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Development Adjustment Scheme of a Low-Permeability Reservoir in the SN Oilfield

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Abstract: Due to the complexity of low-permeability reservoirs, there is no set of established plans to adjust the development of specific low-permeability reservoirs, and the final development adjustment plan should be determined through comprehensive consideration of many aspects. At present, the development of low-permeability reservoirs in the SN oilfield faces problems. It is urgent to formulate corresponding development adjustment plans to improve the current development situation. In view of the problems of the current development surface of low-permeability reservoirs in the SN oilfield, this paper used the previous research results of a low-permeability reservoir development adjustment for reference, evaluated the reservoir development effect, analyzed the remaining oil distribution via numerical reservoir simulation, and finally designed and optimized a development adjustment plan. The research results show that the injection–production ratio and pressure of low-permeability reservoirs in the SN oilfield were generally maintained, the oil production decreased, the water cut increased, and the remaining recoverable reserves were considerable; the historical matching quality of a reservoir numerical simulation was good. There was more remaining oil in the northeast of the J007 well block and the north of the J008 well block, and the potential of the L2 and L3 layers was great. The remaining oil was mainly concentrated in the areas with high positions, poor physical properties, and imperfect well patterns; the predicted cumulative oil production of Scheme IV in 15 years and recovery were the highest, with the best development effect and the highest economic benefit. This was determined as the development adjustment plan for low-permeability reservoirs in the SN oilfield. The research results of this paper aim to improve oil production, the ultimate recovery factor, and economic benefits of low-permeability reservoirs in the SN oilfield, and to provide a reference for the development of similar oilfields.

Keywords: low permeability; development evaluation; numerical simulation; remaining oil distribution; development adjustment scheme

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1. Introduction

With the perennial exploitation of conventional oil and gas, the proportion of resources is declining [1]. Many developers and researchers turned their attention toward unconventional oil and gas. Among unconventional oil and gas resources, low-permeability reservoirs attracted the attention of developers and researchers due to their huge geological reserves [2]. Different from conventional reservoirs, low-permeability reservoirs are more complex, with poor physical properties, developed fractures, strong heterogeneity, and difficulty in determining the law of water cut rise [3]. This causes development to face many problems, and the formulation of development adjustment plans is also full of challenges.

The evaluation of the development effect of low-permeability reservoirs can provide guidance and direction for their development adjustment research, and its significance is very obvious. Many researchers conducted in-depth research on it [4–16], and the research methods mainly include physical experiments and reservoir engineering methods.

Luo et al. [4] conducted an evaluation of the development effect of low-permeability reservoirs using a physical experimental method. Their research results show that formation water sensitivity damage and micro heterogeneity could significantly affect the development effect, causing difficulties in injection, fast breakthrough, and poor liquid-enhancing effect after breakthrough. The oil displacement efficiency and recovery of a single injection of seawater or gas were not high. The development effect of switching from seawater flooding to gas flooding had a good development effect, which could effectively improve the oil displacement effect and enhance oil recovery, indicating the next exploration direction for the efficient development of the WS17-2 low-permeability reservoir. Lei et al. [5] used the dynamic monitoring data of the research area to conduct dynamic analysis, including production capacity analyses, production decline law research, water injection effectiveness analysis, and production rate analysis. By applying the reservoir engineering method, the water cut increase rate, water flooding index, and water storage rate were evaluated. Finally, the degree of utilization and control of water flooding reserves, reservoir pressure, and water flooding recovery were evaluated, laying a solid foundation for better development of the target reservoir. Ma et al. [6] took the Chang3 sandstone reservoir in the Weibei Oilfield of the Ordos Basin as the research object. Firstly, based on the geological characteristics and development and production characteristics of the reservoir, a dynamic analysis of water flooding development was conducted. Secondly, the reservoir engineering method was applied to evaluate the development effect through indicators such as water cut, water displacement volume, and reserve utilization degree. Finally, an optimization plan for injection and production parameters was proposed through well network adaptability analysis. Their research on the evaluation method of water flooding development effect in low-permeability reservoirs provided important theoretical guidance significant to the development of similar reservoirs. In terms of research on the development adjustment of low-permeability reservoirs, although many researchers made many outstanding achievements in the past [17–24], due to the complexity of low-permeability reservoirs, there is still no set of established development adjustment plans for the specific development of low-permeability reservoirs. They all require various research methods with comprehensive consideration and the determination of the development adjustment plan. At present, the development adjustment plan for low-permeability reservoirs is mainly formulated through experiments, reservoir engineering, numerical simulation, or their combination. Hu et al. [22] carried out water sensitivity evaluation experiments on cores with different permeabilities in low-permeability reservoirs; studied the distribution of the pore and throat radius, coordination number, changes in physical parameters, and their effects on flow in the reservoir in the process of water sensitivity; and drew a comparison chart of ultimate injection–production well spacing before and after water sensitivity. By calculating the ultimate injection–production well spacing, the water sensitivity effect was obtained, resulting in a reduction of 153 m in the ultimate injection–production well spacing of the low-permeability reservoir in the Xingouzui Formation; adjusting the injection–production well spacing through infill wells to improve the coverage range of water injection was recommended. Wu et al. [23] applied reservoir engineering methods and numerical simulation techniques to clarify the flow characteristics and remaining oil distribution patterns in the oil–water transition zone, determined the economic and technological boundaries of oil wells in the oil–water transition zone in the oil–water transition zone, analyzed the development potential of different regions in the oil–water transition zone, and proposed reasonable development adjustment strategies for oil–water transition zones with different development potentials. Li et al. [24] used reservoir engineering methods to obtain reasonable well patterns and injection–production parameters for the target block, optimized the optimal injection–production well pattern using the numerical reservoir simulation method, and designed a development adjustment plan for the target block, and it was predicted that the annual oil production could increase by 20.5%. However, these methods also have limitations. The development adjustment plans developed by them are effective for target or specific low-permeability reservoirs, but may not be suitable for other low-permeability reservoirs. Therefore, for the formulation of specific development adjustment plans of low-permeability reservoirs, based on the previous methods, it is still necessary to comprehensively consider multiple factors, conduct specific analysis, and finally determine.

The SN oilfield is located in the hinterland of the Junggar Basin, about 130 km east of Karamay, China. Its development currently faces the following challenges: low injection–production ratio and average pressure maintenance level; most production wells are in the high/ultra-high water cut stage; the remaining oil at the top of the reservoir is relatively rich, but the current well pattern has insufficient control over the remaining oil at the top, and cannot be effectively developed; and in some areas, the well pattern is not perfect, the well control is weak, or there is no production well around, so the uncontrolled reserves are large. Due to many problems, it is necessary to carefully sort out, draw on experience, and propose development adjustment plans to improve oil recovery and economic benefits.

This paper first evaluates the development effect of low-permeability reservoirs in the SN oilfield, uses numerical simulation (ECLIPSE V2013.1 numerical reservoir simulation software) to analyze the distribution law of the remaining oil, and finally designs and optimizes the development adjustment scheme in combination with a development effect evaluation and remaining oil characterization study. The study of this paper can not only solve the problems existing during current production in the SN oilfield, but also achieve the effects of stabilizing oil production, controlling water cut, improving oil production, recovery, and economic benefits by applying the results of this paper. In addition, this study can also provide engineers with ideas to solve the development problems of low-permeability reservoirs, provide method references for low-permeability reservoir development, and have important significance for the efficient development of low-permeability reservoirs.

2. Methods

2.1. Analysis of the Development Effect

Through the analysis of important production indicators of the whole area and single wells, including pressure, oil production, water cut, water cut rise rate, and remaining recoverable reserves; the development effect is evaluated, the reasons for changes in important production indicators of the whole region and single wells, as well as problems in development, are identified, and corresponding countermeasures are proposed to guide the formulation of subsequent development adjustment plans. Development effect evaluation is a relatively routine work in the development direction of oil and gas fields, and the specific method can be referred to [4–16]. The water flooding characteristic curve method is used to determine the remaining recoverable reserves in this paper, and commonly used water flooding characteristic curves include type A, B, C, and D [12,13], as shown in Table 1, where α_1, α_2, α_3, α_4, β_1, β_2, β_3, and β_4 are coefficients; W_p, N_p, and L_p are accumulative water, oil, and liquid production, $\times 10^4$ ton, respectively; R is the recovery; f_{wl} is the limit water cut; and N is the original oil in place, $\times 10^4$ ton. The relevant production indicators of the SN oilfield are used in the water flooding characteristic curves, and the water flooding characteristic curve with a linear relationship can be used. Even if there is a turning point, as long as a straight line segment appears above the turning point, using the water flooding characteristic curve with a linear relationship for prediction can obtain reliable results [14,15]. The correlation coefficient of the straight line segment is used as the selection indicator, and the one with the highest correlation coefficient of the straight line segment is selected as the type of water flooding characteristic curve in the SN oilfield, which can then calculate the remaining recoverable reserves as $NR - N_p$. The specific method can be referred to [16].

Table 1. Relationship and recovery equation of type A, B, C, and D water flooding characteristic curves.

Type	Relationship Equation	Recovery Equation
A	$\lg W_p = \alpha_1 + \beta_1 N_p$	$R = \frac{\lg \frac{f_{wl}}{1-f_{wl}} - \alpha_1 - \lg(2.303\beta_1)}{N\beta_1}$
B	$\lg L_p = \alpha_2 + \beta_2 N_p$	$R = \frac{\lg \frac{1}{1-f_{wl}} - [\alpha_2 + \lg(2.303\beta_2)]}{N\beta_2}$
C	$L_p / N_p = \alpha_3 + \beta_3 L_p$	$R = \frac{1-\sqrt{\alpha_3(1-f_{wl})}}{N\beta_3}$
D	$L_p / N_p = \alpha_4 + \beta_4 W_p$	$R = \frac{1-\sqrt{(\beta_4-1)\frac{1-f_{wl}}{f_{wl}}}}{N\beta_4}$

2.2. Residual Oil Analysis

Based on the geological model of the SN oilfield, the ECLIPSE V2013.1 numerical reservoir simulation software is used to carry out historical matching of the SN oilfield, the specific distribution of the remaining oil is clarified, and corresponding development countermeasures are proposed to provide direction for the formulation of subsequent development adjustment schemes. This residual oil analysis method can be referred to [20,22,23].

2.3. Formulation of the Development Adjustment Plan

Based on the evaluation of the development effect and the distribution of remaining oil, combined with the current situation of the SN oilfield, the corresponding development adjustment scheme is designed, the production indicators of each scheme are predicted through ECLIPSE V2013.1 numerical reservoir simulation software, and economic evaluation is carried out to optimize the development adjustment scheme. The development adjustment plan formulation method can be referred to [21,23,24].

