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Adaptability of Development Methods for Offshore Gas Cap Edge Water Reservoirs under Different Permeability Levels

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Abstract

The BZ 34-1 oilfield is a typical gas cap edge water reservoir in the Bohai oilfield. The main characteristics of the oilfield were multi-phase sand body stacking and the sand body was composed of three parts: gas cap, oil reservoir, and edge water. The actual production site results show that the permeability difference of multi-layer sand bodies has a serious impact on the development effect. This article establishes a typical reservoir model numerical model based on the total recovery degree of the reservoir and the recovery degree of each layer, and analyzes the impact of permeability gradient. As the permeability gradient increases, the total recovery degree of all four well patterns decreases, and the total recovery degree gradually decreases. The recovery degree of low permeability layers gradually decreases, and the recovery degree of high permeability layers gradually increases. As the permeability gradient increases, the degree of recovery gradually decreases under different water contents. As the permeability gradient increases, the reduction rate of remaining oil saturation in low permeability layers is slower, while the reduction rate of remaining oil saturation in high permeability layers was faster. By analyzing the impact of permeability gradient on the development effect of oil fields, we could further deepen our understanding of gas cap edge water reservoirs and guide the development of this type of oil field.

Keywords

Bohai Sea, Gas Cap and Bottom Water Reservoir, Permeability Gradient, Well Pattern, Recovery Degree

1. Introduction

The BZ 34-1 complex fault block oilfield has a variety of reservoir types, including both edge and bottom water reservoirs and gas cap reservoirs. Its river channel is narrow, multiple sand bodies are stacked, and the distribution of oil, gas, and water is complex. The distribution of remaining oil is complex, and it is difficult to tap potential.

The unclear rules of oil and water movement, remaining oil distribution, and potential size in the vertical and horizontal directions of oil fields have resulted in imbalanced injection and production of oil fields with fast bottom water coning speed, and increasingly prominent contradictions between layers, planes, and within layers [1] [2] [3]. The main problems are as follows:

1) Complex fault block reservoirs have strong heterogeneity, obvious injection production contradictions, incomplete or unsuitable well networks for newly added reserves, and are affected by factors such as reservoir heterogeneity, fluid heterogeneity, and injection production relationships. The breakthrough of injected water in a single layer is severe, resulting in uneven oil well efficiency, poor water drive effect, and severe decline in production [4] [5].

2) Due to the dense distribution of complex fault blocks in the oilfield, small differential pressure between ground and saturation, insufficient natural energy, and large vertical permeability range, the vertical utilization of reservoirs is uneven; Narrow river channels, multiple overlapping sand bodies, complex distribution of oil, gas, and water, complex distribution of remaining oil, and great difficulty in tapping potential [6] [7] [8].

3) The formation pressure has decreased, but some water injection wellhead pressures are too high to inject [9].

4) Some wells have a rapid increase in water content and a significant decrease in production [10] [11].

The main development method for multi-layer gas cap edge water reservoirs in the BZ 34-1 oilfield is irregular well networks, but this development method has limitations for such reservoirs. Therefore, it is necessary to conduct development technology research for multi-layer gas cap edge water reservoirs. In the research on the development of multi-layer gas cap edge water reservoirs, the focus of the research is on how to achieve reasonable collaborative exploitation of the oil ring under the influence of gas cap energy and water body energy, analyze the impact of permeability difference on recovery degree, reduce oil gas mutual migration, and maintain the stability of the oil gas interface.

2. Comparison of Total Recovery Degree of Different Well Patterns

Based on the typical reservoir model of the gas cap edge water reservoir in the BZ 34-1 oilfield, a numerical model of the typical reservoir model is established to study the factors affecting the development effectiveness of multi-layer gas cap edge water reservoirs.

Firstly, the total recovery degree of different well networks was compared, with a gas cap index of 0.33, a water body multiple of 0.24, permeability differences of 1, 3, 7, and 15, and an oil recovery rate of 3%. Based on this, the effects of permeability differences and well network changes on the total recovery degree were studied.

From **Figure 1**, it can be seen that as the permeability difference increases, the total recovery degree of all four well patterns decreases. This is due to the increase in permeability difference and more severe interlayer interference, resulting in a gradual decrease in oil mobility in the reservoir and a decrease in development effectiveness. Meanwhile, compared with the four types of well networks, the five point well network has the highest recovery degree, while the triangular well network has the worst recovery degree. In addition, as the permeability difference increases, the difference in recovery degree among the four types of well networks gradually increases.

