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Research on Optimization of Reservoir Perforation Position in Offshore Polymer Flooding Oilfield

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Abstract

In order to enhance the effect of polymer flooding in offshore oilfields, so as to realize the longer stable production period and higher oil recovery, the reservoir perforation positions of production wells and injection wells are taken as research objects. By analyzing the distribution of remaining oil and production characteristics under different perforation positions, the optimum perforation positions of production wells and injection wells are selected. Bohai oilfield L was taken as target oilfield in this article, according to the actual reservoir characteristic parameters, three-dimensional laboratory physical simulation experiments of water flooding and polymer flooding were carried out, the experiments include different perforation positions of production wells and injection wells. The research result showed that the influence of perforation position on residual oil and development characteristics of the model is obvious. When takes the scheme of injection well upper part perforated and production well all part perforated, the least of the remaining oil distribution, the longest of the production period without water. Contrast with other perforation schemes, its stable production period increase about 1.2 times, the oil recovery of water flooding increase 3.7% - 6.0%, the oil recovery of polymer flooding increase 2.5% - 4.1%. So it is recommended as the best perforation scheme. Preferable effect had been achieved when translating research findings into practice. It can serve as a reference to the similar offshore oilfield.

Keywords

Polymer Flooding, Laboratory Experiment, Perforation Position, Remaining Oil Distribution Law, Enhance Oil Recovery, Offshore Oilfield

1. Introduction

Perforation completion is one of the most commonly used completion methods in offshore oilfields, according to the characteristics of different reservoirs, proper perforation technology can effectively communicate reservoir and wellbore, so as to improve the efficiency of oilfield development. Therefore, the optimization of perforation schemes plays a very important role in oilfield development, suitable perforation scheme can avoid production interference of reservoirs with different physical properties, recovery period without water cut can be prolonged, and the excessive increase of water cut in oilfields can be avoided. But it has little effect on improving oil recovery rate, as a tertiary oil recovery technology, polymer flooding has been widely used in oilfield development, because it can effectively improve the water to oil mobility ratio, and then it can expand the swept volume of displacement media [1] [2] [3] [4] [5], however, its scope of application mainly concentrates on the onshore oilfields, while offshore oilfields are relatively small. In China, only a few field tests have been carried out in the Bohai Bay area. After polymer flooding in oilfields, although the effect of increasing oil and decrease water cut can be achieved, it also brings about problems such as the decline of reservoir liquid production capacity, reservoir blockage and difficulty in processing produced liquid [6] [7] [8] [9], that lead to the unsatisfactory effect of polymer flooding on enhancing oil recovery. Therefore, it is necessary to further strengthen the polymer flooding effect through effective measures, thus to ensure the high-efficiency development of offshore oilfields.

There are some scholars have pointed out that through surfactant injection technology, polymer enhanced foam flooding, high and low polymer concentration alternating injection technology can effectively improve polymer flooding effect [10]-[17], However, offshore oilfields are limited by the operating space of production platforms, and the implementation of new chemical flooding or other improvement measures requires a greatly expand and reform of the production platforms, because of the high operating costs of offshore oilfields, it is very difficult to implement new chemical flooding or improvement measures. Reasonable optimization method of perforation position refers to the production wells and injection wells in one production unite, these wells adopt the same or different perforation position in the reservoir, so as to differentiation of injection-production corresponding relations, and that was used to inhibit gravity differentiation or displacement phase breakthrough through. This method only needs to make corresponding decisions in the completion stage of production wells, and it does not need to expand and reform the production platform, nor does it need additional development investment, Therefore, under the condition polymer flooding, the research of reasonable perforation position can obtain the synergistic effect of the two methods, which can further improve the development situation of oil field, but also maintain higher economic benefits.

Previous researchers have done a lot of research, that about the relationship between perforation parameters and productivity and the optimization of perforation technology schemes [18] [19] [20] [21], but there is little research having been done on residual oil distribution in injection wells and production wells with different perforation positions, the existing perforation scheme optimization research is mainly aimed at natural energy or water flooding oilfields, and numerical simulation is the main research method [22] [23] [24] [25]. Under the laboratory physical simulation conditions, the influence of perforation mode optimization on residual oil distribution in polymer flooding is rarely studied. In order to further improve the development effect of Bohai L oilfield, this article compares the remaining oil distribution of water flooding and polymer flooding under different perforation positions by referring to the actual reservoir and fluid parameters, thus providing a strong basis for the optimization of perforation position, rolling expansion of margins and potential tapping adjustment of Bohai L oilfield.

