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Study on Effect Evaluation Method of Weak Gel Flooding Control in Ordinary Heavy Oil Reservoirs

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Abstract. Generally the dynamic methods are used to calculate the oil increase after flooding control in the oilfield, but the evaluation results of different methods are quite different, and the evaluation results are uncertain. Therefore, for flooding control well groups in heavy oil reservoirs, the water flooding characteristic curve method, decline method and net oil increase method are used to calculate the oil increase, and the influence of the method parameter values on the results are analyzed, and the parameter value limits and calculation errors of each method are determined. Based on this, the adaptability of each method is proposed. The results show that the effect evaluation of the whole region flooding control is suitable to use the water flooding characteristic curve method or the decline method, the effect evaluation of the single well group flooding control is more suitable to use the decline method, the net oil increase method is not recommended. The application range and parameter value limit of the effect evaluation method of flooding control are put forward, which can guide the actual production effect evaluation in the oilfield.

1 Introduction

When the ordinary heavy oil reservoirs are developed by water flooding, due to the heterogeneity of oil reservoirs and the low oil-water mobility, the fingering of injected water will occur along the high permeability strip. As a result, the water-absorbing layers are few longitudinally, and the oil producing degree is low. Therefore, the areal sweep efficiency is low, and the injected water breaks through fast to the oil wells. After a long-term period of development, it is easy to form a high permeability channel, resulting in invalid circulation of injected water [1].

To solve these problems, the technologies of profile control, polymer flooding or flooding control can be used to improve the effect of oilfield development. Profile control is conducted mainly with strong gel plugging agent, and the mechanism of profile control is mostly physical barrier plugging. The purpose of profile control is to adjust the injection profile of the formation near the well. Polymer flooding is a method by adding water-soluble polymer into the injected water, increasing the viscosity and reducing the permeability of water phase, improving the oil-water viscosity ratio, thereby increasing the volumetric sweep coefficient, improving the oil displacement efficiency and oil recovery. Deep flooding control technology is developed on the basis of profile control technology and polymer flooding technology, with the dual advantages of polymer flooding technology in improving oil-water mobility ratio and profile control technology in improving water absorption profile. This technology has been widely used in oil field practice in recent years, being an effective method to improve the displacement efficiency of heavy oil fields [2].

By referring to the evaluation methods on the effect of profile control and polymer flooding, the water flooding characteristics curve method, decline method or net oil increase method can be used for calculating the increased oil production after flooding control [3-8]. However, the evaluation results with different methods change greatly, and the results are uncertain. Therefore, in order to improve the calculation accuracy of the increased oil production and guide the field oil production effectively, it is necessary to study on the adaptability of the effect evaluation of flooding control method.

2 Reservoir and Profile Control Overview

X reservoir in Kazakhstan is a lithology-structure heavy oil reservoir, with edge and bottom water and gas cap in some areas. The reservoir is shallow, with a buried depth of 280-590 m. The reservoir is mainly loose sandstone in lithology, being poorly cemented, being good in physical properties, with porosity is 25.2~31.7%, and permeability is 228~1424 mD. The viscosity of formation crude oil is 122-662 mPa • s, with an average

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of 410 mPa • s. The formation temperature is 29~33℃, the original formation pressure is 4.7~5.3 MPa, and the formation pressure coefficient is 1.1, belonging to normal temperature and pressure system [9].

From 2008 to 2019, weak gel flooding control had been implemented in 22 injection wells, with an average injection volume of 0.03 times of the pore volume, an average injection concentration of 2631 mg/L, and an average polymer dosage of 82 mg/L˙PV.

3 Study on Evaluation Method of Weak Gel Flooding Control

The cumulative increased oil production by flooding control is the difference between the actual oil production by flooding control and the predicted oil production by water flooding at the same stage. The oil production by water flooding can be predicted by water flooding characteristic curve method, decline method and net oil increase method.

3.1 Water flooding characteristic curve method

It is generally recommended to use the type B and type C water flooding characteristic curve method to predict oil production by water flooding. With the type B water flooding characteristic curve method, the future developing performance of water flooding oilfield can be predicted based on the linear relationship between cumulative liquid production and cumulative oil production at the middle and late stage of water flooding development in the semi-logarithmic coordinate system. With the type C water flooding characteristic curve method, the future developing performance of water flooding oilfield can be predicted based on the linear relationship between the accumulative fluid-oil ratio and the accumulative liquid production at the middle and late stage of water flooding development in the cartesian coordinate system.