3. Comparison of Recovery Levels of Each Layer

Taking the reverse nine point method well pattern as an example, compare the recovery degree of different layers, and based on this, study the impact of permeability difference changes on the recovery degree of each layer.

From **Figure 2**, it can be seen that as the permeability difference increases, the total recovery degree gradually decreases, the recovery degree of low permeability layers gradually decreases, and the recovery degree of high permeability layers gradually increases. However, the increase in the recovery degree of high permeability layers is not as significant as the decrease in the recovery degree of low permeability layers, resulting in a gradual decrease in the total recovery degree of the two. This is because as the permeability difference increases, the permeability of low permeability layers gradually decreases, and the permeability of high permeability layers gradually increases, However, due to the influence of interlayer interference, the larger the permeability difference, the lower the total recovery degree. Therefore, for multi-layer reservoirs with high permeability differences, it is recommended to develop them in layers. **Figures 3-5** show the variation of recovery degree with permeability gradient for the other three well patterns, with the same pattern as the reverse nine point method well pattern.

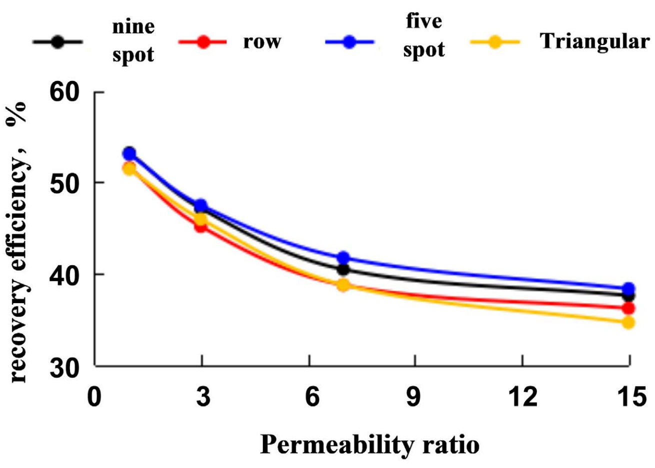

Figure 1. Variation of recovery degree with permeability gradient for different well patterns.

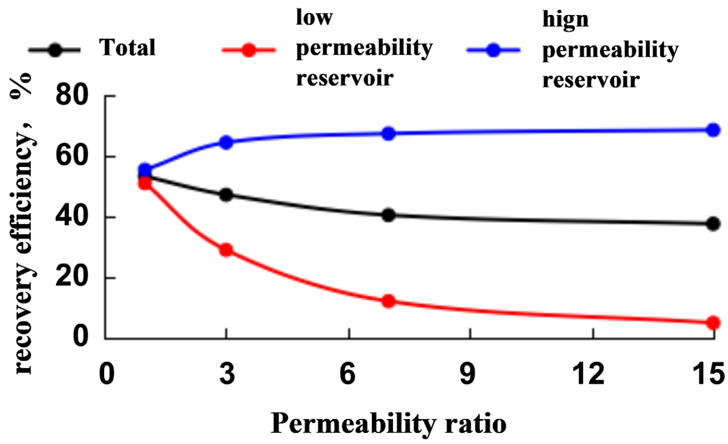

Figure 2. Variation of recovery degree with permeability difference in the reverse nine point method well pattern.

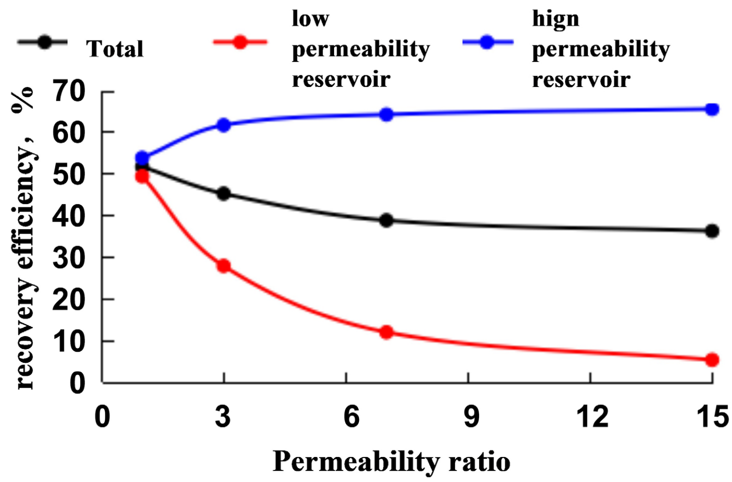

Figure 3. Variation of recovery degree with permeability gradient in a row shaped well network.

