Experiment Research on Enhanced Oil Recovery by Intermittent Gas Injection in Low Permeability Oilfield

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***Abstract*—The existence of low permeability, strong heterogeneity, developing fracture, small pore throat and high capillary forces by specific surface leads to the low water flooding recovery and high injection pressure in developing a low permeability oilfield. As the advantage of injectivity, the gas flooding is introduced. However, gas flooding is easy to cause fluid breakthrough flow. Considering the influence of gas channeling to recovery, the intermittent gas injection is accepted. Based on the theoretical analysis and study of core displacement experiments, the efficacy of intermittent gas injection to enhance oil recovery in low permeability oilfield is evaluated. Also, the influence to recovery caused by intermittent period length and times is analyzed. The results show that the intermittent gas injection can restrain the gas channeling and improve the recovery of low permeability reservoirs effectively. The improved recovery point in each intermittent period has a positive correlation with intermittent period length. And the highest improved recovery point appears at the second or the third intermittent period generally.**

***Index Terms*—low permeability, intermittent gas injection, recovery, experiment research**

I. Introduction

With enormous developing potentiality, the reserves in low permeability reservoirs account for 60% to 80% of new proved reserves [1] [2]. However, the characteristics of high clay content, small pore throat, shortage of natural energy, strong heterogeneity and developing fracture leads to the great difficulties in developing a low permeability oilfield [3]. High injection pressure and poor water-intake capacity of water injection well, rapid pressure and yield drop around developing well cause the low recovery in conventional production by water driving [4]-[8]. So suitable displacement way and fluid attract more and more attention [9].

With the good injectivity, gas is adopted to enhance oil recovery in low permeability oilfield. On the other hand, gas flooding is easy to cause fluid breakthrough flow. Although the intermittent gas injection can control the gas channeling in a way [10], the report is few and the application is in field test stage [11].

Based on the theoretical analysis and study of core displacement experiments, this paper evaluates the efficacy of intermittent gas injection to enhance oil recovery in low permeability oilfield. Also, the influence to recovery caused by intermittent period length and times is analyzed.

II. Mechanism of Intermittent Gas Injection

With the periodical gas injection and oil production, intermittent gas injection is a new way to enhance oil recovery by changing the pressure of oil reservoir According to the progress of intermittent gas injection, it can be divided into two stages with different mechanism to enhance oil recovery.

- Pressure rising and production ceasing stage. In this stage, gas preferentially enter into the high permeability channels, and then turn into the low permeability zone by diffusion, dissolution and other ways, which improve the pressure of reservoir and reduce the viscosity and density of residual oil in the low permeability zone. So that to decrease the flow resistance and to increase the micro oil displacement efficiency.
- Depressurization development stage. In this stage, depressurization appears in the high permeability channels preferentially for the high percolation ability. The differential pressure is formed between

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the low permeability and high permeability zones. Meanwhile, the ability of swelling and expansion for gas, which is dissolved into the oil, can displace the residual oil in low permeability zones, so that to enhance oil recovery in low permeability reservoir.

III. Preparation for the Experiment of Intermittent Gas Injection

A. Experimental Equipment

Fig. 1 shows the experimental equipment. In this figure, a~h respectively stand for 2PB00C type constant-flux pump, the container with the capacity of 500mL (loading oil, water or gas), six-way valve, precision pressure sensor with the range of 30MPa, computer, core holder, back pressure valve, equipment for gas metering. In the equipment, there are some two-way valve, three-way valve and pipe etc.

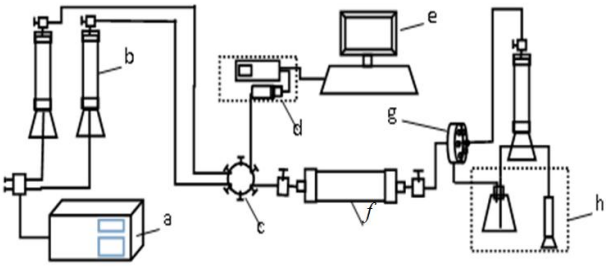

Figure 1. Experimental equipment of intermittent gas injection

B. Experimental Fluids

The total mineralization of experimental water is 90000mg • L^{-1}, the water type is $CaCl_2$, and the viscosity is 0.6mPa s (50℃).

