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Experimental Study on EOR Performance of Natural Gas Injection in Tight Oil Reservoirs

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Abstract. Gas injection is an effective enhanced oil recovery method in tight oil reservoirs. In the case of tight oil fields with sufficient natural gas supply, natural gas injection can significantly reduce the cost of operation, leading economic benefit. Natural gas flooding might be a promising EOR method for tight oil development. Based on the material and reservoir condition of a tight formation in Changqing Oilfield, this study conducted a series of natural gas injection experiments to evaluate the feasibility of natural gas injection after water flooding and analysed the influence of gas injection rate to EOR performance. Experiment results shows that natural gas injection can recover 20.8% more oil after water flooding. Sensitivity analyses indicates that natural gas injection had a higher oil recovery with low injection rate.

1. Introduction

Tight oil reservoirs have extremely low porosity and permeability, and oil would be trapped in small pores of formation during primary oil production [1]. Many tight oil reservoirs, like Changqing Oil Filed in China, have limited natural energy, oil rate of single well by depletion drops quickly and the recovery factor of primary recovery stage are low [2-3]. For conventional reservoirs, water flooding is a common method to maintain pressure in formation and displace oil to well. However, water flooding in tight oil reservoirs has a low injection rate and poor displacement efficiency due to extremely low permeability. Hence, gas flooding becomes a promising method to enhance oil recovery (EOR) due to higher injection rate and displacement efficiency.

The main mechanisms of gas injection are reservoir pressure maintenance, oil swelling and oil viscosity reduction [4,5]. The injected gas widely used includes natural gas, CO₂, N₂, or gas mixture [6]. CO₂ injection is commonly used in North America [7]. However, it is essential to consider economic benefits for tight oil development. The cost of purchase, transportation and storage of CO₂ for CO₂ injection are more expensive than that of natural gas and nitrogen [8]. Tight oil reservoirs with large production of natural gas have sufficient supply of natural gas source. Natural gas can be reinjected into



formation to displace oil, and the cost of natural gas injection is lower than CO₂ injection. Therefore, natural gas injection in tight oil reservoirs might be a promising EOR method and suitable for tight oil reservoirs lacking CO₂ source.

Many researchers had conducted experimental and theoretical studies of natural gas injection for conventional reservoirs. Kumar et al. [9] conducted hydrocarbon gas core flooding experiments, results showed that both miscible and immiscible natural gas injection could improve oil recovery; natural gas injection simulation indicated that gas injection had a gas override problem, and it needed to be considered. Field applications showed great potential of natural gas injection in conventional reservoirs. Handil Field [10] conducted lean gas injection after water flooding for 3 years, oil recovery was increased by 1.2%, the project was considered both technical and economic success. North Buck Draw field [11] conducted natural gas injection, having an incremental recovery of 15 million bbl. Brazeau River Nisku [12] field natural gas injection had a successful result.

For unconventional reservoirs, with the application of hydraulic fracturing treatments combined with horizontal wells, natural fracture and artificial fracture exists in the tight oil formations [3,13,14]. Gas injection might encounter with gas breakthrough and gas override during gas flooding, leading limited sweep efficiency. Many researches focused on huff-n-puff process [5,15]. However, gas huff-n-puff process can only have significant performance near the well. Therefore, EOR potential of gas flooding still need to be evaluated.

Several researchers conducted simulation studies on shale reservoirs. Sheng and Chen [16] simulated water flooding and gas flooding in shale oil reservoir. They found that gas flooding had better EOR performance than water flooding; and miscible flooding only appear around fracture area, therefore the main mechanism of gas injection is pressure maintenance instead of miscible flooding. Liu et al [17] determined the minimum miscible pressure (MMP) of Ansai reservoir in China by high pressure slim tube experiment, the experiment result indicated that the MMP of Ansai field was much higher than reservoir pressure. Moreover, natural gas injection was also applied in shale oil reservoir. Bakken formation in North Dakota [18] conducted a pilot project, using natural gas as injected gas. However, gas injection only continued for 55 days, after natural gas was injected, oil rate increased for a short time.

In this work, natural gas injection after water flooding and sensitivity analyses of gas injection rate experiments were conducted based on the material of Chang-7 tight oil formation of Ordos Basin. The core flooding experiments evaluated the feasibility of natural gas injection in tight oil reservoirs and compared the EOR performance in different injection rate.