3. Results and Discussion

3.1. Development Effect Evaluation

3.1.1. Injection–Production Ratio and Pressure Maintenance Level

The injection–production ratio and pressure maintenance (its comparative reference is the initial formation pressure, 24.60 MPa) of low-permeability reservoirs in the SN oilfield are shown in Figure 1. Figure 1 shows that the injection–production ratio and pressure maintenance of low-permeability reservoirs in the SN oilfield roughly experienced the trend of "maintain-reduce-recovery" from 2010 to 2021, and are still in the recovery period. From 2010 to 2012, the water flooding development situation was stable, the injection–production ratio was reasonable, and the pressure remained good. From 2013 to 2015, due to the water out and water breakthrough, as well as the acceleration of water cut increase, the water injection volume was reduced, and some water injection wells were closed, resulting in a decrease in injection–production ratio and a decrease in pressure maintenance level. After 2015, the injection–production ratio and pressure were gradually recovered by adjusting the well pattern reasonably and optimizing the injection–production parameters. There is still room for improvement in the injection–production ratio and pressure maintenance level. Given this situation, it is important to appropriately increase the injection volume of water injection wells and reduce/stop the production of high water cut production wells.

3.1.2. Production, Water Cut, and Water Cut Rise Rate

The production and water cut of low-permeability reservoirs in the SN oilfield are shown in Figure 2. Figure 2 shows that the liquid production and oil production of low-permeability reservoirs in the SN oilfield are generally decreasing, and the water cut is increasing. Currently, the oilfield is in the ultra-high water cut stage. The water cut increase rate of low-permeability reservoirs in the SN oilfield is shown in Figure 3. Moreover, Figure 3 shows that the water cut of low-permeability reservoirs in the SN oilfield decreases after the water cut reaches 90%, which is due to the improvement in production conditions due to the adoption of stimulation measures. However, after the recovery reaches 18%, the effect of the stimulation measures worsens, the water cut rises rapidly, and the development situation worsens. Given this situation, suitable measures for stabilizing oil and controlling water can be considered based on the actual development situation of low-permeability reservoirs in the SN oilfield, including injection well injection increase, production reduction/shutdown of high/ultra-high water cut production wells, liquid increase in high production wells, gas injection, and the drilling of new wells. The working system of the injection well and production well can be determined by analyzing the production status and influencing factors through conventional reservoir engineering methods and combining the distribution of the remaining oil. Gas injection and the drilling of new wells are more focused on combining with the distribution of the remaining oil.

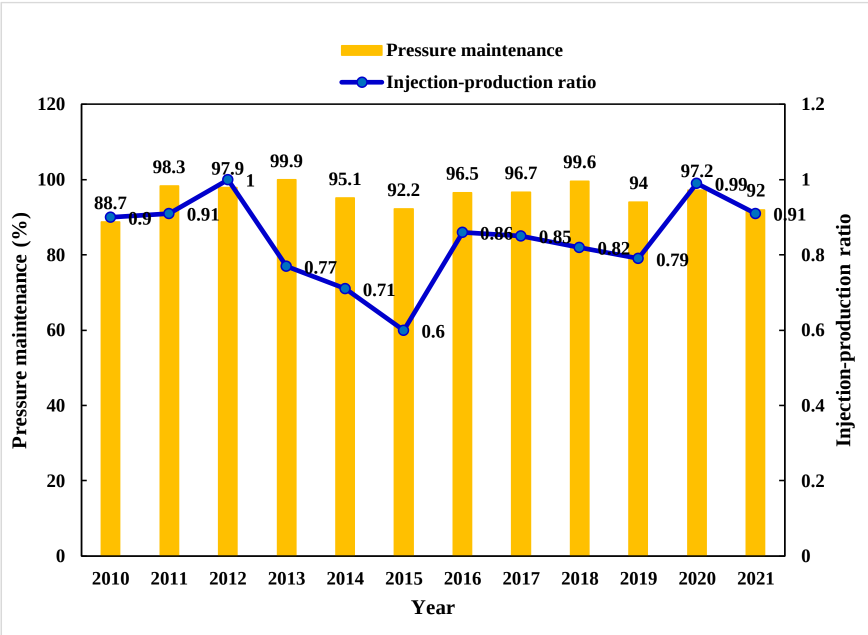


Figure 1. Injection–production ratio and pressure maintenance level of low-permeability reservoirs in SN oilfield.

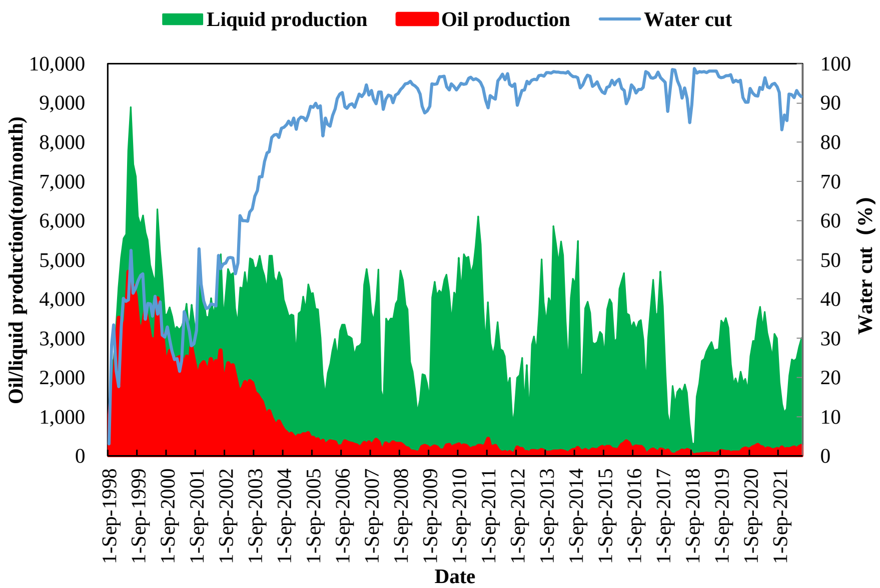


Figure 2. Production and water cut curve of low-permeability reservoirs in the SN oilfield.

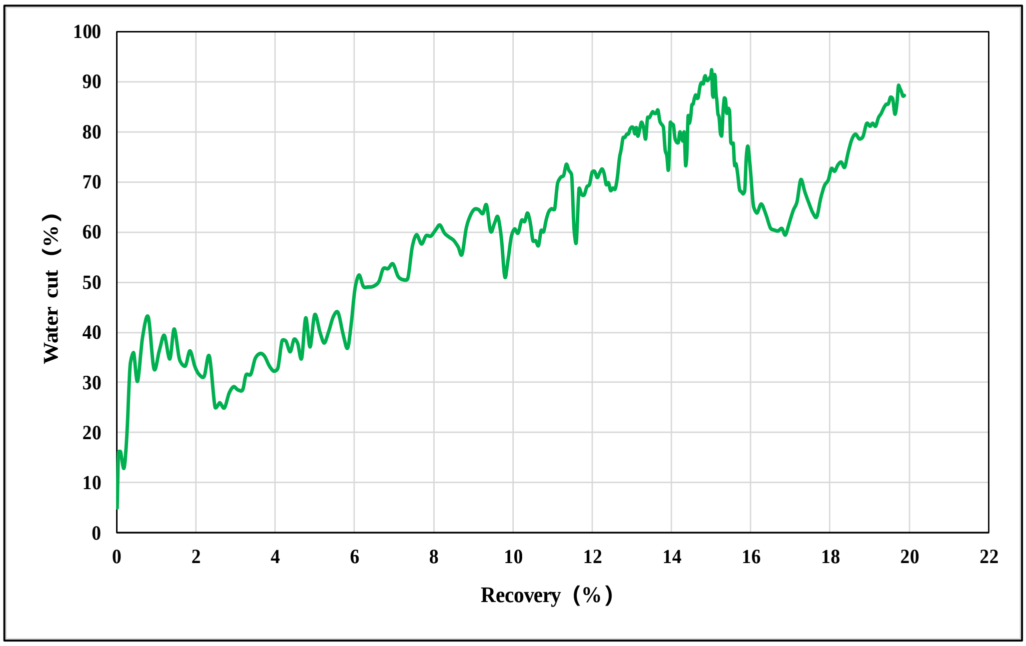
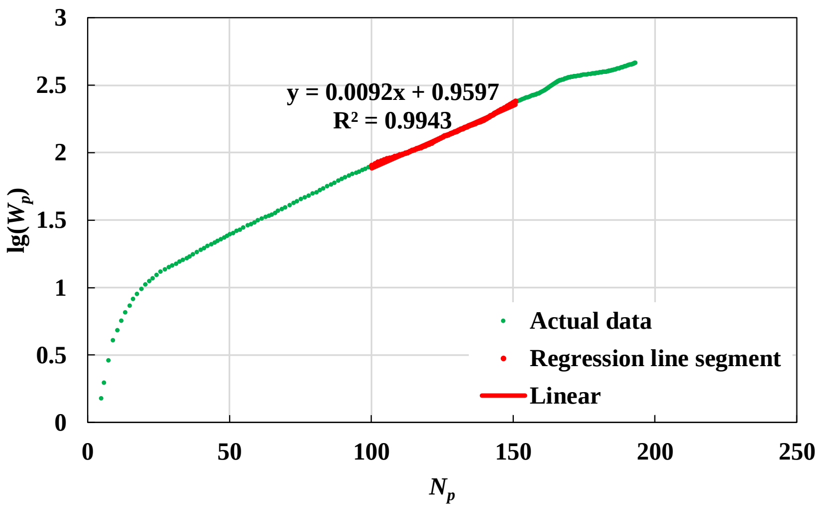


Figure 3. Water cut rise rate curve of low-permeability reservoirs in the SN oilfield.