2. Experimental Materials and Conditions

The experimental materials mainly include:

1) Artificial displacement models with specifications of 35.0 cm × 7.8 cm × 0.5 cm, according to the reservoir physical parameters of Bohai oilfield L, the average porosity is 35.1% - 37.5%, and the average permeability is 1800 mD, the detailed parameters are shown in **Table 1**.

2) The experimental water using for displacing is compounded according to the ion composition of injected water in the actual production. Its total salinity is 3680 mg/L.

3) The experimental oil is made up of vacuum pump oil and kerosene at a volume ratio of 2:1. Its viscosity simulates the viscosity of crude oil in the real reservoir. The simulated oil viscosity is 16.9 mPa·s at 61˚C.

4) The experimental polymer is the real injected polymer into Bohai oilfield L. The concentration of polymer solution was 1200 mg/L and the effective viscosity was 7.6 mPa·s.

The experimental conditions mainly include:

1) The experimental temperature simulates the middle and deep temperature of the reservoir at 61˚C in Bohai oilfield L.

2) The displacement pressure is 0.1 MPa in the experiment.

Table 1. Basic parameters of displacing models.

Model No.	Dry weight/g	Wet weight/g	Porosity/%	Saturated oil/mL
1	478.16	509.43	35.1	31.4
2	485.80	518.42	37.3	33.1
3	481.60	513.65	36.2	32.4
4	483.07	514.65	35.5	31.8
5	481.22	513.32	36.7	32.4
6	483.71	516.56	37.5	33.4
7	482.48	514.00	35.6	31.7
8	483.01	514.35	35.4	31.5

3) In order to make the experiment more visible, methyl blue was added to simulated injection water to dye blue, and Sudan red was added to simulated oil to dye red.

3. Experimental Scheme and Steps

In order to compare the inhibiting effects of perforation modes on gravity differentiation of injected water, combining with the practicability of perforation operation, two methods of upper and all part perforated are studied in this paper, the two methods are applied to injection wells and production wells respectively, 4 combinations were carried out. At the same time, in order to study the synergistic effect of polymer flooding on perforation scheme, water flooding and polymer flooding are carried out in each scheme, a total of 8 groups of displacement experiments were designed. The specific experimental scheme is shown in Table 2.

The experimental steps include:

1) Using organic glass, quartz sand and cementing agent to make displacement model.

2) The model was weighed dry, the simulated oil was saturated after vacuum pumping, and the porosity was measured by weighing again.

3) Water flooding and polymer flooding processes were carried out, the time of displacement injected into the model is recorded as the time zero point. Pressure, production and water cut during displacement were recorded, and images were continuously collected during the experiment.

4) Replace the model and repeat the steps of 1), 2) and 3) to 8 groups of displacement experiments were finished.

4. Experimental Results and Analysis

4.1 Effect of Perforation Position on Water Flooding

4.1.1. Distribution of Remaining Oil after Water Flooding

Oil and water distribution under different perforation schemes after water flooding

Table 2. Design of experimental scheme.

Scheme	Perforation position		Water flooding	Polymer flooding
	Injection well	Production well		
1	All part	All part	Until water cut 98%	/
2	Upper part	All part		
3	Upper part	Upper part		
4	All part	Upper part		
5	All part	All part	Until breakthrough (Water cut greater than 30%)	Until water cut 98%
6	Upper part	All part		
7	Upper part	Upper part		
8	All part	Upper part		

is shown in **Figure 1**. In scheme 1, the vertical displacement of the model is uneven, as shown in **Figure 1(a)**, on the side of the injection well, the injected water mainly seepage along the bottom of the model, and so the displacement of crude oil in the upper part of the model is weak. On the side of the production well, the water flooding degree of the bottom part is higher, in the middle and upper parts, especially in the top of the model, there is still a large amount of residual oil enrichment, and the overall displacement effect is weak.

