A New Method for Dynamic Recognition of Multi-point Water Breakthrough in Horizontal Wells

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Abstract

A horizontal well can achieve a higher oil productivity index than a vertical well under the same conditions, usually 3 to 10 times. At the same time, oil well drainage area is larger and waterless production period is longer. Especially for thin reservoirs and low permeability reservoirs, oil recovery can be significantly improved. However, water cut of horizontal wells rises rapidly after water breakthrough. Effective water control measures are important means to increase production of horizontal wells. The distribution characteristics of different permeability of fan delta marine sandstone are studied, and the typical permeability distribution models of homogeneous, two-member heterogeneous and three-member heterogeneous are proposed. By studying the mechanism model of numerical model of horizontal well development under different permeability distribution modes, this paper summarizes various water flooding modes and their corresponding dynamic curve response characteristics, puts forward a new method of multi-point water breakthrough dynamic identification of horizontal wells based on permeability distribution mode, establishes a typical water cut and cumulative oil production derivative curve template, and successfully guides a horizontal well to control water use this method. The water cut of the well decreases by 16% after water control, and the initial daily increase of oil reaches 130 m3/d, which shows that the method is practical and reliable.

Keywords

Horizontal Well, Multi-point Water Breakthrough, Observed Data, Recognition Methods.

1. Introduction

Horizontal wells are widely used in offshore oilfields for the development of edge and bottom water reservoirs. Under the restriction of offshore platform wellhead location, horizontal wells encounter long reservoir, large reservoir seepage area, high degree of reserves control, long waterless production period and low cost. However, in the production process of horizontal wells, water cut rises rapidly after water breakthrough, it is difficult to predict the outlet water level, and the distribution of remaining oil is not clear, which leads to the lack of purpose of water control measures. Water control is the main control measure after water breakthrough in horizontal wells. The judgment of water breakthrough mode and water outlet position is particularly important to the effectiveness of water control measures. Zhou Daiyu et al. analyzed the difference of water flooding dynamic characteristics of horizontal wells and its influencing factors, and put forward the linear water flooding model, the point water flooding model and the point water flooding model. Jiang Hanqiao put forward the application of water cut change rate and water-oil ratio derivative to judge the water production mode of horizontal wells. Sun Yanchun et al. proposed a quadratic derivative discriminant method of water content versus time based on permeability distribution characteristics. The practical application of the above method is greatly influenced by the fluctuation data of production performance, and its regularity and identifiability are not strong, and its operability is small. The water breakthrough position of horizontal wells is affected by reservoir type, reservoir physical properties, fluid properties, horizontal section length, horizontal section location and other factors. Generally, water breakthrough of oil wells is point water breakthrough. The accurate identification of the second point water breakthrough time is particularly important to grasp the timing of water control. In the follow-up, the water breakthrough position of horizontal wells is analyzed with specific geological reservoir parameters to control water and stabilize oil in time. Through numerical simulation study on permeability distribution characteristics of different horizontal sections, the dynamic characteristics and rules of production data change are summarized, and a method of identifying multi-point water breakthrough time of horizontal wells with cumulative oil production derivative curve is established, which has important guiding significance for the implementation of water control measures of horizontal wells.

2. Seepage Theory

Assuming that there are two holes in the two sections of a horizontal well, A1 and A 2, the potential generated by the convergence of A and B at a point M (x, z) in the reservoir is expressed as Formula 1 and Formula 2.

$$\Phi_1 = \frac{q_1}{2\pi} ln r_1 + C_1 \tag{1}$$

$$\Phi_2 = \frac{q_2}{2\pi} ln r_2 + C_2 \tag{2}$$

If the A1 and A2 holes in the wellbore are produced at the same production rate, i.e. Q1 = q2, then according to the potential superposition theory, the M-point potential can be expressed as formula 3, the ridge shape is symmetrical double wave type, and the water can be seen in both holes at the same time.

$$\Phi = \frac{q}{2\pi} ln(r_1 r_2) + C_3 \tag{3}$$

If the whole horizontal section of a horizontal well is considered to be composed of multiple holes, the superposition potential generated at any point in the reservoir can be expressed as Formula 4 when the production of each hole is equal. The distribution of the isopotential line shows that the foreseeable water in the middle extends to both wings.