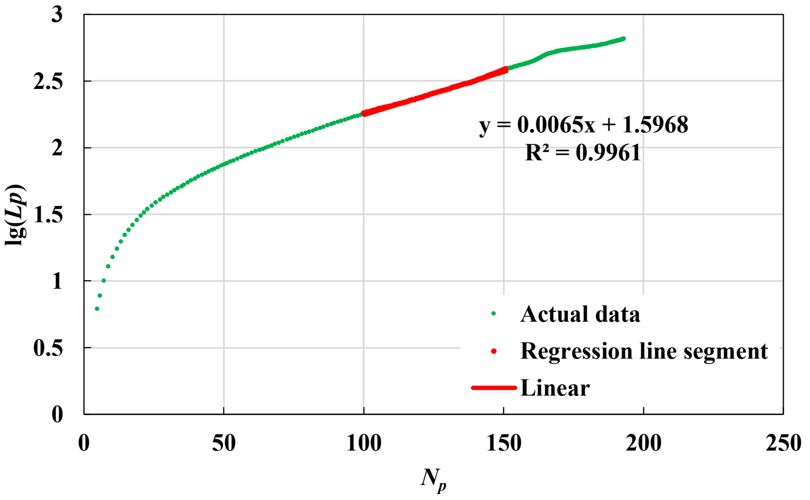
3.1.3. Remaining Recoverable Reserves

The four types of water flooding characteristic curves of low-permeability reservoirs in the SN oilfield are shown in Figure 4. It can be seen in Figure 4 that the correlation coefficients of the type A, B, C, and D water flooding characteristic curves of low-permeability reservoirs in the SN oilfield are 0.9943, 0.9961, 0.9995, and 0.9981, respectively, of which the correlation coefficient of the type C water flooding characteristic curve is the highest, indicating that low-permeability reservoirs in the SN oilfield are more in line with the type C water flooding characteristic curve. The final cumulative oil production and recovery of the low-permeability reservoir in the SN oilfield are 213.28×10^4 ton and 26.8%, respectively, calculated using the type C water flooding characteristic curve. By May 2021, the cumulative oil production, recovery percentages, and remaining recoverable reserves are 189.50×10^4 ton, 23.81%, and 23.78×10^4 ton, respectively. The remaining recoverable reserves are considerable and have great tapping potential.

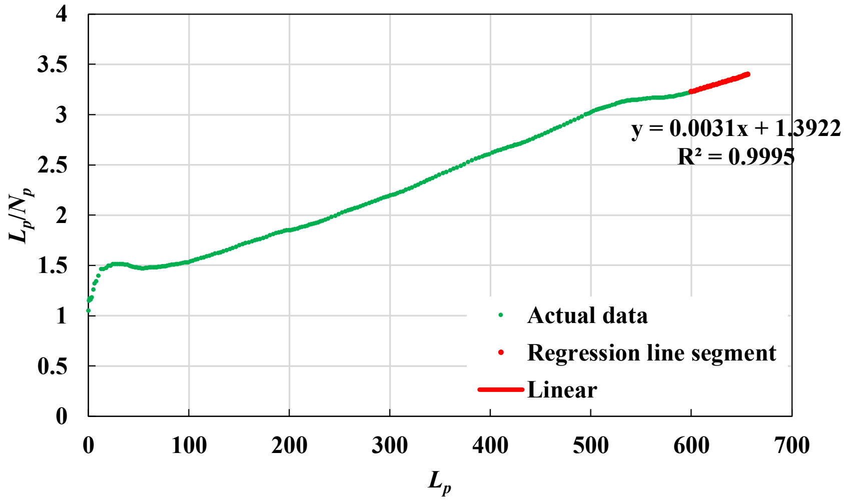


(**a**) Type A water flooding characteristic curve.

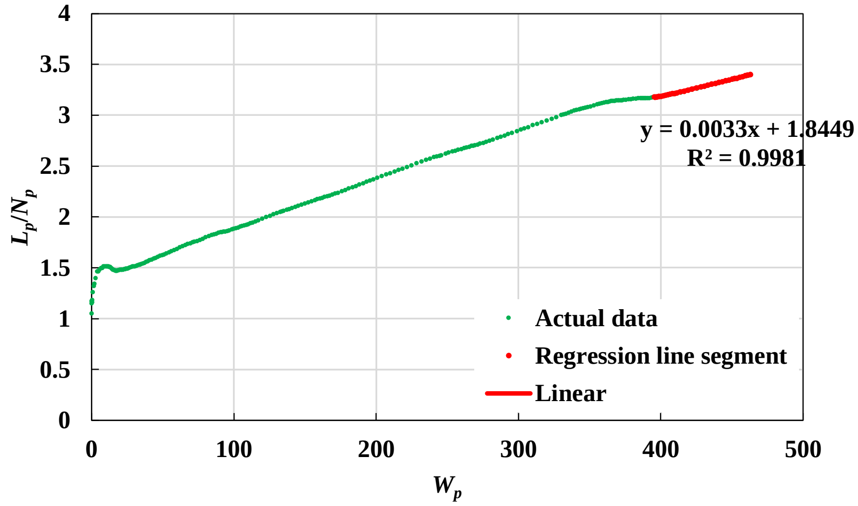
Figure 4. *Cont.*



(**b**) Type B water flooding characteristic curve.



(**c**) Type C water flooding characteristic curve.



(**d**) Type D water flooding characteristic curve.

Figure 4. Water flooding characteristic curve of low-permeability reservoir in the SN oilfield.

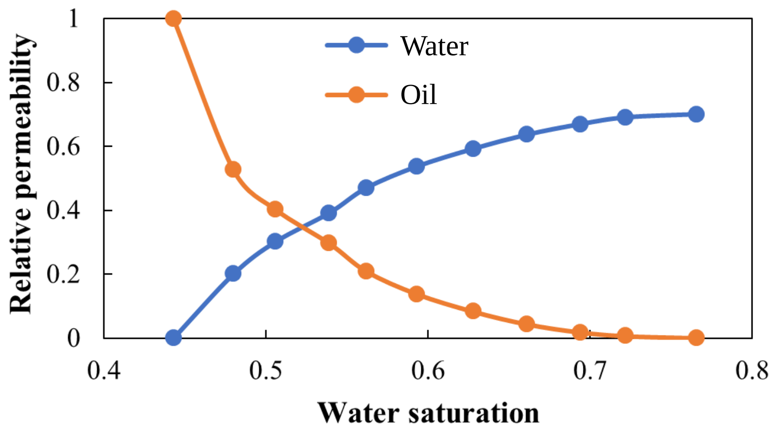
3.2. Characterization of Remaining Oil

3.2.1. Historical Matching

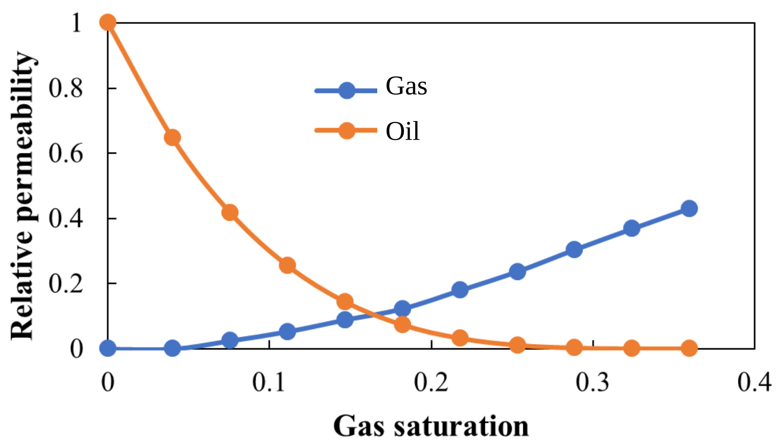
The numerical model of SN oilfield is shown in Table 2, Figures 5 and 6.

Table 2. Main parameters in the numerical model of the SN oilfield.

Parameter	Value
Number of grids in the x, y, and z directions	375, 290, 50
Block size along x, y, and z directions, m	25, 25, 1.1
Rock compressibility, MPa^{-1}	1.9×10^{-4}
Density of oil, kg/m^3	872
Initial viscosity of oil, mPa·s	1.03
Compressibility of oil, MPa^{-1}	5.7×10^{-4}
Oil volume factor	1.25
Density of water, kg/m^3	1020
Viscosity of water, mPa·s	0.48
Compressibility of water, MPa^{-1}	4.3×10^{-4}
Water volume factor	1.01

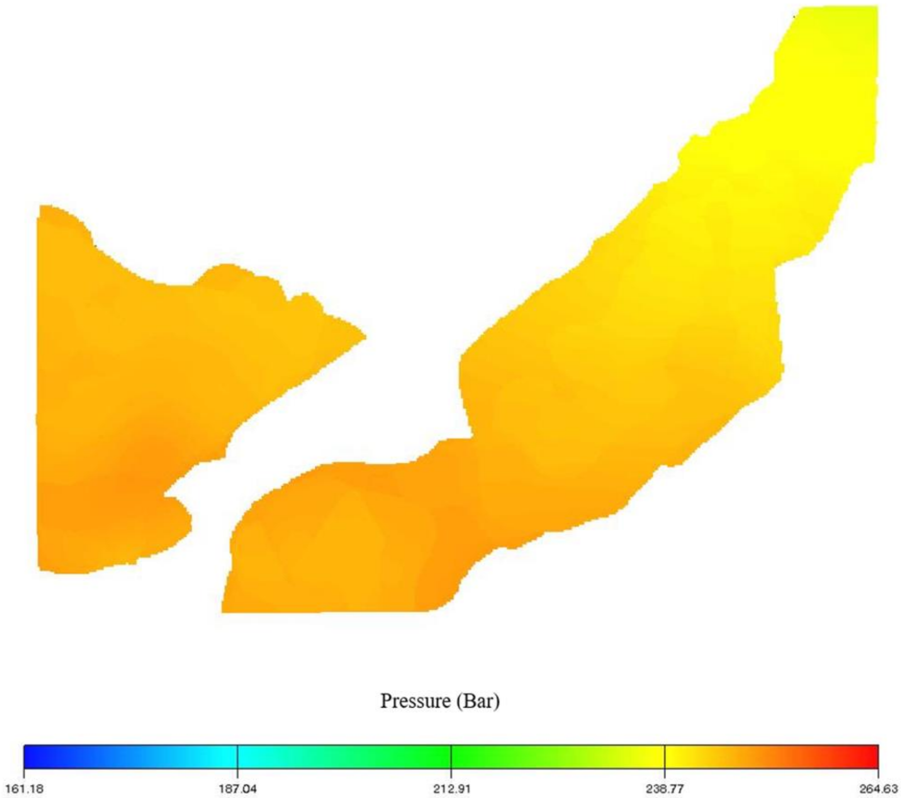


(**a**) Oil and water relative permeability curve.