Figure 1(b) shows that the vertical displacement degree of scheme 2 model is more uniform. This is because the dual effects of injection-production pressure distribution and oil-water weight ratio difference on displacing water, it can enlarge the overall vertical sweep volume of the model. The whole displacement process is closer to piston displacement, so the water displacing degree of the model is higher when flooding finished. The remaining oil only concentrates in a small amount at the top of the side of the production well, the overall displacement effect is strong.

Figure 1(c) shows that the vertical displacement degree of model in scheme 3 is relatively uniform. This is because the injection-production pressure difference mainly acts on the upper part of the model, so the displacement of the upper crude oil is better. However, the injection-production pressure difference decreases because the production wells are only perforated in the upper part and the production capacity decreases, meanwhile, effected by the gravity differentiation of oil and water, the continuity of transverse seepage of injected water in displacement process becomes worse, and the degree of water displacing of model after flooding is weaker. On the side of the production well, the remaining oil distributes fragmentary, and the remaining oil at the top of the side of production well is relatively enriched.

Figure 1(d) shows that the vertical displacement uniformity of scheme 4 model is weak. Because the injection-production pressure difference is still mainly distributed in the upper and middle parts of the model, the vertical displacement at the side of the injection well is relatively high, however, the injection water is easily channeled along the bottom of the model due to all part of injection water perforated, resulting in weak displacement of the upper side of production well. Compared with schemes 2 and 3, the remaining oil at the top of the model is more enriched.

The conclusions can be drawn from the experimental results of water flooding: The different perforation positions of production wells and injection wells have great differences in oil and water distribution. To perforation of water injection wells and oil production wells in the upper part, the scheme can inhibit the injection water channeling to a certain extent, and that can strengthen the vertical sweep degree in the displacement process. The upper part perforation of injection well has a significant effect on the remaining oil distribution of the whole model, and the vertical displacement uniformity of the model has been improved. However, the upper part perforation of production wells only affects the distribution of remaining oil in the nearby of the production well side.

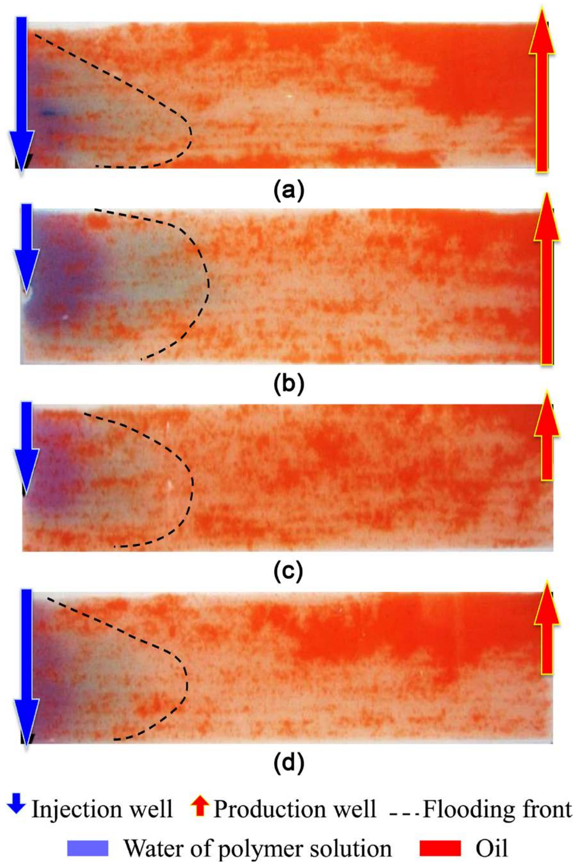

Figure 1. Remaining oil distribution of different perforation scheme after water flooding. (a) Injection well all part and production well all part perforated; (b) Injection well upper part and production well all part perforated; (c) Injection well upper part and production well upper part perforated; (d) Injection well all part and production well upper part perforated.

4.1.2. Production Performance of Water Flooding

The relationship between recovery rate and injection PV number of water flooding is shown in Figure 2. Reference to multiple of injected pore volume, the corresponding injection PV number at the end of stable production period in scheme 2 was 0.38, whereas, The corresponding injection PV numbers of scheme 1, 3 and 4 were between 0.31 - 0.33 at the end of stable production period, the stable production period is the longest when the upper part of the injection well is perforated and all part of the production wells are perforated. When the injection PV number is less than 0.80, the oil recovery rate is higher than that of other perforation schemes. For water flooding, once the production of each perforation schemes decreases, the oil recovery rate decreases greatly, when the injection PV number is more than 0.72, the oil recovery rate decreases to less than 20% of the initial oil recovery rate.

