Numerical Simulation Study for Water Breakthrough Law of Horizontal Well in Edge Water Reservoir

SUN Guangyi[a],*; ZHANG Jianmin[a]; LEI Yuan[a]; WANG Yuejie[a]; CHANG Huijiang[a]; ZHAI Shangqi[a]

[a] Bohai Petroleum Research Institute, Tanggu, Tianjin, China.
*Corresponding author.

Abstract

There are abundant research achievements for water breakthrough law of horizontal well in bottom water reservoir, but fewer in edge water at home and abroad. BZ Oilfield of Bohai Bay has characteristics of active edge water, well pattern of directional and horizontal wells. At present, there is a lack of understanding of water breakthrough law of horizontal well in edge water reservoir. The paper established a method considering permeability heterogeneity for identifying water breakthrough position of horizontal well in edge water reservoir by using numerical simulation. It has proved that this method is feasible and reliable in BZ Oilfield. Combined with *WI* decision in breakthrough, put forward some measures for stabilizing oil production and water control, guided the implementation of oilfield measures and stable production.

Key words: Edge water; Horizontal well; Water breakthrough position; Numerical simulation; Heterogeneity

INTRODUCTION

Horizontal wells have high initial capacity, large drainage area and other advantages, are widely used in land and offshore[1-3]. Complex fluvial reservoir of Bohai bay has characteristics of thin bed thickness, distribution of instability and active edge water. Due to complex geological conditions, low productivity of vertical wells, conventional well networks are difficult to effectively drive, development with horizontal well has greater advantage. At present, Bohai fluvial oilfield had formed development technology of single sand body by using horizontal well, and achieved good results. BZ oilfield is active in edge water, the horizontal wells are relatively large proportion of the number of wells, about62%. With the development of the oilfield, the horizontal wells gradually flooded or formed water breakthrough, thus the natural decline rate increasing greatly. Studying on water breakthrough law of horizontal well in bottom water, then puts forward measures for stable production and water control, relieves decline, is urgently needed and very important for output programming.

There are abundant research achievements for water breakthrough law of horizontal well in bottom water reservoir, but fewer in edge water[4-6]. In addition, to offshore oilfield the horizontal well test costs high, the research puts forward a new and simple method for identifying water breakthrough position of horizontal well in edge water by dynamic analysis, which saving money and promoting effect.

1. ESTABLISHMENT OF THE THEORETICAL MODEL OF HORIZONTAL WELL IN EDGE WATER

The research of water breakthrough pattern of horizontal well should be established for the foundation with a reasonable geological model, the paper uses X sand body of BZ Oilfield to establish model, Parameters are actual and representational. There is only one horizontal well witch relying on the energy of edge water.

1.1 Parameters of Theoretical Model

The research considered complexity, heterogeneity and anisotropy of the reservoir when establishing model. The reservoir parameters are shown in Table 1.

Table 1
Model Parameters

Name	Value
Reservoir depth (m)	1,657
Reservoir thickness (m)	10
Reservoir pressure (MPa)	16.6
Porosity (%)	30
Oil saturation (%)	68
Reservoir oil viscosity (mPa·s)	8
Horizontal permeability ($\times 10^{-3}$um^2)	1,500
Vertical permeability ($\times 10^{-3}$um^2)	150

1.2 Grid Division

Grid numbers of X-direction are 42, Y-direction are 30, length of grid are 50 m. The Z direction is divided into 12 layers, thickness of each layer is 1m. There is edge water in reservoir.

2. ADAPTABILITY OF THE MODEL

In order to ensure the applicability of the theoretical model in the research process, established geological models with different permeability, distances and well locations. Research shows that the laws of water cut change rate curves are almost consistent (Figures 1-3). Thus, the model is general and universal.
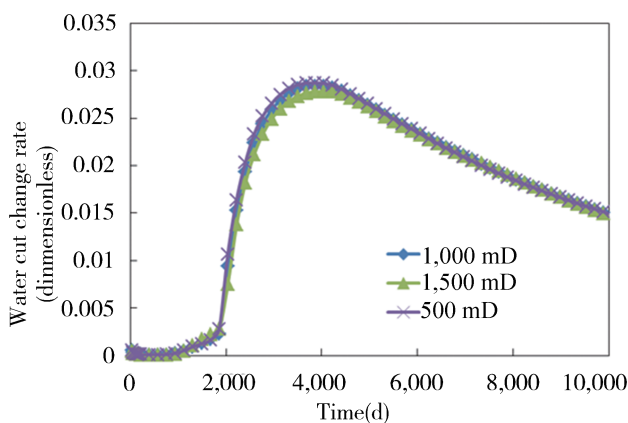