The experimental oil is simulated oil, mixed the degassing oil and kerosene with a certain volume ratio. And the viscosity is 2.04mPa s. The experimental gas is natural gas.

C. Experimental Method

In order to study the effect of period length on oil displacement efficiency for intermittent gas injection, the intermittent gas injection experiments are carried in low permeability core (the permeability is $18.86\times10^{-3}\mu m^2$), core parameters are shown in Table I, and four groups of experiment is designed. The experimental scheme is shown in Table II. Gas driving will be used on the cores after saturating oil, and keep gas injection until no oil driven out by gas any more, then switch to the intermittent gas injection. The pressure can rise to 12MPa in pressure rising and production ceasing stage, then cut off the gas injection when the pressure is steady. Build the pressure as designed. Then depressurizing development will be started through decreasing backpressure slowly according to the designed period length until the pressure drop to the initial one, which is 10MPa, then repeat these steps.

According to the virgin pressure of reservoir, the simulation pressure, controlled by the backpressure, is 10MPa, and the experimental temperature is 50℃.

TABLE I. Core Parameters

number	length /cm	height×width /cm×cm	porosity /%	permeability $/10^{-3}\mu m^2$
HP-1	30.0	4.50×4.50	8.745	18.86

TABLE II. Experimental Scheme for Intermittent Gas Injection

number	period length/min		period times
	pressure rising and production ceasing	depressurization development	
JX-1	60	40	9
JX-2	120	60	9
JX-3	240	120	11
JX-4	1080	360	9

IV. Result and Analysis

According to the experimental scheme, the production behavior of each experiment showed as follows:

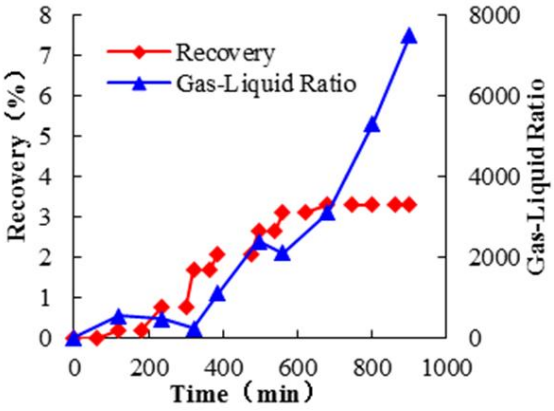

Figure 2. Production behavior of JX-1

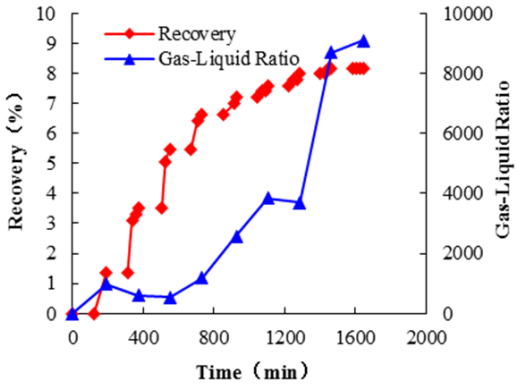

Figure 3. Production behavior of JX-2

Comparing the producing characteristic from Fig. 2 to Fig. 5, we can conclude that the shorter the period length is, the faster the gas/liquid ratio rising, and the gas breakthrough will be easier to happen. When the period length is more than 360min, the gas/liquid ratio rises slowly at the beginning of scheme JX-3 and JX-4, and the oil displacement efficiency keeps high. At the beginning, few gas can be displaced, because injected gas are dissolved into the oil, but the oil displacement efficiency increases fast. From the experiments, we can see that the

pressure decreases obviously at the beginning and lots of gas can be gathered, but oil cannot be displaced until the decompression slows down in each period, from which we can conclude that gas in the big pore is driven out first, and then the pressure of high permeability zones start to decline, then crude oil in the pore throat will be driven out under the effect of differential pressure between high permeability zones and low permeability zones, and the swelling effect will also be considered.