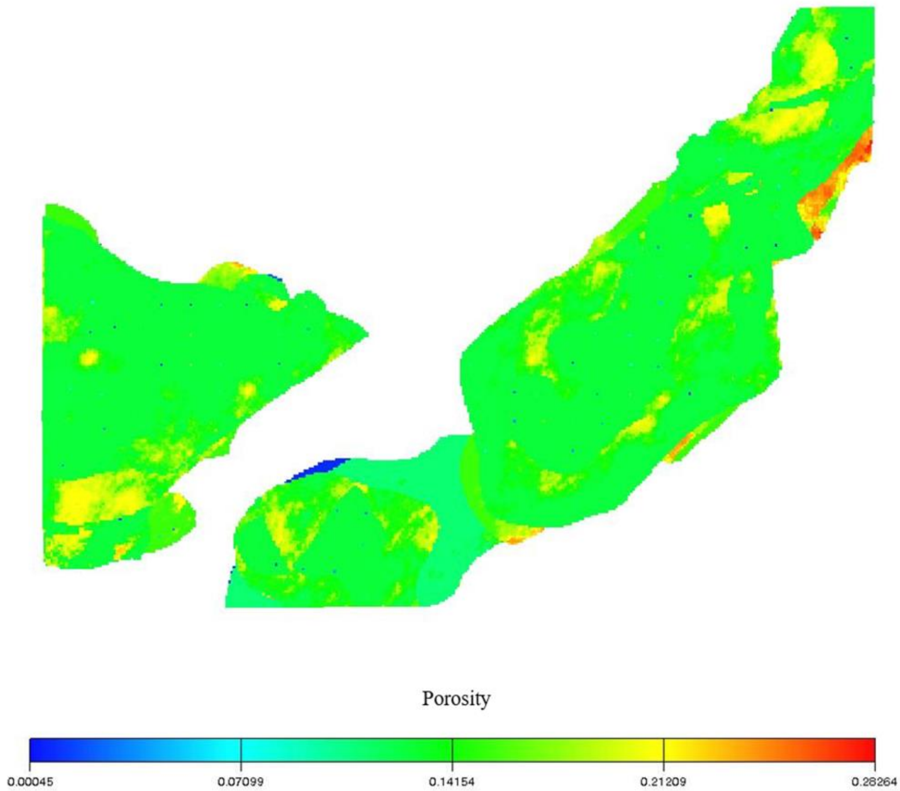


(**b**) Oil and gas relative permeability curve.

Figure 5. Relative permeability curve in the numerical model of the SN oilfield.

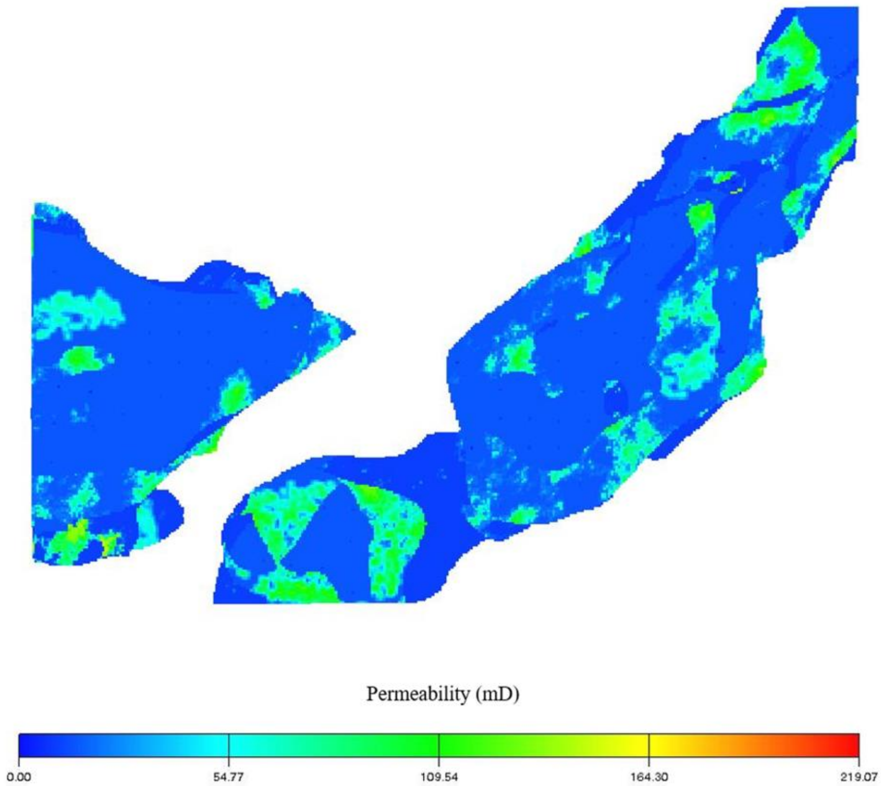


(**a**) Distribution of initial pressure.

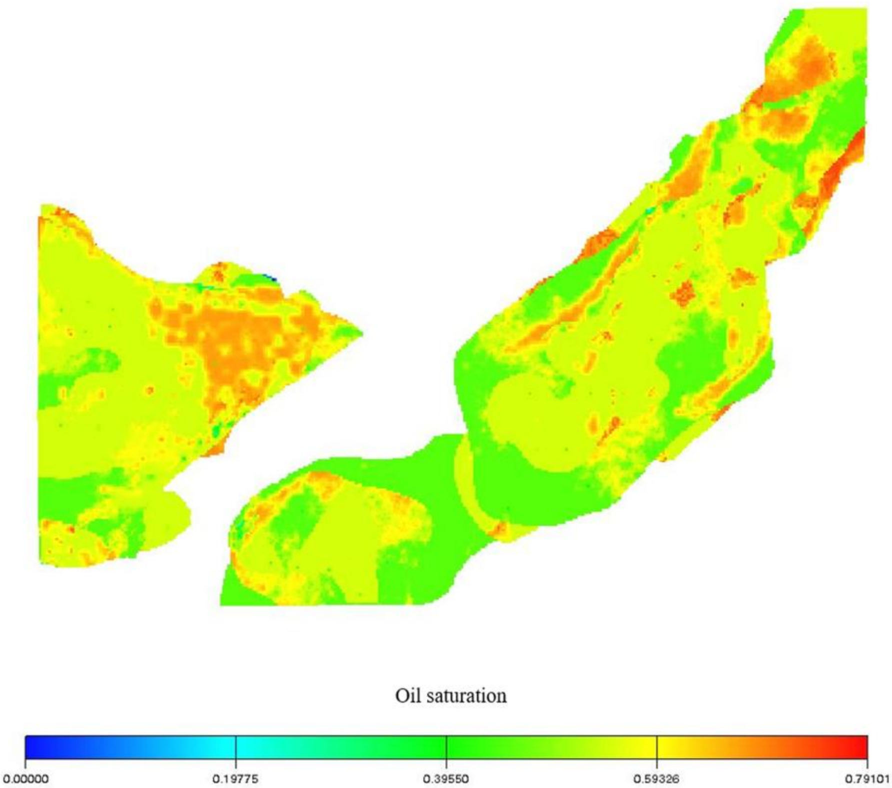


(**b**) Distribution of initial porosity.

Figure 6. *Cont*.



(**c**) Distribution of initial permeability in the x direction.



(**d**) Distribution of initial oil saturation.

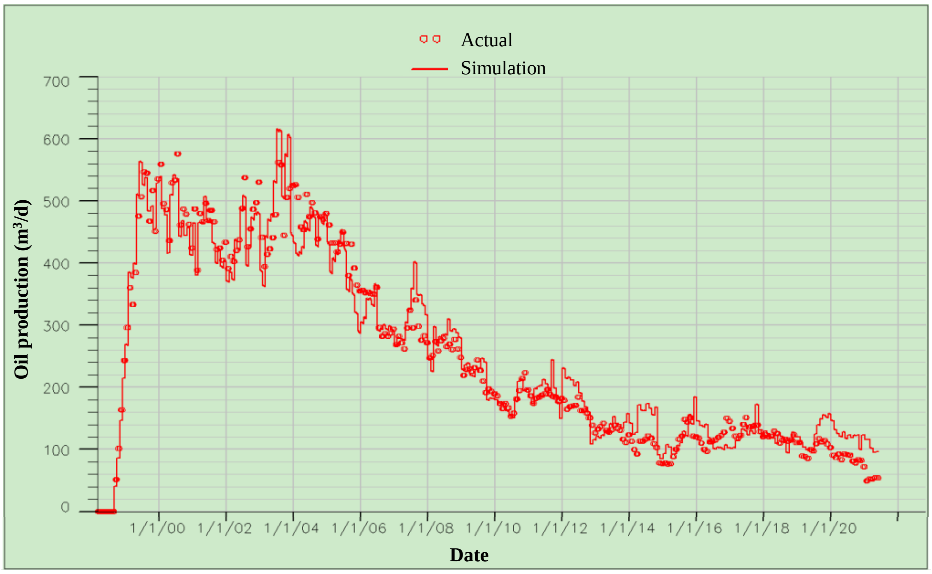
Figure 6. Distribution of initial pressure, porosity, permeability, and oil saturation.

The matching results of geological reserves of low-permeability reservoirs in the SN oilfield are shown in Table 3. It can be seen in Table 1 that the matching errors are less than 2%, and the matching results of geological reserves are good.

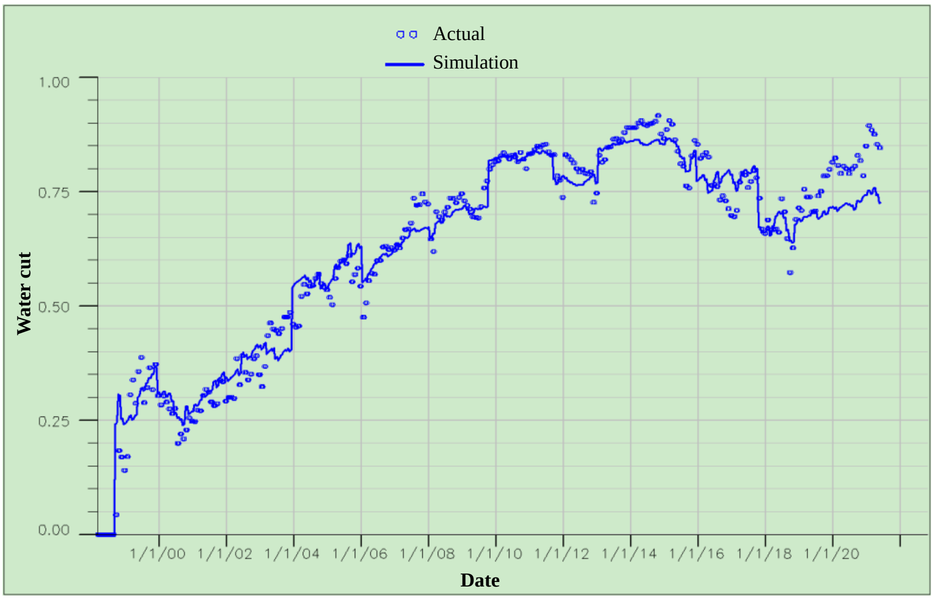
Table 3. Geological reserve matching results of the low-permeability reservoir in the SN oilfield.