Figure 1
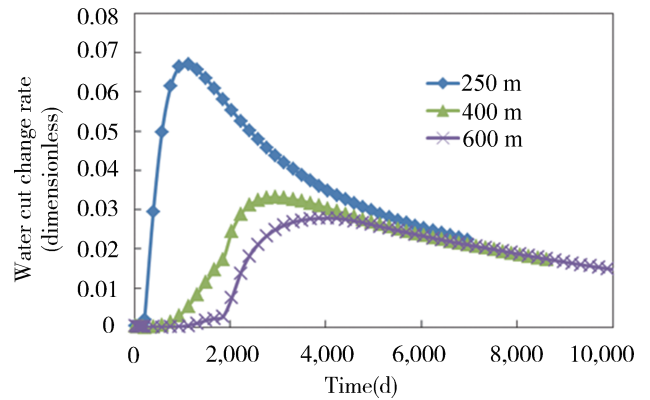**Water Cut Change Rate Curves of Different Permeability**

Figure 2
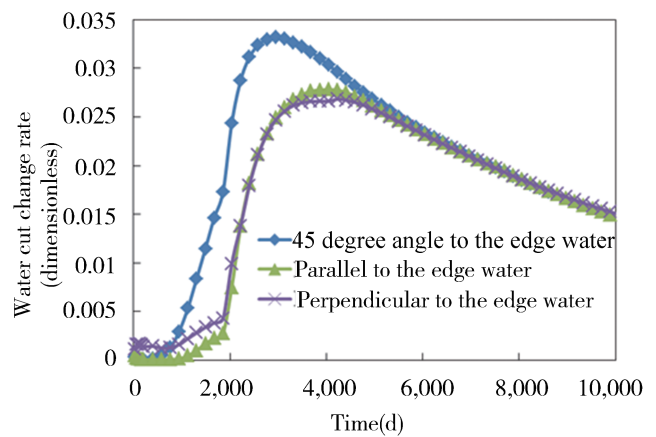**Water Cut Change Rate Curves of Different Distances from Edge Water**

Figure 3
Water Cut Change Rate Curves of Different Well Locations

3. STUDY FOR WATER BREAKTHROUGH LAW OF HORIZONTAL WELL IN EDGE WATER RESERVOIR

The research simulated three water types of root，middle and linear of horizontal well by establishing high permeability stripe, quantitative parameter is water cut change rate, other parameters are section water distribution and residual oil distribution. The research introduced permeability inhomogeneity coefficient K_R to characterize the effect of reservoir heterogeneity on the horizontal well water breakthrough law, where K_R is the ratio of the average permeability and the highest permeability. Simulated 7 schemes of water breakthrough in edge water from root and middle (Table 2).

Table 2
Table of Simulation Program

Program	K_R
1	0.3
2	0.15
3	0.075
4	0.06
5	0.05
6	0.0375
7	0.03

The simulation shows that there are two peak values of water cut change rate curves for the case of water breakthrough from root. According to the well section water distribution, the first peak indicates water breakthrough form root, the second from the whole well. Generally speaking, the stronger heterogeneity, the higher peak value, the faster water breakthrough from root (Figure 4).
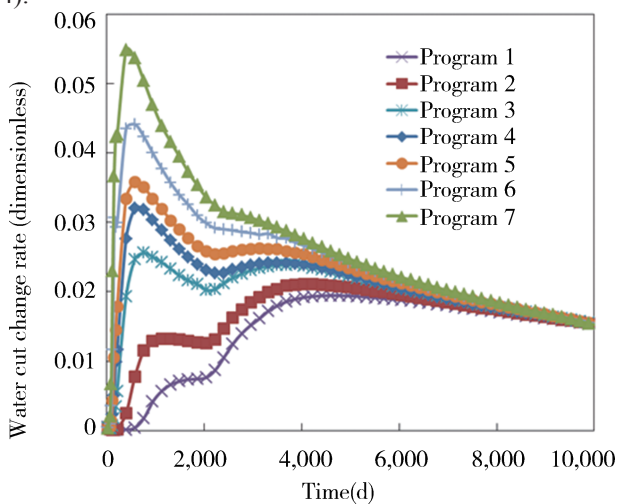

Figure 4
Water Cut Change Rate Curves When Water Breakthrough from Root in Horizontal Well of Different K_R