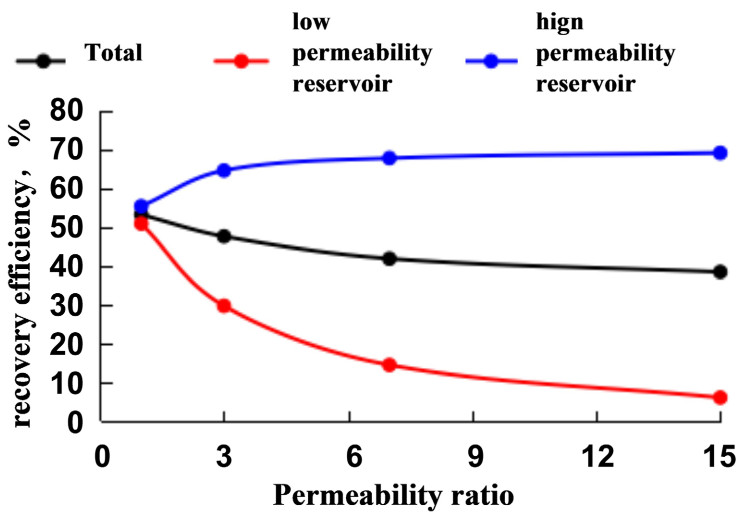

Figure 4. Variation of recovery degree of five point well pattern with permeability difference.

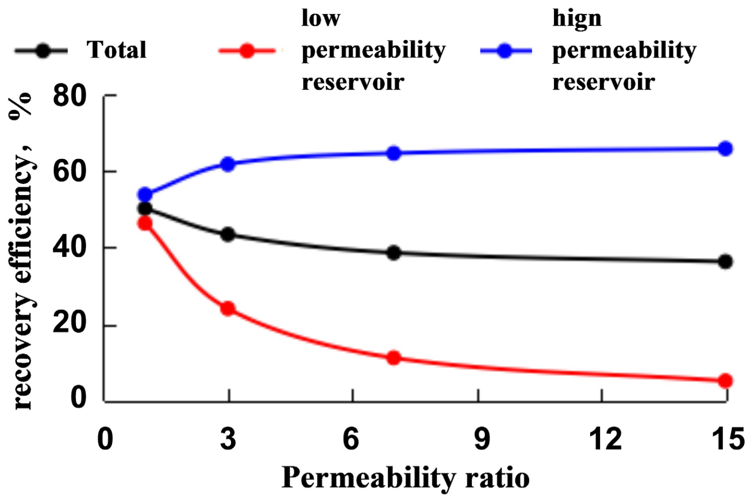

Figure 5. Variation of recovery degree of triangular well network with permeability gradient.

4. Comparison of Recovery Degree under Different Water Content

Taking the inverse nine point method well pattern as an example, compare the recovery degree under different water content, and based on this, study the influence of permeability difference and water content change on the recovery degree of each layer.

Figure 6 shows the variation of recovery degree with permeability level difference under different water content in the inverse nine point method well pattern. It can be seen that as the permeability level difference increases, the total recovery degree gradually decreases, and the recovery degree also gradually decreases under different water content. As the water content gradually increases, the increase in recovery degree gradually increases for every 20% increase in water content, especially during the medium to high water content period, when the recovery degree increases the most during the 60% to 80% water content period. **Figures 7-9** show the variation of recovery degree with permeability gradient for three other well patterns with different water content, and the pattern is the same as that of the inverse nine point method well pattern.

5. Comparison of Remaining Oil Saturation Field Maps

Taking the inverse nine point method well network as an example, compare the changes in oil saturation field maps under different permeability levels, and analyze the impact of different permeability levels on the distribution of remaining oil in two layers.

