Journal of Geoscience and Environment Protection, 2022, 10, 80-97
https://www.scirp.org/journal/gep
ISSN Online: 2327-4344
ISSN Print: 2327-4336

Study on Development Law of Complex Fluvial Reservoir under Water

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How to cite this paper: Wang, S. P., Lei, Y., Tan, J., Mu, P. F., & Sun, G. Y. (2022). Study on Development Law of Complex Fluvial Reservoir under Water. *Journal of Geoscience and Environment Protection, 10,* 80-97.
https://doi.org/10.4236/gep.2022.108007

Received: July 22, 2022
Accepted: August 22, 2022
Published: August 25, 2022

Abstract

The Bozhong oilfield (Hereinafter referred to as BZ oilfield) is a typical representative of complex fluvial reservoirs in the Bohai Sea, located in the southern Bohai Sea, with an average porosity of 30.3% and an average permeability of 643 × 10^{-3} μm^2, belonging to medium high porosity and permeability reservoir, the reservoir has good connectivity, and the average underground crude oil viscosity is 5 mPa·s. There are many plane fault blocks, and the longitudinal oil well section is long, so the oil-water relationship is very complex. With the further development of the oilfield, the vertical and horizontal oil-water movement law, residual oil distribution and potential are unclear, resulting in rapid bottom water coning, unbalanced injection and production in the oilfield, and increasingly prominent contradictions among layers, planes and layers in the oilfield. Through numerical simulation analysis and comparison of displacement law and recovery degree under different influence conditions, this paper studies the development effect of actual sand body under different influence conditions such as different well types, different development methods and well layout positions, and takes appropriate development methods for the oilfield, which is of great significance to improve the development effect of the oilfield.

Keywords

The Bohai Sea, Complex Fluvial Facies, Water Body, Development Law

1. Introduction

There are many plane fault blocks in complex fluvial facies reservoirs, and the vertical oil well section is long, so the oil-water relationship is very complex (Zhang et al., 2022; Guo et al., 2019; Er, 2016; Qu et al., 2013; Yang et al., 2021). With the further in-depth development of the oilfield, the vertical and horizontal oil-water movement law, residual oil distribution and potential are unclear, resulting in rapid bottom water coning, unbalanced injection and production in the oilfield, and increasingly prominent contradictions among layers, planes and layers in the oilfield (Zhang et al., 2020; Shi, 2020; Zhu, 2012; Baker, 1988; Lu et al., 2011). The main problems are as follows:

1) The complex fault block reservoir has strong heterogeneity, the injection production contradiction appears, and the well pattern of newly increased reserves is imperfect or unsuitable. Affected by the reservoir heterogeneity, fluid heterogeneity, injection production relationship and other factors, the single layer breakthrough of injected water is serious, the oil wells are affected unevenly, the water drive effect is poor, and the production reduction is serious.

2) Due to the dense distribution of complex fault blocks in the oil field, small ground saturation pressure difference, insufficient natural energy, and large vertical permeability difference, the vertical production of the reservoir is uneven; narrow channel, multi-stage sand body superposition, complex distribution of oil, gas and water, complex distribution of remaining oil, and great difficulty in tapping potential.

3) The formation pressure has decreased, but some water injection wellhead pressures are too high to be injected.

4) The water content of some wells increases rapidly, and the production decreases greatly. Some old wells have been in production for 7 years, and now they have entered the stage of high water cut mining.

In order to study the influence of different factors on the development effect in the process of complex reservoir development and accurately characterize the characteristics of bottom water reservoir in numerical simulation, the influence law and mechanism of complex reservoir development are studied through numerical simulation method, so as to provide basis for further improving the development effect of complex reservoir.

2. Mining Laws of Different Influencing Factors

2.1. Design of Influencing Factors of Typical Sand Body

According to the existing well types and typical sand body characteristics of BZ oilfield, the main development mode of this block is water injection development, which adopts irregular well pattern, and some sand body water bodies have obvious strengths and weaknesses. Therefore, it is of great significance to study the development effect under different influence conditions such as different well types, different development methods and well layout positions in the actual sand body, so as to adopt appropriate development methods and improve the development effect.

For different influencing factors of typical sand body setting, the design is shown in **Table 1**. The well types are horizontal well and vertical well respectively, the development mode research is exhaustion development and water

Table 1. Design of influencing factors of typical sand body.

Well type	Mining method	Influence conditions
Horizontal well	Exhaustion development	Production well location
		Multiple of different water bodies
	Water injection development	Location of water injection well
		Injection production ratio
		Location of water injection well and production well
Vertical well	Exhaustion development	Production well location
	Water injection development	Location of water injection well
		Location of water injection well and production well

injection development, as well as different well layout positions and water multiple.

When studying the effect of reservoir exploitation, the evaluation index should be formulated in combination with the field conditions and research objectives. Therefore, the recovery degree is taken as the evaluation index of model research. Considering that in the actual production, the production of production wells will stop when the daily oil production is low, therefore, when the horizontal well of the oil well in the model is 5 m^3/d and the vertical well is 2.5 m^3/D, the oil well will be shut in.

2.2. Influence of Distance between Production Well and Bottom Water

The X sand body is developed by exhaustion of horizontal wells. Five horizontal well layout positions are set, and the dimensionless distances from the edge water are 0.125, 0.25, 0.375, 0.5625 and 0.75 respectively. The production effect and displacement law of production wells at different positions are studied. The production wells are closed when the liquid production rate of the production wells is 300 m^3/d, the water content is more than 98% or the oil production is less than 5 m^3/d. The production wells are located as shown in Figure 1.

The recovery degree curve plates of production wells at different positions are shown in Figure 2.

It can be seen from the recovery degree chart of the dimensionless distance between different production wells and the bottom water that when the production well is close to the edge bottom water, the recovery effect is the worst, because the closer the production well is to the bottom water, the faster the bottom water invasion speed is, and the premature water breakthrough of the production well leads to the shut in of the well, and the recovery degree is low, as shown in the oil saturation field diagram of the production well layout in the low part

