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Study on the Fine Optimization of Water Injection in SZ Oilfield of Bohai Bay

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Abstract
Bohai SZ Oilfield has entered into high water cut stage, how to realize the goal of fine optimization of water injection to enhance oil recovery is an important problem for reservoir engineers. Fine optimization of water injection needs 'inject enough', 'inject well' and 'inject effectively'. The paper gets relationship between annual oil production rate and annual water production rate of different water cut stages of SZ Oilfield with the life cycle theory and draws the annual water injection rate and annual oil production rate chart to ensure 'inject enough', optimizes injection allocation method according to new reservoir research and gets a very good precipitation effect of increasing oil production. The paper also puts forward the method to recognize low effective and ineffective injection circulation to guide the oilfield 'inject effectively'.

Key words: Fine optimization of water injection; Logistic theory; Prediction of water injection; Injection allocation; Low effective and ineffective injection circulation

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INTRODUCTION

Bohai SZ oilfield is a large offshore heavy oilfield in Liaodong Bay with high porosity, high permeability and strong heterogeneity. The oilfield has entered into high water cut stage after 20 years of development which some development contradictions gradually exposed: It's difficult to improve the usage of inject water in this stage and the oilfield needs more accurate inject water during comprehensive adjustment and liquid production structure adjustment stage; Regional contradictions have become increasingly prominent, the remaining theoil distribution is complex, the displacement and inter block injection is imbalance. Vertically, the absorption strength in some layers of some wells is difference which causes water channeling because of heterogeneity. How to accomplish more fine water injection work is a Grand Challengesbig challenge to reservoir engineers[1-5].

1. NEW METHOD FOR PREDICTION OF INJECTION WATER RATE TO ENSURE THE OIL FIELD 'INJECT ENOUGH'

SZ Oilfield predicts the water injection rate by using the rise of water law and the method of reservoir numerical simulation presently. There have some limitations of this two methods: firstly, It's difficult to determine the rise of water law, So the methods have high prediction accuracy in the near future but not in long terms; Secondly, The numerical simulation method to predict the water injection can not consider the future year yield variation and the rate of water cut increase is more quickly in models, so the results are not accurate enough.

Research shows that the process of oil field development is in accordance with the life cycle theory (Logistic theory)[6], The study used this theory to predict the reasonable water injection rate of oilfield.

The following mathematical model is Logistic model:

$$X=\frac{D}{1+Ae^{-Bt}} \quad (1)$$

In the formula: X represents the system; t represents development time or process of the system; D is a constant in process; A, $B$are fitting coefficients.

The model represents the process of system from rise of the development to X be close to $\lim_{t\to\infty} \to D$.

Define the cumulative water consumption rate with H_{cum} and the cumulative water oil ratio with WOR_{cum}:

$$H_{cum}=\frac{W_i}{N_p},\ WOR_{cum}=\frac{W_p}{N_p} \quad (2)$$

In the formula: H_{cum} represents the cumulative water consumption rate, Dimensionless; $W_i$represents the cumulative water injection rate, 10^4 m^3; N_p represents the cumulative oil production rate, 10^4 m^3; WOR_{cum} represents the cumulative water oil ratio, Dimensionless; W_p represents cumulative water production rate, 10^4 m^3.

The cumulative water consumption rate and cumulative water oil ratio increase with the development, which come with comprehensive water cut rising, so $\lim_{t\to\infty} f_w \to f_{wlim}$. We can use logistic model to establish elationship between the cumulative water consumption rate and the cumulative water oil ratio: $\lim_{t\to\infty} f_w \to f_{wlim}$.

$$f_w=\frac{f_{wlim}}{1+A_1e^{-B_1H_{cum}}} \quad (3)$$

$$f_w=\frac{f_{wlim}}{1+A_2e^{-B_2WOR_{cum}}} \quad (4)$$

By suing Logarithmic transformation with formula (3) and (4), then

$$\ln(f_{wlim}/f_w-1)=\ln A_1-B_1H_{cum} \quad (5)$$

$$\ln(f_{wlim}/f_w-1)=\ln A_2-B_2WOR_{cum} \quad (6)$$

In the formula: f_w represents water cut, Dimensionless; f_{wlim} represents limit of water cut, the general value is 0.98; A_1、B_1、A_2、B_2 are fitting coefficients.