Matching Index	Actual Reserves	Simulated Reserves	Error (%)
Reserves ($\times 10^4$ ton)	795.83	806.75	1.4

The historical matching results of the whole area and single wells (taking J001 and SN5 as examples) of low-permeability reservoirs in the SN oilfield are shown in Figures 7–9. In Figures 7–9, the historical matching result of the whole area and single wells is good and can be used for scheme prediction.

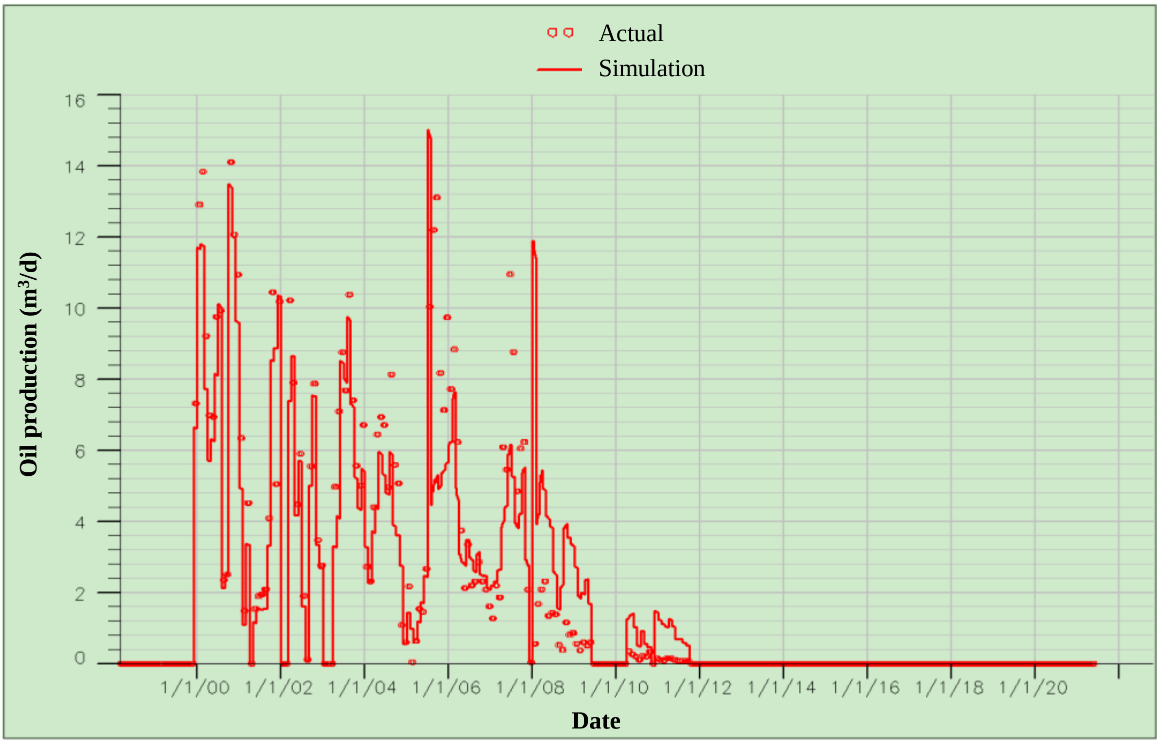


(**a**) Oil production matching curve of the whole area.

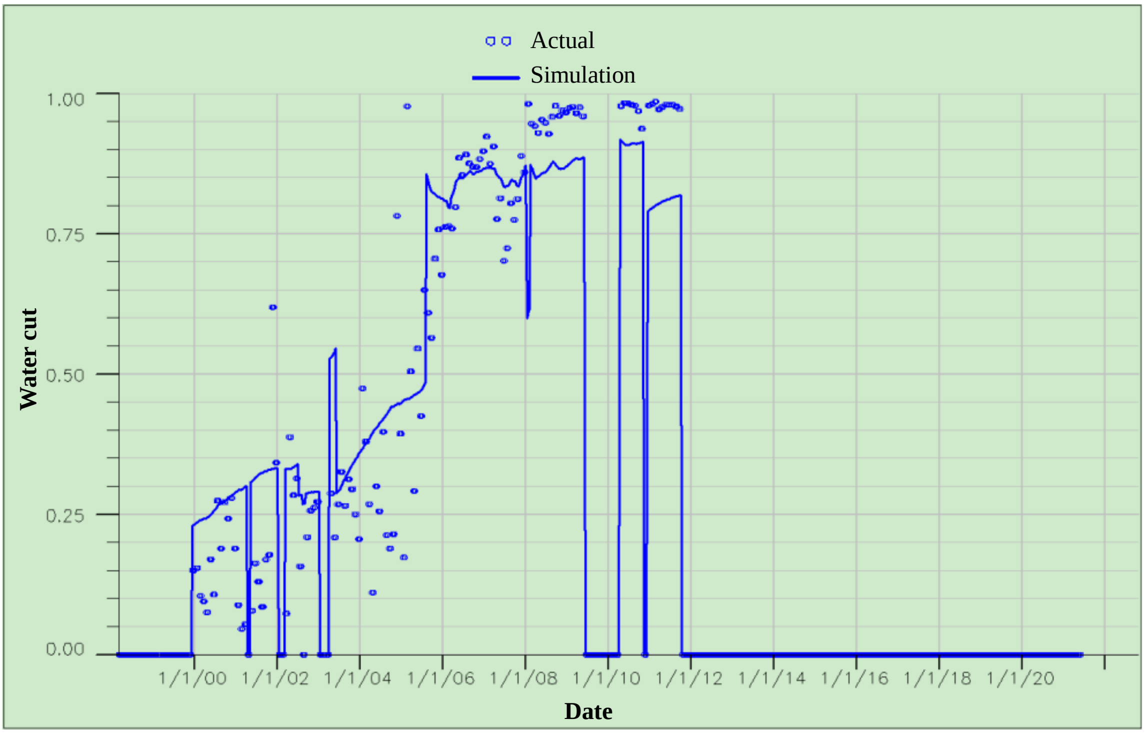


(**b**) Water cut matching curve of the whole area.

Figure 7. Historical matching results of the whole region.

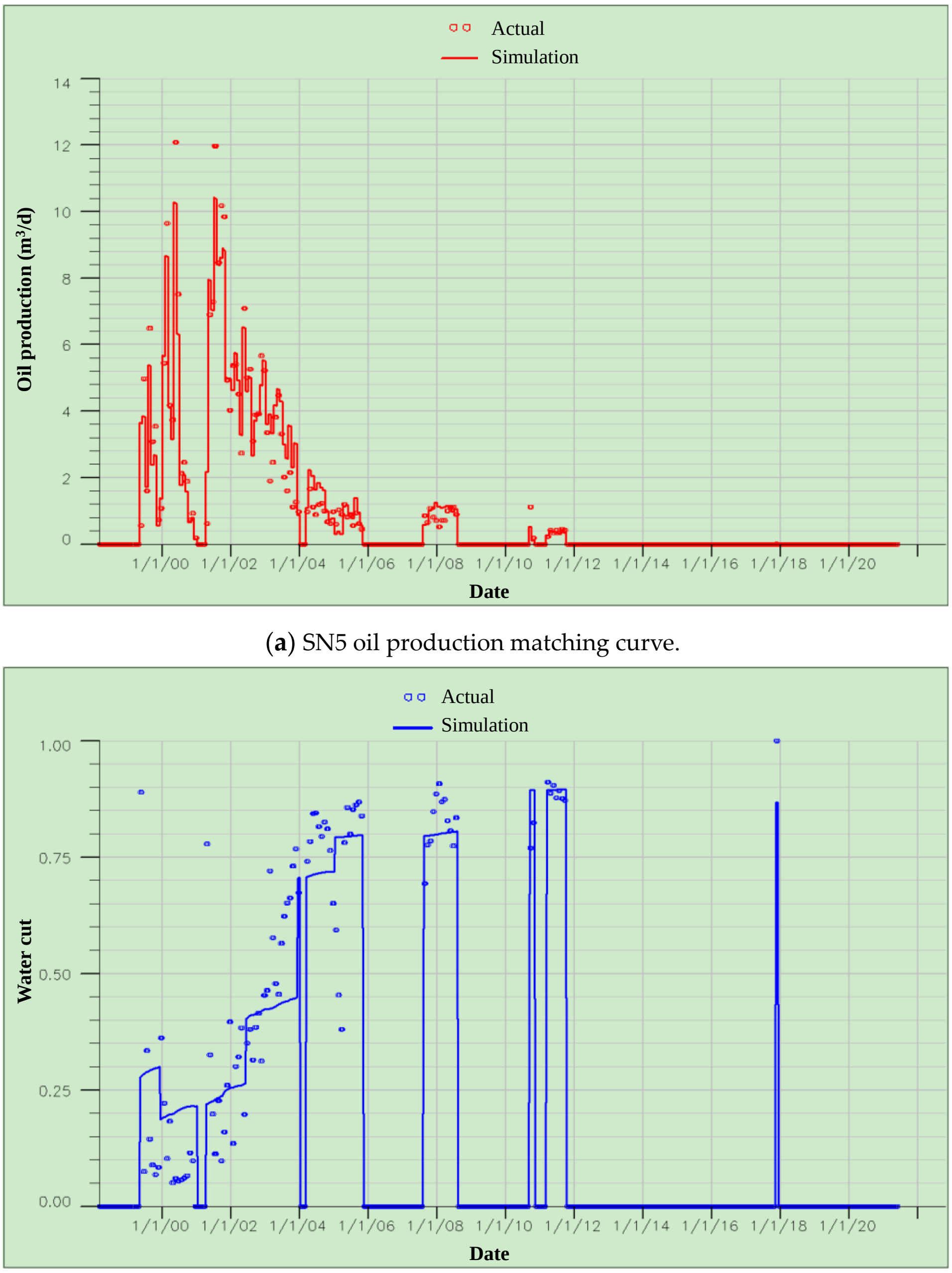


(**a**) J001 oil production matching curve.



(**b**) J001 water cut matching curve.

Figure 8. J001 historical matching results.



(**a**) SN5 oil production matching curve.

(**b**) SN5 water cut matching curve.

Figure 9. Historical matching results of oil production and water cut of the SN5 well.