$$\Phi = \frac{q}{2\pi} ln(r_1 r_2 \ldots r_i) + C_3 \tag{4}$$

If there is unequal production of A1 and A2 holes in the wellbore, i.e. q1_q2, then according to the potential superposition theory, the M-point potential can be expressed as Formula 5, and the isopotential line shows that the wave peak of the high-yield hole is large, the prescient water is small, and the small-yield hole wave peak is small, then the water is visible, and the oil detention area moves towards the small-yield hole.

$$\Phi = \frac{1}{2\pi} \left(\frac{q_1}{ln r_1} + \frac{q_2}{ln r_2}\right) + C_3 \tag{5}$$

Similarly, the whole horizontal section of a horizontal well is considered to be composed of multiple holes. When each hole produces unequal production, the superposition potential generated at any point in the reservoir can be expressed as Formula 6. The production of each hole in each horizontal well will determine the shape of the water ridge along the wellbore direction.

$$\Phi = \frac{q}{2\pi} ln(r_1 r_2 \ldots r_i) + C_3 \tag{6}$$

In a certain section of a horizontal well, one-dimensional piston displacement is assumed, without considering gravity and other factors. Water content is 100% when water is seen at the production end. If K is high: K is low = 2:1, then the seepage velocity is the same 2:1. The calculation shows that when water breaks through, the recovery degree of high permeability is 100%, the permeability of low permeability is 50%, and the whole is 75%. At this time, the water content is 66.7%, and the water content rises step by step. In the same way, three microelements are taken, K is high: K is middle: K is low = 4:2:1, the overall water content of initial water is 57.1%, the recovery degree is 58.3%, the seepage water appears step, the overall water content is 85.7%, and the recovery degree is 83.3%. From the curve, we can see that the number of steps is the number of micro-elements of water, the heterogeneity is stronger than water, the curve is "convex" and the number of micro-elements can be identified by water cut breakthrough point (Fig. 1).

According to the results of three-dimensional physical simulation experiment of horizontal wells in heterogeneous bottom-water reservoirs carried out by Liu Xinying, when horizontal heterogeneity distributes along three-stage horizontal wells, the water cut of horizontal wells rises step by step, and the number of steps is consistent with the number of high permeability intervals continuously distributed. The results are consistent with the theoretical analysis. The reliability of judging the water breakthrough mode of horizontal wells based on the characteristics of production dynamic data is verified by theoretical and physical simulation.

In the actual production process, it is difficult to identify the above curve characteristics by using single well daily production dynamic data curve because of the large fluctuation of production data and the disorder of data points. Therefore, this paper presents the method of derivative curve of water cut to cumulative oil production to judge and summarize the water breakthrough mode of horizontal wells.

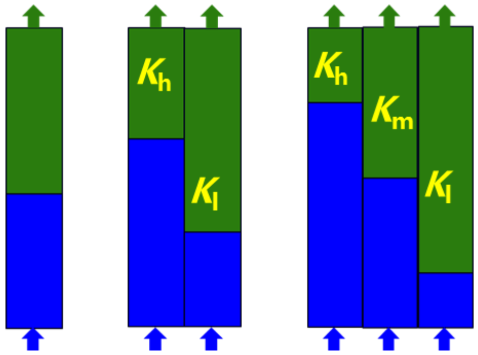

Fig.1 Schematic diagram of one-dimensional piston displacement under ideal conditions

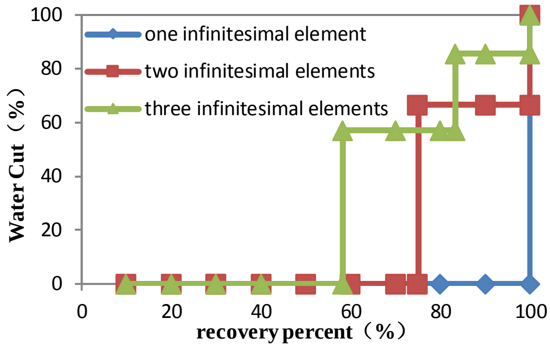

Fig.2 Curve of relationship between water cut and recovery percent

3. Establishment of a new method

Using Eclipse numerical simulation software, a black oil development model for horizontal wells in bottom water reservoirs with different permeability distribution modes along the horizontal section is established. The geological reservoir parameters of the model refer to the actual data of the oilfield.

3.1 Typical Curve Characteristics of Homogeneous Reservoir

For the development of horizontal wells in homogeneous reservoirs, the numerical simulation results show that after water breakthrough, the whole horizontal section is flooded and the whole section is watered out. From the relationship curve between water cut derivative and cumulative oil production, it has the characteristic of "single peak" (fig. 2). That is to say, there is an obvious peak value in the water cut derivative curve of horizontal wells. In anhydrous period, the derivative value is 0. After water breakthrough, the derivative value increases rapidly. The water breakthrough curve of horizontal wells reaches its peak value. Later, the curve drops slowly, the rising speed of water cut slows down, and the wings of water ridge rise slowly.