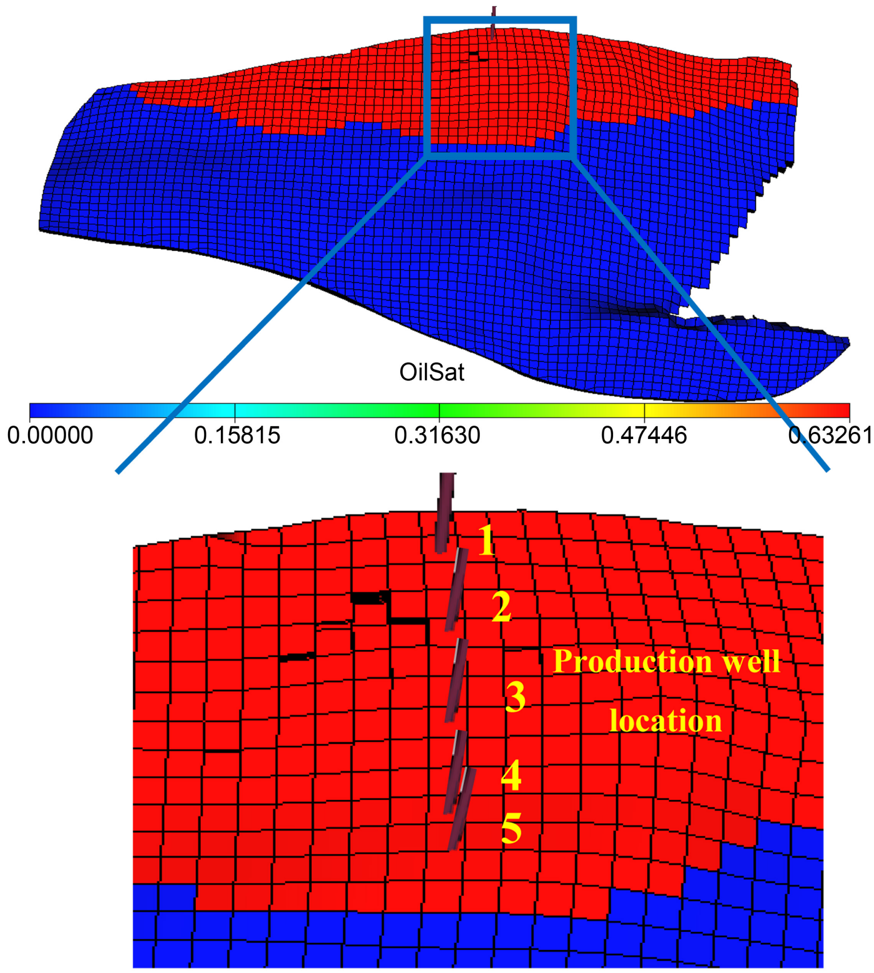


Figure 1. Schematic diagram of different positions of X sand production well.

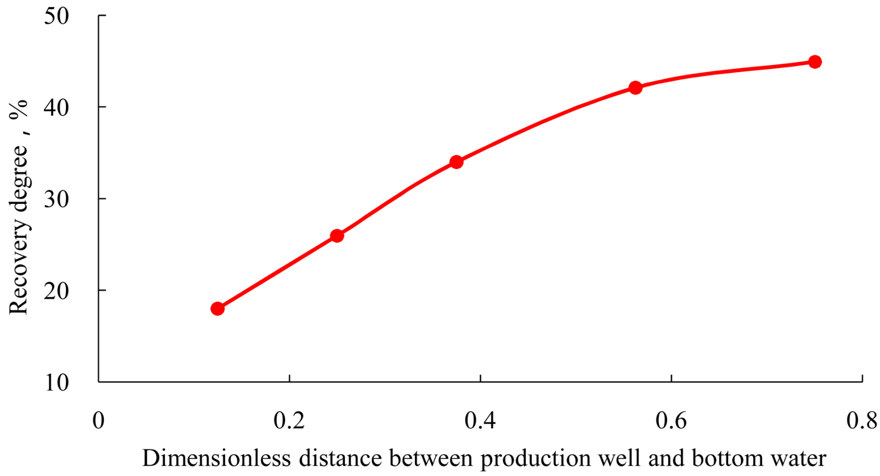
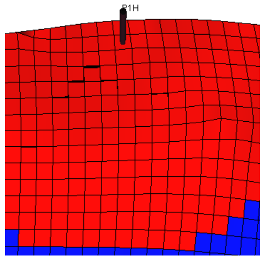
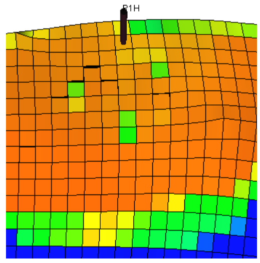
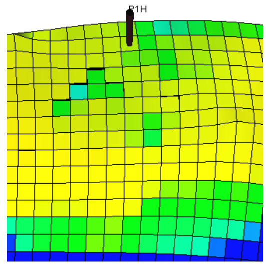
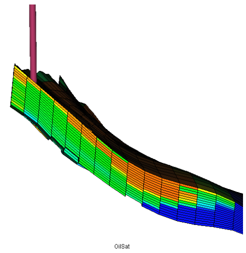
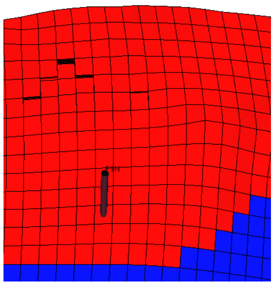
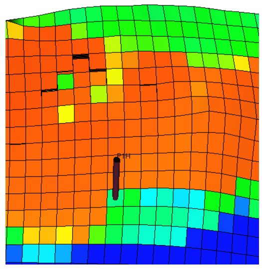
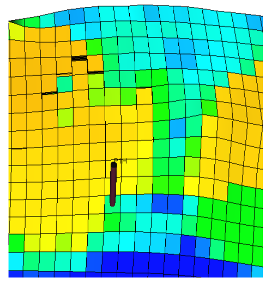
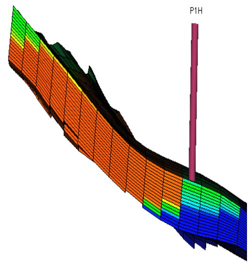


Figure 2. Dimensionless distance between production well and bottom water-recovery degree chart.

of the structure in Table 2; when the production wells are distributed in the high part of the reservoir, the slower the water invasion speed is, the longer the

Table 2. Oil saturation field diagram of different water cut conditions at different locations of production wells.

	Initial	Water cut 80%	Water cut 95%	Side view with 80% water cut
High part of production well structure				
Low part of production well structure				

anhydrous oil production period of the production wells is, the greater the recoverable reserves of the production wells are, and the higher the recovery degree of the oilfield is. As shown in the side view of oil saturation when the production wells are located in the high part of the structure in Table 2, the production degree of formation crude oil is better.

2.3. Influence of Distance between Production Well and Bottom Water

The X sand body is developed by exhaustion of horizontal wells, and the production wells are produced at constant pressure. The dimensionless distances between the production wells and the edge and bottom water are 0.125, 0.25, 0.375, 0.5625 and 0.75 respectively. When the water content of the production wells is >98% or the oil production is <5 m^3/d, the wells are shut in. The location of the production wells is shown in Figure 1. The oil production rate and recovery degree at the initial stage of development at different locations of the production wells are shown in Figure 3.

