

## Research Article

# Experimental Study on Enhanced Oil Recovery by Nitrogen-Water Alternative Injection in Reservoir with Natural Fractures

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The production of a low permeability reservoir decreases rapidly by depletion development, and it needs to supplement formation energy to obtain stable production. Common energy supplement methods include water injection and gas injection. Nitrogen injection is an economic and effective development method for specific reservoir types. In order to study the feasibility and reasonable injection parameters of nitrogen injection development of fractured reservoir, this paper uses long cores to carry out displacement experiment. Firstly, the effects of water injection and nitrogen injection development of a fractured reservoir are compared through experiments to demonstrate the feasibility of nitrogen injection development of the fractured reservoir. Secondly, the effects of gas-water alternate displacement after water drive and gas-water alternate displacement after gas drive are compared through experiments to study the situation of water injection or gas injection development. Finally, the reasonable parameters of nitrogen gas-water alternate injection are optimized by orthogonal experimental design. Results show that nitrogen injection can effectively enhance oil production of the reservoir with natural fractures in early periods, but gas channeling easily occurs in continuous nitrogen flooding. After water flooding, gas-water alternate flooding can effectively reduce the injection pressure and improve the reservoir recovery, but the time of gas-water alternate injection cannot be too late. It is revealed that the factors influencing the nitrogen-water alternative effect are sorted from large to small as follows: cycle injected volume, nitrogen and water slug ratio, and injection rate. The optimal cycle injected volume is around 1 PV, the nitrogen and water slug ratio is between 1 and 2, and the injection rate is between 0.1 and 0.2 mL/min.

## 1. Introduction

Water flooding is the most applied traditional enhanced oil recovery technology, and it can replenish formation energy and expand oil sweeping efficiency compared to depletion development [1, 2]. However, it is much easier to cause water channeling which leads to a sharp increase of the water cutting off the producing well, especially in fractured and strongly heterogeneous reservoirs [3, 4]. Therefore, it is necessary to focus on techniques that are more effectively for water-flooding reservoirs. Fractured or vuggy reservoirs, such as carbonate reservoirs, are considered to have high heterogeneity, with multiple scaled porous structures and a complex pore connection, and the liquid seepage and distri-

bution are more complicated [5, 6]. The development of water-flooding reservoirs is difficult because of the existence of water channeling.

It is shown that miscible-phase displacement will happen by injecting high pressure compressed carbon dioxide which is better in maintaining formation pressure and enhancing oil recovery [7]. Compound flooding of carbon dioxide and nitrogen can maintain reservoir pressure and alter the position of oil and water which is better in improving the potential of reservoir development [8]. Nitrogen injection is one of the most effective techniques to improve the development effect of reservoirs [9]. The technique includes pure nitrogen injection, nitrogen foam injection, and nitrogen-water alternative injection for different kinds of reservoirs. The

advantages of nitrogen injection are shown as high compressibility and expansibility. By injecting nitrogen into the formation, it can effectively replenish energy and maintain the pressure of the reservoir. Meanwhile, compared with carbon dioxide, it is noncorrosive, with steady chemical properties, ease of obtainment, and low cost [10, 11].

Early in 1993, experiments of gas injection in fractured reservoirs were complemented with 2D glass microsamples [12]. The influences of wettability and heterogeneity of samples are discussed, and it is shown that over 20% of oil will be recovered with gas injection. The existence of fractures is harmful for enhancing oil recovery. In 2003, long core displacement experiments were conducted in the laboratory to study enhanced oil recovery of nitrogen injection in low permeability sandstone reservoirs. Combined with numerical simulation, it is verified that nitrogen injection can effectively improve recovery percent of reserves in different developing periods [13]. Gas injected into the reservoir will reduce the oil viscosity, and it is verified that water alternating gas can reduce mobility of the gas and effectively release this situation [14]. For fractured reservoirs, displacement experiments are conducted using carbonatite samples, and it showed that injecting nitrogen and carbon dioxide will obtain different effects, which is determined by gravity drainage and component exchange of gas in fractures and oil in matrix [15]. Nitrogen injection has been verified to be more useful in both light and heavy oil reservoirs [16]. Laboratory tests show that nitrogen foam injection in the development of heavy oil is feasible in improving oil production, and nitrogen can effectively relieve the high heterogeneity in the low permeability region and improve the oil recovery [17]. Nitrogen injection is also verified to enhance the oil recovery of shale oil. Experiments are conducted by applying CT to monitor in real time the residual oil distribution. Results show that oil recovery increases sharply in early periods and then slows down in late periods after gas channeling.

