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Evaluation of Nitrogen EOR in Yanchang Tight Oil Reservoir

Xisen Zhao*, Bin Chang, Tao Gao, Hailong Dang, Bin Liu

Corresponding Author:** ***Xisen Zhao, *Yanchang Petroleum Research Institute, Xi'an City, Shaanxi Province, China.*

Abstract: *Tight oil is the most potential reservoir in the future. A large amount of EOR methods are developed to enhance the oil recovery in America and Canada, such as CO_2 EOR method, N_2 EOR method, solvent assisted method and water flooding. In this research, Yanchang oil field is selected as the research sample to compare N_2 replacing method and water flooding method. 12 experiments are completed and the experimental and simulation results indicate that N_2 has the better effect but it costs more.*

Keywords: *tight oil, N_2 EOR method, water flooding, numerical simulation*

1. Introduction

The tight oil resource accounts for the largest part in North Dakota, Montana in America and Saskatchewan and Alberta in Canada [1]. Numerical simulation of enhanced oil recovery in the middle Bakken and upper Three Forks tight oil reservoirs of the Williston basin are used to describe the tight oil exploit [2]. In Iwereet, water flooding is simulated which improves that this method will do benefits for the oil recovery. In 1980s, CO_2 flooding method was used in Little Knife and South Pine oil field, the recovery improved 13% in the pilot experiment. CO_2 flooding method was proved to be efficient by Ghedan in 2009 in the low permeability reservoir [3]. Nitrogen is a more economical resource in gas flooding which is also easy to obtain. In this study, water flooding and nitrogen replace methods are utilized to select the best parameters such as injecting flow rate, close time and pressure depletion. And three dimension experiments with the best efficiency parameters are completed to compare the oil recovery. In addition to this, numerical simulation is considered to describe the residue oil in the reservoir.

2. Experimental Section

2.1. Materials

The tight oil sample is collected from Yanchang oil field in Shanxi, China. The mineralized water is configured as the formation water. The oil viscosity is the same as the reservoir crude oil. The injection gas is nitrogen with the purity of 99.95%.

2.2. Experimental Setup

ISCO pump, resistance saturation detection device and pressure detection device are required in this experiment. The maximum temperature and pressure for the replacing system is 150℃ and 70MPa. The flow rate range of ISCO pump is 90 ml/min.

2.3. Experimental Procedure

Before the experiment, pretreatment is prepared for core. The core should be cut neatly and grind finely to maintain the end face vertical. They are also need to be washed and leached salt before stoving. After the end of the preprocessing stage, the diameters of core and gas permeability should be measured. According to the order of permeability, every 10 samples are divided into one group. And the first group with the lowest permeability is the core is combined with the largest permeability in next group, which ensures the similar physical property of the long core after the splicing.

2.3.1. Water injection experiment of long core

Five experiments with three variables are considered in this procedure (Table 1). Three parameters are different water injection velocity, pressure depletion rate and close time. There are five long tubes in the experiments to simulate water huff and puff. Each tube can reach 50 centimeters. The experimental results provide the initial parameters of the simulation model which are the permeability, porosity and initial water and oil saturation. The dynamic parameters supplied are pressure, water injection volume in each stage and the production of oil and water.

Table1. *Water Injection Experiment Schedule*

NO.	Experiment Conditions				
	Water Injection Velocity (ml/min)	Maximum Pressure (MPa)	Pressure Depletion Rate (MPa/h)	Reservoir Pressure (MPa)	Close Time (h)
1	0.025	30	1	20	3
2	0.025	30	1	20	3
3	0.025	30	1	20	3
4	0.05	30	1	20	3
5	0.05	30	3	20	9

2.3.2. Gas injection experiment of long core

Five experiments with three variables are considered in this procedure (Table 2). Three parameters are different gas injection velocity, pressure depletion rate and close time. There are five long tubes in the experiments to simulate gas huff and puff. Each tube can reach 50 centimeters. The experimental results provide the initial parameters of the simulation model which are the permeability, porosity and initial water and oil saturation. The dynamic parameters supplied are pressure, gas injection volume in each stage and the production of oil, water and gas.