3.2.2. Plane Residual Oil Distribution

The abundance distribution of the remaining reserves in the low-permeability reservoirs of the SN oilfield is shown in Figure 10. It can be seen in Figure 10 that the plane remaining oil is mainly distributed in the high part of the reservoir structure. The overall recovery percentage of the J007 well block is 26.01%; its remaining reserve is 329.67 $\times$ 10^4 ton, and the northeast oil area is the main potential area. The overall recovery percentage of the J008 well block is 18.06%; its remaining reserve is 204.43 $\times$ 10^4 ton, and the area with more remaining oil in the north has certain development potential. The recovery percentage of the SN 4 well block is 16.22%; its remaining reserves are 99.97 $\times$ 10^4 ton, and the later development potential is small.

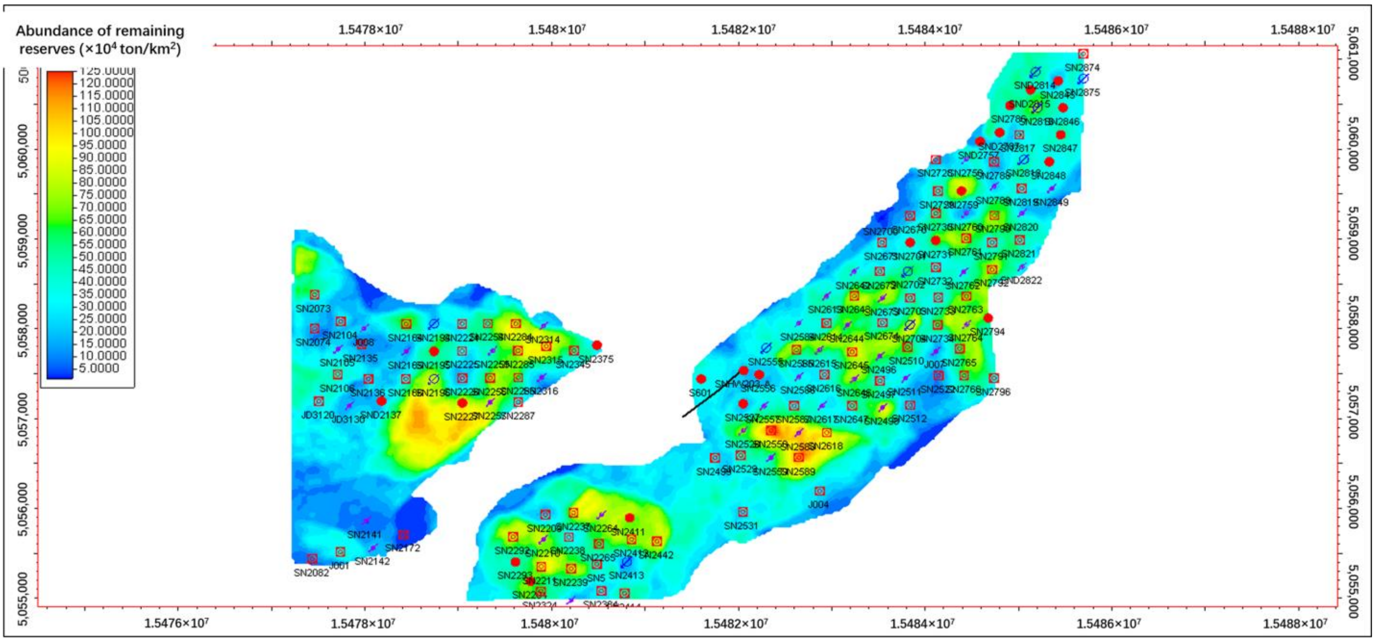


Figure 10. Abundance distribution of remaining reserves in low-permeability reservoirs of the SN oilfield.

3.2.3. Vertical Residual Oil Distribution

The remaining reserve abundance of layers L1~L4 in low-permeability reservoirs in the SN oilfield is shown in Figures 11–14. It can be seen in Figures 11–14 that the remaining reserves of layer L1 are only 146.5×10^4 ton, which is due to the poor physical properties of the reservoir and low original reserves. There are many remaining reserves in layer L2, up to 342.1×10^4 ton, which is the main potential layer due to the large reserve base. The water flooded degree of layer L3 is relatively high, and the edge and bottom water are channeled along the oil–water transition zone. The remaining reserve in the J007 well block in this layer is 175.4×10^4 ton, with certain potential. In the L4 layer, the SN 4 well block is the main production area. The remaining reserves in the SN 4 well block in this layer L4 are 65.7×10^4 ton; they are dominated by oil–water layers, which are not effectively developed in the region; the oil saturation is relatively high, but the reserve abundance is low and the risk of bottom water invasion is high. The remaining oil enrichment area and its causes are shown in Table 4. In Figures 11–14 and Table 4, the remaining oil in the low-permeability reservoirs of the SN oilfield is mainly distributed in the areas with high structure, poor physical properties, and imperfect well patterns.

Table 4. Remaining oil enrichment area and reasons.

Layer	Area No.	Reasons for Remaining Oil Enrichment
L1	1	Top of structure
	2	Top of structure
	3	Poor physical properties and incomplete well pattern
	4	Residual oil between wells
	5	Incomplete well pattern
L2	1	Poor physical properties and top of structure
	2	Incomplete well pattern
	3	Residual oil between wells
L3	1	Poor physical properties and top of structure
	2	Incomplete well pattern
	3	Residual oil between wells and incomplete well pattern

Table 4. *Cont.*

Layer	Area No.	Reasons for Remaining Oil Enrichment
L4	1	No production
	2	Poor physical properties and incomplete well pattern
	3	Residual oil between wells

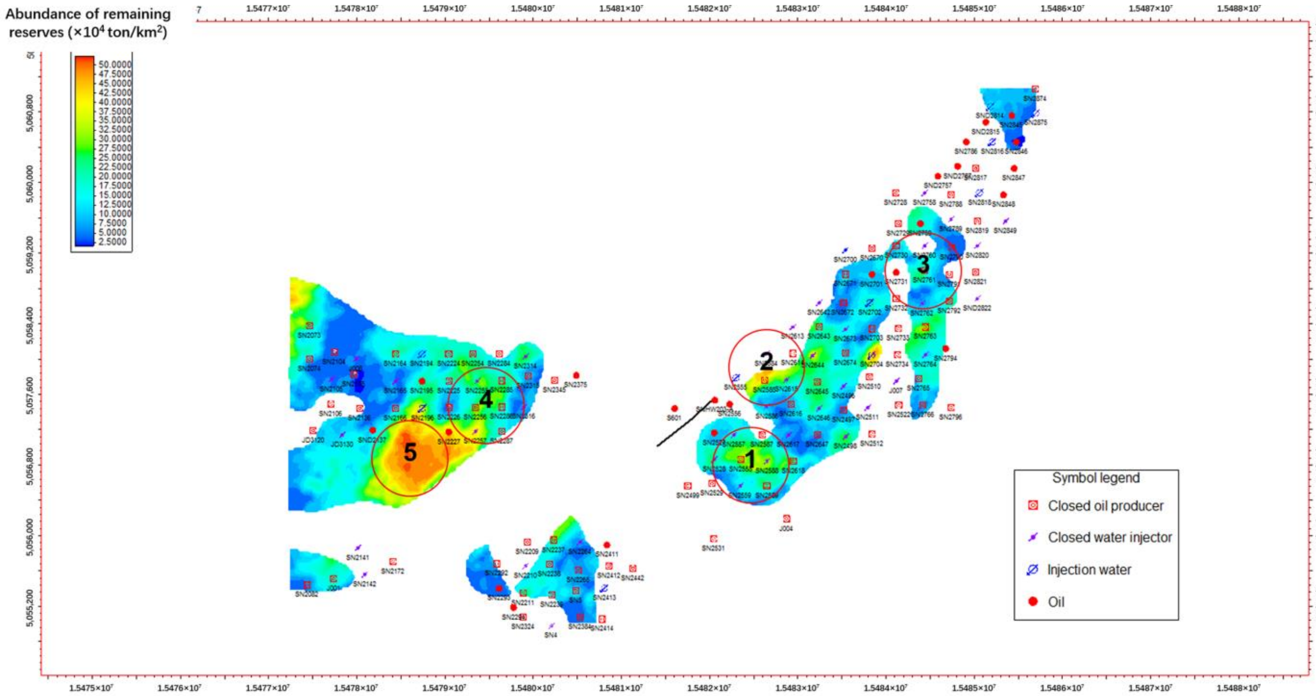


Figure 11. Abundance of the remaining reserves of layer L1 in the low-permeability reservoir in the SN oilfield.

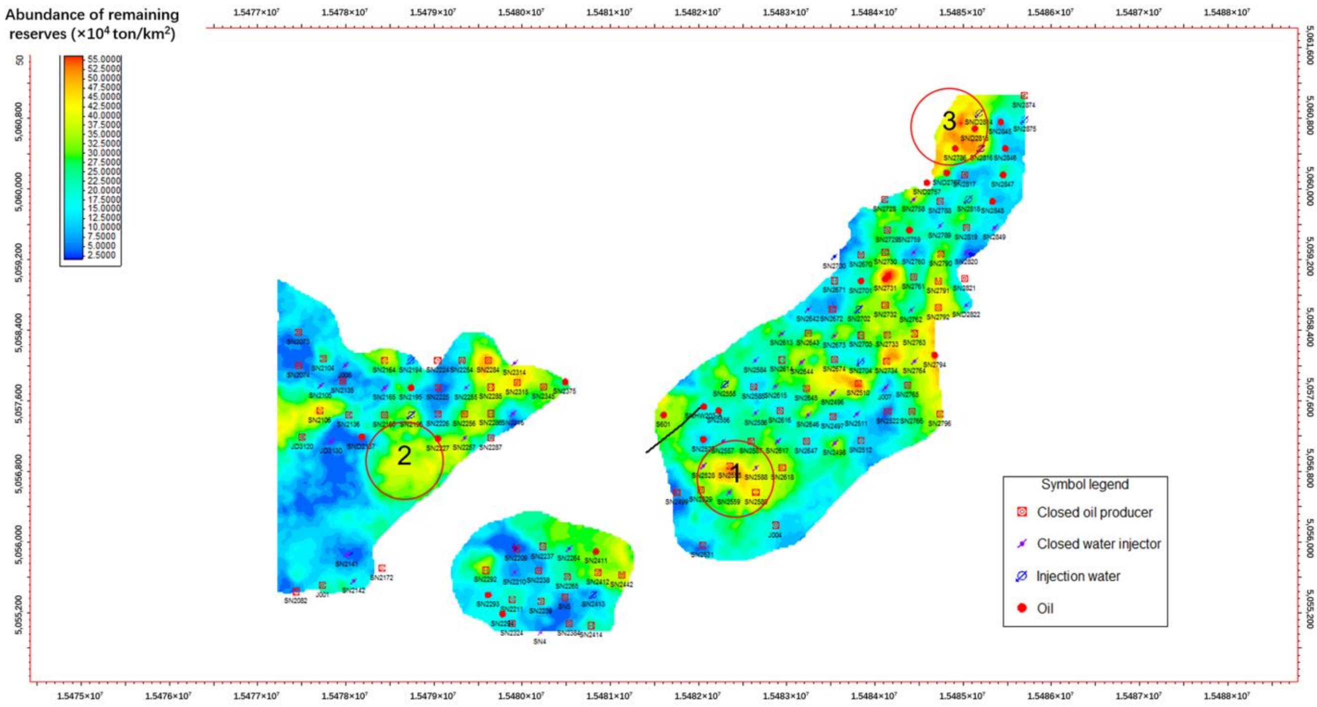


Figure 12. Abundance of remaining reserves of layer L2 in the low-permeability reservoir in the SN oilfield.