The relationship between water cut and oil recovery of water flooding is shown in Figure 3. The recovery degree before water breakthrough is 32.1%, water flooding oil recovery is 50.1% in scheme 1. The recovery degree before water breakthrough is 38.2%, water flooding oil recovery is 56.1% in scheme 2.

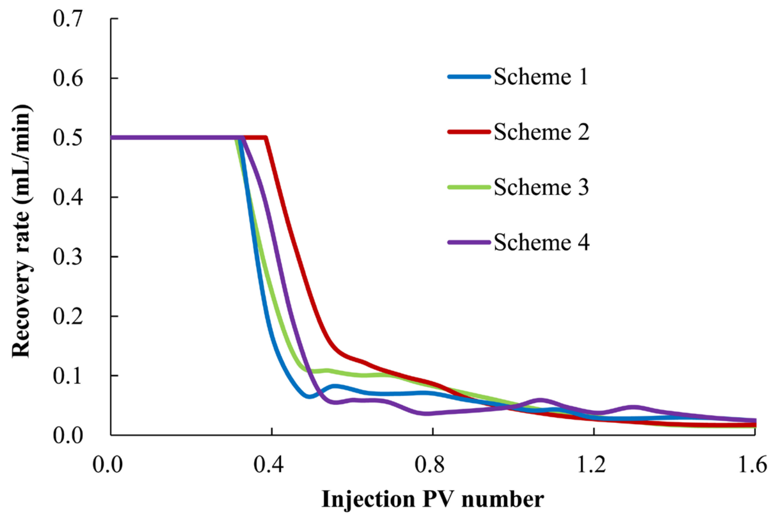

Figure 2. Relationship between recovery rate and injection PV number of water flooding.

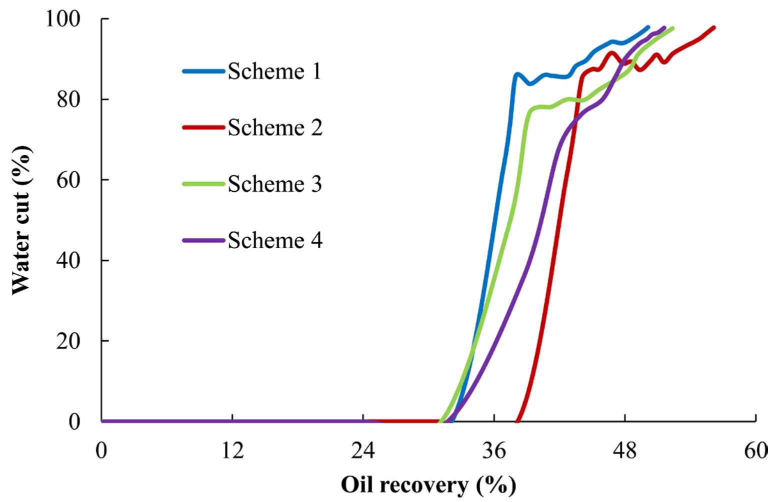

Figure 3. Relationship between water cut and oil recovery of water flooding.

The recovery degree before water breakthrough is 31.2%, water flooding oil recovery is 52.4% in scheme 3. The recovery degree before water breakthrough is 31.7%, water flooding oil recovery is 51.6% in scheme 4.

It can be concluded the stable production period is longest in scheme 2 before water breakthrough, and its corresponding oil recovery is the greatest. Compared with the other schemes, stable production period in scheme 2 is 1.2 times that of other schemes, the oil recovery of scheme 2 was 3.7% - 6.0% higher than that of other schemes. The results show that the scheme of upper part of injection well perforated and all part of production perforated can effectively inhibit the premature breakthrough of injection water, and significantly expand the swept volume of displacing phase.