Table2. *Gas Injection Experiment Schedule*

NO.	Experiment Conditions				
	Gas Injection Velocity (ml/min)	Maximum Pressure (MPa)	Pressure Depletion Rate (MPa/h)	Reservoir Pressure (MPa)	Close Time (h)
6	2	30	1	20	3
7	2	30	2	20	3
8	2	30	3	20	3
9	4	30	1	20	3
10	4	30	1	20	9

2.3.3. Three dimensional huff and puff experiment

The optimal parameters are optimized through long core water flooding and huff and puff experiments. Combined with the conditions of field well pattern and construction feasibility, three-dimensional physical simulation experiments of water injection and huff and puff are designed. The designed physical model size is 40cm*40cm*4cm (Figure 1) as follows, which red points are stand for huff and puff well and blue ones are pressure detection points. The well in the middle is huff and puff well with surrounding four wells located at the middle point between huff and puff well and the corner connection, which are regarded as the pressure detection points during the experiment.

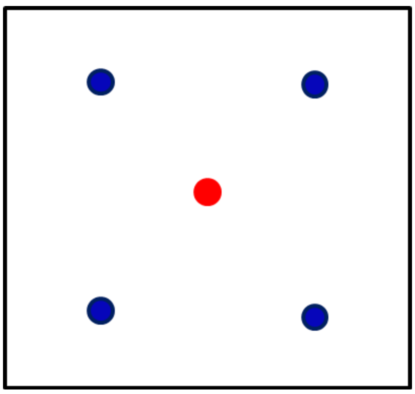

Figure1. *Three dimensional huff and puff model*

The model is placed in a constant temperature environment of 40°C for 24 hours. The simulated oil is injected to the model after configuration. What followed is to calculate the irreducible water saturation with the initial pressure 15MPa. The amount of liquid production was calculated after the first depletion production till 5MPa. According to the pre-set water and gas injection velocity, gas is injected into the system to enhance model pressure as high as 20MPa. The simulated well begins to produce after shutting in for 1h by controlling the rate of liquid and gas production to maintain the pre-set pressure depletion speed. At the second time that the pressure deceases to 5MPa during depletion production, recovery can be calculated at the end of the producing. Repeat this step and continue to huff and puff for two cycles.

Because of the starting pressure in non-Darcy flow of low permeability core, there will be huge differences of the pressure among inlet, middle part and outlet. So how to control the whole pressure during experiment is a difficult problem. An addition experiment is recommended to offer an acknowledgement for the water huff and puff experiment. This problem will solved through a pure water huff and puff experiment as the reason that there is no starting pressure gradient in single-phase flow.

3. RESULTS

In addition experiment, 0.0559PV liquid needs to be produced when the pressure is reduced from 15MPa to 5MPa by using volume equivalent principle,. And when the pressure changes from 5MPa to 20MPa, it needs to supplement 0.08PV liquid.

3.1. Water Injection Experiment Analysis of Long Core

The average permeability, pore volume and porosity of the five long cores of water injection experiments are shown as follows (Table 3). The physical properties are similar after the combination.

Table3. *Water Injection Experiment Schedule*

No.	Average Permea bility	Core length	Pore Volume	Porosity	Saturated Oil Volume	Initial Oil Saturation	Pressure Depletion Rate	Water Injection Velocity	Close Time
	(mD)	(cm)	(ml)	(decimal)	(ml)	(decimal)	(MPa/h)	(ml/min)	(h)
1	0.180	49.427	23.534	0.097	13.649	0.580	1	0.025	3.000
2	0.220	47.144	23.040	0.100	13.166	0.563	2	0.025	3.000
3	0.220	49.965	23.396	0.096	13.270	0.567	3	0.025	3.000
4	0.237	47.446	24.760	0.107	13.420	0.574	1	0.050	3.000
5	0.228	47.196	25.439	0.110	13.420	0.528	1	0.050	9.000

In the experiment of water injection huff and puff, the final recovery with the exhaustion speed of 1MPa/h is higher than 12% (Figure 2). And the recovery with exhaustion speed in 2MPa/h is 10.44%. The lowest recovery is that with exhaustion speed of 3Mpa/h, which is only 8.92%. As time goes on, the fastest water injection velocity and the longest close time do the worst to the recovery (Figure 3). To close time, ultimate recovery after shutting in three hours is higher than 9 hours, but almost the same. The velocity of water injection with 0.025ml/min does better than 0.05ml/min in enhancing oil recovery.