Figures 10-13 show the residual oil saturation field under different permeability levels in the inverse nine point method well network. It can be seen that as the permeability level difference increases, the reduction rate of residual oil saturation in the low permeability layer is slower, while the reduction rate of residual oil saturation in the high permeability layer is faster. When the permeability

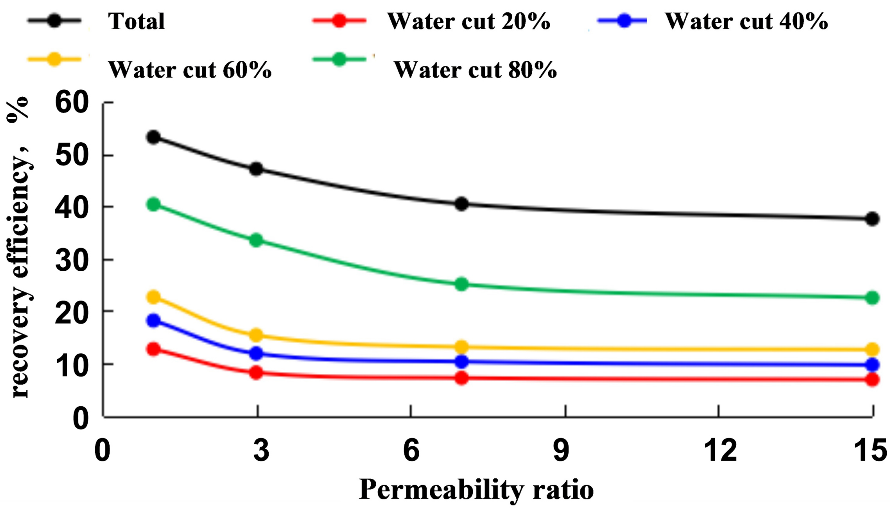

Figure 6. Variation of recovery degree with permeability differential under different water content in the reverse nine point method well pattern.

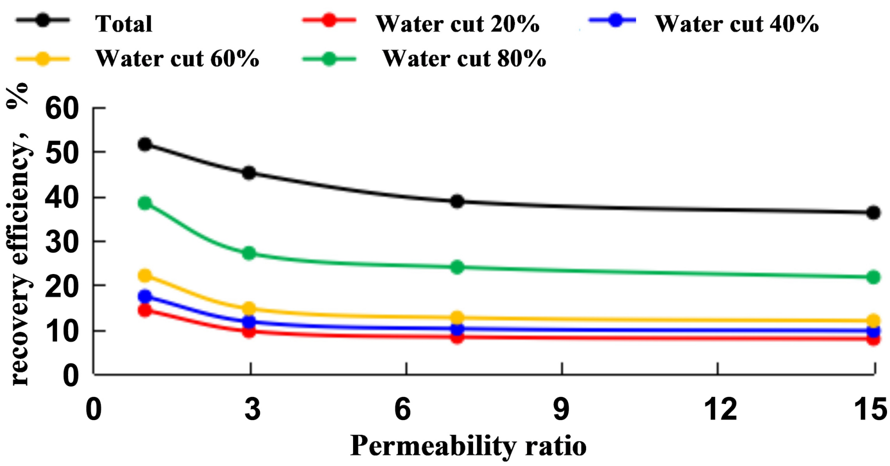

Figure 7. Variation of recovery degree with permeability gradient under different water content in a row well network.

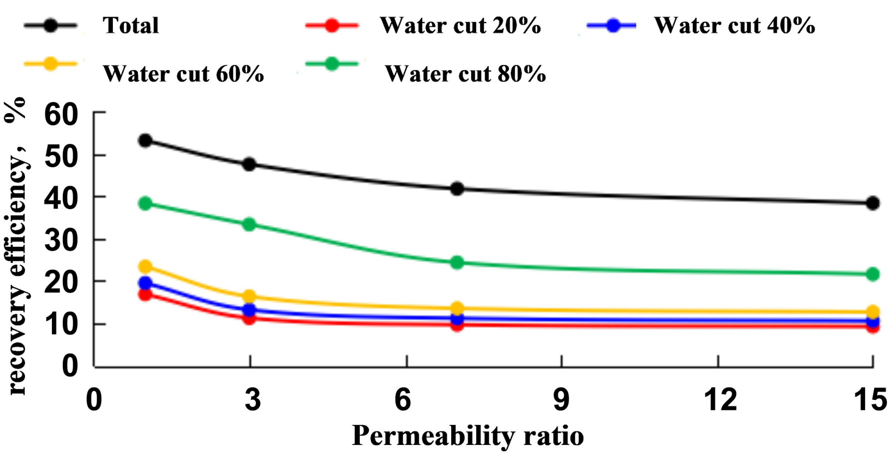

Figure 8. Variation of recovery degree with permeability gradient under different water content in the five point method well network.