4.2. Effect of Perforation Position on Polymer Flooding

4.2.1. Distribution of Remaining Oil after Polymer Flooding

After the displacement of scheme 5, as shown in **Figure 4(a)**, the front edge of

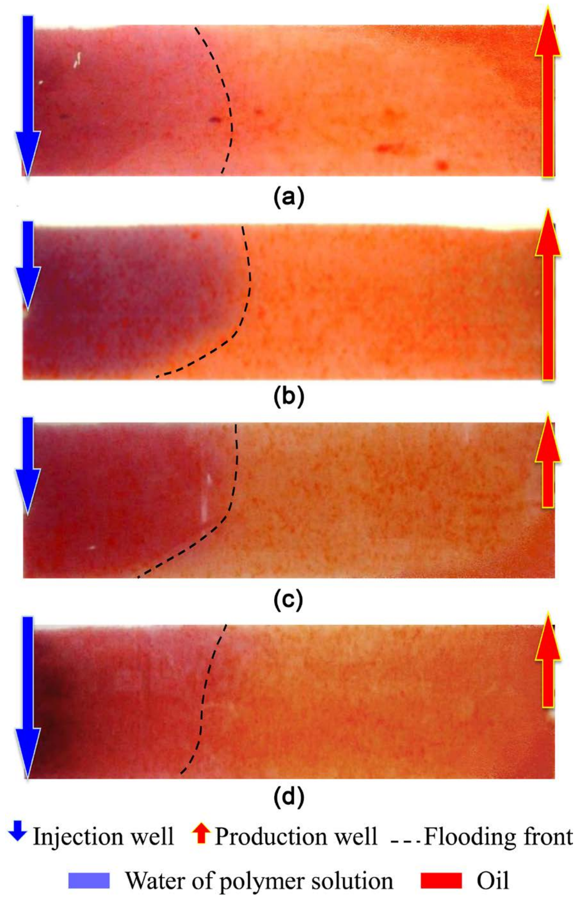

Figure 4. Remaining oil distribution of different perforation scheme after polymer flooding. (a) Injection well all part and production well all part perforated; (b) Injection well upper part and production well all part perforated; (c) Injection well upper part and production well upper part perforated; (d) Injection well all part and production well upper part perforated.

pure polymer zone is upper narrow and lower wide, compared with water flooding, the overall displacement degree in vertical direction has been significantly improved, that shows the polymer can improve the water to oil mobility ratio in the model, thus weakening fingering phenomenon. However, under this perforation scheme, the effect of polymer flooding on reducing gravity differentiation is limited, there is still a certain degree of residual oil enrichment near the upper side of the production well.

Figure 4(b) shows that the front edge of the pure polymer zone is upper wide and lower narrow after displacement of scheme 6. Compared with water flooding, the vertical displacement degree is stronger, for the difference of vertical perforation degree between injection wells and production wells, pressure distribution field can synergize with polymer flooding, the gravity differentiation can be effectively restrained, the displacement degree of remaining oil in the upper part of the model can be improved, and the whole oil reserves in vertical direction can be effectively displaced. After displacement, the remaining oil near the side of production well distributes less, and the swept volume is expanded by polymer solution obviously.

For scheme 7, compared with water flooding, the phenomenon of bottom channeling in the model has been effectively restrained. **Figure 4(c)** shows that the front edge of the pure polymer zone is upper wide and lower narrow, but its range is obviously smaller than that of scheme 6. This is because the injection-production pressure difference mainly distributes in the upper part of the model, so the seepage of polymer solution in the upper part of the model is strong, and the displacement degree is also strong. Whereas the lower part of the model is the secondary area of injection-production pressure difference effective, at the same time, because the resistance of polymer solution seepage is greater than that of water, the seepage capacity of polymer is weak, there's a small amount of remaining oil is enriched at the bottom of the side of production well.

For the scheme 8, compared with water flooding, the remaining oil at the top of the side of production well has also been effectively displaced. **Figure 4(d)** shows that the front edge of the pure polymer zone is closer to the piston type. This is because all part of injection wells are perforated, the vertical injection-production pressure difference distribution at the side of the injection wells more uniform relative to the schemes 6 and 7. The vertical seepage velocity difference of polymer solution is small, although the gravity differentiation effect is effectively restrained compared with scheme 5, but the productivity of production wells is limited due to the upper part perforated only, resulting in scattered remaining oil distribution after displacement, especially in the middle and bottom of production well, there is a certain degree of residual oil enrichment.