There are many researches of numerical simulation for gas or nitrogen injection to verify its ability on enhanced oil recovery. Models of fractured reservoirs are simulated to research the influence factors of oil recovery for water flooding and gas flooding [18]. Depletion, gas flooding, and water flooding developments are compared to optimize the best developing method. The component simulation technique is applied to verify the feasibility of nitrogen flooding in enhanced oil recovery. Numerical simulation results show that oil recovery can be improved by nitrogen flooding, and it is highly influenced by the time of gas channeling [19]. For the carbonate reservoir with natural fractures using nitrogen flooding to enhance oil recovery, the injecting rate of nitrogen can reduce gravity differentiation of gas and water [20].

With literature review, many experimental and numerical researches have been done to study the enhanced oil recovery mechanisms of nitrogen injection. In this paper, long core displacement experiments are conducted to systematically study the enhanced oil recovery of nitrogen-water alternative injection. Feasibility of enhanced oil recovery is verified, influence of injected parameters is analyzed, and injected parameters are optimized by many groups of

tests. Researching results can provide some guidance for developing fractured reservoirs.

## 2. EOR Mechanism of Nitrogen Injection

$N_2$  content in the air is about 78%, and the air source is very rich. With the development of nitrogen production technology and nitrogen injection equipment manufacturing technology, nitrogen injection has become one of the widely used stimulation techniques in oil field development and has gradually developed from the initial nitrogen flooding to nitrogen huff-n-puff, nitrogen foam flooding, gas-water alternate flooding, gas-liquid alternate flooding, and other complex stimulation techniques. Generally speaking, nitrogen injection can improve oil recovery mainly through the following mechanisms.

*2.1. Miscible and Immiscible Flooding.* After contacting with crude oil, the injected  $N_2$  will continuously vaporize the crude oil, extracting light and intermediate hydrocarbons from the crude oil, so that the proportion of light hydrocarbons contained in  $N_2$  increases. When the interaction between injected gas and crude oil reaches a critical equilibrium point, the oil-gas interface disappears, and miscibility occurs. More importantly, the oil displacement efficiency in the front miscibility zone can reach 90%.

The mechanism of nitrogen immiscible flooding is mainly reflected in the following aspects: the compressibility of nitrogen is large, nitrogen injection can effectively supplement formation energy and maintain reservoir pressure, nitrogen has limited evaporation and extraction effect on crude oil, and nitrogen partially dissolves in crude oil and has a certain effect of expanding crude oil and reducing crude oil viscosity. After nitrogen injection, dissolved gas flooding can occur while production pressure drops.

*2.2. Gravity Drainage.* When nitrogen is injected, the reservoir pressure is maintained by the two-phase flow caused by the difference in gas-liquid density, which is called gravity flooding.

*2.3. Maintaining Formation Pressure.* For condensate reservoirs, if developed by depletion, when the pressure drops below dew point pressure, a large amount of retrograde condensate oil will remain in the reservoir and oil recovery will be very low. By injecting nitrogen into the reservoir, the reservoir pressure is maintained above the dew point and saturation pressure to prevent retrograde condensate or dissolved gas from escaping, which means low oil recovery.

In general, the main stimulation mechanism of nitrogen injection can be summarized as follows.

*2.4. Viscosity Reduction.* Under the condition of lower saturation pressure and the same temperature,  $N_2$  is partially dissolved in crude oil, the solubility increases with the increase of pressure, and the viscosity of crude oil decreases with the increase of dissolved gas.

*2.5. Expansion Pressurization.* The injected nitrogen is insoluble in water and partially soluble in crude oil; its good

expansion performance can not only improve the pressure of the reservoir but also expand the volume of crude oil, which allows the oil to flow into more channels, thereby enhancing oil recovery.

**2.6. To Reduce the Oil-Water Interfacial Tension.** The injected nitrogen can reduce the water-phase relative permeability and improve the oil-phase relative permeability, thus reducing the oil-water interfacial tension and increasing the oil displacement efficiency.