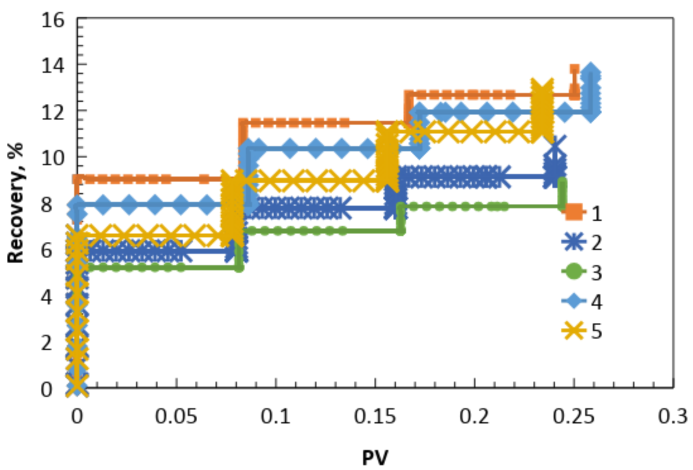

Figure2. *Relationship between recovery and water injection pore volume*

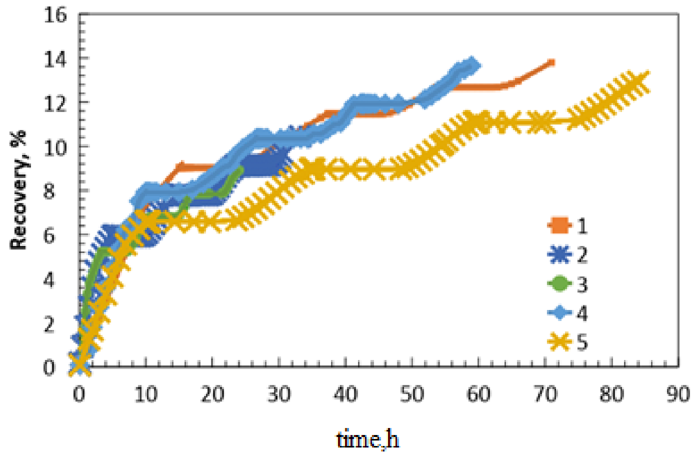

Figure3. *Relationship between recovery and water injection time*

In the first circle, water cut rate runs the first in the fifth experiment which has the highest water injection rate. At the second and third circles, water cut is located in the first with the fastest pressure depletion in experiment three (Figure 4). The final water cut rate is basically the same after three rounds of water huff and puff. The experiment with fastest pressure depletion has the shortest water breakthrough time (Figure 5).