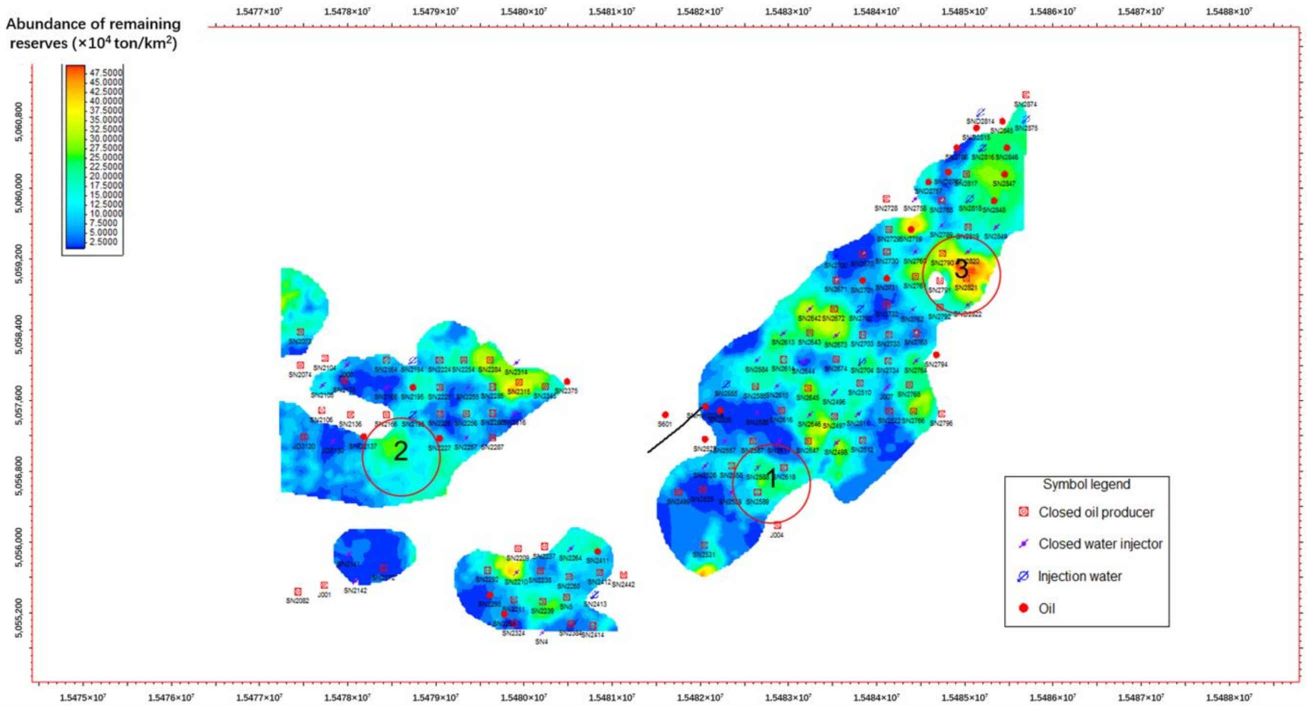


Figure 13. Abundance of remaining reserves of layer L3 in the low-permeability reservoir in the SN oilfield.

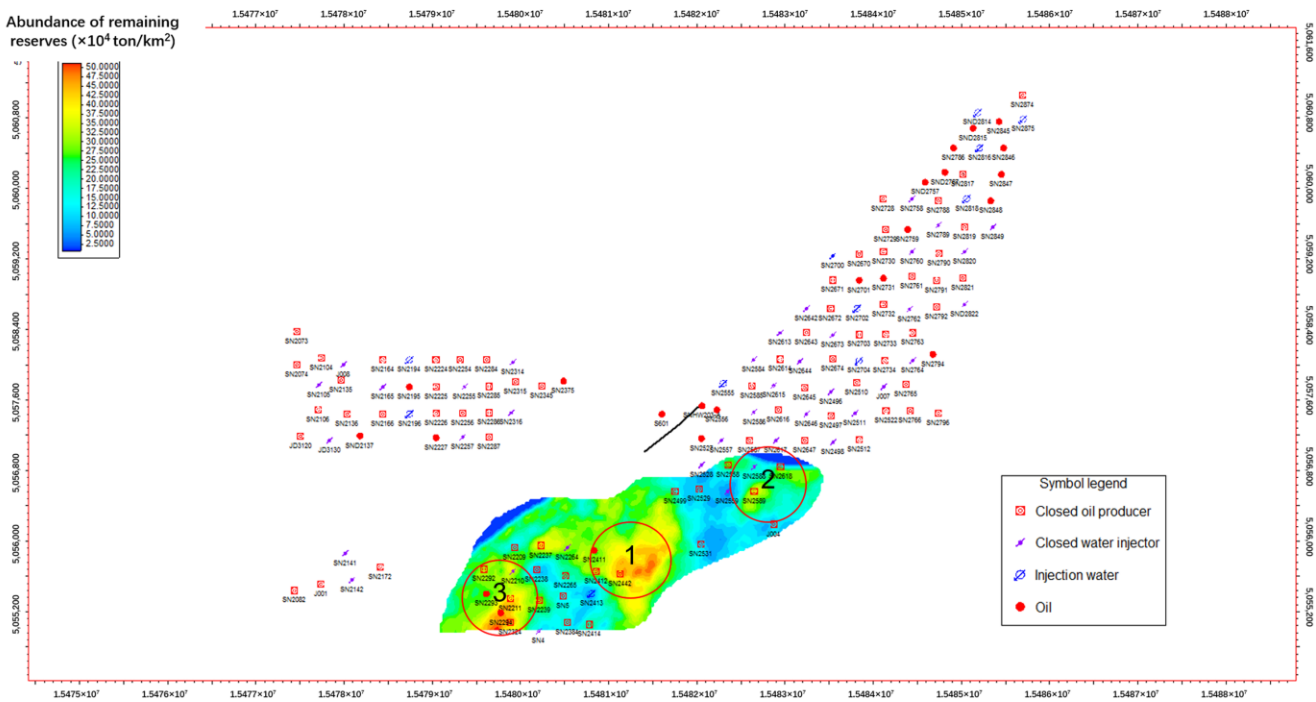


Figure 14. Abundance of remaining reserves of L4 layer in the low-permeability reservoir in the SN oilfield.

3.3. Development Adjustment Scheme

3.3.1. Design

Based on the above development effect evaluation and remaining oil characterization study, the following four adjustment schemes are proposed:

Scheme I: optimizing injection–production parameters;

Scheme II: optimizing injection and production parameters and gas injection;
Scheme III: optimizing injection and production parameters and new wells;
Scheme IV: optimizing injection and production parameters, gas injection, and new wells.

3.3.2. Optimization

The comparison of 15-year cumulative oil production forecasts for each scheme is shown in Figure 15, where Scheme 0 is the basic scheme—that is, no adjustment is made. Table 5 shows the comparison results of production indicators between the basic plan and the four adjustment schemes. Figure 15 and Table 5 show that Scheme IV has the highest cumulative oil production over 15 years (46.15×10^4 m^3) and recovery (28.87%). The distribution of the predicted remaining oil saturation in Scheme 0 and Scheme IV is shown in Figures 16 and 17, respectively. Compared with Figures 16 and 17, the predicted remaining oil saturation in Scheme IV is lower than that in Scheme 0, and Scheme 4 has a good oil-increasing effect. The economic evaluation indicators and the results of the economic evaluation of each scheme are shown in Tables 6 and 7, respectively. Comparing Tables 6 and 7, Scheme IV has the best economic benefits (an increase of CNY 7.21×10^8 under the oil price of USD 70/bbl). Therefore, Scheme IV was finally determined as the development adjustment scheme for low-permeability reservoirs in the SN oilfield.

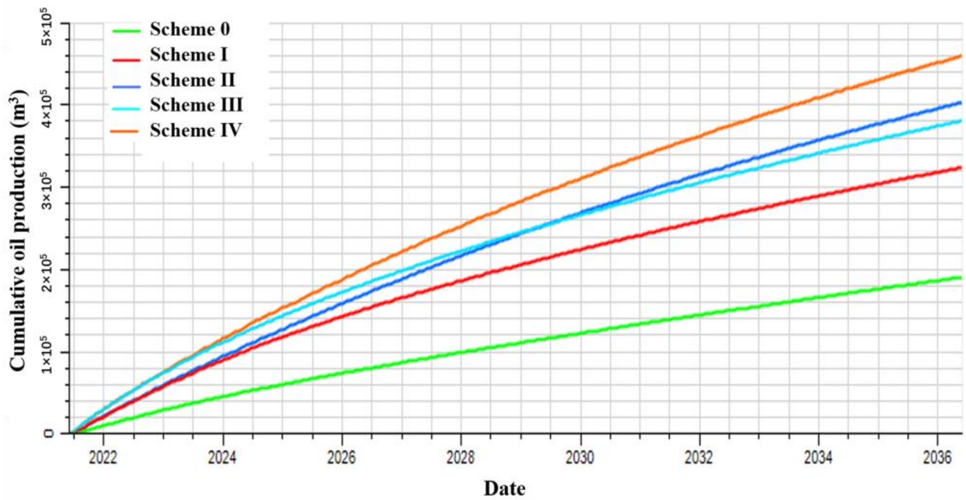


Figure 15. Comparison of the cumulative oil production of each scheme over 15 years.

Table 5. Comparison of the production indexes of each scheme over 15 years.