**2.7. Gravity Differentiation.** Due to the large density difference between the injected nitrogen and the crude oil, the injected nitrogen will have a gravity differentiation effect with the crude oil in reservoir, forming a secondary roof on the top of the oil-bearing structure. Then, the crude oil on the top of the structure will flow downward and expand the swept volume.

### 3. Displacement Experiment Design

In order to study the effect of nitrogen flooding on oil displacement in fractured reservoirs, laboratory long core water displacement experiments were conducted to compare the oil displacement effect under different media and different displacement modes, and the injection parameters under a reasonable displacement mode were optimized.

#### 3.1. Experiment Conditions

**3.1.1. Water.** Standard brine with a salinity mass fraction of 8% (the formula was salt water with a mass ratio of  $\text{NaCl}:\text{CaCl}_2:\text{MgCl}_2\cdot 6\text{H}_2\text{O} = 7:0.6:0.4$ ).

**3.1.2. Oil.** The viscosity range of the prepared standard oil sample is 20~40 mPa·s.

**3.1.3. Temperature and Pressure.** At room temperature, the confining pressure was kept above the injection pressure of 2 MPa.

**3.1.4. Core.** The standard core was taken from the full diameter core, diameter of 25 mm, and length 1.5 times greater than diameter.

10 cores are used to splice the long core. To eliminate the end effect, each short core was connected with a filter paper. The arrangement of the long core from the inlet to the outlet is arranged according to the harmonic mean method, and the specific core arrangement is shown in Table 1. The combined core has a total length of 51.078 cm, an average permeability of 0.923 mD, an average porosity of 9.635%, a total pore volume of 24.24 mL, an initial oil saturation of 0.636, and an initial oil volume of 15.43 mL.

Considering the relatively high degree of reservoir fracture development, and most of them are high angle fractures, artificial fractures are constructed in the middle section of the combined cores as shown in Figure 1.

Core nos. C-1~C-3 at the inlet and C-8~C-10 at the outlet are not fractured, and random distributed fractures are created in the middle C-4~C-7 to form oblique fractures to simulate natural fractures. The average dip angle of fractures

in a single core is 30°~60°, the fracture length is 3.5~4.5 cm, and the fractures are not filled to ensure the natural opening, as shown in Figure 2.

#### 3.2. Experiment Preparation

- (1) Prepare standard oil sample and water sample
- (2) Measure porosity and gas permeability of core samples
- (3) Saturate the core sample
- (4) Establish irreducible water saturation
- (5) Carry out water drive or gas drive and gas-water alternate drive experiments according to the specific experiment design and steps

**3.3. Experiment Design.** In the experiment design, injection optimization was carried out in four ways: continuous water flooding, alternating gas-water flooding after water flooding, continuous gas flooding, and alternating gas-water flooding after gas flooding. On this basis, optimization of nitrogen gas-water alternating injection parameters was carried out to determine three key gas injection parameters, including the optimal slug ratio, injection velocity, and total injection volume.

A total of 24 groups of experiments were designed, including 2 groups of single displacement experiment, 3 groups of alternating gas-water flooding after water flooding experiment, 3 groups of alternating gas-water flooding after gas flooding experiment, and 16 groups of gas-water alternate flooding parameter optimization experiment.

### 4. Experiment Design and Results

#### 4.1. Continuous Water and Nitrogen Injection

- (1) Set the back pressure value and establish a certain pressure at the inlet of the rock sample before water flooding
- (2) The pump drives water or nitrogen in the intermediate vessel to carry out constant flow displacement, records the oil production in the water free production period, and accurately records the water breakthrough time, cumulative oil production, cumulative liquid production, and pressure difference between the core inlet and outlet at this time
- (3) At the beginning of water breakthrough, the recording frequency is increased and the time interval according to the amount of oil produced is determined. With continuous decline of oil production, the recording time interval is gradually lengthened. When water injection reaches 30 PV (or when water cut reaches 99.95%), the experiment is stopped

The experimental results are as shown in Figures 3 and 4. It can be obtained that, compared with water flooding, gas flooding has a faster oil recovery rate in the early stage and thus has obvious advantages, which is performed as low

TABLE 1: Core sequencing results in long core displacement experiment.