According to (5) and (6) we have,

$$H_{cum}=\frac{\ln A_1-\ln A_2}{B_1}+\frac{B_2}{B_1}WOR_{cum}$$, then

$$W_i=\frac{\ln A_1-\ln A_2}{B_1}N_p+\frac{B_2}{B_1}W_p \quad (7)$$

Differentiate formula (7), then

$$\frac{dW_i}{dt}=\frac{\ln A_1-\ln A_2}{B_1}\frac{dN_p}{dt}+\frac{B_2}{B_1}\frac{dW_p}{dt} \quad (8)$$

Make $Q_i=\frac{dW_i}{dt}$, $Q_o=\frac{dN_p}{dt}$, $Q_w=\frac{dW_p}{dt}$ fed into the formula (8), then

$$Q_i=\frac{\ln A_1-\ln A_2}{B_1}Q_o+\frac{B_2}{B_1}Q_w \quad (9)$$

In the formula: Q_i represents the annual water injection rate, 10^4 m^3; Q_o represents the annual oil production rate, 10^4 m^3; Q_w represents annual water production rate, 10^4 m^3.

After finishing transform with (9), we have

$$Q_i=\left(\frac{\ln A_1-\ln A_2}{B_1}+\frac{B_2}{B_1}\frac{f_w}{1-f_w}\right)Q_o \quad (10)$$

Formula (10) is the relationship between annual oil production rate and annual water production rate of different water cut stages. By making regression fitting with practical development data of SZ Oilfield we can get A_1, A_2, B_1, B_2 and the prediction of reasonable water injection rate: regression fitting regression fitting regression fitting regression fitting.

$$Q_i=\left(0.0909+1.4368442\frac{f_w}{1-f_w}\right)Q_o \quad (11)$$

The formula (11) considers the factors of adjustment and measures based on oilfield development course and law. This method is more reasonable if there is no significant adjustment of the oilfield. By using this formula we can predict the reasonable injection water rate of SZ Oilfield in year 2014 and guide water injection.

Draw the annual water injection rate and annual oil production rate chart of different water cut stage of SZ Oilfield according to the formula (11), according to the chart we can predict annual water injection rate on the condition of different production rate and different water cut stage, as shown in Figure 1.

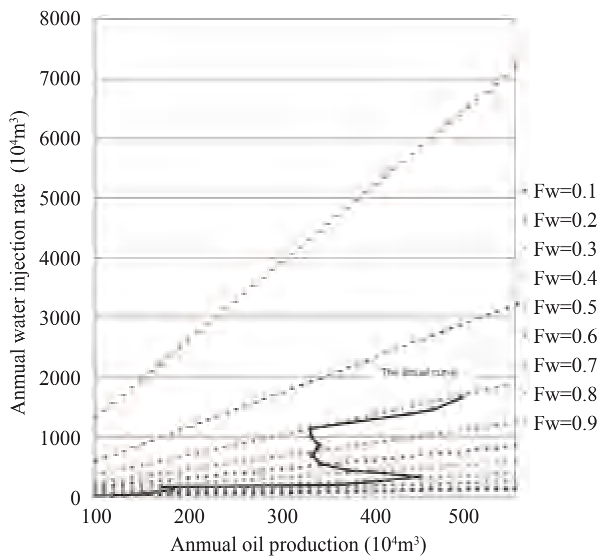

Figure 1
Chart of the Annual Water Injection Rate and Annual Oil Production Rate of Different Water Cut Stage of SZ Oilfield

2. OPTIMIZE INJECTION ALLOCATION METHOD TO ENSURE THE OIL FIELD 'INJECT WELL'

'Inject well' is more significant on the premise of 'inject enough', to determine the injection allocation method is the prerequisite[7-11]. The number of wells and ttt he oil-water relationship has changed with development and comprehensive adjustment of SZ Oilfield. Problems gradually exposed: the split coefficient has changed of individual well group which failed to corrected in time;

Oil field injection allocation has been considered only for single well, not accurately to layer which gf failed to consider the corresponding oil-water wells connectivity during injection allocationinjection prorationinjection prorationinjection prorationinjection allocation, also Some wells have cross streamline. The oilfield has optimized injection allocation method in year 2013 in view of the problems exposed.

The method counts the net pay and permeability of each layer of each well, and sssspssfsplits liquid rate of production wells by *Kh*, then gets a reasonable water allocation amount by adjusting injection production ratio. At the same time, teases the connectivity of production and injection wells in each layer, and optimize the method according to reservoir dynamic recognition. The result shows that the new method is more reasonable by changing flow field distributionflow field distribution and increases oil production rate. As an example of well C32, the well is mainly affected by 4 water injection wells (As shown in Figure 3). By using the new method, the injection allocationinjection allocation of group reduced 185 m^3/d in February, but the water cut has sharply declined (As shown in Figure 4).