The relation of type B water flooding characteristic curve method is as follows:

$$lnL_p = A + BN_p \tag{1}$$

The relation of type C water flooding characteristic curve method is as follows:

$$\frac{L_p}{N_p} = A + BL_p \tag{2}$$

Where, L_p is the cumulative liquid production of the oilfield, 10^4t. N_p is the cumulative oil production of the oilfield, 10^4t. A and B are the intercept and slope of the regression line respectively.

For the B3 and B7 well groups, firstly, the production data of 21 and 11 months before flooding control were fitted with the type B and type C water flooding characteristic curves, respectively. The correlation coefficients were above 0.998, and the intercept and slope of the regression line could be obtained (Fig. 1~2). Then, based on the current water cut of the well groups, the cumulative oil production of water flooding at the same stage after flooding control can be predicted, namely the cumulative increased oil production can be calculated (Table 1).

The results show that when the production data from different time intervals are used with the type B and type C water flooding characteristic curve method, the calculated results of the increased oil production after flooding control is quite different. When the production data from the same time interval are used with the type B and type C water flooding characteristic curve method, the calculated results of increased oil production after flooding control is also quite different. If the type B water flooding characteristic curve method is used to fit the production data of 21 months and 11 months before flooding control for the B3 well group, the calculated cumulative increased oil production is 15000t and -86000t respectively; while if the type C water flooding characteristic curve method is used, the calculated cumulative increased oil production is 65000t and 55000t respectively. Similarly, if the type B water flooding characteristic curve method is used to fit the production data of 21 months and 11 months before flooding control for the B7 well group, the calculated cumulative increased oil production is 44000t and -22000t respectively; while if while if the type C water flooding characteristic curve method is used, the calculated cumulative increased oil production is 22000t and 6000t respectively.

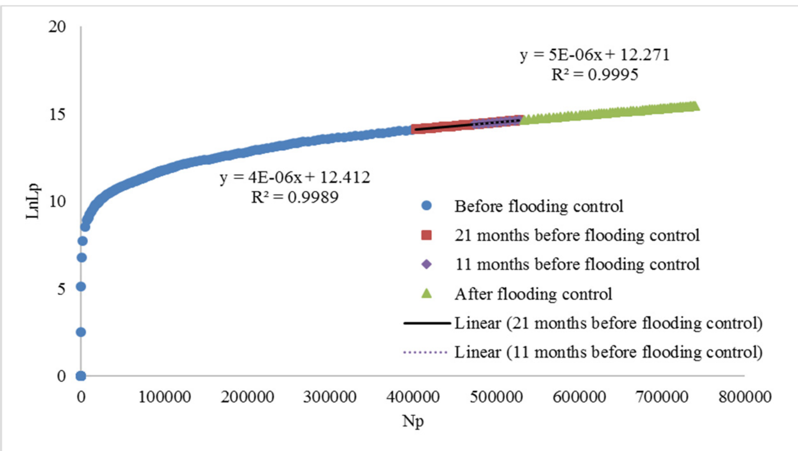

Fig.1 The fitting results of production data for B3 well group before flooding control with type B water flooding characteristic curve method

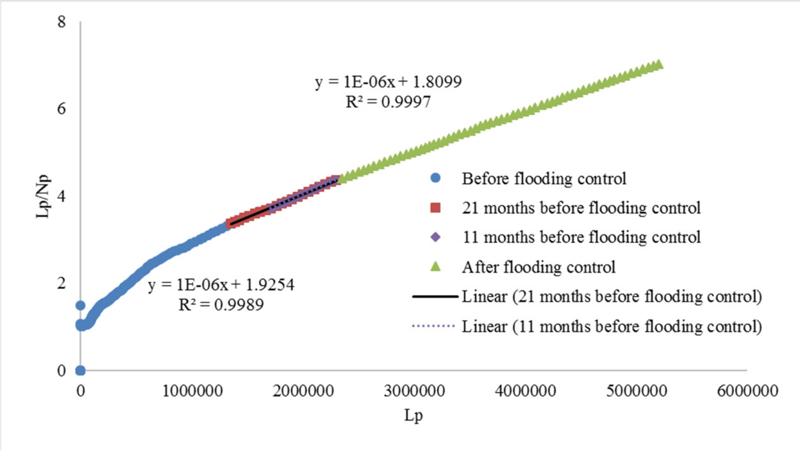

Fig.2 The fitting results of production data for B3 well group before flooding control with type C water flooding characteristic curve method