No.	Core no.	Diameter cm	Length cm	Porosity %	Permeability mD	Oil saturation %	Pore volume mL	Initial oil volume mL
1 (inlet)	C-1	2.502	4.812	9.626	0.759	58.15	2.28	1.32
2	C-2	2.502	5.517	9.536	1.152	58.84	2.59	1.52
3	C-3	2.501	5.451	11.342	0.807	64.79	3.04	1.97
4	C-4	2.505	4.985	9.558	0.700	67.00	2.35	1.57
5	C-5	2.502	5.057	8.712	1.193	63.83	2.17	1.38
6	C-6	2.505	4.956	8.759	0.954	60.51	2.14	1.29
7	C-7	2.505	5.334	9.104	0.901	67.59	2.39	1.62
8	C-8	2.504	4.965	9.465	0.775	66.35	2.31	1.54
9	C-9	2.504	4.934	10.934	1.048	63.36	2.66	1.68
10 (outlet)	C-10	2.503	5.067	9.317	0.943	66.02	2.32	1.53

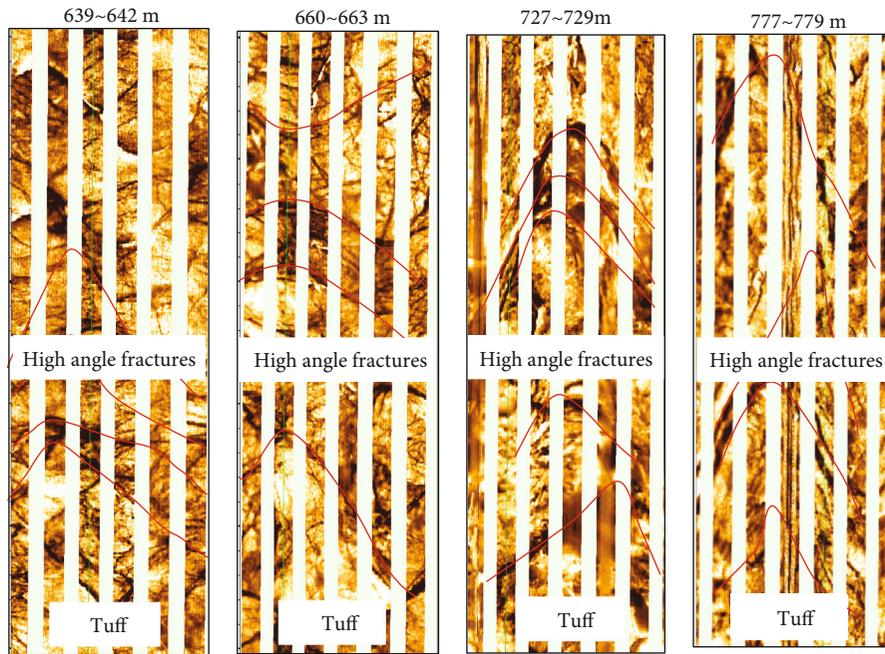


FIGURE 1: Description of imaging logging results in different well sections.

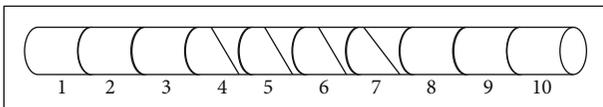


FIGURE 2: Schematic diagram of experimental core and fracture simulation.

displacement pressure gradient and fast seepage flow velocity. It indicates that the single gas flooding has a better displacement effect in the early stage, and the increased range of oil displacement efficiency is larger.

At the same time, according to the injection pressure curve, the injection pressure of gas flooding is significantly lower than that of water flooding, indicating that nitrogen is easier to flow into the micropores than water. However,

after high-permeability channels are formed, the displacement pressure of both water and gas flooding drops sharply, and the pressure drop of gas flooding is higher than that of water flooding.

However, from the perspective of final displacement, the ultimate recovery of water flooding is higher than that of gas flooding, mainly because gas breakthrough is more likely to occur in gas flooding in fractured reservoirs, and the reduction of sweep efficiency results in invalid displacement after gas breakthrough. However, by comparing the recovery factor with the injected PV, when the ultimate recovery is reached, the injected PV of gas flooding is significantly less than that of water flooding.

