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Research on the Adaptability of Development Methods for Offshore Gas Cap Edge Water Reservoirs

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Abstract: ***The X oilfield has complex reservoir types, including edge bottom water reservoirs and gas cap reservoirs, with complex oil, gas, and water distributions, making it difficult to tap the remaining oil. To optimize the development effect, a typical numerical model of a multilayer gas cap edge water reservoir was established, and the influence of different water body multiples on the degree of recovery was analyzed. The injection production rules for four different area well networks (the reverse nine-point method, the row method, the five-point method, and the triangular well network) were explored. The results show that as the number of water bodies increases, the total degree of recovery of the four well networks decreases, but after the number of water bodies exceeds 10, the degree of recovery decreases to zero. In addition, the gas–oil ratio and remaining oil distribution of different well networks are also affected by water multiples. The reverse nine-point method has the highest recovery rate in the well network, whereas the triangular well network has the lowest, but the final recovery rates of the four well networks are not significantly different.***

Keywords: Offshore gas cap edge water reservoir, Water body multiple, Adaptability of development methods, Numerical simulation, Optimization of recovery efficiency.

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1. Introduction

As a typical complex fault block oilfield, the X oilfield has a variety of reservoir types, including edge bottom water reservoirs and gas cap reservoirs. These oil reservoirs have significant characteristics, such as narrow river channels and multiple overlapping sand bodies, resulting in an abnormally complex distribution of oil, gas, and water, which poses great challenges to the development of oil fields. The uneven distribution of remaining oil increases the difficulty of tapping potential, and the current irregular well network development method is inadequate for dealing with such complex oil reservoirs, limiting the development effect [1-9].

To improve the development efficiency of multilayer gas cap edge water reservoirs in the X oilfield, it is particularly important to conduct in-depth research on the adaptability of different development methods. In particular, development strategies under different water body multiples directly affect the recovery degree and economic benefits of oil reservoirs. The water body multiple, as an important parameter for describing the energy level of water in oil reservoirs, has a significant effect on fluid flow, pressure distribution, and the final recovery rate during reservoir development. Therefore, systematically analyzing the advantages and disadvantages of various development methods under different water body multiples is highly important for optimizing reservoir development plans and improving recovery rates [10-18].

This study aims to establish a typical numerical model of multilayer gas top edge water reservoirs, simulate the dynamic response of reservoirs under different water body multiples and development methods, and analyze the impact mechanism of various factors on the degree of recovery. By comparing the development effects of different area well networks (such as the reverse nine-point well network, row well network, five-point well network, and triangular well network), the injection production rules are revealed, providing a theoretical basis and technical support for the efficient development of X oilfield reservoirs and similar complex reservoirs.

2. Establishment of Numerical Models for Typical Reservoir Models

The X oilfield is a complex fault block with diverse types of oil reservoirs, including edge and bottom water reservoirs as well as gas cap reservoirs. The river channel is narrow, with multiple overlapping sand bodies; a complex distribution of oil, gas, and water; and a complex distribution of remaining oil, making it difficult to tap into the potential. At present, the main development method for multilayer gas top edge water reservoirs in the X oilfield is an irregular well network, but this development method has limitations for this type of reservoir. Therefore, it is necessary to conduct research on development technology for multilayer gas top edge water reservoirs. In research on the development of multilayer gas cap edge water reservoirs, the influence of different water body multiples on the degree of recovery is analyzed, and the reasonable rules of model injection and production under different area well networks are explored.

A numerical model for the development of multilayer gas top edge water reservoirs under typical reservoir model conditions (see Table 1) is established, as shown in Figure 3.4. The inclination angle of the numerical model is 10°, where the gas cap index is 0.33, the water body multiplier is 0.24, and the permeability levels are 1, 3, 7, and 15. The permeability is 800 mD, which means that the sum of the two layers of permeability remains at 1600 mD.