The above analysis shows that compared with water flooding, polymer flooding with different perforation schemes can effectively expand the vertical sweep volume, thus significantly improving the development effect than water flooding. The remaining oil distribution after polymer flooding is the least and the displacement degree is the strongest in scheme 6.

4.2.2. Production Performance of Polymer Flooding

Under the condition of polymer flooding, the relationship between oil recovery rate and injection PV number is shown in **Figure 5**. Polymer flooding in low water cut stage, the oil recovery rate of different perforation schemes began to rise. The stable production period is shortest in water flooding stage in scheme 5, the remaining oil distribution under the scheme is the largest, and the development performance improved of polymer flooding is obvious, compared with water flooding, oil recovery rate increased by 0.37 mL/min, but recovery time is the shortest. The displacement front zone is closest to the piston in scheme 6 in water flooding stage, and the stable production period is the longest, compared with water flooding, oil recovery rate increased by 0.39 mL/min, and recovery time is the longest. Compared with the water flooding, the recovery rate of scheme 7 increased by 0.38 mL/min and the recovery time is relative long. Compared with the water flooding, the recovery rate of scheme 8 increased by 0.36 mL/min and the recovery time is relative short. The results show that polymer flooding can effectively improve the oil recovery rate in the early stage of development, and the effect of improving oil recovery rate after polymer flooding in scheme 6 is the best.

The relationship between water cut and oil recovery of polymer flooding is shown in Figure 6. After development method turn into polymer flooding, there are obvious reduction funnels for water cut in different perforation schemes. The oil recovery of scheme 5 is 69.7%, which is 1.4 times higher than that of water flooding. The oil recovery of scheme 6 is 73.8%, which is 1.3 times higher than that of water flooding. The oil recovery of scheme 7 is 71.3%, which is 1.4 times higher than that of water flooding. The oil recovery of scheme 8 is 70.5%, which is 1.4 times higher than that of water flooding. It shows that polymer flooding has an obvious effect of water cut decrease and oil increase for different perforation schemes. The polymer flooding oil recovery of scheme 6 is 2.5% - 4.1% higher than other perforation schemes, and the displacement degree is the best.

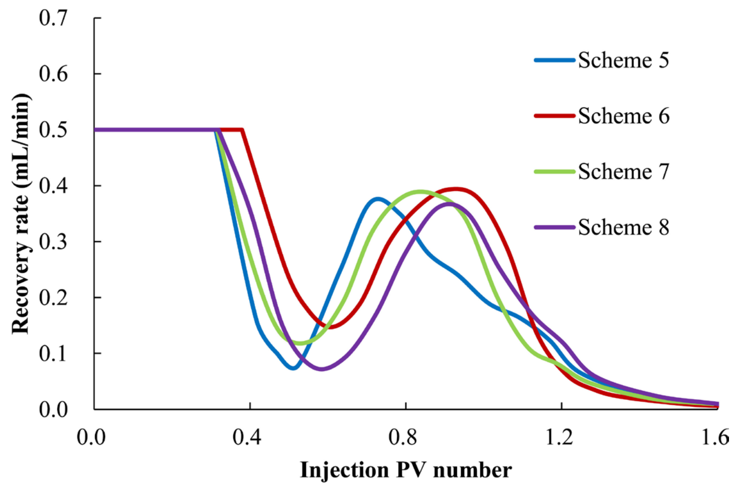

Figure 5. Relationship between recovery rate and injection PV number of polymer flooding.

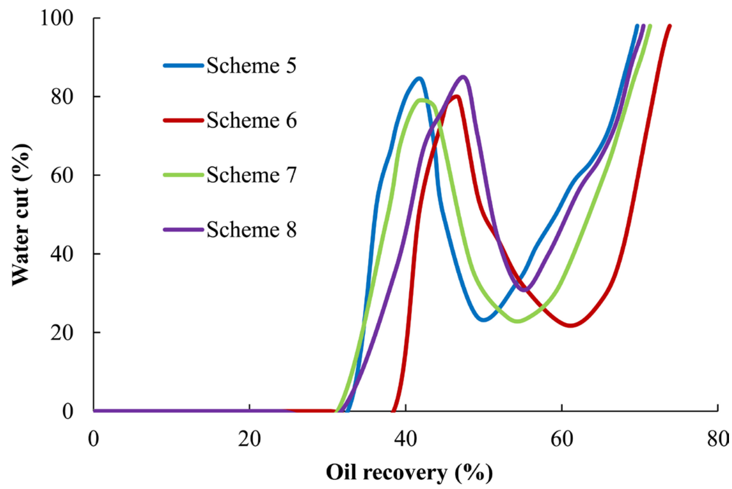

Figure 6. Relationship between water cut and oil recovery of polymer flooding.