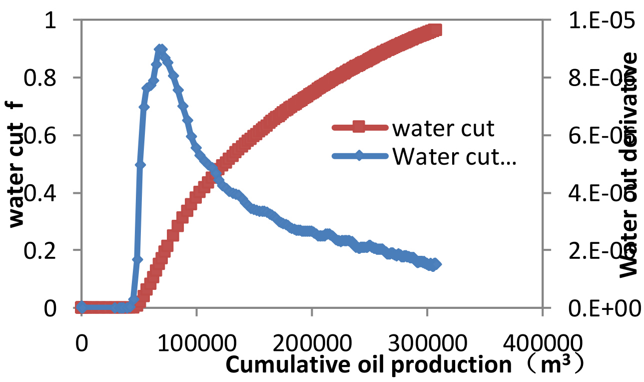

Fig.2 Curve of relationship between water cut, Water cut derivative and Cumulative oil production

3.2 Typical Curve Characteristics of Two-member Heterogeneous Reservoir

Taking the midpoint of horizontal section of horizontal well as the demarcation point, the permeability of reservoirs on both sides is assigned to different permeability, thus forming an ideal two-stage heterogeneous model with different permeability gradient distribution. The numerical simulation shows that the bottom water advances first along the high permeability section, and when water breaks through in the high permeability section, the reservoir in the low permeability section is not flooded, showing a step-like advance along the wellbore profile. The larger the permeability gradient, the faster the water breakthrough in the high permeability zone. According to the formation coefficient splitting method, the larger the proportion of liquid production in the high permeability zone, resulting in the deformation of the water ridge, which is consistent with the theoretical analysis. From the water content curve (fig. 3), it is impossible to recognize the two characteristics of successive water-seeing. From the derivative curve of water content to cumulative oil production, the curve shows the characteristics of "double peaks". That is, with the advancing of bottom water, the first water in the high permeability section, the derivative curve rises sharply, the curve falls after flooding in the whole high permeability section, and the curve rises again rapidly after flooding in the low permeability section. After all flooding in the low permeability section, the curve reaches the second peak value, and the water flooding derivative curve in the whole well section begins to drop.

In order to consider the identifiability of curves under different permeability gradients, the mechanism models of permeability gradients 2, 3, 4, 5, 10, 20 and 40 are studied. The results show that the method has better identifiability in the permeability gradient of 3-10. When the permeability gradient is 2, it can be regarded as homogeneous treatment. When the permeability gradient is more than 10, according to the formation coefficient splitting method, it can be seen that the ratio of liquid production in low permeability section is small, and the influence of pure oil production and water breakthrough in this section on the water cut of the whole wellbore is small, and the wave crest is not obvious.

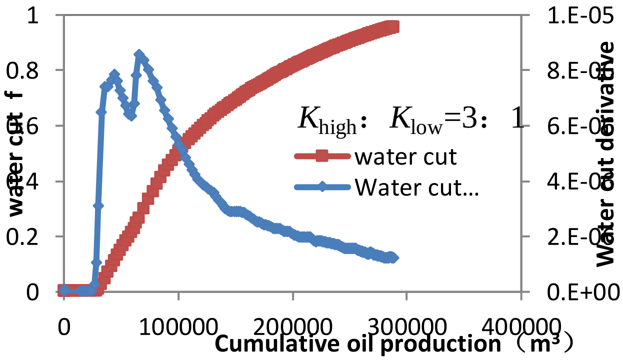

Fig.3 Curve of relationship between water cut, Water cut derivative and Cumulative oil production

3.3 Typical Curve Characteristics of Three-member Heterogeneous Reservoir

For horizontal wells in offshore oilfields, in general, according to the interpretation of interlayer distribution by logging while drilling, multiple external sealing tubes are placed at the corresponding interlayer at completion to meet the follow-up central water control requirements, usually about two. According to the actual situation, this ideal model considers the three-stage distribution model of permeability. The reservoir model is divided into three sections with the boundary of the trisection points along the wellbore. Considering certain permeability gradient distribution and arrangement of high, medium and low permeability, the reservoir model is divided into three sections. Seen from the water-seepage model (fig. 4), the three-stage model is similar to the two-stage model, that is, within a certain permeability gradient, the high permeability section, the middle permeability section and the low permeability section see water successively, showing "three peaks" in the water-cut derivative curve.