When the production well is closer to the edge and bottom water, the more sufficient the bottom water energy is, the greater the daily oil production of the production well at the initial stage of production is. After a period of production, the closer the production well is to the edge and bottom water, the faster the water invasion speed is, the faster the water cut rises, and the smaller the recovery degree is; when the production well is arranged at the high part of the sand body, the oil production is small at the initial stage of production, but the water cut rises slowly, and the recovery degree is higher.

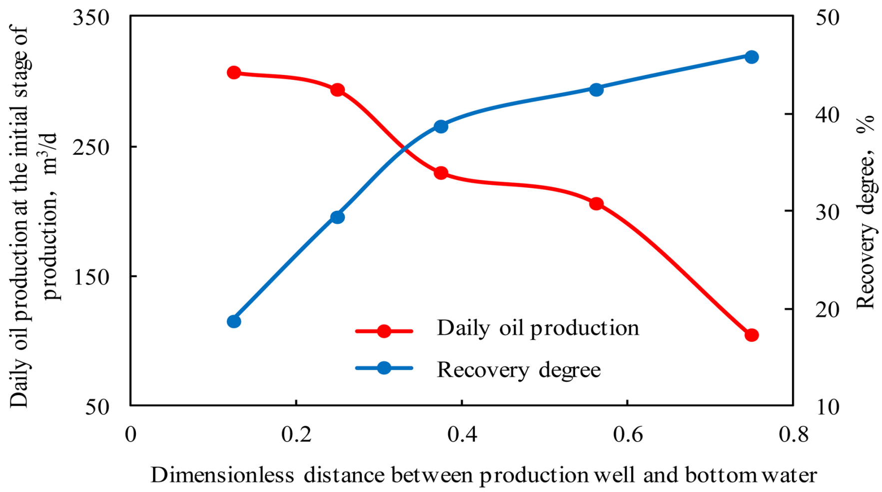


Figure 3. Daily oil production and recovery degree at different positions of production wells during constant pressure production.

2.4. Influence of Production Well Spacing and Bottom Water Position during Water Injection Development

X sand body adopts the water injection development method. The water injection well layout adopts edge water injection at the oil-water boundary. Four horizontal well layout positions are set, and the dimensionless distances from the edge water are 0.25, 0.375, 0.5625 and 0.75 respectively. The production effect at different positions of the production well is studied. The production well has a liquid production rate of 300 m^3/d, an injection production ratio of 1, and the production well is shut in when the water content is >98% or the oil production is <5 m^3/d. The location of the water injection well and different production well locations are shown in Figure 4.

The recovery degree of production wells at different positions is shown in Figure 5.

From the dimensionless distance between production wells and bottom water-recovery degree curve, the larger the dimensionless distance between production wells and bottom water, the higher the recovery degree. The water injection development law and recovery degree of different production well locations are similar to that of depletion development. When the production well is close to the bottom water, the faster the water content rises, the earlier the production well is shut in, the lower the recovery degree, and the poor production effect. As shown in Table 3 oil saturation field diagram of the production well at the bottom of the structure, the farther the production well is from the bottom water, the slower the water invasion rate, the longer the production time, the better the formation crude oil production effect, and the better the production effect, The higher the recovery degree is.

2.5. Influence of Injection Production Ratio in Water Injection Development

X sand body adopts water injection development mode, sets different injection

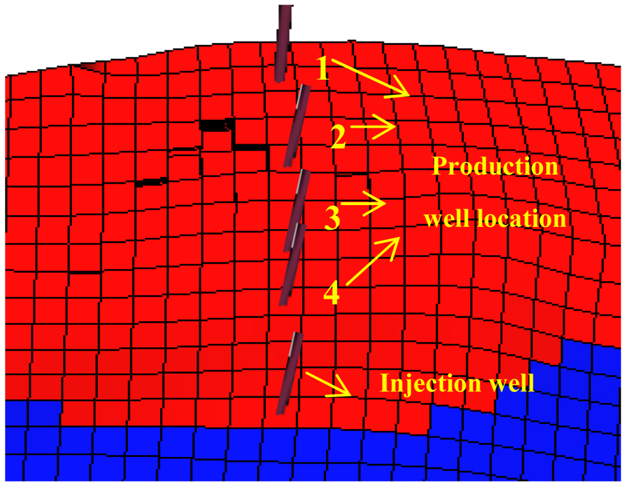


Figure 4. Schematic diagram of different positions of water injection production wells.