#### 4.2. Alternating Gas-Water Flooding after Water Flooding

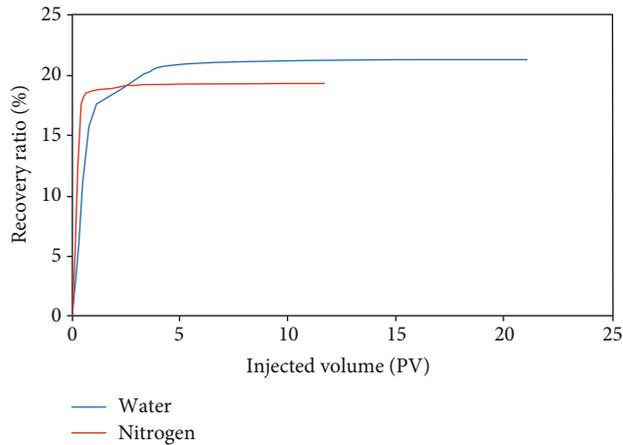


FIGURE 3: Curve of the relationship between injection volume and sweep efficiency in different media.

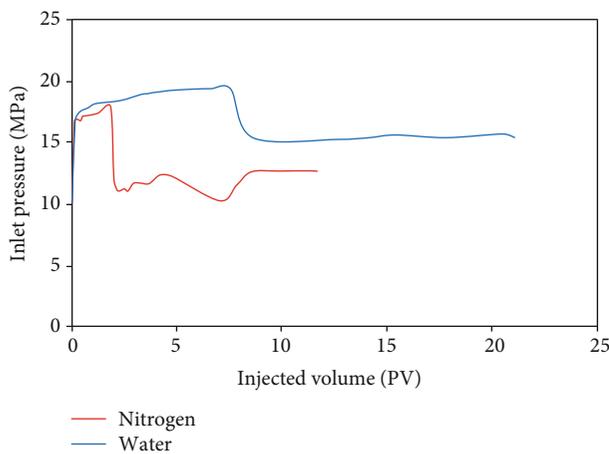


FIGURE 4: Curve of the relationship between injection volume and pressure of core inlet in different media.

- (1) Set the back pressure value and establish a certain pressure at the inlet of the rock sample before water flooding
- (2) The pump drives water in the intermediate vessel to carry out constant flow displacement and records the cumulative oil production, cumulative liquid production, and pressure difference between the core inlet and outlet
- (3) When the water cut reaches 20%, alternate gas-water injection is started. Set the slug ratio to 1:1, and the single injection volume is 1 PV. Determine the time interval according to the amount of oil produced. With continuous decline of oil production, gradually lengthen the recording time interval until no oil is produced and record the correlated data during this period
- (4) Repeat steps 1 and 2. When the water cut reaches 50% and 80%, start the alternate gas-water injection and record the correlated data

The experimental results are as shown in Figures 5 and 6. It can be obtained that the alternative gas-water flooding after water flooding can effectively reduce injection pressure and improve oil recovery. In the meantime, the earlier the gas-water alternations, the lower the water cut, the better the displacement efficiency, the higher the final recovery, and the lower the injection amount required to achieve the final recovery. Comparing continuous water injection with alternate water flooding after water flooding, it can be concluded that gas injection can effectively supplement the formation energy. And the gas can partially dissolve in crude oil, resulting in volume expansion of oil and rise of the initial displacement pressure.

#### 4.3. Alternating Gas-Water Flooding after Gas Flooding

- (1) Set the back pressure value and establish a certain pressure at the inlet of the rock sample before gas flooding
- (2) The pump drives gas in the intermediate vessel to carry out constant flow displacement and records the cumulative oil production, instantaneous gas production velocity, and pressure difference between the core inlet and outlet
- (3) When oil recovery reaches 5%, alternate gas-water injection is started. The water is injected first, and then, the air is injected circularly. Set the slug ratio to 1:1, and the single injection volume is 1 PV. Determine the time interval according to the amount of oil produced. With continuous decline of oil production, gradually lengthen the recording time interval until no oil is produced and record the correlated data during this period
- (4) Repeat steps 1 and 2. When oil recovery reaches 10% and the nitrogen begins to break through, start the alternate gas-water injection and record the correlated data

The experimental results are as shown in Figures 7 and 8. It can be obtained that the alternating gas-water flooding after gas flooding can alleviate the gas breakthrough caused by single gas flooding, improve the displacement efficiency, and enhance oil recovery. In addition, since the formation energy is improved by gas flooding at the initial stage, the earlier gas-water alternations are implemented, the better the displacement will be. However, after serious gas channeling is formed, the effect of gas-water alternations becomes worse.