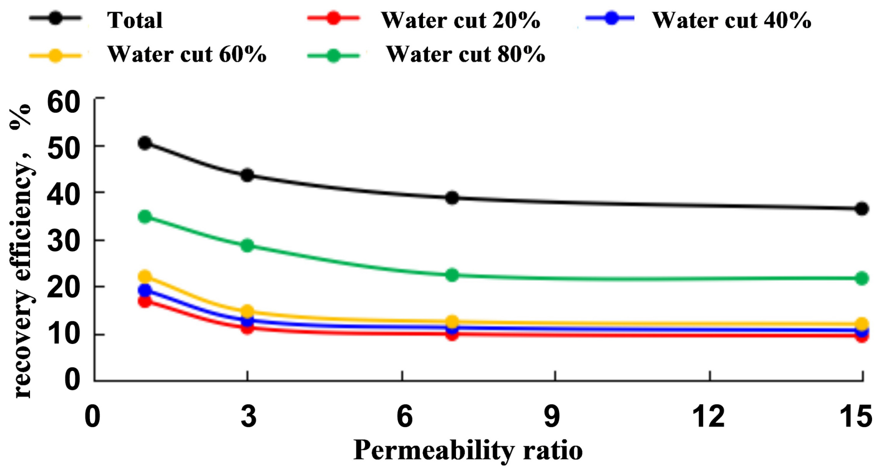

Figure 9. Variation of recovery degree with permeability gradient under different water content in triangular well network.

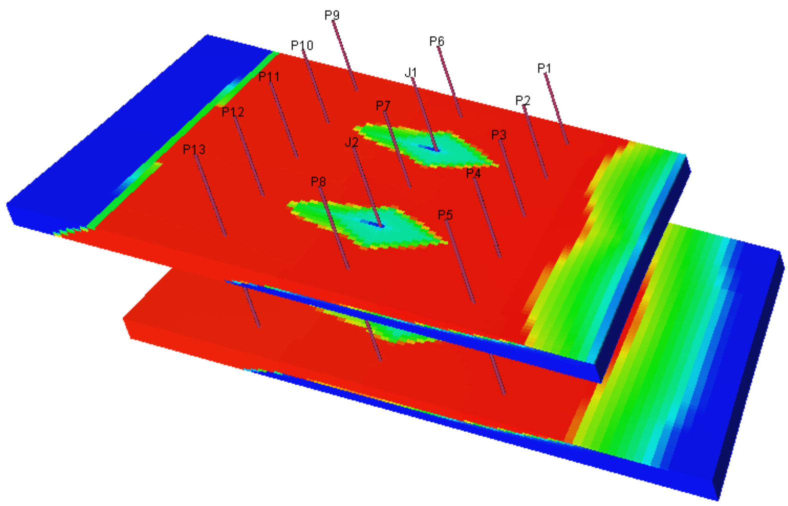

Figure 10. Residual oil saturation field with permeability level difference of 1.

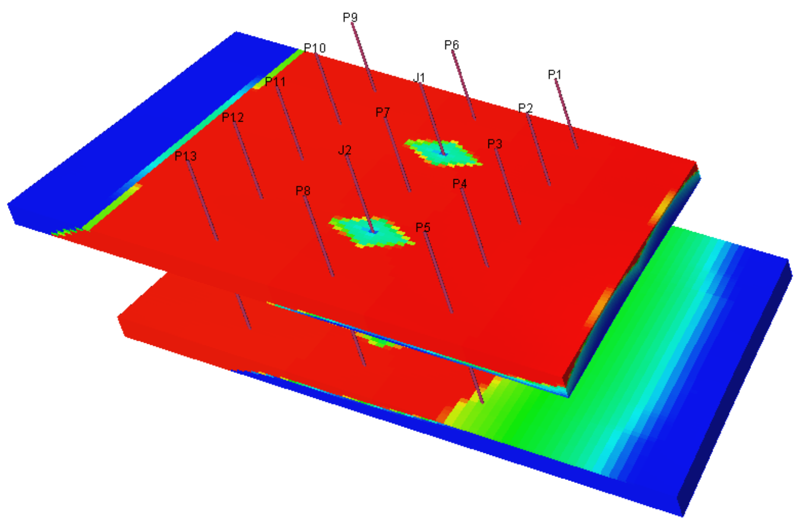

Figure 11. Residual oil saturation field with permeability level difference of 3.