Table 1: Model parameter settings

Parameter	Experimental parameters
Gas cap index	0.3
Water body multiple	0.3
Dip angle of reservoir	10°
Reservoir width(m)	1600
Reservoir width(m)	1500
Reservoir thickness(m)	20+20
Grid size(m^3)	20×20×2
Porosity(%)	30
Permeability($\times 10^{-3}\ \mu m^2$)	800、800
Oil production rate (%)	3

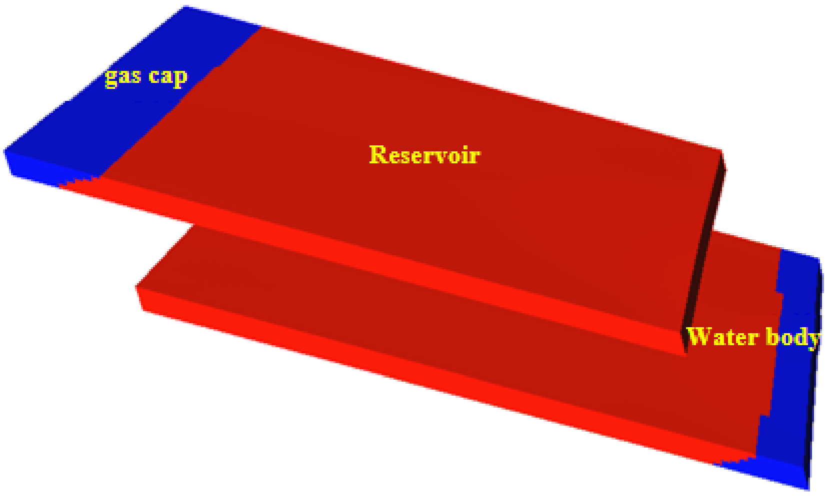


Figure 1: Schematic diagram of a typical multilayer gas top edge water reservoir model in the X oilfield

The upper vertical part of the first layer of the sand body represents natural gas in the gas cap, the middle part represents crude oil in the reservoir, the upper vertical part of the second layer of the sand body represents crude oil in the reservoir, and the lower part represents water in the water body.

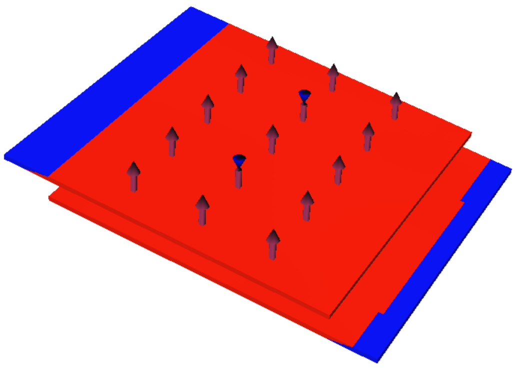
When studying the collaborative development of oil and gas in multilayer gas cap reservoirs, it is necessary to combine onsite conditions and research objectives to develop corresponding evaluation indicators. Therefore, to better achieve the ideal development effect, the recovery degree of the reservoir and the recovery degree of each layer are selected as the evaluation indicators for numerical model research. On the basis of these evaluation indicators, termination conditions for the operation of the gas cap reservoir numerical model are formulated. Considering that in actual production, production wells will stop production when the daily oil production is low, when the single-well production of the gas cap reservoir numerical model is reduced to 2.5 m3/D, the oil well will be shut in. At the same time, in actual production, when the water content is high, the oil well stops production. Therefore, when the water content reached 98%, the oil well was closed. Moreover, the gas oil reservoir numerical model is also considered. The well was closed when the ratio was greater than 1000.

On the basis of the actual geological and production characteristics of the multilayer gas top edge water reservoir in the X oilfield, vertical interlayer interference, gas channeling, and water invasion are the main factors influencing reservoir development. Interlayer interference mainly reflects the impact of permeability differences on oil reservoirs.

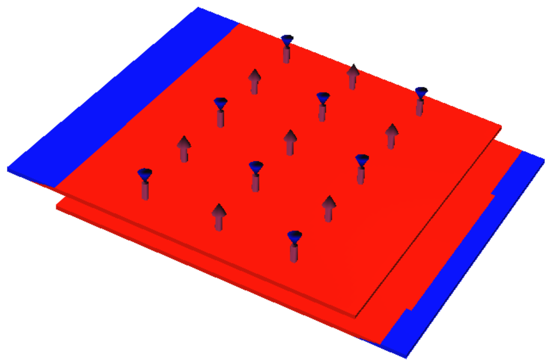
In addition, on the basis of the actual site conditions, four different area well networks were set up for production, namely, the reverse nine-point method well network (Figure 2a), with a well spacing of 300 m, 13 production wells, and 2 injection wells; the row-shaped well network (Figure 2b), with a well spacing of 300 m, 10 production wells and 5 injection wells; the five-point well network (Figure 2c), with a well spacing of 300 m, 7 production wells and 8 injection wells; and the triangle well network (Figure 2d), with a well spacing of 300 m, 17 production wells and 22 injection wells. Table 2 shows the selection of four different parameter schemes.