Table 1 The comparison of the cumulative increased oil production with water flooding characteristic curve method

Index	B3 well group				B7 well group			
	Type B		Type C		Type B		Type C	
	21 months	11 months	21 months	11 months	21 months	11 months	21 months	11 months
A	12.412	12.271	1.925	1.810	11.313	10.378	1.279	0.913
B	4E-6	3E-6	1E-6	1E-6	8E-6	1E-5	2E-6	2E-6
Predicted cumulative oil production by water flooding, 10^4t	68.0	78.1	63.1	64.0	34.0	40.7	36.3	37.9
Real cumulative oil production, 10^4t	69.5	69.5	69.5	69.5	38.5	38.5	38.5	38.5
oil incr. after flooding control, 10^4t	1.5	-8.6	6.5	5.5	4.4	-2.2	2.2	0.6

The water cut of the actual production well group shows a trend of fluctuation during a short period of time, while the water flooding characteristic curve method relies on the current water cut to calculate the increased oil production after flooding control. Therefore, it is necessary to consider the influence of small fluctuation of water cut on increased oil production. For the B3 and B7 well groups, the type B and type C water flooding characteristic curves have been used to fit the production data of the 21 months before flooding control, and the increased oil production after flooding control has been calculated considering the increase or decrease of water cut by 0.1-0.2 percentage (Table 2).

The results show that the small fluctuation of water cut has a great influence on the amount of increased oil production calculated with the type B or type C water flooding characteristic curve method. If the water cut of B3 well group increased or decreased by 0.1-0.2 percentage, the change of cumulative increased oil production calculated with the type B water flooding characteristic curve method ranges from 27.3% to 56.2%, while with the type C water flooding characteristic curve method, the change ranges from 4.2% to 8.6%. Similarly, for the B7 well group, if the water cut increased or decreased by 0.1-0.2 percentage, the change cumulative increased oil production calculated with the type B water flooding characteristic curve method ranges from 5.1% to 10.6%, while with the type C water flooding characteristic curve method, the change ranges from 5.9% to 11.9%.

Table 2 The sensitivity analysis on calculation of increased oil production after flooding control with water flooding characteristic curve method

Change of water cut, PCT	B3 well group				B7 well group			
	Type B		Type C		Type B		Type C	
	Oil incr., 10^4t	Change, %	Oil incr., 10^4t	Change, %	Oil incr., 10^4t	Change, %	Oil incr., 10^4t	Change, %
-0.2	2.3	54.2	7.0	8.4	4.9	10.1	2.5	11.7
-0.1	1.9	27.3	6.8	4.2	4.7	5.1	2.4	5.9
0.0	1.5	0.0	6.5	0.0	4.4	0.0	2.2	0.0
+0.1	1.1	-27.8	6.2	-4.3	4.2	-5.2	2.1	-5.9
+0.2	0.7	-56.2	5.9	-8.6	4.0	-10.6	2.0	-11.9

For each well group, the cumulative increased oil production calculated with water flooding characteristic curve method changes a lot according to time interval and water cut. The water flooding characteristic curve method is used mainly for the developed oil fields which have entered into the high water-cut period. By plotting the two dynamic parameters on the semi-logarithmic coordinates, an obvious linear relationship can be obtained. By using this relationship, the future production performance of the oil field can be predicted [10]. Although the linear relationship can be obtained from the production data of the single well group of the actual reservoir, the fitted linear relationship cannot accurately reflect the production situation of the well group because the production performance of the well group is greatly affected by the surrounding production wells, resulting in a great error in the calculation of increased oil production after flooding control. The water flooding characteristic curve method is more suitable for calculating the increased oil production in whole block.

3.2 Decline prediction method

The production decline can be divided into three type, including exponential decline, hyperbolic decline and harmonic decline. At the beginning of the decline stage, the three types of decline are close to each other, and the easy-to-use exponential decline is generally used [10].

The equation of exponential decline method is as follows：

$$Q_{wo} = Q_c e^{-Dt} \quad (3)$$

Where, Q_{wo} is the monthly oil production predicted at water flooding stage, 10^4t. Q_c is the average oil production in the six months before chemical flooding control, 10^4t. D is the monthly decline rate of water flooding. T is the time corresponding to the production decline prediction method, month.