The simulation shows that water cut change rate curves relatively smoothly and there are two peak values of water cut change rate curves for the case of water breakthrough from middle when high heterogeneity, and only one peak when low. According to the well section water distribution, the first peak indicates water breakthrough form middle, the second from the whole well. Generally speaking, the second peak value is higher than the first, the reason is the water change rate is more intense when water breakthrough form root and the whole well (Figure 5).
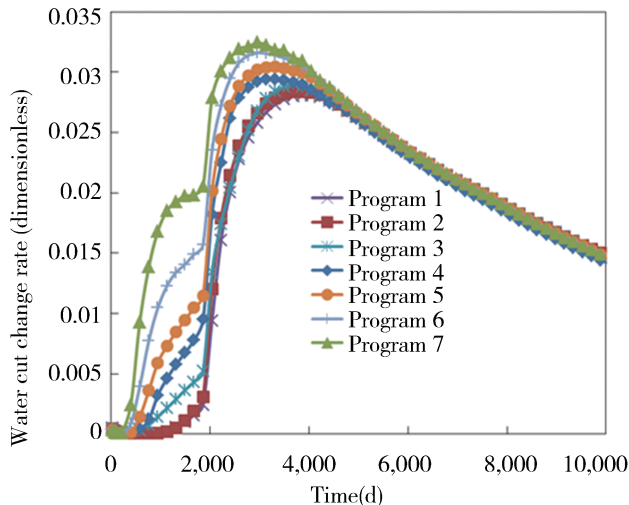

Figure 5
Water Cut Change Rate Curves When Water Breakthrough from Middle in Horizontal Well of Different K_R

The results show that the law of water breakthrough form root in case of less heterogeneity is similar with water breakthrough form middle in case of strong heterogeneity. So it is necessary to distinguish the two water breakthrough types. In root case, define demarcation point with the same peak value in case of water breakthrough from root and the whole well. In middle case, define demarcation point with the peak value in case of water breakthrough from middle. Thus the research established a method considering permeability heterogeneity for identifying water breakthrough position of horizontal well in edge water (Table 3).

Table 3
The Method Considering Permeability Heterogeneity for Identifying Water Breakthrough Position of Horizontal Well in Edge Water

Water breakthrough position	Water breakthrough type	K_R	Water brekthrough character
Root	Type I	<0.075	the peak vaule is higherin root than in the whole well
	Type II	>0.075	the peak vaule is lower in root than in the whole well
Middle	Type I	<0.075	the peak vaule is steep, and is lower than in the whole well
	Type II	>0.075	the peak vaule is stable, and is lower than in the whole well

Comparing of results of water breakthrough from root and middle indicates that in general the law of water cut change rate is higher in root than in middle. From the theoretical curve of BZ Oilfield, the law of water breakthrough form root when $K_R = 0.075$ is similar with water breakthrough form middle when $K_R = 0.3$. That is, character is similar when the permeability of high permeable zone in middle case is 4 times the root case (Figure 6).
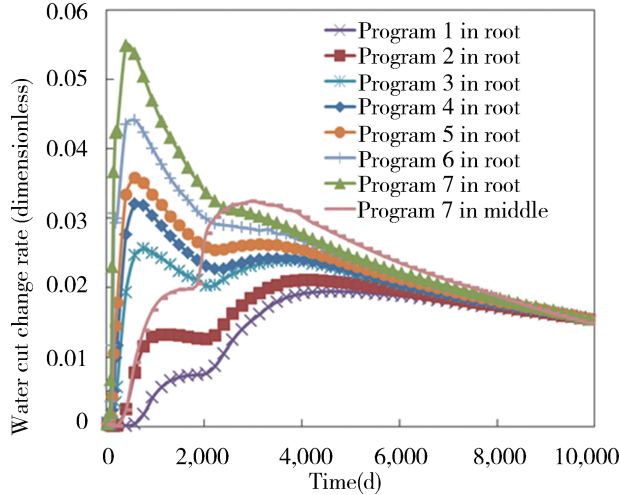

Figure 6
Comparison of the Characteristics of Water Breakthrough Position From Root and Middle

Water cut change rate feature can be explained by the horizontal wellbore pressure gradient model, that is, there is pressure drop in horizontal flow, which is associated with horizontal section length. The pressure drop is maximum in root and minimum in toe. There is a monotonic relationship between pressure gradient and permeability, the toe position requires a higher permeability to generate pressure drop which due to water breakthrough slowly.

The results show that water change rate increasing rapidly with a linear upward trend, which slowing down when water breakthrough from whole well, this condition usually appear when high heterogeneity (Figure 7), which is rarely happen in BZ oilfield.
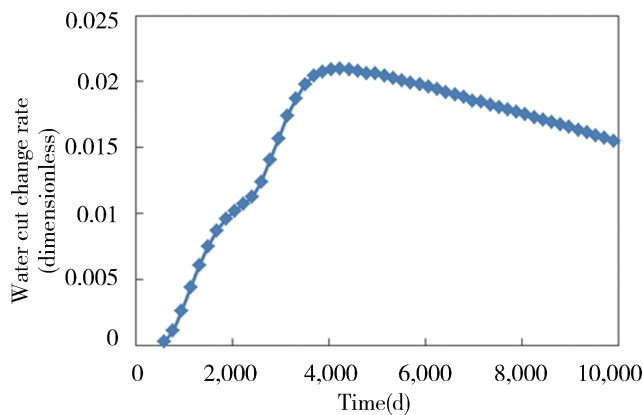