2. Experiment

A series of core flood experiments was conducted by using material from a typical tight oil reservoir, Chang-7 tight oil formation of Ordos Basin.

2.1. Material

2.1.1. Fluid properties. The dead oil used in the experiment was obtained from Chang-7 Formation of Ordos Basin, and brine was prepared according to the ion composition of Chang-7 Formation water. The properties of oil and formation water are shown in Table 1. The compositions of dead oil and formation water were analysed at 60°C and atmosphere pressure condition. The analyses results are listed in Table 2 and Table 3. The concentration of methane in the natural gas used in the experiments is over 95%.

Table 1. Summary of oil and formation water properties (at 60°C and 0.1MPa)

Parameter	Oil	Formation water brine
Density, g/cm ³	0.775	1.12
Viscosity, mPa·s	4.0	0.5

Table 2. Summary of dead oil components

Componets	Mole fraction	Componets	Mole fraction
C ₃ -C ₄	0.013	C ₁₁ -C ₁₄	0.201
C ₅ -C ₆	0.095	C ₁₅ -C ₂₀	0.214
C ₇ -C ₈	0.218	C ₂₀₊	0.149
C ₉ -C ₁₀	0.112	Total	1

Table 3. Summary of formation water ion composition

Ion	Concentration, mg/L
K ⁺ / Na ⁺	16207
Mg ²⁺	270
Ca ²⁺	2528
Cl ⁻	29703
HCO ₃ ⁻	337
SO ₄ ²⁻	734
Total	53900

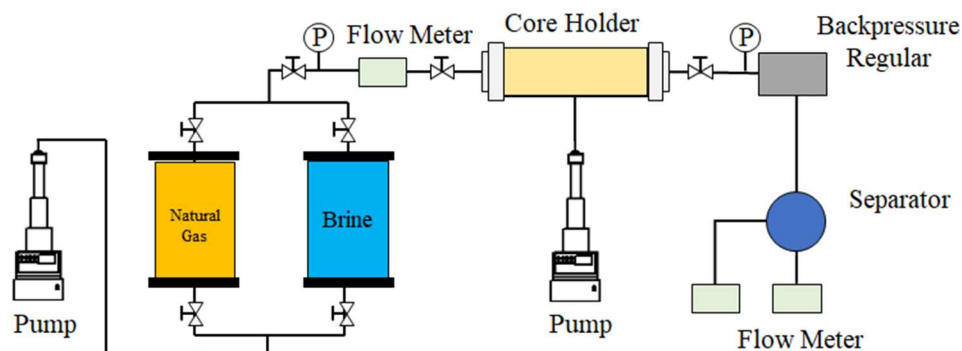
2.1.2. Core samples. Core samples from Ordos Basin were used in core flooding experiments. Before the experiment, core samples were cleaned and then core samples were saturated with formation water brine and dead oil for experiment preparation. The summary of core samples properties is shown in Table 4.

Table 4. Summary of core sample properties

Sample	Length, cm	Porosity, %	Permeability, mD	Initial Oil Saturation, %
H-1	6.02	12.53	0.21	54.68
H-2	5.97	11.97	0.18	56.34
H-3	5.73	11.52	0.16	54.96
H-4	6.11	12.88	0.15	55.67

2.2. Experimental setup and procedure

Figure 1 illustrates the core flooding experiment setup. It mainly consists of pump, vessel, core holder, backpressure regular, separator and flow meter.

**Figure 1.** Schematic diagram of core flooding experiment setup

The core flooding experiment mainly had 2 stages of injection. The core was flooded by formation water brine first, then natural gas was injected into the core. The detail of experiment procedure is shown as follows.

2.2.1. Water injection. The formation water brine was injected into the core at a constant rate of 0.1 mL/min. The pressure of outlet side was controlled at a constant value of 8 MPa. After no more oil produced from outlet side, continued to inject formation water brine until the total injected brine volume reached 2 PV.

2.2.2. Gas injection. After 2 PV formation water brine was injected, natural gas was injected into the core at a constant rate of 0.1 mL/min. After no more oil produced from outlet side, continued to inject gas until the total injected gas volume reached 2 PV (4 PV for total injected fluid).