**4.4. Summary of Displacement Experiments.** Three types of displacement experiments are conducted: single displacement experiment, alternating gas-water flooding after gas flooding, and alternating gas-water flooding after water flooding.

For fractured reservoirs, continuous gas flooding easily forms gas channeling, and oil displacement efficiency is the worst. Alternating gas-water flooding after gas flooding has the best displacement efficiency (shown in Table 2 and

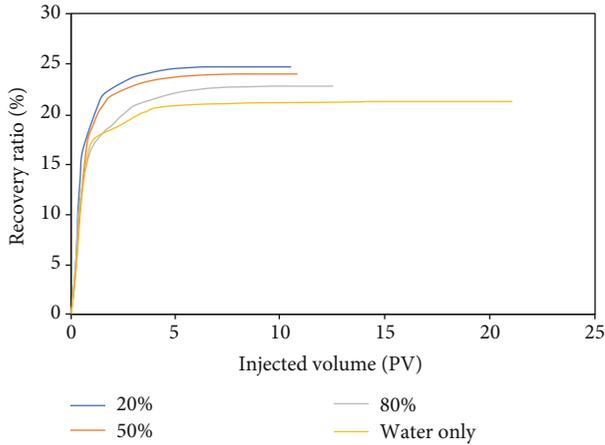


FIGURE 5: Curve of the relationship between injection volume of alternating gas-water flooding and sweep efficiency in different times.

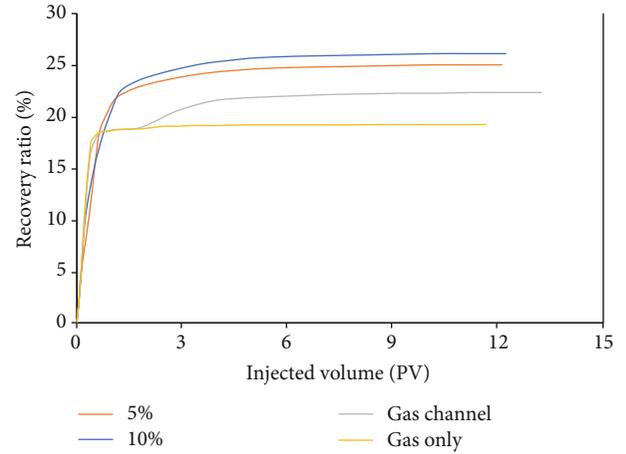


FIGURE 7: Curve of the relationship between injection volume of alternating gas-water flooding and sweep efficiency in different times.

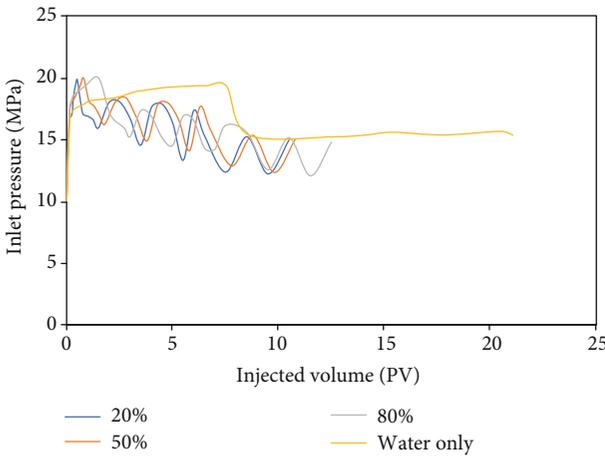


FIGURE 6: Curve of the relationship between injection volume of alternating gas-water flooding and injection pressure in different times.

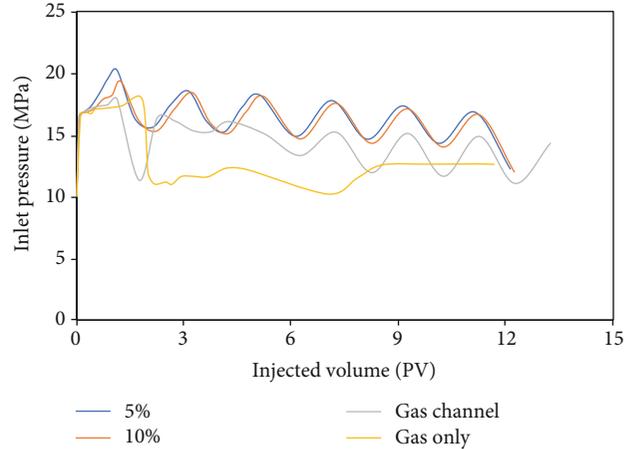


FIGURE 8: Curve of the relationship between injection volume of alternating gas-water flooding and injection pressure in different times.