Figure 7
Water Cut Change Rate Curves of Linear

Verify the research methods in this paper according to the actual situation of oilfield. HOR1 is a horizontal well which affected by edge water, by analyzing, the well is in accord with middle-Ⅱ type character. The streamline simulation shows that the streamline in middle of the well is concentrated in early production, That is, edge water break form middle (Figures 8-9).
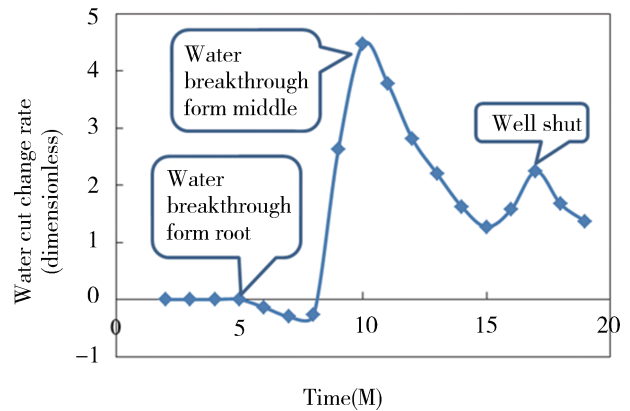

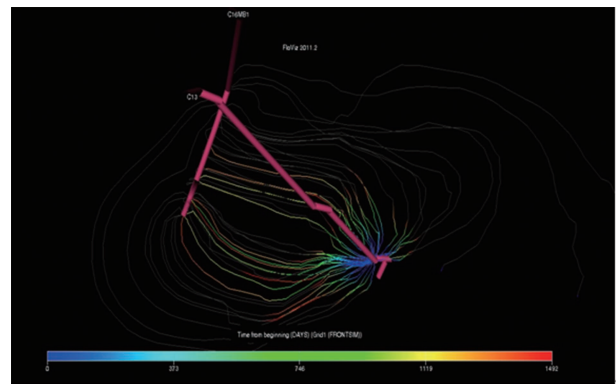**Figure 8**
Water Cut Change Rate Curves of HOR1

Figure 9
Streamline Simulation of HOR1

4. APPLICATION EFFECT

For type Ⅰ situation in both root and middle, There is percolation dominant channel because of the strong heterogeneity of the reservoir, water cut of horizontal well increased quickly, For this type of horizontal wells should be given priority to manage (Table 4).

Identify the water breakthrough position of horizontal wells in BZ Oilfield combined with *WI* decision in breakthrough, The greater *WI* value, the faster water invasion rate of wells, and greater risk of well water channeling , put forward measures of stabilizing oil and water control for this wells (Table 5). By the implementation of injection well measures and the comprehensive adjustment of oilfield in 2015, the oilfield achieved good development results: Oil stimulation rates were 7.97×10^4 m³. Oilfield water rising rate for the first time negative growth, and natural decline rate decreased by 8.1% compared with 2014.

Table 4
Measures for Stabilizing Oil Production and Controlling Water Cut

Water breakthrough position	Water breakthrough type	Reservior measures	Technology measures	Implementation level
Root	Type I	Improve the injectionpro duction relation ship & raising liquid production for potential well	Mechanical plugging	Priority
	Type II			
Middle	Type I		Chemical & mechanical plugging	Priority
	Type II			

Table 5
Identify Water Breakthrough Law of Horizontal Well in Edge Water and Suggestion of Measures for BZ Oilfield

Oilfield	Well name	Water breakthrough position	Water breakthrough type	WI	Suggestion of measures
BZ	A8h	Root	Type I	0.55	Raising liquid production & plugging
	A36h			0.16	improve the injection-production relationship
	A37h	Root	Type II	0.27	Raising liquid production & plugging
	A18h			0.24	improve the injection-production relationship
	A11h			0.15	Raising liquid production
	A12h	Middle	Type I	0.18	improve the injection-production relationship
	Average			0.26	

CONCLUSION

(a) Establish a theoretical model for studying water breakthrough law of horizontal well in edge water considering permeability heterogeneity, put forward methods for identifying water breakthrough position in root, middle, and linear.

(b) Practice has proved that the method is based on the production of dynamic, which is reliable and practical, saving the cost of testing. The method guided the identification of water breakthrough position of horizontal wells in edge and the implementation of water stable and water control measures in BZ oilfield.

(c) Discrimination method based on theory model of BZ Oilfield, when using in other oil fields, it should considering the characteristics and using flexible.

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