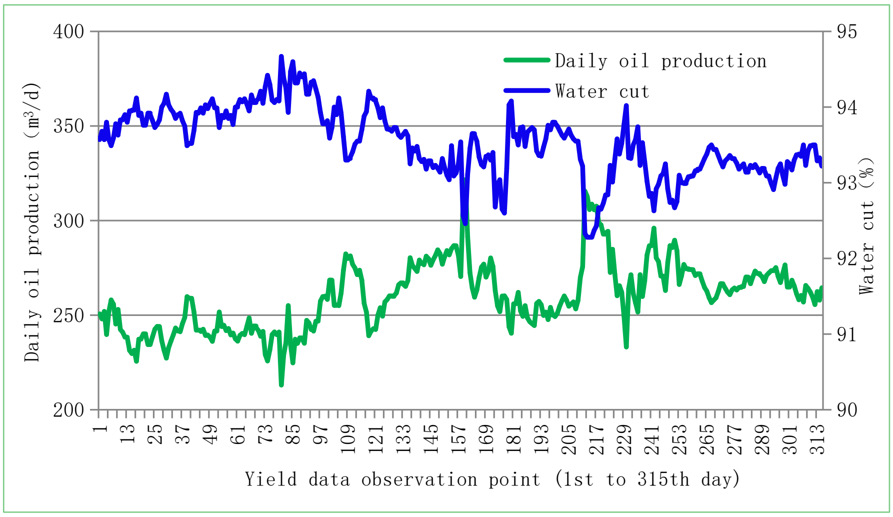

Figure 6. Production curve of K oil field.

5. Conclusions

1) This paper establishes a streamline model based on the complex potential function, draws a streamline diagram, counts the number of streamlines per unit area, and divides the K oilfield's dominant channels into three according to the cumulative frequency distribution of 25% and 75%. Levels include 10 main dominant channels, 14 sub-dominant channels, and 7 non-dominant channels.

2) Compared with the conventional dominant channel identification method, the data of this research method is easy to obtain and can realize rapid quantitative evaluation.

3) According to the dominant channels of different levels, the streamlines of the oilfield are redistributed through the adjustment of the liquid production rate of the oil well and the water injection rate of the water injection well. The practice of K Oilfield proves that 8 wells increase the liquid production rate by 40% - 107%;

1 well reduces the liquid production rate by 34%; 3 wells increase the water injection rate by 17% - 19%; 2 wells reduced the water injection rate by 12% - 32%; the average daily oil production of the oilfield increased by 40 m^3/d, and the average water cut decreased by 0.7%.

Symbolic description

a_j and C_j are both complex constants; q_j is the liquid volume of the *j*th point source (sink), m^3/s; θ_j is the auxiliary angle and the angle between the vector Z-a and the x-axis; C_{j1} is the real part of the complex constant C_j; C_{j2} is the imaginary part of the complex constant C_j; x represents a certain position within the streamline, m; x_0 is the initial position, m; $f_w'(S_w)$ is the derivative of water cut relative to water saturation; ϕ is the porosity, %; A is the cross-sectional area, m^2; Q is the water injection rate, m^3/s.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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