Figure 9). Compared with continuous water injection and continuous gas injection, oil recovery is improved by 4.89% and 6.88%, respectively.

In addition, alternating gas-water flooding after water flooding can also significantly improve the performance of continuous water injection, and the recovery can be increased by 3.43%.

The overall analysis shows that it is not suitable for continuous gas injection in fractured reservoir. High displacement pressure difference can be formed by alternating gas-water injection, which can effectively reduce the influence of gas breakthrough and maximize oil recovery. For the carboniferous reservoirs in the No. 6 middle area, under the current development condition, it is suggested to implement alternating gas-water flooding after gas flooding, which can improve the reservoir development effectively and enhance the final recovery.

**4.5. Parameter Optimization of Alternating Gas-Water Flooding Experiment.** According to similar reservoir con-

struction experience, three key parameters of alternating gas-water flooding are gas-water injection slug ratio, gas-water injection velocity, and injection volume in one single cycle. But what parameters have great influence on displacement? What is the best displacement mode? Generally, we use the orthogonal experimental design method for parameter optimization, which can not only qualitatively analyze the influences of injection parameters on the alternating gas-water flooding but also quantitatively rank the effects of different injection parameters on the displacement. Then, the optimal injection parameters can be determined to guide field injection design.

**4.5.1. Orthogonal Experimental Design.** For the carboniferous reservoirs in the No. 6 middle area, injection parameters mainly include gas-water injection slug ratio, gas-water injection velocity, and injection volume in one single cycle. Each parameter usually uses four values: gas-water ratios of 0.5:1, 1:1, 2:1, and 4:1; injection velocities of 0.6, 0.4,

TABLE 2: Statistical table of oil recovery and displacement pressure difference under different displacement modes.

Displacement mode	Oil recovery (%)	Displacement pressure difference (MPa)
Continuous water injection	21.22	9.34
Continuous gas injection	19.23	7.88
Alternating gas-water flooding after water flooding	24.67	9.82
Alternating gas-water flooding after gas flooding	26.11	9.32

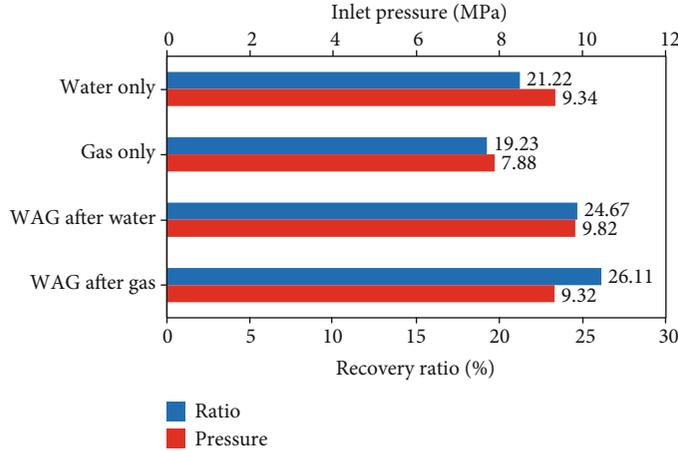


FIGURE 9: Comparison of oil displacement experimental results under different displacement modes.

0.2, and 0.1 mL/min; and injection volumes in one single cycle of 0.5, 1, 2, and 5 PV (as shown in Table 3). Therefore, there are 64 feasible combination schemes, while the orthogonal experimental design method only needs to design 16 experiments, and then, the law represented by 64 experiments can be obtained by range analysis.

So, the orthogonal experimental method was adopted in this laboratory experiment design to analyze the injection parameters affecting displacement efficiency to determine the main controlling factors and select the optimal parameter interval, as shown in Table 3.

4.5.2. Experimental Procedure

- (1) Set the back pressure value and establish a certain pressure at the inlet of the rock sample before gas flooding
- (2) The pump drives gas in the intermediate vessel to carry out constant flow displacement. Injection velocity, injection volume, and injection volume per slug are set according to the experimental design scheme to conduct a gas flooding, and cumulative oil production and pressure difference between two ends of the rock sample are recorded
- (3) Switch the intermediate vessel to the water flooding mode quickly, then conduct water flooding with the designed injection velocity, injection volume, and injection volume per slug, and record the cumulative oil production and pressure difference between two ends of the rock sample

TABLE 3: Orthogonal experimental scheme design table of alternating gas-water flooding.