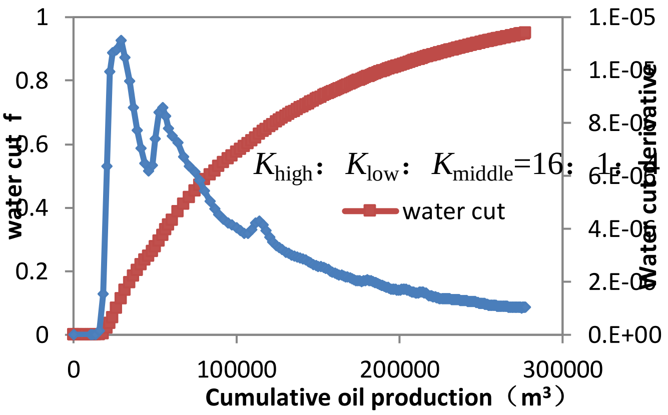

Fig.4 Curve of relationship between water cut, Water cut derivative and Cumulative oil production

According to the number of peak values of the curve, this method can judge the water-breaking mode, thus providing water-finding support for water control in horizontal wells. It is not practical to judge the number of integral curve peaks according to the ultra-high water cut period. In the actual production process of oil wells, there is water control demand for horizontal wells in the middle and high water cut period. In daily dynamic management, the shape of the curve can be closely observed. If the derivative curve appears obvious upward warping, it means that the second point of water breakthrough occurs. At the same time, the reliability of water control operation can be improved by synthetically judging the water point based on the distribution of permeability along the wellbore and the relationship between oil level and other data.

4. Case application

The effective length of horizontal section of A1H well in W oilfield is 620m, and the drilling rate is 90%. Non-neutron density logging, combined with resistivity curve analysis, the overall resistivity value of horizontal section is higher, and the resistivity of fingertip is slightly lower than that of heel and middle section. Based on the analysis of comprehensive geological data, it is concluded that the water breakthrough model of this well may be a piecewise point flooding water breakthrough model. Judging by the derivative curve method of cumulative oil production with water content, it can be seen that a sudden upward warping point appears after a horizontal section, that is to say, the second water point appears, and there is no peak value after the upward warping, that is, the second section is not completely flooded. Combining with numerical simulation software analysis, it is predicted that the toe end of A1H well will be completely flooded, while the heel end and middle section will be partly flooded.

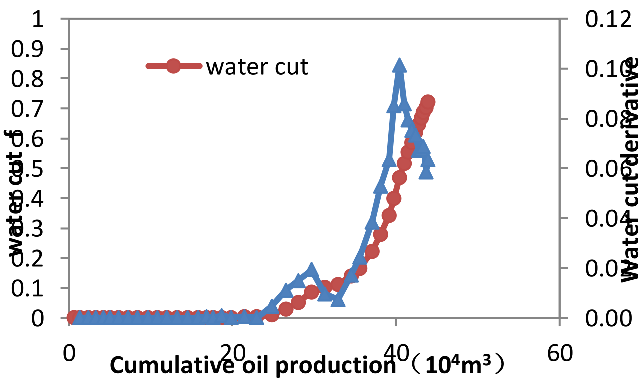

Fig.5 Curve of relationship between water cut, Water cut derivative and Cumulative oil production

The well implemented water control measures in early 2018, stuck toe and middle section, and produced heel separately. Before water control, 363 cubic meters per day were produced with water content of 72.2% and oil production of 104 cubic meters per day. After water control, 543 cubic meters per day of liquid production, 56.2% of water content and 234 cubic meters per day of oil production were produced. After water control measures have been implemented, 130 square meters of oil per day has been increased and water cut has been reduced by 16%, which is consistent with the predicted results of water level. It lays a foundation for dynamic monitoring, identification and water control measures of other oil wells in the future.

5. Conclusion

(1) Through the study of mechanism model of horizontal wells, the "peak" characteristics of cumulative oil production derivative curve with point water breakthrough are summarized, and the judgment method basis of multi-point water breakthrough is put forward, which provides a new judgment method for reservoir dynamic managers.

(2) The new method has been applied to A1H well in W oilfield. The two water breakthrough points of the well have been identified successfully, and the water control operation has been guided. The good effect of increasing oil by 130 m^3/d has been achieved, which proves the reliability of the method.

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