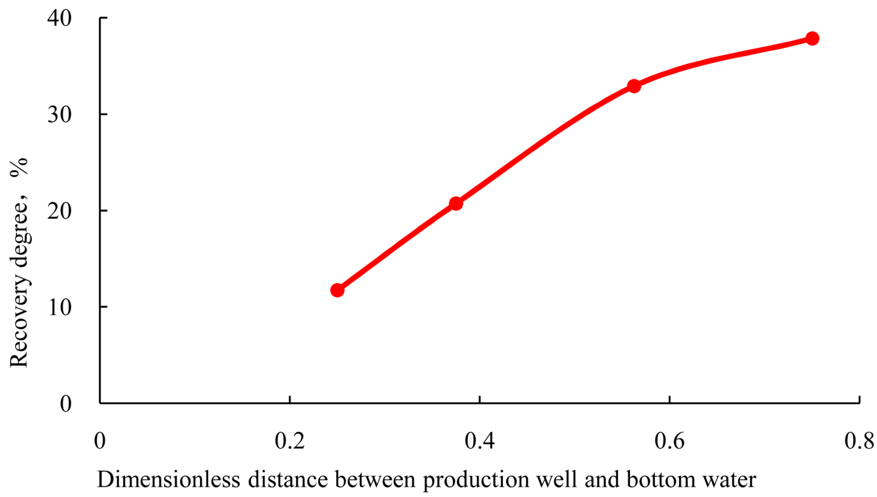


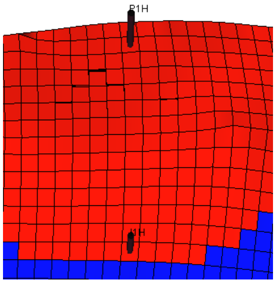
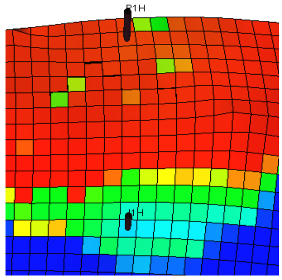
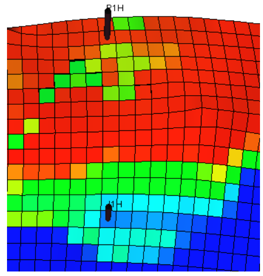
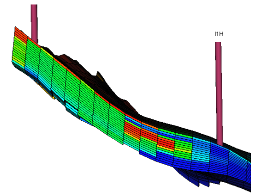
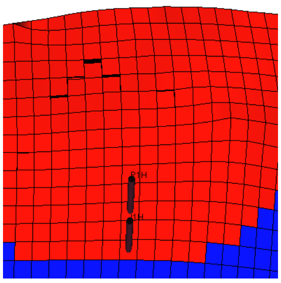
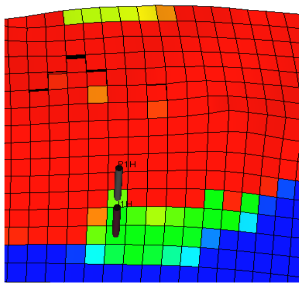
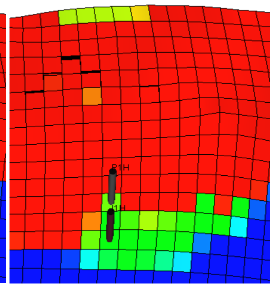
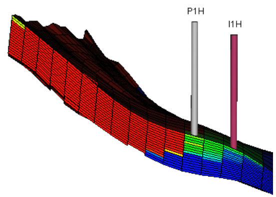
Figure 5. dimensionless distance between production well and bottom water-recovery degree chart.

production ratio, studies the development impact of different injection production ratio, and determines a reasonable injection production ratio. The water injection well layout adopts the edge water injection method on the oil-water interface. The production well layout is at the high part of the structure, as shown in Figure 6. Set different injection production ratios, the liquid production rate of the production well is 300 m^3/d, set different injection production ratios as 0.8, 1, 1.2, and shut in when the water content of the production well is more than 98% or the oil production is less than 5 m^3/d.

The recovery degree of different injection production ratio is shown in Figure 7.

According to the recovery degree of different injection production ratio, there is a reasonable injection production ratio in the oilfield. With the increase of water injection volume of water injection wells, the water content of oil wells

Table 3. Oil saturation field at different positions of production wells.

	Initial	Water cut 80%	Water cut 95%	Side view with 80% water cut
High part of production well structure				
Low part of production well structure				

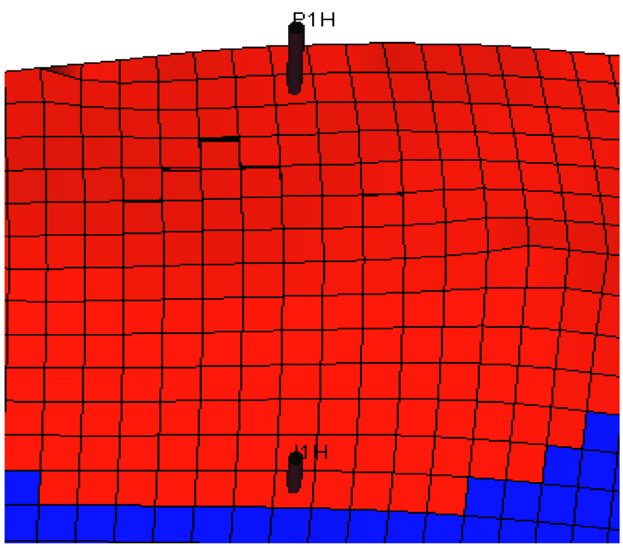


Figure 6. Location of production well and water injection well.

rises faster and the water invasion speed is faster, which is easy to form water channeling channels, and the swept area and oil displacement efficiency will be reduced, resulting in the reduction of oil recovery. Appropriate water injection development can maintain the pressure of the formation, supplement energy to the formation, and improve the development effect.

See Table 4 for oil saturation fields produced by different injection production ratios.

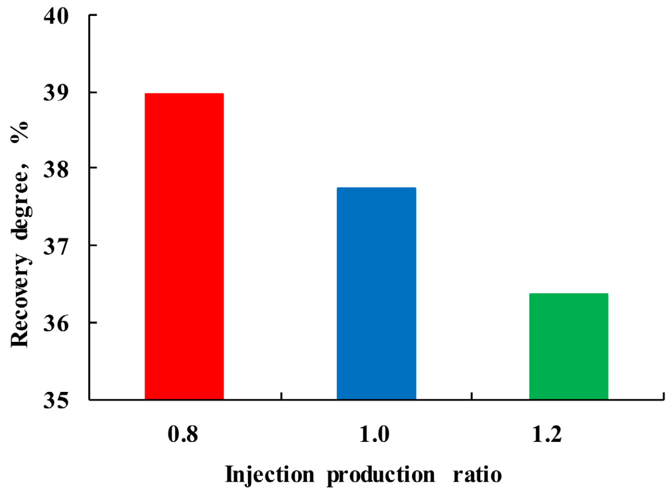
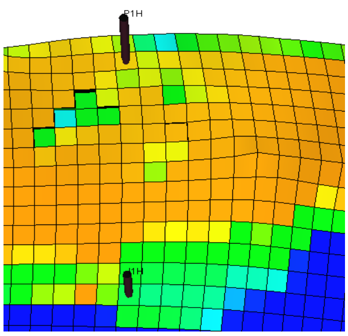
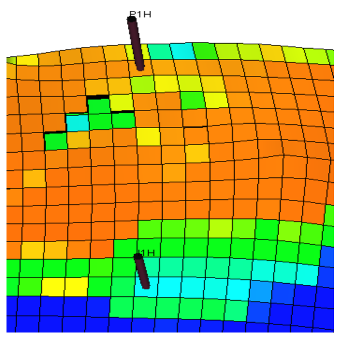
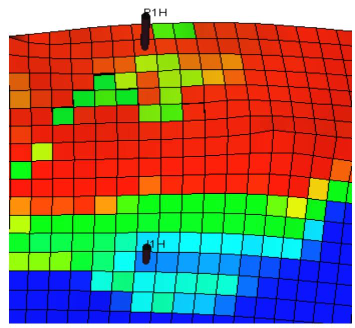
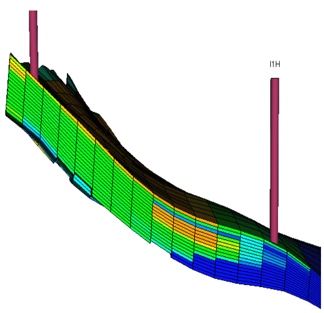
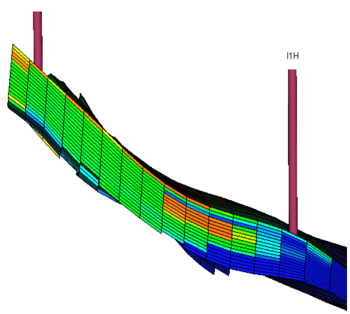
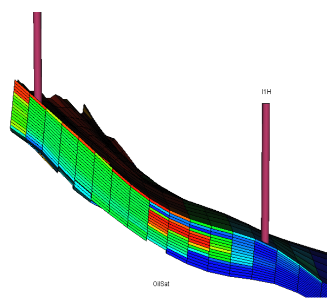


Figure 7. Injection production ratio recovery degree chart.