Table 2: Selection of Scheme Parameters

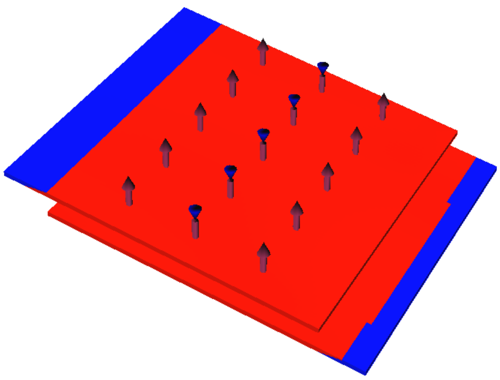
Serial Number	Water body multiple	Development method
1	1	Anti nine point method well network
2	5	Row well pattern
3	10	Five point method well network
4	20	Triangular pattern



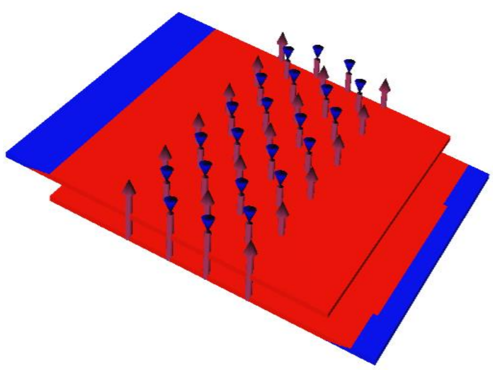
a) reverse nine-point method well network



c) Five-point method well network



b) arranged well network



d) Triangular well network

Figure 2: Schematic diagram of different well network reservoir models

On the basis of the typical reservoir model of the X oilfield gas cap edge water reservoir, we need to establish a numerical model of the typical reservoir model and study the main controlling factors that affect the development effect of the multilayer gas cap edge water reservoir. On the basis of the results obtained from the actual production site, the main controlling factors affecting the development effect of the gas cap edge water reservoir in the X oilfield include permeability, the gas cap index, the water body multiplier, the oil recovery rate, and the well network. Therefore, this section analyzes the main controlling factors of water body multiples using the total degree of recovery of the reservoir and the degree of recovery of each layer as indicators.

3. Comparison of Total Recovery Levels of Different Well Networks

When the total recovery degree of different well networks is compared, a permeability difference of 1 is set, which means that the permeability of the upper and lower layers of the reservoir is 800 mD, the gas cap index is 0.33, the water body multiples are 1, 5, 10, and 20, the oil recovery rate is 3%, and the injection production ratio is 0.8. On this basis, the influence of water body multiples and well network changes on the total degree of recovery is studied.

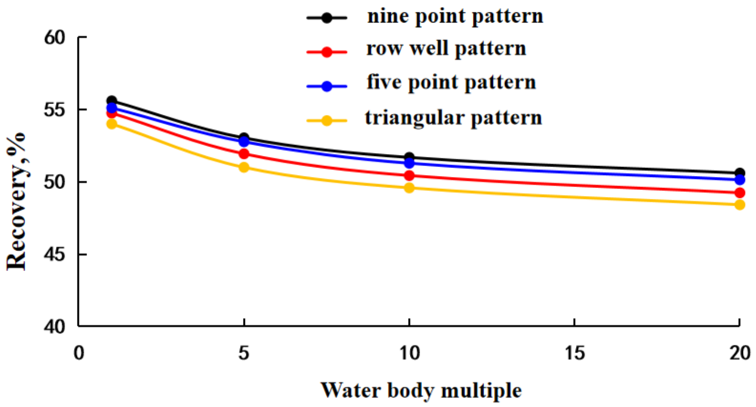


Figure 3: Variations in the degree of recovery of different well networks with water body multiplication

Figure 3 shows that as the water body number increases, the total degree of recovery of all four well networks decreases. However, when the water body multiple is greater than 10, the degree of recovery is essentially zero. This occurred because as the number of water bodies increases, the water content of the reservoir increases, resulting in a faster increase in water content and a decrease in oil production near the water body, causing some oil wells to shut prematurely. This can be seen from the remaining oil saturation field map. The other four well networks have the highest degree of recovery when the reverse nine-point method is used, whereas the triangular well network has the lowest degree of recovery. However, the final recovery rates of the four well networks are not significantly different.