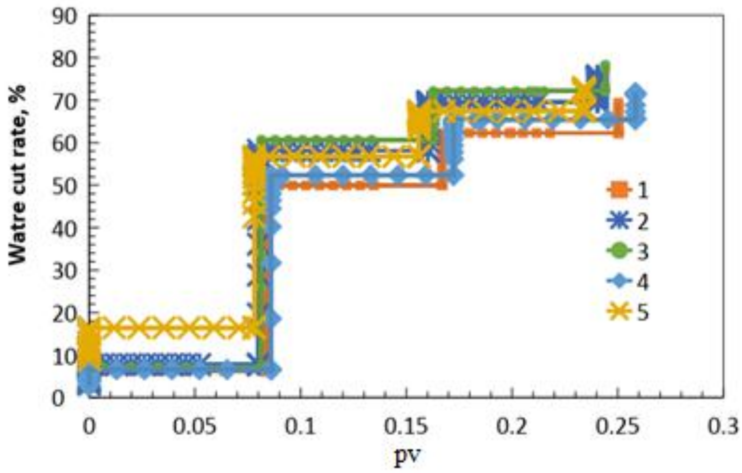

Figure4. *Relationship between water cut rate and water injection pore volume*

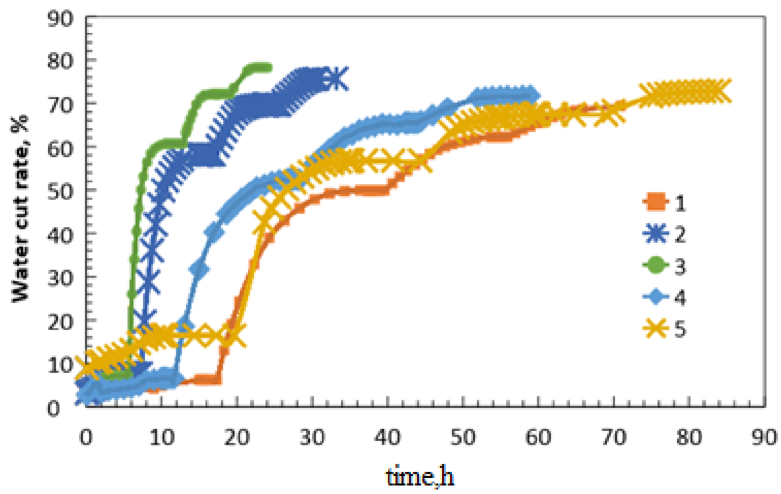

Figure5. *Relationship between water cut rate and water injection time*

The optimal parameter settings for the first set of experiments with 0.025ml/min water injection velocity, pressure depletion rate 1MPa/h and closed time 3h is the best.

3.2. Gas injection experiment analysis of long core

The average permeability, pore volume and porosity of the five long cores of gas injection experiments are shown as follows (Table 4). The physical properties are similar after the combination.

Table4. *Gas Injection Experiment Schedule*

No.	Average Permeability	Core length	Pore Volume	Porosity	Saturated Oil Volume	Initial Oil Saturation	Pressure Depletion Rate	Gas Injection Velocity	Close Time
	(mD)	(cm)	(ml)	(decimal)	(ml)	(decimal)	(MPa/h)	(ml/min)	(h)
6	0.237	47.677	24.760	0.106	13.420	0.542	1	2.000	3.000
7	0.250	49.924	24.852	0.102	13.520	0.544	2	2.000	3.000
8	0.230	51.527	26.105	0.103	14.100	0.540	3	2.000	3.000
9	0.340	52.168	26.360	0.103	15.200	0.577	1	4.000	3.000
10	0.370	49.890	26.110	0.107	14.800	0.567	1	4.000	9.000

In the experiment of gas injection huff and puff, the final recovery with the exhaustion speed of 1MPa/h is higher than 15% (Figure 6). And the recovery with exhaustion speed in 2MPa/h is 14.25%. The lowest recovery is that with exhaustion speed of 3Mpa/h, which is only 14.11%. To close time (Figure 7), ultimate recovery after shutting in three hours is higher than 9 hours, but there are not too many differences between them. The velocity of gas injection with 2ml/min does better than 4ml/min in enhancing oil recovery.