Table 4. Oil saturation field diagram of different injection production ratios.

	Injection production ratio 0.8	Injection production ratio 1.0	Injection production ratio 1.2
Top view of oil saturation			
Side view of oil saturation			

When a large injection production ratio is adopted for the water injection well, the water injection volume of the water injection well increases, and the water invasion speed becomes faster, which is easy to form a high-permeability water channeling channel in the formation and reduce the water drive sweep coefficient. As shown in the oil saturation field diagram when the injection production ratio is 1.2 in the table, a large amount of remaining oil is retained in the upper part of the oil layer. Due to the excessive water injection, the injected water is rapidly pushed along the high-permeability channel to the production well, resulting in a small recovery degree.

2.6. Influence of Water Injection Well Location on Development in Water Injection Development

Three water injection methods, i.e. inner edge water injection, upper edge water injection and outer edge water injection, are set to study the impact of different water injection methods on production. The liquid production rate of the production well is 300 m^3/d, the water injection rate of the water injection well is 300 m^3/d, and the well is shut in when the water content of the production well is more than 98% or the oil production is less than 5 m^3/d. the positions of the water injection well and the production well are shown in Figure 8.

The recovery degree at different water bearing stages is shown in Figure 9.

The development law of different locations of water injection wells can be divided into two stages. At the initial stage of production, the effect of waterflooding in the margin is better. When there is no water invasion in the production well, the area of waterflooding formation affected by water injection in the water

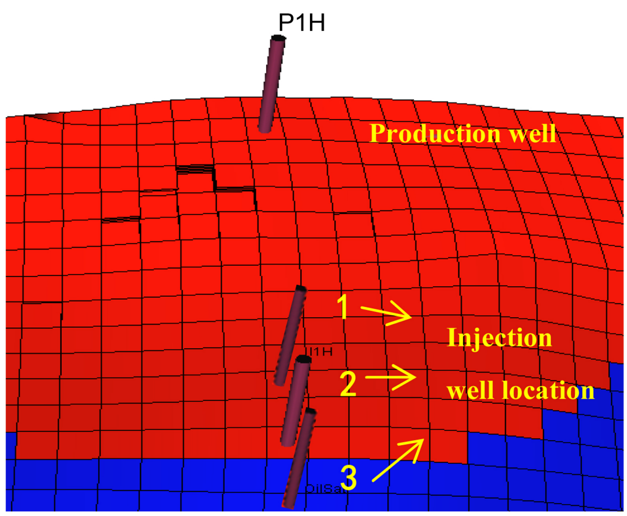


Figure 8. Schematic diagram of different positions of production well and water injection well.

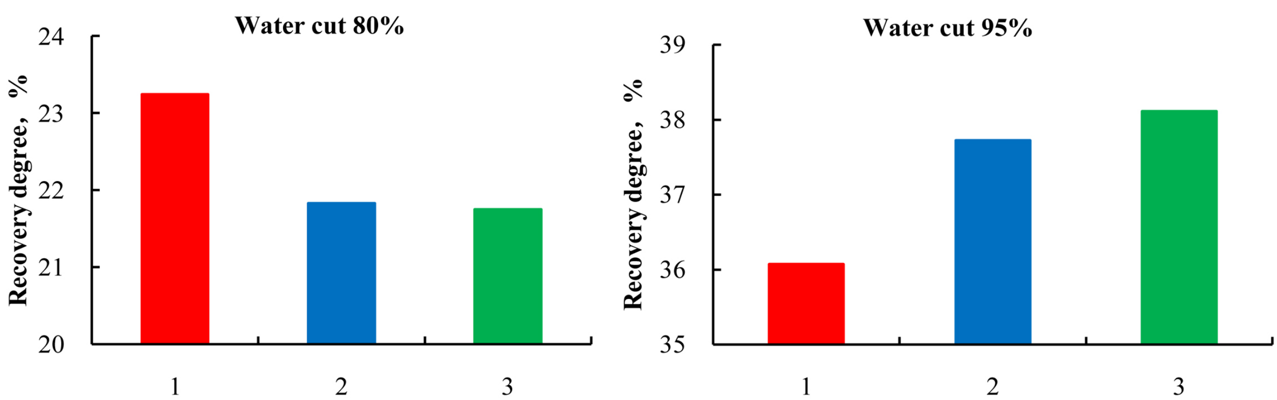


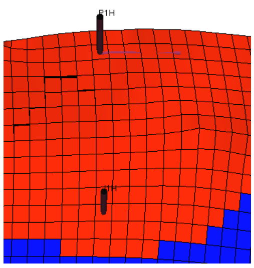
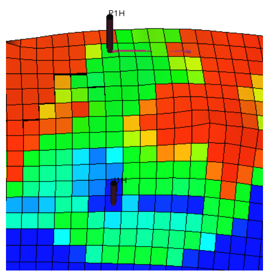
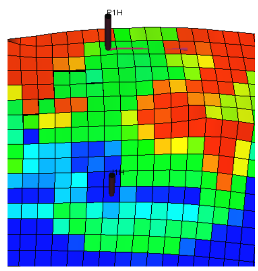
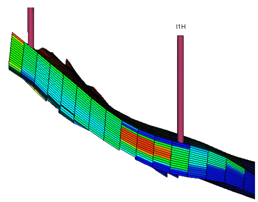
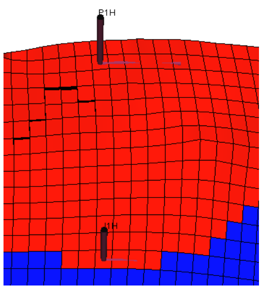
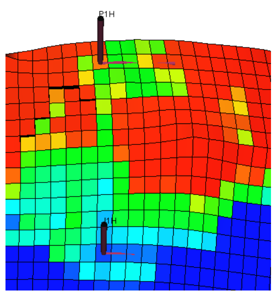
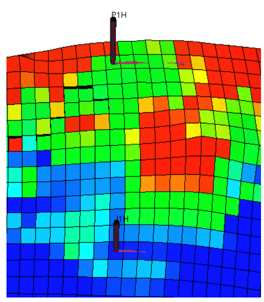
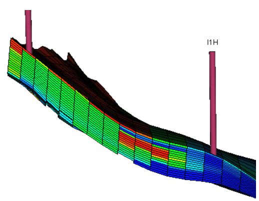
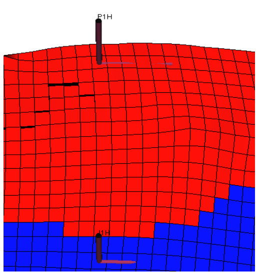
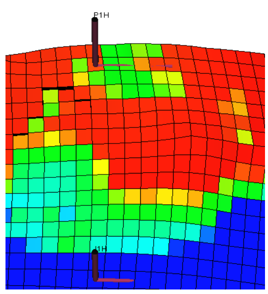
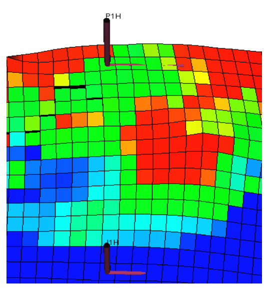
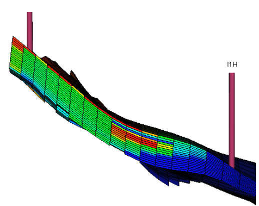
Figure 9. Recovery degree at different water cut stages at different water injection well locations.