Production Index	Scheme 0	Scheme I	Scheme II	Scheme III	Scheme IV
Accumulative oil production ($\times 10^4$ m^3)	19.23	32.59	40.5	38.26	46.15
Accumulative water production ($\times 10^4$ m^3)	159.54	347.96	362.52	389.29	403.86
Accumulative water injection ($\times 10^4$ m^3)	174.58	356.82	350.89	404.54	398.62
Accumulative gas injection ($\times 10^4$ m^3)	0	0	109.58	0	109.58
Increase in accumulative oil production ($\times 10^4$ m^3)	-	13.36	21.27	19.03	26.92
Recovery (%)	25.92	27.38	28.25	28.00	28.87
Enhanced oil recovery (%)	-	1.46	2.33	2.09	2.95

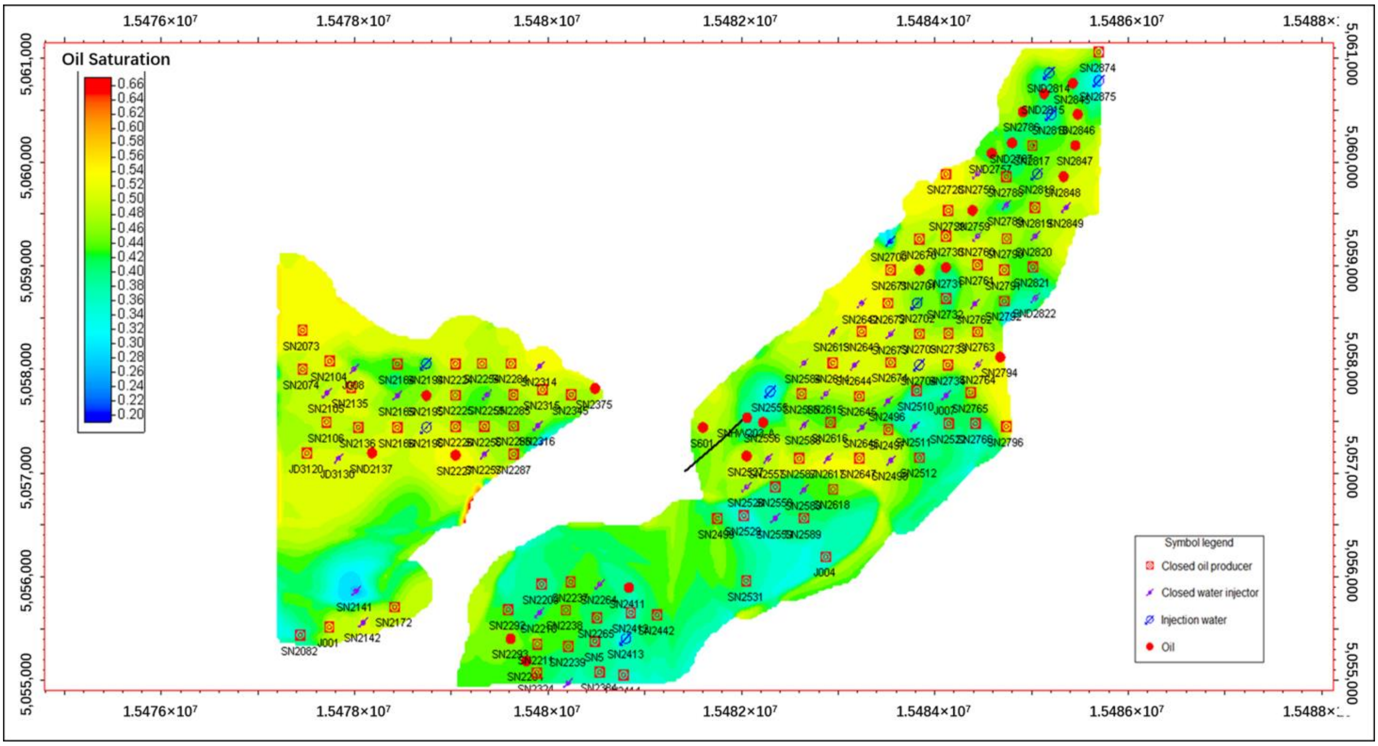


Figure 16. Distribution of predicted residual oil saturation of Scheme 0 (2036).

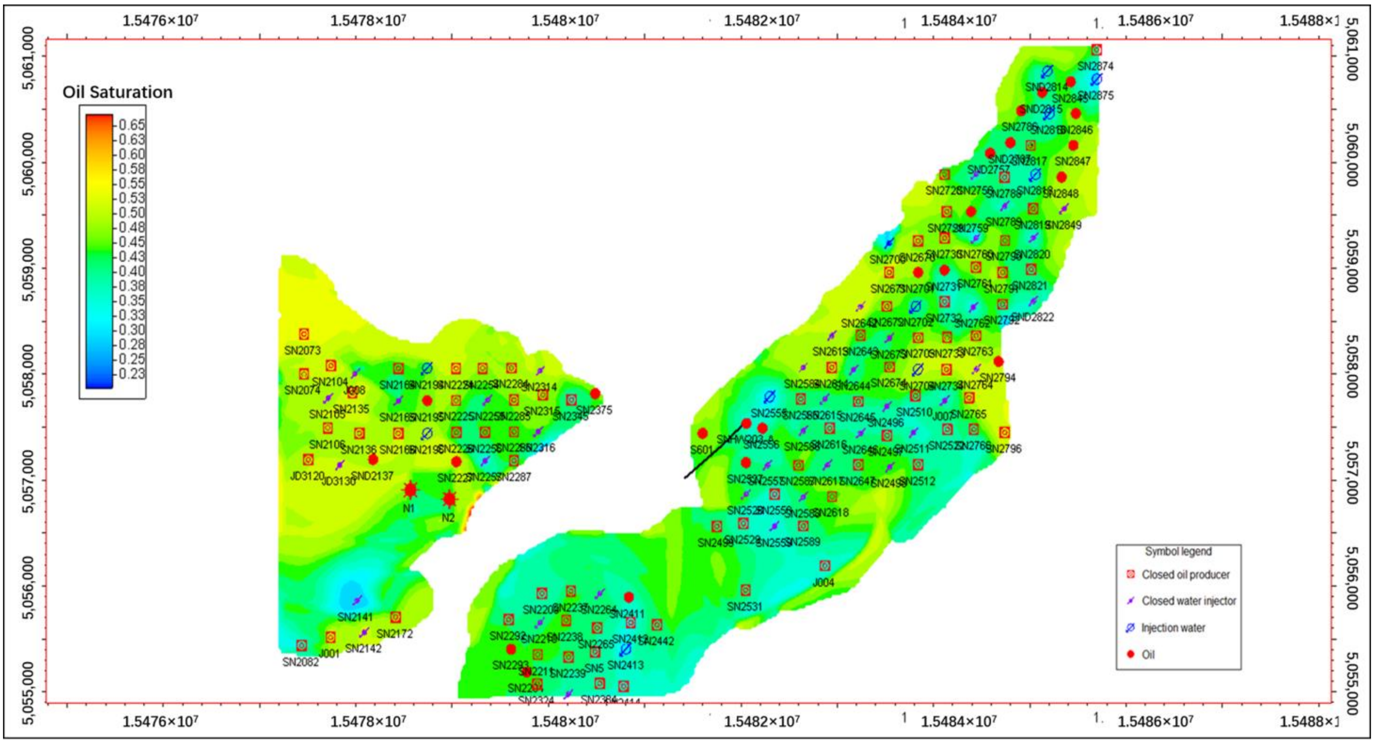


Figure 17. Distribution of predicted residual oil saturation of Scheme IV (2036).

Table 6. Relevant indicators of economic evaluation.

Items	Price
USD exchange rate	6.4
Water injection cost	4.7 CNY/m^3
Water treatment	4.7 CNY/m^3
Gas injection cost	1.5 CNY/m^3
Decontamination cost	18×10^4 CNY/well
Conversion cost	30×10^4 CNY/well
Workover cost	40×10^4 CNY/well
Fracturing cost	60×10^4 CNY/well
Cost of new well	500×10^4 CNY/well

Table 7. Economic evaluation results.

Scheme	Scheme I	Scheme II	Scheme III	Scheme IV
Increase in accumulative oil production ($\times 10^4$ m^3)	13.36	21.27	19.03	26.92
Increase in accumulative water production ($\times 10^4$ m^3)	188.42	202.98	229.75	244.32
Increase in accumulative water injection ($\times 10^4$ m^3)	182.24	176.31	229.96	224.04
Increase in accumulative gas injection ($\times 10^4$ m^3)	0	109.58	0	109.58
Decontamination well (well)	9	9	9	9
Gas injection well (well)	0	2	0	2
Workover (well)	2	2	2	2
Fractured well (well)	2	2	2	2
New well (well)	0	0	2	2
Increase in income under the oil price of USD 50/bbl ($\times 10^8$ CNY)	2.48	4.04	3.48	5.04
Increase in income under the oil price of USD 60/bbl ($\times 10^8$ CNY)	3.02	4.90	4.24	6.12
Increase in income under the oil price of USD 70/bbl ($\times 10^8$ CNY)	3.55	5.76	5.01	7.21

4. Conclusions

In this paper, a development effect evaluation and a remaining oil analysis of low-permeability reservoirs in the SN oilfield were conducted, and a development adjustment scheme was designed and optimized. The conclusions obtained mainly include the following:

(1) The injection–production ratio and pressure remained at a general level, the oil production decreased, the water cut and the water cut rise rate increased rapidly, and the remaining recoverable reserve was 23.78×10^4 ton, which is a considerable scale.

(2) The historical matching results are good, meeting the forecast requirements of the scheme. On the plane, there is much remaining oil in the northeast of the J007 well block and in the north of the J008 well block, with great development potential; the remaining reserve in the SN 4 well block was 99.97×10^4 ton, with small potential. Vertically, the remaining reserve of layer L1 was only 146.5×10^4 ton, which is due to the poor physical properties of the reservoir and low original reserves. The potential of layers L2 and L3 was large, while that of layers L1 and L4 was small. The remaining oil was mainly concentrated in the areas with high structure, poor physical properties, and imperfect well patterns.

(3) Four adjustment schemes were proposed and compared. Finally, it was found that the development effect of Scheme IV (optimizing injection and production parameters, gas injection, and new wells) was the best, and the cumulative oil production and recovery were the highest over 15 years. Via economic evaluation, it was found that Scheme IV had the best economic benefits. Via production index prediction and economic evaluation, Scheme IV was finally determined as the development adjustment scheme for low-permeability reservoirs in the SN oilfield.

The research scheme in this paper can provide a reference for similar oil fields and is of great significance for improving the recovery of similar oil reservoirs.

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