Figure 2
Group of Well C32

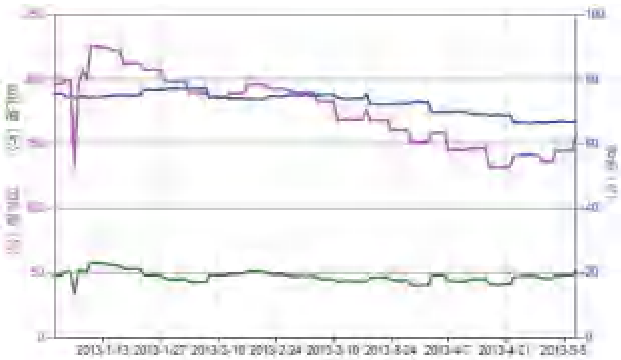

Figure 3
Curve of Well C32

Table 1
The Injection Well Change Table of Optimization of Injection Allocation Method

Well name	The injection volume and injection allocation rate difference between February and January (m^3/d)				
	First sand section	Second sand section	Third sand section	Fourth sand section	The whole well
A28	-257	76	-16	0	-197
A32	-3	-73	-63	2	-138
C5	0	-140	0	0	-140
C9	-64	409	49	-104	289
sum	-325	272	-30	-102	-185

3. RECOGNIZE LOW EFFECTIVE AND INEFFECTIVE INJECTION CIRCULATION TO GUIDE THE OILFIELD 'INJECT EFFECTIVELY'

The injected water usually causes water channeling along the dominant channel because of heterogeneity and injecting with the sand section, which can cause water waste and bring to adversely affect to development. By testing injection profile we can recognize which layers are water channeling, thus water plugging measures can put forward. Because of the large amount of work in platform and the limitative test plan we process a comprehensive evaluation method for recognizing low effective and ineffective injection circulation by using fuzzy mathematics method[12]. Based on the characteristic of low effective and ineffective injection circulation, the method selects sensitive parameters and analyzes influence weight of the parameters, then establishes the evaluation criteria and evaluates by mathematical method.

The method is applied to the platform J, the results are as follows:

Table 2
The Well Parameter Weight of Effective Water Circulation Layers in Platform J

Influencing factors	Weight	Influence parameters	The weight of each parameter	
			Injection well	Production well
Static factors	0.3	The whole well permeability	0.25	0.25
		Net thickness	0.3	0.3
		Permeability variation coefficient	0.45	0.45
Dynamic factors	0.7	Daily water injection rate	0.175	0.3
		Injection pressure	0.125	0.3
		injectivity index per meter	0.3	0.15
		The thickness of cumulative water injection unit	0.4	0.25

Table 3
The Low Effective and Invalid Water Cycle Evaluation Results of Production Wells in Platform J

Well ID	Evaluation index	Effect evaluation
J21	0.13	Normal production
J22	0.16	
J20	0.23	
J19	0.23	
J16	0.36	Low effective circulation
J11	0.41	
J1	0.63	
J5	0.68	Invalid cycle
J9	0.73	
J13	0.71	
J12	0.79	
Ave	0.46	

Table 4
The Low Effective and Ineffective Injection Circulation Results of Platform J

Well ID	Evaluation index	Effect evaluation
J10	0.23	Normal production
J2	0.27	
J4	0.45	Low effective circulation
J15	0.49	
J6	0.63	
J3	0.66	
J14	0.78	ineffective circulation
J8	0.89	
Ave	0.55	

As can be seen, the injection wells which recognized low effective and ineffective injection circulation that corresponding production wells are also low effective and ineffective injection circulation (As shown in Figure 4). And the PI test results of these wells are low (as shown in Table 5). According to the analysis and test results, the whole plug measures of platform J proposed in 2013 with 4 wells (J4, J8, J14, J15), which achieved good results.

Therefore, the proposed method has applicability and good accuracy, especially can give correct judgment for PI which cannot be measured or has less well testing data, which deepens the reservoir research at the same time, also saves the cost of testing.

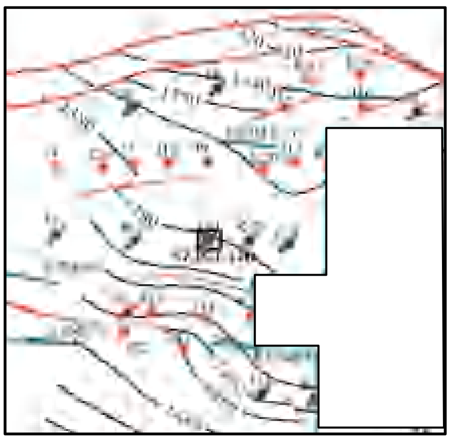

Figure 4
Platform J

Table 5
PI Index Test Results Table of Platform J

Well ID	PI	Remarks
J4I	5.2	The average PI=6.4 of injection well in platform J (2012.6)
J8I	5.3	
J8II	5.1	
J14II	4.4	
J15II	5.5	

CONCLUSIONS

a. The paper gets relationship between annual oil production rate and annual water production rate of different water cut stages of SZ Oilfield with the life cycle theory and draws the annual water injection rate and annual oil production rate chart for predicting injection water rate.

b. The paper optimizes injection allocation method of SZ Oilfield and gets a more accurate and reasonable result.

c. The paper puts forward a new method to recognize low effective and ineffective injection circulation and guides injection wells plug which achieves good results.

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