injection well is larger, and the larger the swept area is, the higher the efficiency of waterflooding in the injection water is. Waterflooding in the margin promotes the development, and the production effect is the best; however, in the late stage of production, the water influx of production wells will occur earlier due to the water injection in the margin, and the crude oil between the water injection well and the bottom water will be wasted, resulting in the inability to recover this part of crude oil and the poor development effect, indicating that the development potential of water injection outside the margin is greater.

See Table 5 for the production oil saturation field of water injection wells at different locations.

From the oil saturation field diagram, it can be seen that the swept area in the initial stage of marginal water injection production is larger, but it will also invade the production well earlier, resulting in a large amount of remaining oil between the water injection well and the bottom water that cannot be recovered. The displacement efficiency of injected water in the initial stage of marginal water injection is low, but the formation crude oil will not be wasted in the later

Table 5. Oil saturation field diagram at different positions of water injection wells.

	Initial	Water cut 80%	Water cut 95%	Side view with 80% water cut
High part of production well structure				
Middle part of production well structure				
Low part of production well structure				

stage of production, and the development potential is greater.

2.7. Influence of Production Well Spacing and Bottom Water Position during Vertical Well Production

During the development of X sand body exhaustion, five kinds of vertical well layout positions are set, and their dimensionless distances from the edge water are 0.125, 0.25, 0.375, 0.5625 and 0.75 respectively. The production effect of vertical wells and the production effect and displacement law at different positions of production wells are studied. The production well liquid production rate is 300 m^3/d, the production well water content is >98% or the oil production is <2.5 m^3/d, and the production well location is shown in Figure 10.

The recovery degree at different positions of the production well is shown in Figure 11.

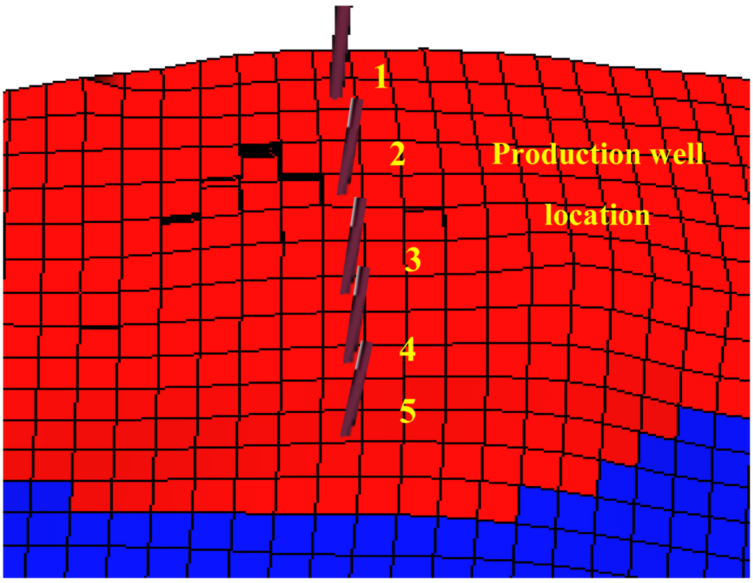


Figure 10. Schematic diagram of different positions of production wells.

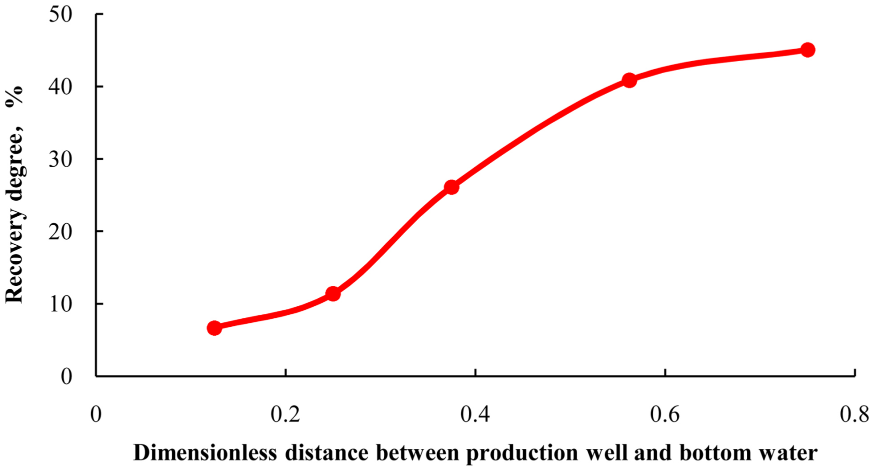


Figure 11. Recovery degree curve at different positions of production well.

When the production well is close to the edge and bottom water, the water influx of the production well is premature, resulting in the premature shut in of the production well, low recovery degree and poor development effect; when the production well layout is in the high part of the reservoir, the slower the water invasion speed is, the later the water breakthrough of the oil well is, the higher the recovery degree is, and the development effect is good.

2.8. Influence of Water Injection Production Well Location

When injecting water into the edge of X sand body, five kinds of vertical well layout positions are set, and the dimensionless distances from the edge water are 0.25, 0.375, 0.5625 and 0.75 respectively. The production effect of different positions of production wells is studied. The production rate of production wells is 300 m^3/d, the injection production ratio is 1, and the wells are shut in when the water content of production wells is >98% or the oil production is <2.5 m^3/d. The location of production wells is shown in Figure 12.

The recovery degree at different positions of the production well is shown in Figure 13. During water injection development, the closer the production well is to the edge and bottom water, the faster the water cut of the production well rises The earlier the well is shut in, the lower the recovery degree. The farther the production well is from the edge and bottom water, the better the water injection displacement effect of the water injection well and the better the production effect.

2.9. Influence of Water Injection Well Location in Water Injection Development

During the development of vertical wells, three water injection methods, i.e.