2.2.3. Gas injection rate sensitivity analyses. After 2 PV formation water brine was injected, natural gas was injected into the core at a constant rate of 0.3 mL/min, 0.5 mL/min, 0.7 mL/min at inlet respectively. After no more oil produced from outlet side, continued to inject gas until the total injected gas volume reached 2 PV (4 PV for total injected fluid).

3. Result and discussion

3.1. Natural gas injection EOR experiments

Figure 2 and Table 5 illustrate the results of natural gas injection EOR core flooding experiments.

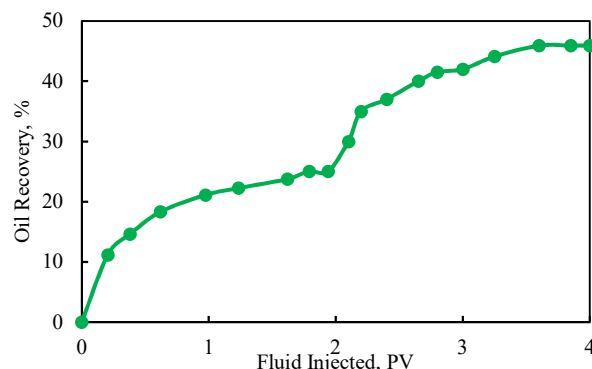


Figure 2. Results of natural gas injection EOR core flooding experiments

Table 5. Results of natural gas injection EOR core flooding experiments

Item	Value
Core sample	H-1
Oil recovery after water injection, %	25.05
Oil recovery after gas injection, %	45.92
Incremental oil recovery, %	20.87

As it can be seen in Figure 2 and Table 5, natural gas injection could increase oil recovery significantly after water flooding by an incremental oil recovery of 20.87%. Natural gas is easily dissolved in oil, leading oil swelling and improving displacement efficiency. Therefore, natural gas flooding could be a promising EOR method for tight oil reservoirs.

3.2. Sensitivity analysis experiment of different injection rate

Figure 3 and Table 6 illustrate the results of natural gas injection EOR core flooding experiments in different injection rate.

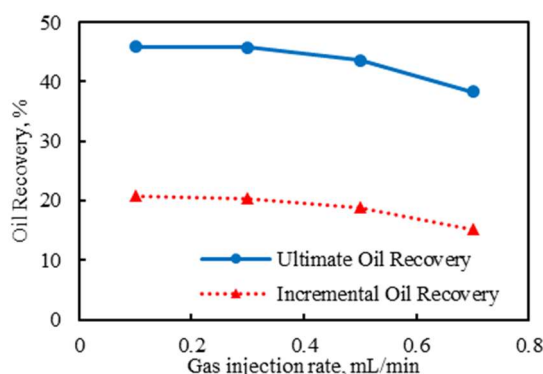


Figure 3. Results of core flooding experiments in different gas injection rate

Table 6. Results of core flooding experiments in different gas injection rate

Experiments	2	3	4	5
Core sample	H-1	H-2	H-3	H-4
Oil recovery after water injection, %	25.05	25.41	24.73	23.15
Gas injection rate, mL/min	0.1	0.3	0.5	0.7
Oil recovery after gas injection, %	45.92	45.77	43.61	38.36
Incremental oil recovery, %	20.87	20.36	18.88	15.21

Figure 3 and Table 6 compared the EOR performance of natural gas injection with different injection rate after water flooding. It can be seen that incremental oil recovery declined with the increasing of gas injection rate. Theoretically, with higher injection rate, pressure in the core would increase and more gas would dissolve in oil. However, gas breakthrough or gas override would easily happen with high injection rate, leading lower sweep efficiency and incremental oil recovery. Therefore, it is necessary to consider the possibility of gas breakthrough and gas override during natural gas injection. It is essential to determine a reasonable gas injection rate during natural gas flooding.

4. Conclusion

The following main conclusions can be drawn based on the experiment results presented in this paper:

- (1) Natural gas injection after water flooding had an incremental oil recovery of 20.87%, indicating great potential of EOR performance.
- (2) Incremental oil recovery decline with the increase of injection rate during natural gas injection after water flooding. Therefore, it is necessary to select a suitable gas injection rate during natural gas flooding for better EOR performance.

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