4. Comparison of the Extraction Degree of Each Layer

Taking the reverse nine-point method well network as an example, the extraction degrees of different layers are compared, and on this basis, the influence of multiple water body changes on the extraction degree of each layer is studied.

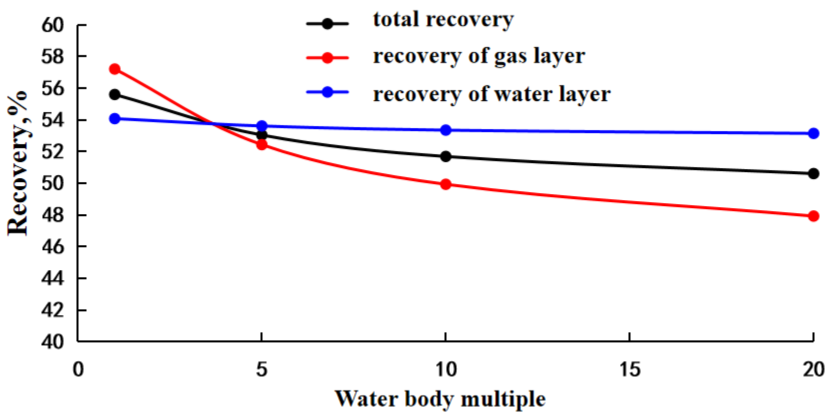


Figure 4: The degree of recovery of the inverted nine-point method well network varies with the water body multiple

Figure 4 shows that as the number of water bodies increases, the total degree of recovery gradually decreases, and the degree of recovery of the gas cap layer gradually decreases. The recovery degree of the water body layer remains essentially unchanged. This occurs because as the number of water bodies increases, the energy of the water body layer affects the gas cap layer, resulting in a decrease in the recovery degree of the gas cap layer. Figures 5-7 show the variation in the degree of recovery with water body multiples for three other well networks, which follows the same pattern as the inverse nine-point method well network.

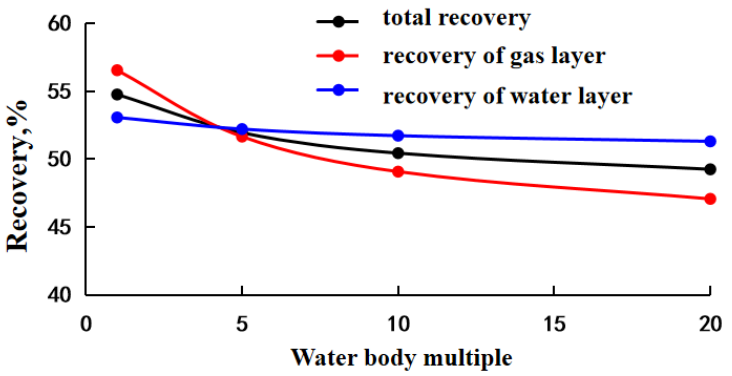


Figure 5: The degree of extraction of a row-shaped well network varies with the number of water bodies

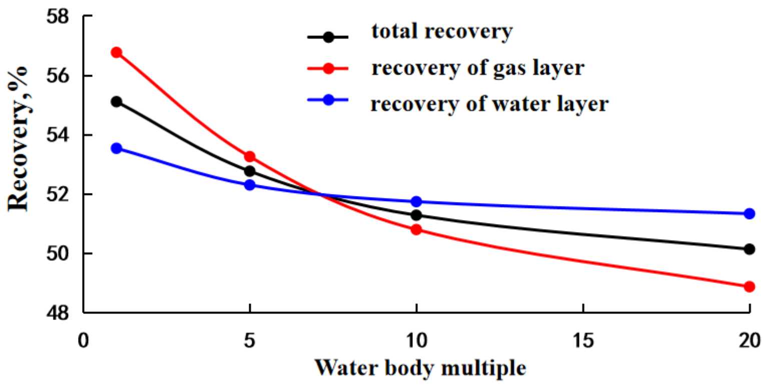


Figure 6: The degree of extraction of the five-point method well network varies with the water body multiple