For the B3 well group, the exponential decline method was firstly used to fit the production data of 21 months and 11 months before flooding control, obtaining the monthly decline rate. We can take the average daily oil production in the six or three months before flooding control as the datum mark to predict the monthly oil production of water flooding at the same stage after flooding control. If the increased oil production lasts zero for three consecutive months, it is judged that the period of validity is over. At last, the cumulative increased oil production can be calculated (Fig. 3).

The results show that when using the decline method used, if the decline trend is at different time intervals before flooding control, the production data at the same intervals is used as the datum mark, the calculated results of the increased oil production will change little. When using the decline method used, if the decline trend is at the same time intervals before flooding control, and the production data at different intervals is used as the datum mark, the increased oil production calculated will also change little. For the B3 well group, the decline method was used to fit the production data of 21 months and 11 months before flooding control, and the production data of 6 months before flooding control was used as the datum mark. The calculated cumulative increased oil production was 8000 and 11000 tons, respectively. If the production data of 3 months before flooding control was used as the datum mark, the calculated cumulative increased oil production was 6000t and 900t, respectively.

Since the recent stable production data can reflect the actual production situation without any important adjustment measures. It is suggested that the decline rate should fit the production data of 6-12 months before flooding control, and the production data of 3-6 months before flooding control can be used as the datum mark.

3.3 Net Oil Increase Method

When using the net oil increase method, the production data before flooding control is used as the datum mark. Considering that the monthly oil production of water flooding at the same stage after flooding control remains unchanged, the cumulative increased oil production is calculated with this method.

For the B3 well group, the average monthly oil production during the six or three months before flooding control is used as the monthly oil production of water flooding at the same stage after flooding control. If the increased oil production lasts zero for three consecutive months, it is judged that the period of validity is over. Then, the cumulative increased oil production can be calculated (Fig. 3).

The calculation results show that when using the net oil increase method, if the production data from different time interval before flooding control is used as the datum mark, the calculated results of the increased oil production after flooding control varies little. For the B3 well group, by using net oil increase method, the daily production of six and three months before flooding control was used as the datum mark, the calculated cumulative increased oil production was 1300t and 1600t, respectively.

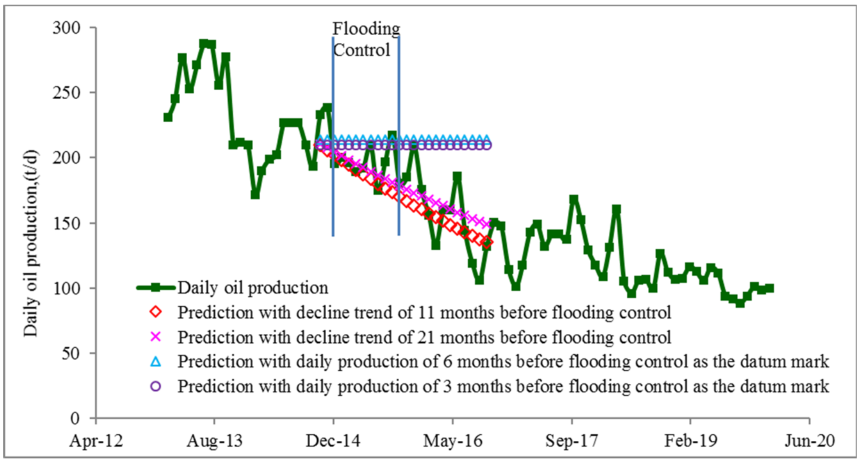

Fig.3 Increased oil production after flooding control with decline method

When using the net increase oil production method, the monthly oil production of water flooding at the same stage is unchanged after the flooding control, but the actual oil production of the well group shows a decreasing trend. The calculated cumulative increased oil production is small. Therefore, it is recommended that this method should not be used.

4 Conclusion

(1) The water flooding characteristic curve method is suitable for calculating the increased oil production after flooding control in the whole block. It is not suitable for calculating the production of single well group because the production performance of single well group is greatly affected by the surrounding production wells.

(2) The decline method is suitable for calculating the increased oil production after flooding control in whole block or a single well group. It is recommended to fit the production data of 6-12 months before flooding control, the production data of 3-6 month before flooding control should be taken as the datum mark.

(3) When using the net oil increase method, it is believed that the monthly oil production of water flooding at the same stage remains unchanged after flooding control. But the actual oil production of the well group shows a decline trend, and the calculated cumulative increased oil production is relatively smaller. Therefore, it is recommended that this method should not be used.

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