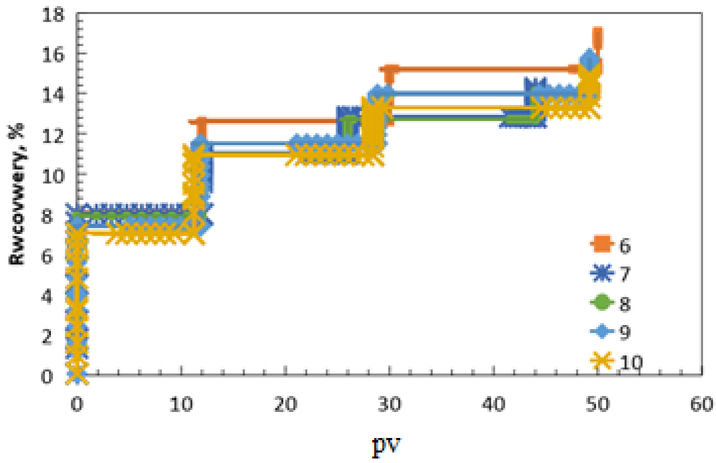

Figure6. *Relationship between recovery and gas injection pore volume*

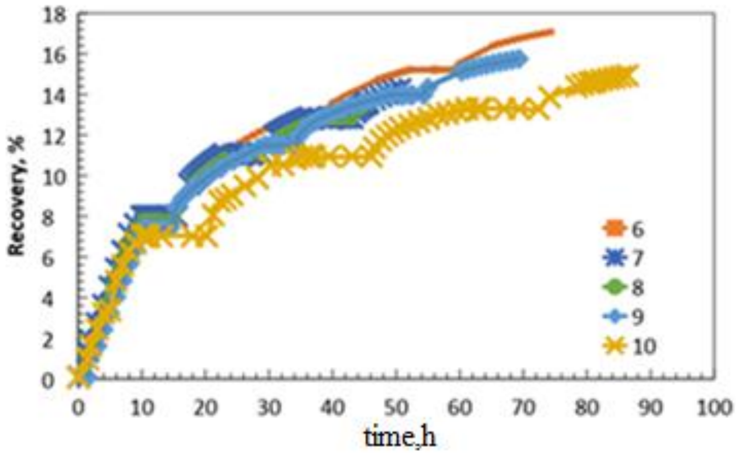

Figure7. *Relationship between recovery and gas injection time*

The optimal parameter settings for the sixth set of experiments with 2ml/min gas injection velocity, pressure depletion rate 1MPa/h and closed time 3h is the best. The gas oil ratio increases with the time. When the depletion pressure is 3MPa/h, the gas oil ration ranked the first (Figure 8).

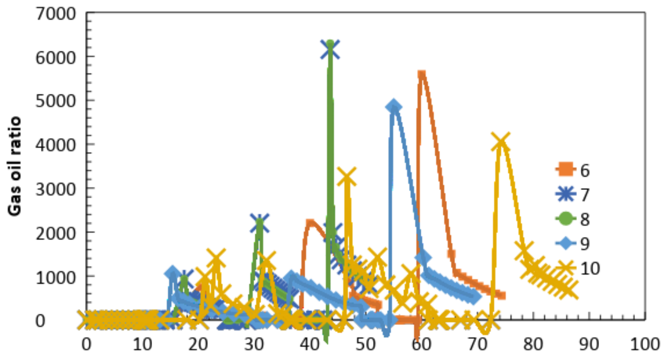

Figure8. *Relationship between gas oil ratio and gas injection time*

3.3. Three dimensional huff and puff experiment analysis

The average permeability, pore volume and saturated oil volume of the three dimensional huff and puff experiments are shown as follows (Table 5). The initial temperature and pressure for the three dimensional model is 40°C and 15MPa separately. Experiment 11 is water injection and experiment 12 is gas injection.

Table5. *Three Dimensional Huff and Puff Experiment*

No.	Average Permeability	Model Size	Pore Volume	Initial Temperature	Saturated Oil Volume	Initial Pressure	Pressure Depletion Rate	Water/Gas Injection Velocity	Close Time
	(mD)	(cm)	(ml)	(°C)	(ml)	(MPa)	(MPa/h)	(ml/min)	(h)
11	1.360	40*40*4	646.56	40	323.214	15	1	0.025	3.000
12	1.410	40*40*4	672.15	40	333.520	15	1	2.000	3.000

According to the pressure in the middle of the model or at the end, under the same conditions, the pressure in the process of gas injection can spread farther and faster. The production process can exploit the residue oil production far away from the well, which is an important reason why the effect of gas injection is better than water injection (Figure 9-10).

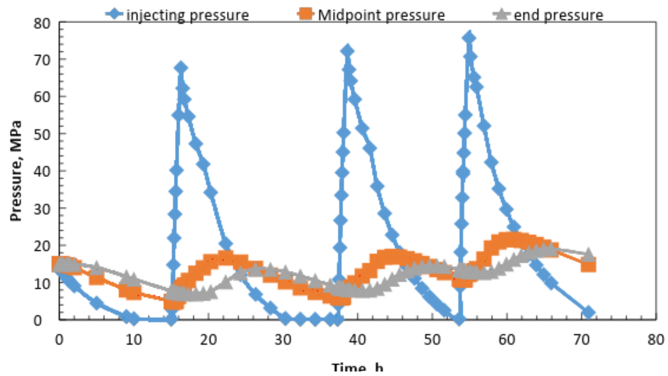

Figure9. *Pressure of midpoint and terminal point in injecting water*

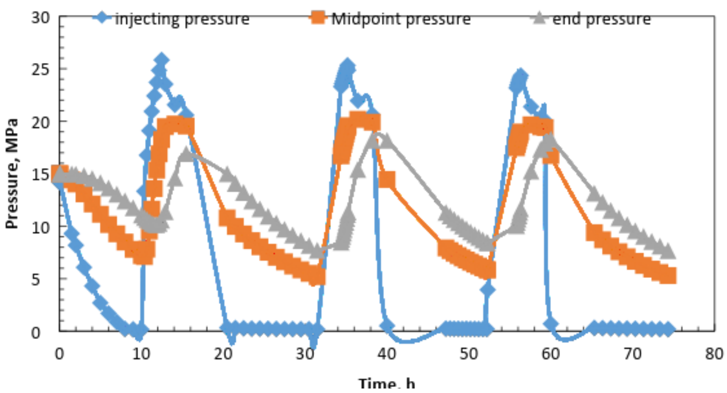

Figure10. *Pressure of midpoint and terminal point in injecting gas*

The numerical simulated results of three-dimensional huff and puff experiments indicate that the natural energy is the single-phase flow of oil phase under the action of elastic energy from the results of the residual oil saturation field. The oil is continuous phase during this period and the development effect is the best. Nature depletion exploiting is adopted until the reservoir pressure decreases to 5MPa (Figure 11).