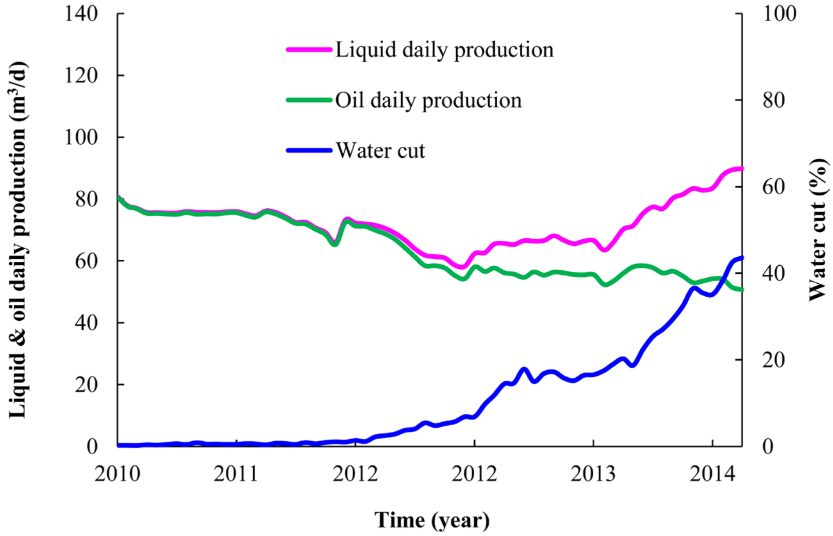

Figure 7. Production performance curve of well LT2 in Bohai oilfield L.

5. Application and Practice in the Field

Natural energy development method was adopted in the initial stage of Bohai oilfield L. In 2002, the development mode has gradually changed to water flooding. In order to restrain the excessive increase of water cut in oilfields, polymer flooding was carried out in 2007, and the overall effect of oil increase and water cut control was obviously. In order to further improve the overall utilization of the oilfield and increase the development effect of polymer flooding, In 2010, an injection well LT1 and a production well LT2 were constituted to use for field test of the optimize perforation scheme, and these two wells located in areas with high residual oil enrichment at the edge of the reservoir. According to the above research results, perforation schemes of upper injection wells and full production wells are adopted, the polymer concentration of well LT1 is 1200 mg/L, and the recovery rate of well LT2 is 0.5%. As shown in Figure 7, well LT2 maintained stable production period for two years from 2010 to 2012, that's longer than the average level of the surrounding old wells, good results have been achieved in field practice. It shows that the research results are of generalization.

6. Conclusions

1) Based on the reservoir characteristics of Bohai oilfield L, artificial three-dimensional physical simulation experiments were designed to study the residual oil distribution and production performance, of which in water flooding and polymer flooding with different perforation schemes.

2) Compared with water flooding, polymer flooding with different perforation schemes can effectively improve the oil recovery rate in the early stage and ultimate oil recovery, thus improving the early development performance of offshore oilfields.

3) For perforation schemes of upper part of injection wells and all part of production wells perforate, the stable production period of water flooding and

polymer flooding is the longest, and the oil recovery is the highest, so it is the recommended perforation scheme.

4) The optimized perforation scheme has been applied to the actual production of the oilfield, and good application results have been achieved, which can provide a reliable reference for oilfield development.

5) The experimental results are based on the reservoir, fluid properties and production system of Bohai oilfield L, therefore, it has a certain scope of application. For oilfields with large physical properties difference from Bohai oilfield L, it can refer to the research method in this paper, but at the same time, it should combine the actual situation of oilfield.

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Conflicts of Interest

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

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