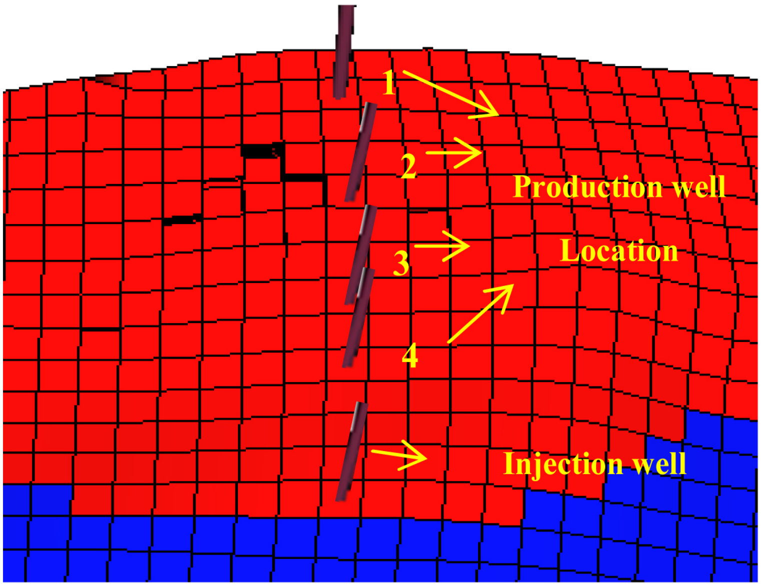


Figure 12. Schematic diagram of different locations of production wells and water injection wells.

inner edge water injection, upper edge water injection and outer edge water injection, are set to study the impact of different water injection methods on production. The liquid production rate of production wells is 300 m^3/d, the water injection rate of water injection wells is 300 m^3/d, the injection production ratio of water injection wells is 1, and the wells are shut in when the water content of production wells is >98% or the oil production is <2.5 m^3/d. the locations of different water injection wells are shown in Figure 14.

At the initial stage of production, the recovery degree of water injection in the edge is high, and the crude oil production effect between the water injection well and the production well is good, and the recovery degree is higher; in the late stage of production, water invasion occurred earlier in the edge water injection, and the edge water injection has the best production effect and greater development potential (Figure 15).

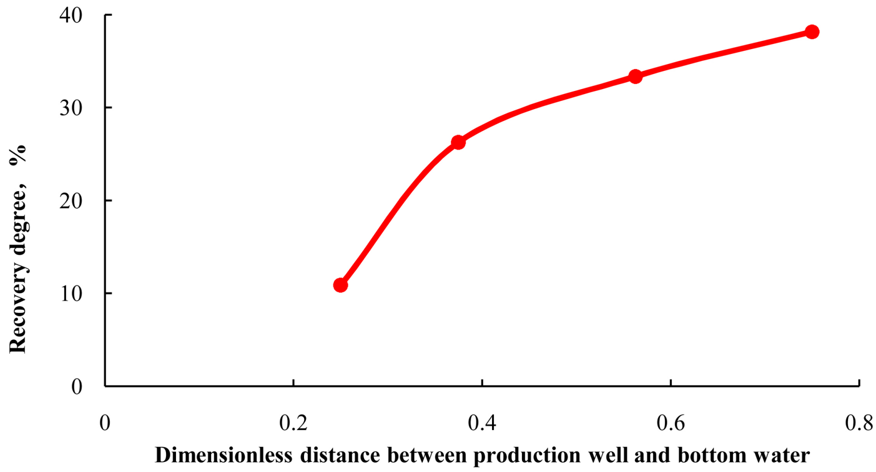


Figure 13. Recovery degree chart at different positions of production wells.

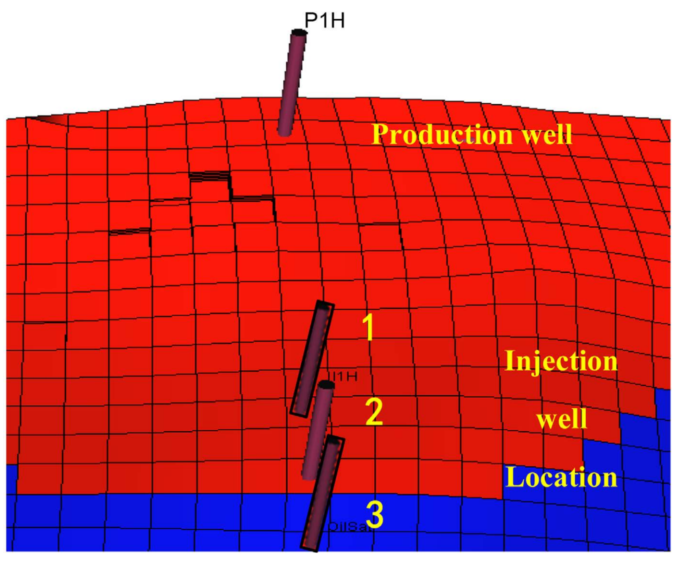


Figure 14. Schematic diagram of different positions of production well and water injection well.

2.10. Development Law of Different Water Multiples

By setting different water multiples of X sand body, the influence of different bottom water energy on development is studied. Set the water multiple of X sand body as 1, 9 and 20 times respectively. The production wells of horizontal wells are arranged at the high part of the sand body, as shown in Figure 15. The daily liquid production is set at 300 m^3/d. the development method adopts depletion development and water injection development. The injection production ratio of water injection wells is 0.3 and 0.5 respectively. The development effects under different development methods are studied.

The recovery degree under different water body multiples and different development methods is shown in Figure 16.

It can be seen from the recovery degree (Figure 17) that different water energy sand bodies have different reasonable development methods. Waterflooding in small water bodies is conducive to oilfield development. Waterflooding can fully supplement the formation energy, making the oil well exploitation life

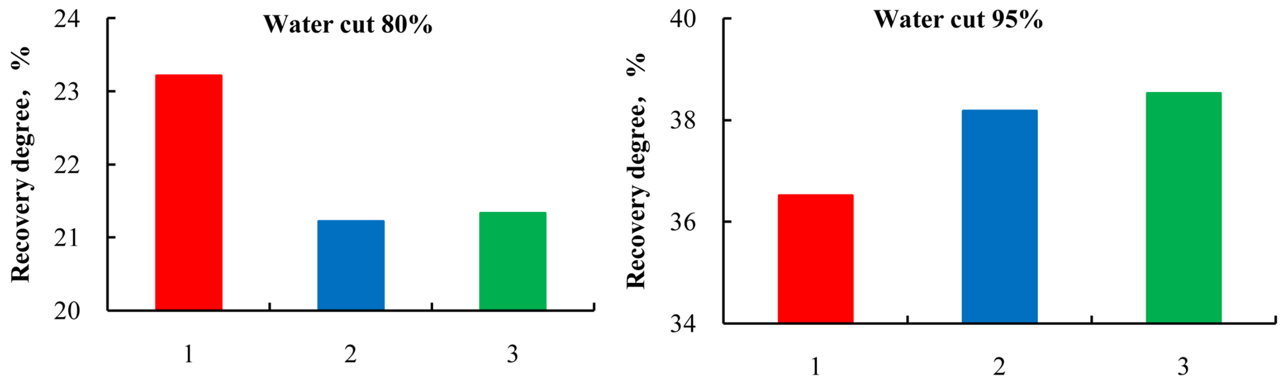


Figure 15. Recovery degree at different water cut stages at different locations of water injection wells.

