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The Research of Capillary Pressure in The Process of CO₂ Displacement in Low-permeability Reservoir

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Abstract: The function of capillary pressure in the process of CO₂ displacement in low-permeability reservoir is researched through combination indoor experiments and numerical simulation. On the basis of different displacement experiments in long core chamber, one-dimensional numerical simulation component model is built to research the function of capillary pressure under the different CO₂ displacement ways. The results show that the capillary pressure under the different CO₂ displacement ways is not consistent. Capillary pressure is driving force in the process of CO₂ displacement while resistance force in the process of CO₂ pressure buildup and displacement. In order to promote reasonable and efficient development of low-permeability reservoirs, it is suggested that further study about microscopic effects and laws of the capillary pressure in the reservoir should be done through experiment.

Key words: low-permeability reservoir; capillary pressure; carbon dioxide; displacement; numerical simulation

1. INTRODUCTION

Rocks show different wettability for different reservoir properties and fluid properties, thus the value and function of the capillary pressure are different^[1-7]. In low-permeability reservoirs, because of the existence of start-up pressure gradient, the seepage law is different from conventional medium and high permeable reservoirs^[8-10]. When developing low permeable reservoir with CO₂ injection, there are a variety of displacement ways^[11-15]. At present, in different displacement processes, researches on the function of the capillary pressure are little, even often be neglected. In this paper, combining indoor experiment and numerical simulation methods, the function of the capillary pressure in the process of CO₂ displacement in low-permeability reservoirs are researched.

2. THE FUNCTION OF CAPILLARY PRESSURE IN CO₂ DISPLACEMENT EXPERIMENTS

2.1 The establishment of indoor experiments scheme and numerical simulation model

A total of 22 cores with total length of 973.44 mm are adopted in the experiment with Bragg sequence method. Harmonic-mean permeability is $2.261 \times 10^{-3} \mu\text{m}^2$ and the average diameter is 25.39 mm. Related parameters are shown in Table 1. In displacement experiments, CO₂ is injected into the long core with a rate of 0.5 ml/min.

Table 1. Core parameter of experiments (test7)

Saturated water volume(pore volume), ml	The volume of saturated oil, ml	Oil saturation, %	Irreducible water saturation, %
49.5	32.1	64.85	35.15

A horizontal ID numerical simulation component model is used in numerical simulation with grid number of 110. Simulation grids are shown in Fig. (1).

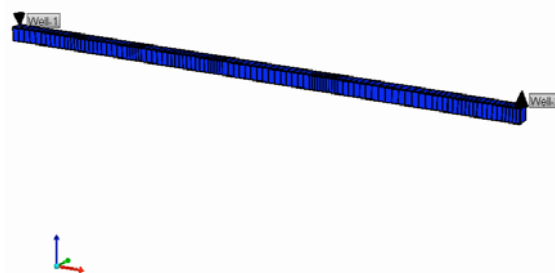


Fig. (1). One-dimensional model diagram

2.2 Research of capillary pressure function

Capillary pressure is common in low-permeability reservoirs. The function of capillary pressure is different in various reservoirs and it is one of the important factors in oil and gas seepage. Based on history match of the experimental data, through change of the capillary pressure, numerical simulation study is done and the sensitivity is studied. The simulation results are shown in Table 2. From cumulative oil production rate and recovery degree, it is indicated that the higher the capillary pressure is, the higher the cumulative oil production rate and recovery degree are, and the capillary pressure is driving force.

Table 2. Sensitivity analysis of capillary pressure

Item	Cumulative oil production, g	Recovery degree, %
Experimental data	10.96	39.78
Increase capillary pressure	11.18	40.59
Decrease capillary pressure	10.60	38.49

2.2.1 The influence of decreasing capillary pressure

Decrease the capillary pressure to a quarter of original value (test7-cp-1), as shown in Fig. (2). The impact of decreasing capillary pressure on oil production rate is shown in Fig. (3) and Table 2. The results indicate that the peak oil production rate decreases with the decrease of capillary pressure, also the time appearing peak oil production rate delays (peak oil production rate

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decreases from $6.8 \times 10^{-4} \text{ m}^3/\text{d}$ before reducing capillary pressure to $4.25 \times 10^{-4} \text{ m}^3/\text{d}$, the time appearing peak oil production rate delays from 0.047 days to 0.063 days).

Analyzing simulation results, the capillary pressure is driving force in the experiments. Decreasing the capillary pressure, the driving force of CO₂ decreases, and the injection velocity of CO₂ decreases, the contact area and dissolve degree of CO₂ and oil decreases, then the swept area and the displacement efficiency decreases, therefore the cumulative oil production rate decreases compared with the condition not decreasing capillary pressure.