Factors	Gas-water slug ratio	Injection velocity (mL/min)	Injection volume in one cycle (PV)
1	0.5 : 1	0.6	0.5
2	1 : 1	0.4	1.0
3	2 : 1	0.2	2.0
4	4 : 1	0.1	5.0

- (4) Switch between gas drive and water drive circularly, repeat steps 2 and 3 until no oil is produced, and record the correlated data

It can be seen from the orthogonal experimental results (in Table 4) that the injection volume in one single cycle has the greatest influence on the displacement in the case of alternating gas-water flooding, followed by the gas-water injection slug ratio and the injection velocity. It indicates that excessive injection volume leads to the formation of gas channeling. Although it can be improved by alternating the injection of gas and water, the result is not good. However, if the gas-water slug ratio is too large, the elastic energy utilization rate of injected gas will be low, and the water volume is too small, it is not conducive to the formation of plug flow, and the gas breakthrough cannot be effectively suppressed.

If the gas-water slug ratio is too small, the gas energy will be insufficient to improve the development. At the same time, excessive injection velocity will lead to a sharp increase

TABLE 4: Summary of orthogonal experimental design results.

No.	Gas-water slug ratio	Injection velocity (mL/min)	Injection volume in one cycle (PV)	Gas injection volume in one cycle (PV)	Water injection volume in one cycle (PV)	Oil recovery (%)
1	0.5:1	0.6	0.5	0.17	0.33	24.15
2	0.5:1	0.4	1	0.33	0.67	24.75
3	0.5:1	0.2	2	0.67	1.33	26.09
4	0.5:1	0.1	5	1.67	3.33	22.68
5	1:1	0.6	1	0.50	0.50	24.82
6	1:1	0.4	0.5	0.25	0.25	25.43
7	1:1	0.2	5	2.50	2.50	22.34
8	1:1	0.1	2	1.00	1.00	26.15
9	2:1	0.6	2	1.33	0.67	23.34
10	2:1	0.4	5	3.33	1.67	22.27
11	2:1	0.2	0.5	0.33	0.17	26.22
12	2:1	0.1	1	0.67	0.33	26.35
13	4:1	0.6	5	4.00	1.00	21.14
14	4:1	0.4	2	1.60	0.40	23.14
15	4:1	0.2	1	0.80	0.20	23.48
16	4:1	0.1	0.5	0.40	0.10	22.74

TABLE 5: Mean response statistics of orthogonal experiments.

No.	Gas-water slug ratio	Injection velocity	Injection volume in one cycle
1	24.42	23.36	24.63
2	24.69	23.90	24.85
3	24.55	24.53	24.68
4	22.63	24.48	22.11
Delta (range)	2.06	1.17	2.74
Order	2	3	1

in pressure gradient and low gas energy utilization and will even accelerate gas breakthrough, which means a worse result.

Through the mean response analysis of orthogonal experimental design (Table 5), in the case of alternating nitrogen gas-water flooding, the reasonable injection volume in a single cycle is around 1 PV, the gas-water injection slug ratio should be 1:1~2:1, and the best injection velocity is between 0.1 and 0.2 mL/min.

## 5. Conclusions

Long core displacement experiments are conducted to systematically study enhanced oil recovery of nitrogen-water alternative injection. Feasibility of enhanced oil recovery is verified, influence of injected parameters is analyzed, and injected parameters are optimized.

- (1) Nitrogen injection can effectively enhance oil production of fractured reservoirs in early periods, but gas channeling will be occurred in late periods which can be released by nitrogen-water alternative injection

- (2) For the reservoir that is developed by water flooding, it is better to apply nitrogen-water alternative injection early to enhance oil recovery
- (3) It is revealed that the factors that influence nitrogen-water alternative effect are ordered as follows: cycle injected volume, nitrogen and water slug ratio, and injection rate
- (4) Optimal cycle injected volume is around 1 PV, nitrogen and water slug ratio is between 1 and 2, and injection rate is between 0.1 and 0.2 mL/min

## Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

## Conflicts of Interest

The authors declare no competing interest.

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