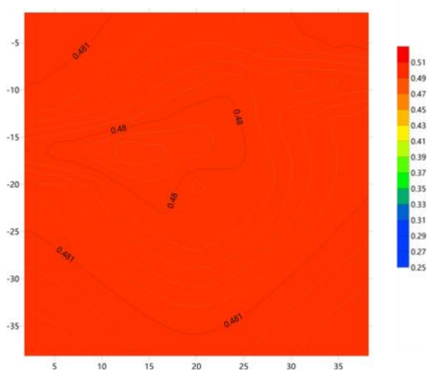

Figure11. *Saturation field of natural energy exhaustion to 5MPa*

The first round of water injection (gas injection) supplemented energy. The sweeping volume accounts for a quarter of total by injecting water (gas). The injected water (gas) replaces the crude oil in the pores during the process of elastic mining, which do benefits to the recovery. The oil saturation field after the first round and the second round is shown as follows (Figure 12).

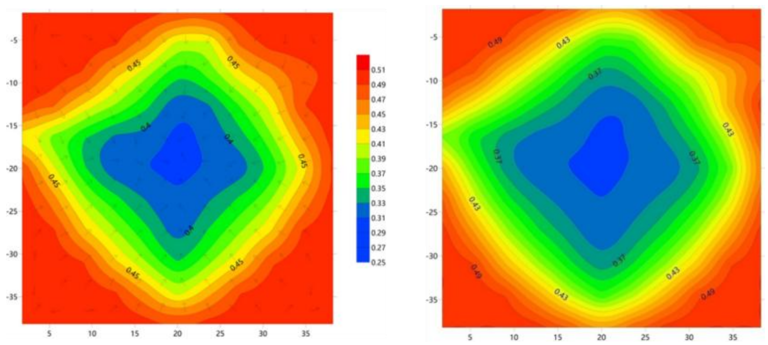

Figure12. *Oil saturation field at the end of first round and the second round*

The second round and third round of injecting water (gas) cannot greatly improve the degree of sweeping inefficiency. What more, the residual oil in sweep area has already been segmented and blocked during the first round of injecting water (gas). That is the reason why the effect is unsatisfied after two rounds of injecting water (gas). The oil saturation field after the second round and the third round is shown as follows (Figure 13).

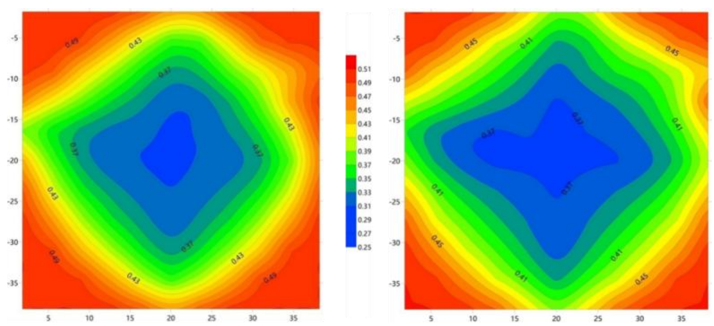

Figure13. *Oil saturation field at the end of second round and the third round*

4. CONCLUSIONS

- The effect of gas huff and puff is better than water huff and puff, but the cost of water injection and puff is far lower than that of gas injection and puff.
- The pressure propagation in the gas huff and puff process is much farther and faster, which is an important reason for the perfect effect of gas huff and puff.

- The pressure depletion rate is the prime factor of enhance oil recovery. Meanwhile, the injection velocity and the close time have little effect on the results.
- Natural energy exhaustion is an important mining stage during the exploitation of low permeability reservoir, which accounts for more than half of the total production generated by huff and puff. Supplemented energy accounts for about a quarter of the total oil production at the first circle of water or gas injection.

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