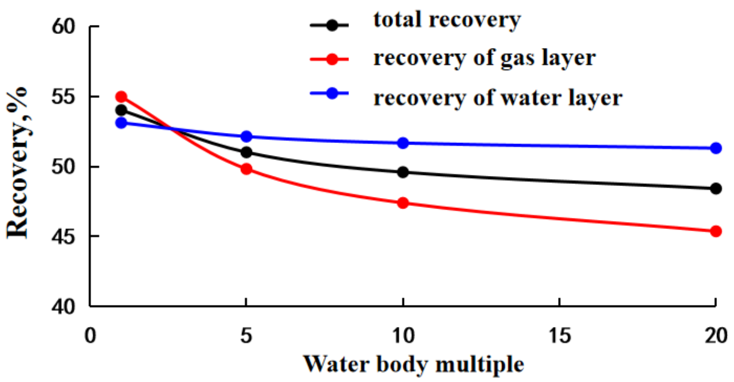


Figure 7: The degree of extraction of the triangular well network varies with the number of water bodies

5. Comparison of Gas–oil Ratios in Different Well Networks

Comparing the changes in the gas–oil ratios of different well networks with the water body size, as shown in Figure 8, when the water body ratio is low, the final gas–oil ratio of the reservoir is greater than the dissolved gas–oil ratio. Although the water body and gas cap are not in the same layer, the energy of the water body affects the energy of the gas cap. When the energy of the water body is low, the gas in the gas cap quickly reaches the production well and is produced.

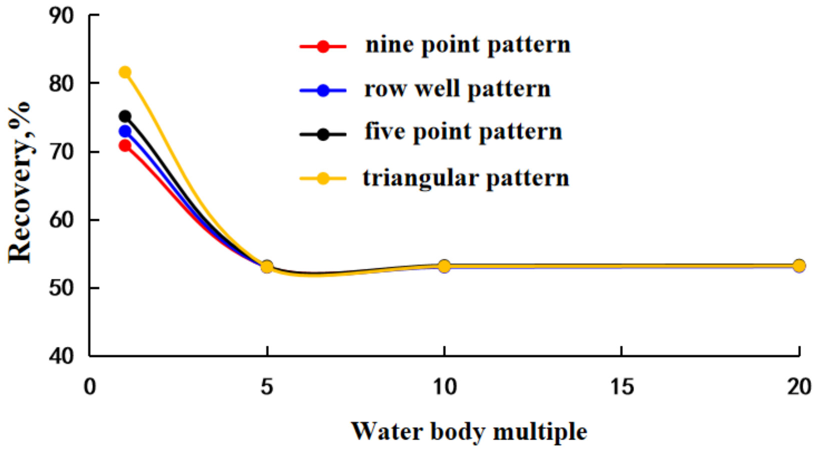
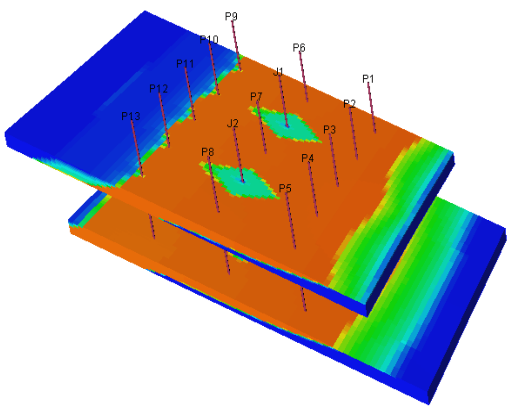


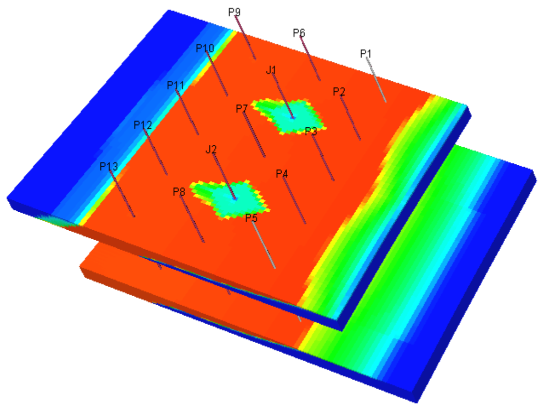
Figure 8: Gas–oil ratio variation with water body ratio