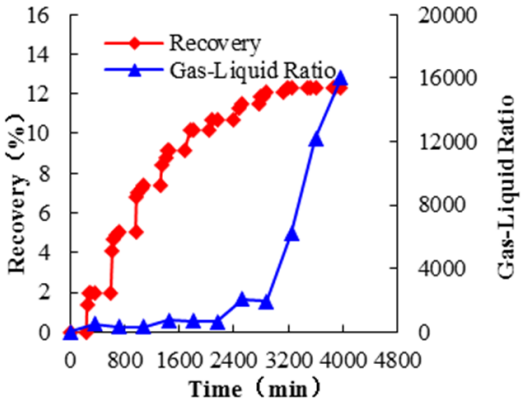

Figure 4. Production behavior of JX-3

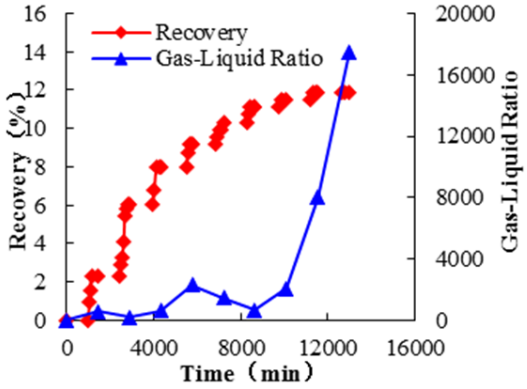

Figure 5. Production behavior of JX-4

Fig. 6 shows the relationship between recovery and intermittent period.

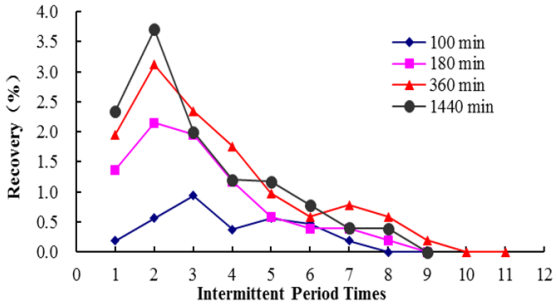

Figure 6. Recoveries of different intermittent period lengths

From Fig. 6, we can get some conclusions:

- For the same intermittent period length: With the development of intermittent period, the oil displacement efficiency increases first and then declines slowly. The highest recovery appears in the second or the third intermittent period, not the first one.

Analyze: most injected gas is dissolved in the oil at the first intermittent period. This progress declines the pressure difference between low permeability area and high permeability area in core, which influence the recovery. After the first intermittent period, the gas dissolved in oil is saturated; the pressure difference and gas expansion are high enough to bring out the oil in the low permeability area, which makes the recovery increasing. With the reducing of oil in low permeability area, the recovery then declines slowly.

- For different intermittent period lengths: The longer intermittent period length is, the higher recovery in intermittent period is. In program JX-4, the intermittent period length is 1440min, and the highest recovery is 3.71%, while in program JX-1, the intermittent period length is 100min, the highest recovery is only 0.941%.

Fig. 7 shows the relationship between total recovery and intermittent period length.

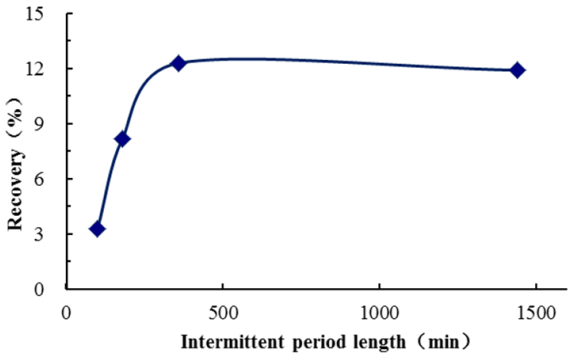

Figure 7. Recoveries in different intermittent period lengths

From Fig. 7, we can see:

With the increasing of different intermittent period lengths, the total recovery of all periods raises first and then keeps constant. When the intermittent period length arrives to 360min, the recovery keeps 12%.

V. Conclusions

Intermittent gas injection can retard gas channeling. The longer the period length is, the slower the gas/liquid ratio rising, and the gas breakthrough will be harder to happen.

The improved recovery point in each intermittent period has a positive correlation with intermittent period length. And the highest improved recovery point appears at the second or the third intermittent period generally.

With the increasing of intermittent period lengths, the total recovery of all periods raises first and then keeps constant. There exists an optimum intermittent period length.

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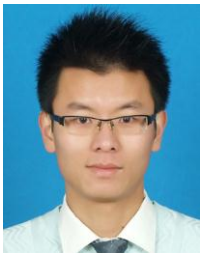

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