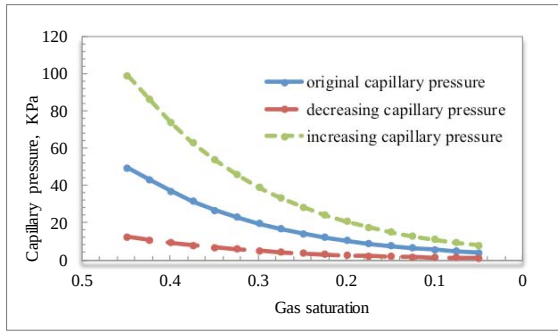


Fig. (2). Capillary pressure curve

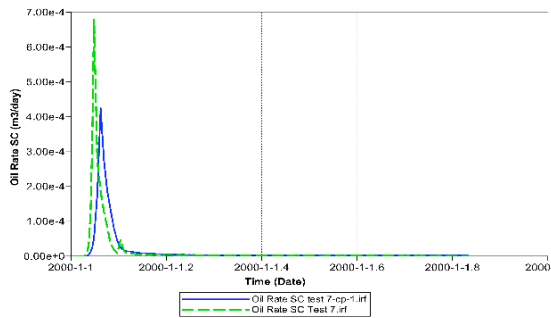


Fig. (3). Oil production rate comparison when decreasing capillary pressure (note: due to the timing unit of experiments is minutes, the date in X-axis expressed with a decimal point)

2.2.2 The effect of increasing capillary pressure

Capillary pressure increases to 2 times of original value (test7-cp-2), as shown in Fig. (2). The impact on oil production rate is shown in Fig. (4) and Table 2. Along with the increase of capillary pressure, the peak production rate decreases, the time appearing peak production rate advances (peak oil production rate decreases from $6.8 \times 10^{-4} \text{ m}^3/\text{d}$ before increasing capillary pressure to $3.94 \times 10^{-4} \text{ m}^3/\text{d}$, the time appearing peak oil production rate advances from 0.047 days to 0.038 days).

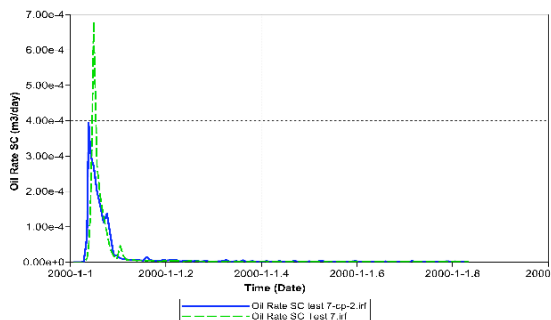


Fig. (4). Oil production rate comparison when increasing capillary pressure

Simulation results further indicate that the capillary pressure is driving force. Increase of capillary pressure

leads to the increases of driving force in CO₂ injection, and the increases of CO₂ injection rate into the core, also the increases of contact area and dissolve degree between CO₂ and oil. Then the swept area and displacement efficiency increases, therefore the cumulative oil production rate increases compared with the condition not increasing capillary pressure.

3. THE RESEARCH OF CAPILLARY PRESSURE IN THE PROCESS OF CO₂ PRESSURE BUILDUP AND DISPLACEMENT EXPERIMENTS

3.1 The experiment scheme of pressure buildup and displacement experiments

Basic data of core is the same with displacement experiment, other parameters are shown in Table 3. In the experiment, gas is injected into the core with a certain injection rate in the early 442 minutes. When the pressure reaches up to 20 MPa, CO₂ is rejected into the core with a rate of 0.5 ml/min, and then CO₂ displacement process is implemented in the experiment.

Table 3. Core parameter of pressure buildup displacement experiment (test8)

Saturated water volume(pore volume) ml	Saturated oil volume ml	Oil saturation %	Irreducible water saturation %
48.20	31.90	66.18	33.82

3.2 Research on capillary pressure function

Based on history match of the experimental data, through change of the capillary pressure, numerical simulation study is done and the sensitivity is studied. The simulation results are shown in Table 4. From cumulative oil production rate and recovery degree, it is indicated that the higher the capillary pressure is, the lower the cumulative oil production rate and recovery degree are, and the capillary pressure is resisting force.