6. Comparison of the Remaining Oil Saturation Field Maps

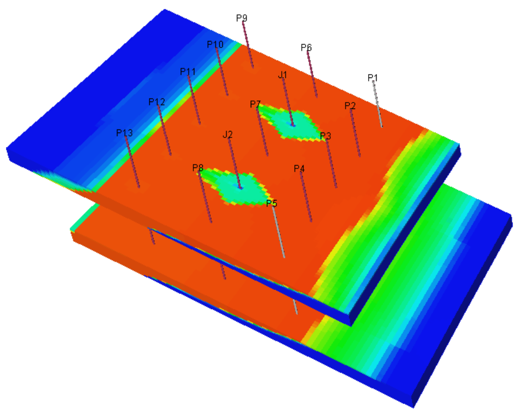
Taking the reverse nine-point method well network as an example, the changes in oil saturation field maps under different water body multiples are compared, and the impacts of different water body multiples on the distribution of remaining oil in the two layers are analyzed.



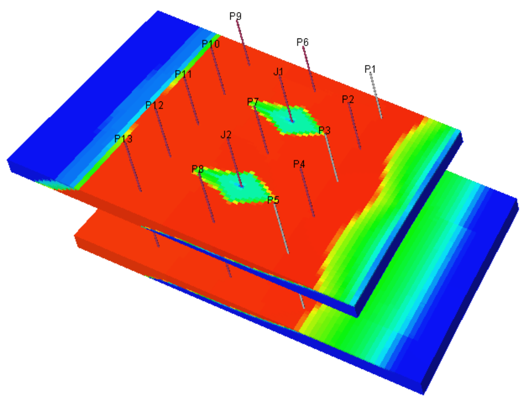
a) The water body ratio is 1



c) The water body ratio is 10



b) The water body ratio is 5



d) The water body ratio is 20

Figure 9: shows the residual oil saturation field of the reverse nine-point method well network under different water body multiples.

Figure 9 shows the residual oil saturation field of the inverted nine-point method well network under different water body multiples. As the number of water bodies increases, the distance from the water layer to the production well varies. When the number of water bodies is small, the distance from the water layer to the production well is greater, and when the number of water bodies is large, the distance from the production well to the water layer is greater. This phenomenon can also be seen from the production wells that have been shut in. When the water body multiple is 1, no production wells are shut in at the end of production. When the water body multiple is 5 and 10, two wells are shut in, and when the water body multiple is 20, three wells are shut in. At the same time, changes in the water body ratio also have a certain impact on the gas cap. As the water body ratio increases, the distance between the gas cap and the production well gradually increases, indicating that the impact of the gas cap on the production well decreases. The water body has an inhibitory effect on the gas cap.

7. Conclusion

1) Adaptability analysis of development methods: Research has shown that as the number of water bodies increases, the total recovery rates of the four well networks (the reverse nine-point method, row method, five-point method, and triangular well network) decrease. However, when the water body multiple exceeds 10, the reduction in the recovery rate is essentially zero. The reverse nine-point method has the highest recovery rate in the well network, whereas the triangular well network has the lowest, but the final recovery rates of the four well networks are not significantly different.

2) The impact of multiple water bodies on oil recovery: An increase in multiple water bodies leads to an increase in the water content in the reservoir. Production wells near the water body experience a faster increase in water content, resulting in a decrease in oil production and premature closure of some oil wells. This effect is particularly significant in the gas cap layer, where the degree of gas cap extraction gradually decreases as the water body ratio increases, whereas the degree of water cap extraction remains essentially unchanged.

3) Gas–oil ratio and remaining oil distribution: The gas–oil ratio of different well networks is also affected by the water body ratio. When the number of water bodies is low, the final gas:oil ratio of the reservoir is greater than the dissolved gas:oil ratio. In addition, as the water body ratio increases, the distribution of remaining oil also changes, and the inhibitory effect of water in the water layer on the gas cap gradually increases, resulting in a decrease in the impact of the gas cap on production wells.

4) Optimization of the development strategy: In response to the complex characteristics of multilayer gas cap edge water reservoirs in the X oilfield, this study simulates the dynamic response of reservoirs under different development methods through numerical models, providing a theoretical basis for optimizing development strategies. The antineiline point method well network performs the best in terms of recovery degree and is a key consideration in future development strategies.

5) Practical application value: The research results not only have guiding significance for the development of the X oilfield but also provide reference technical support and methodology for the efficient development of similar complex reservoirs, which helps to improve the overall recovery rate and economic benefits of the reservoir.

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