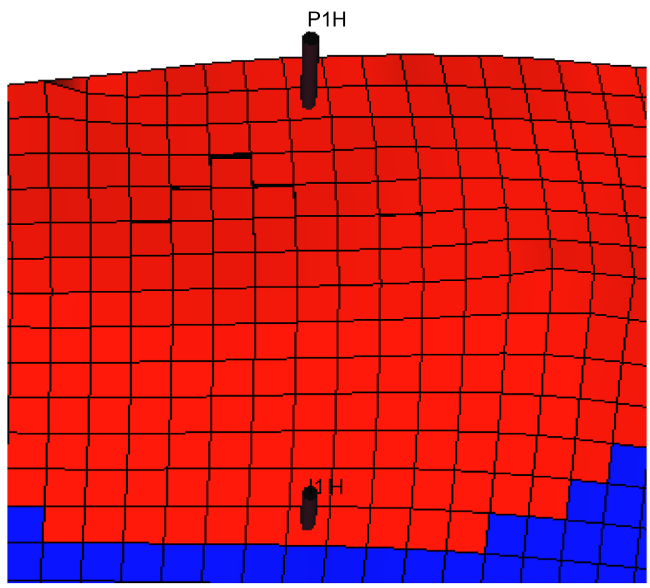


Figure 16. Location of production well and water injection well.

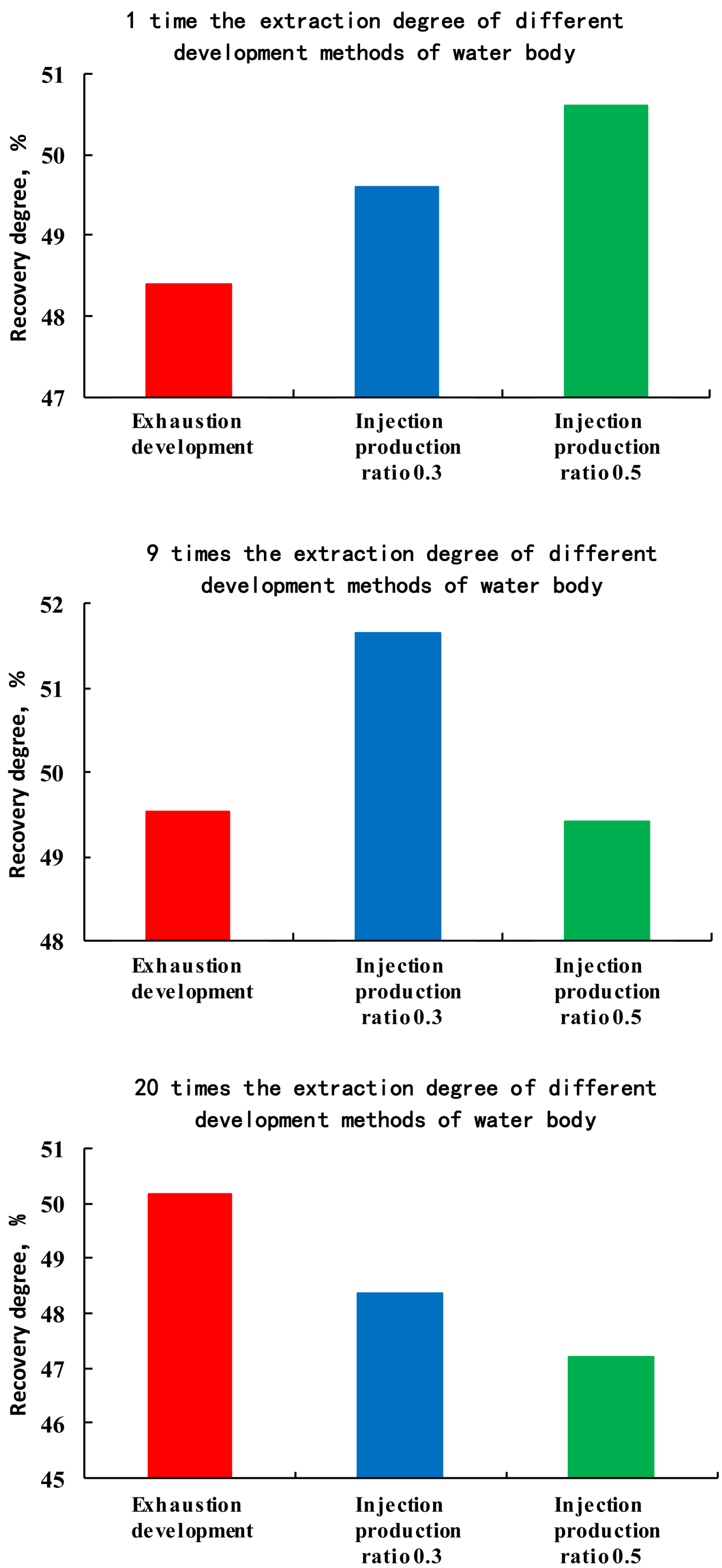


Figure 17. Recovery degree under different water multiples and different development methods.

longer and the final recovery higher; water injection development in large water bodies will lead to faster increase of water content in oil wells, worse development effect, and lower ultimate recovery.

3. Summary

For complex fluvial oil fields, the development effects under different influencing factors are studied, and the following conclusions are obtained:

1) Different formation energies have reasonable development methods, large water bodies are suitable for depletion development, make full use of formation energy, and small water bodies are suitable for water injection development to supplement formation energy.

2) During water injection development, the closer the production well is to the edge and bottom water, the faster the water cut of the production well rises. The earlier the well is shut in, the lower the recovery degree. The farther the production well is from the edge and bottom water, the better the water injection displacement effect of the water injection well and the better the production effect.

3) Waterflooding in small water bodies is conducive to oilfield development. Waterflooding can fully supplement the formation energy, making the oil well exploitation life longer and the final recovery higher; water injection development in large water bodies will lead to faster increase of water content in oil wells, worse development effect, and lower ultimate recovery.

Conflicts of Interest

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

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