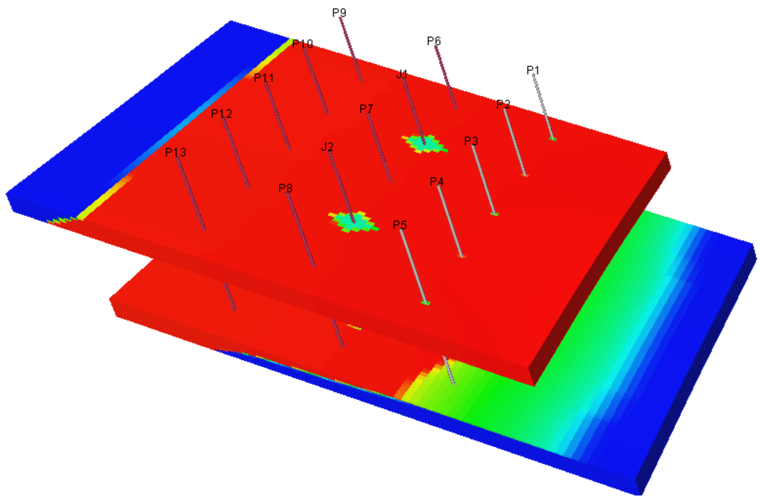

Figure 12. Shows a permeability gradient of 7 and a residual oil saturation field.

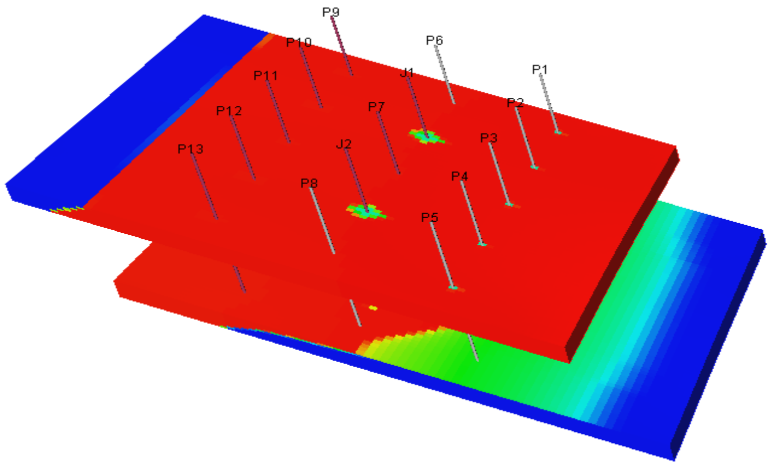

Figure 13. Residual oil saturation field with permeability difference of 15.

level difference is 7, 5 wells have been shut in due to oil production rate below 2.5 m^3/d, and when the permeability level difference is 15, another 2 wells have been shut in due to low oil production rate, This is because the permeability of the low permeability layer gradually decreases, while the permeability of the high permeability layer gradually increases, resulting in an increase in the permeability difference between the two layers and a more severe interlayer interference. This can be seen from the graph of the degree of recovery of the reverse nine point well pattern with the permeability difference.

6. Summary

Through this study, the following conclusions can be drawn:

1) As the permeability gradient increases, the total recovery degree of all four well patterns decreases, with the highest recovery degree of the five point well pattern and the worst recovery degree of the triangular well pattern. In addition, as the permeability gradient increases, the difference in recovery degree of the

four well patterns gradually increases.

2) As the permeability gradient increases, the total recovery degree gradually decreases, the recovery degree of low permeability layers gradually decreases, and the recovery degree of high permeability layers gradually increases. As the permeability difference increases, the degree of recovery gradually decreases under different water contents. As the water content gradually increases, the increase in degree of recovery gradually increases for every 20% increase in water content.

3) From the residual oil saturation field diagram under different permeability levels, it can be seen that as the permeability level difference increases, the reduction rate of residual oil saturation in the low permeability layer is slower, while the reduction rate of residual oil saturation in the high permeability layer is faster. The permeability of the low permeability layer gradually decreases, and the permeability of the high permeability layer gradually increases, leading to an increase in the permeability level difference between the two layers and more severe interlayer interference.

Conflicts of Interest

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

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