Table 4. Sensitivity analysis of capillary pressure

item	cumulative oil production, g	Recovery degree, %
Experimental data	13.64	49.84
Increasing capillary pressure	12.99	47.46
Decreasing capillary pressure	13.73	50.16

3.2.1 The effect of decreasing capillary pressure

Decrease the capillary pressure to a quarter of original value (test8-cp-1), as shown in Fig. (5). The impact of decreasing capillary pressure on oil production rate is shown in Fig. (6) and Table 4. The results indicate that cumulative oil production rate increases a little along with the decrease of capillary pressure. The peak oil production rate and the time appearing peak oil production rate are the same (peak oil production rate is $6.57 \times 10^{-4} \text{ m}^3/\text{d}$ and the time appearing peak oil production rate is 0.356 days).

Analyzing simulation results, the capillary pressure is resistance force in the experiments. Decreasing the capillary pressure, the resistance force of CO₂ decreases, and the injection velocity of CO₂ increases, the contact area and dissolve degree of CO₂ and oil increases, then the swept area and the displacement efficiency increases,

therefore the cumulative oil production rate increases compared with the condition not decreasing capillary pressure.

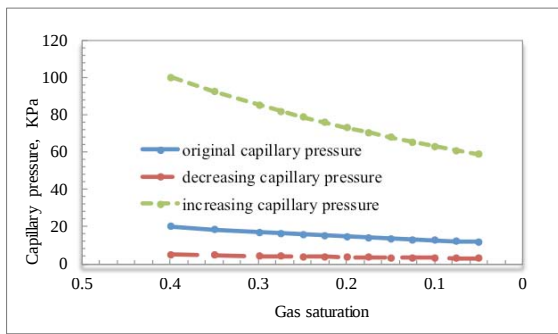


Fig. (5). Change of capillary pressure curve

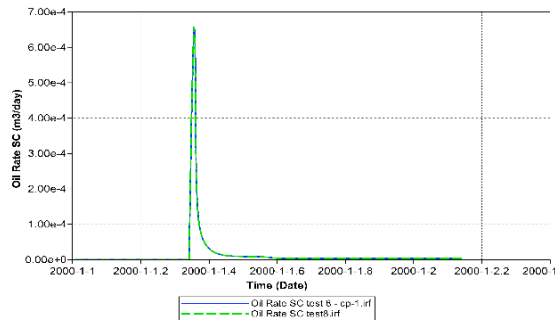


Fig. (6). Oil production rate comparison when decreasing capillary pressure

3.2.2 The effect of increasing capillary pressure

Capillary pressure increases to 5 times of original value (test8-cp-2), as shown in Fig. (5). The impact on oil production rate is shown in Fig. (7) and Table 4. Along with the increase of capillary pressure, the peak production rate decreases, the time appearing peak production rate is the same (peak oil production rate decreases from $6.57 \times 10^{-4} \text{ m}^3/\text{d}$ before increasing capillary pressure to $6.09 \times 10^{-4} \text{ m}^3/\text{d}$, the time appearing peak oil production rate is 0.356 days).

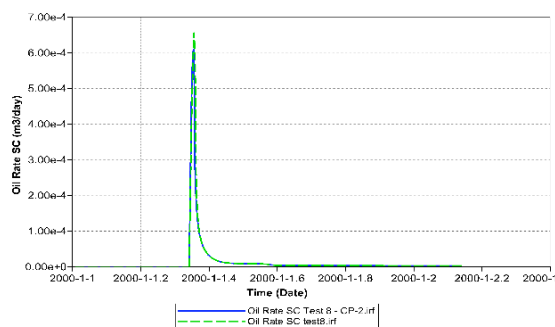


Fig. (7). Oil production rate comparison when increasing capillary pressure

Simulation results further indicate that the capillary pressure is resistance force. Increase of capillary pressure leads to the increases of resistance force in CO₂ injection, and the decreases of CO₂ injection rate into the core, also the decreases of contact area and dissolve degree between CO₂ and oil. Then the swept area and displacement efficiency decreases, therefore the cumulative oil production rate decreases compared with the condition not increasing capillary pressure.

4. CONCLUSIONS

1. Capillary pressure is driving force in the process of CO₂ displacement. Along with the increase of capillary pressure, the time appearing peak production rate advances, the cumulative oil production rate increases. It is mainly because that driving force enhances CO₂ injection ability and improves the displacement efficiency of CO₂.

2. Capillary pressure is resistance force in the process of pressure buildup and CO₂ displacement. Along with the increase of capillary pressure, peak oil production rate and the cumulative oil production rate decreases. It is mainly because that resistance force decreases CO₂ injection ability and reduces the displacement efficiency of CO₂.

3. In the low-permeability reservoir, the capillary pressure appears different forms in the process of CO₂ displacement. In further research, it is suggested that microscopic effects and laws of the capillary pressure in the reservoir should be done through experiments.

CONFLICT OF INTEREST

The author confirms that this article content has no conflict of interest.

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