Microscopic Oil Displacement Experiment of CO_2 in Ultra-low Permeability Sandstone

Shu-man Li[1(✉)], Guang-ming Yu[1], Fan Wei[1], Jing-tao Ge[2], and Jin-long Yang[1]

[1] Exploration and Development Research Institute of Changqing Oilfield Company, Xi'an, China
{lsm2013_cq, ygm_cq, fanwl_cq, yjlong_cq}@petrochina.com.cn

[2] Linfen Coalbed Methane Branch of China Petroleum Chemical Co., Ltd., Linfen, China
gejt@163.com

Abstract. CO_2 flooding is considered to be a very important way to solve the problems of high starting pressure gradient, poor reservoir water absorption and low water flooding recovery in ultra-low permeability reservoirs. Moreover, the long-term storage underground of CO_2 can be achieved, and the social benefits of CO_2 emission reduction can also be realized. In order to study on the sweep region of CO_2 miscible and immiscible flooding, ascertain the displacement efficiency of CO_2 under different conditions. Through the micro-displacement experiment of CO_2 in real sandstone, It is clear that the oil displacement efficiency of CO_2 miscible flooding is the best, sweep region is the widest. Moreover, CO_2 miscible/near miscible flooding can greatly improve micro-displacement efficiency. The analysis results of the experiment will provide guidance for the field test.

Keywords: Ultra-low permeability · CO_2 flooding · Miscible phase · Immiscible phase · Oil displacement efficiency

A lot of research and practice at home and abroad show that CO_2 flooding can effectively improve reservoir development effect and enhance oil recovery [1–3]. The reservoir of ultra-low permeability reservoir has dense core and poor physical properties. Therefore, the CO_2 flooding test needs to study the effect of CO_2 flooding first. The purpose of this research is to clarify the CO_2 flooding effect of ultra-low permeability sandstone through the experiment of real sandstone CO_2 micro-flooding, and to provide guidance for mine testing.

1 Experimental Overview

1.1 Experimental Device

According to the specific content of this study, we have designed a real sandstone CO_2 micro-displacement experimental device (atmospheric pressure) (Fig. 1) ,and real sandstone CO_2 micro-displacement experimental device (high pressure) (Fig. 2).

J. Lin (Ed.): *Proceedings of the International Field Exploration and Development Conference 2019*, SSGG, pp. 81–89, 2020.
https://doi.org/10.1007/978-981-15-2485-1_9

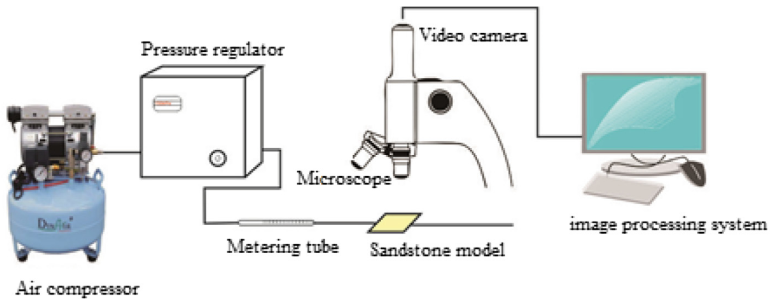

Fig. 1. Real sandstone CO_2 micro-displacement experimental device diagram (atmospheric pressure)

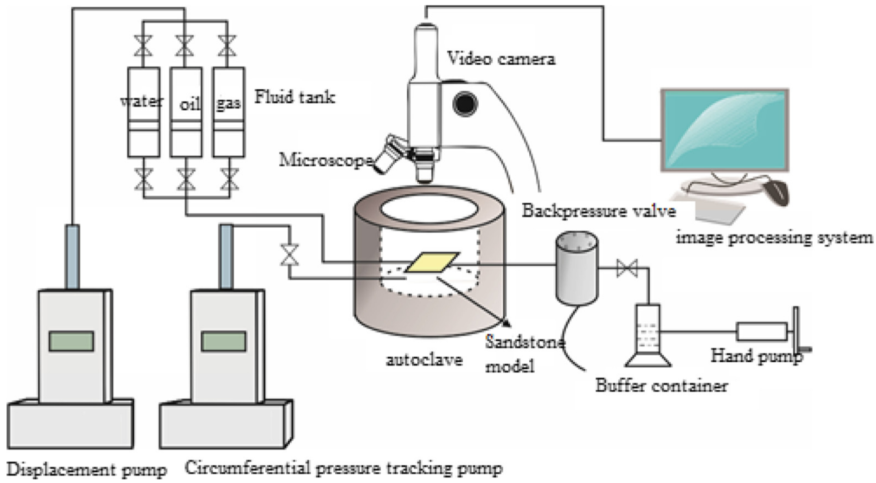

Fig. 2. Real sandstone CO_2 micro-displacement experimental device diagram (high pressure)

1.2 Experimental Condition

The formation pressure of the reservoir where the core is located is 15.8 MPa, comprehensive water cut is 35.0%, reservoir porosity is 8.3% and permeability is 0.27 mD. It is a typical ultra-low porosity with ultra-low permeability reservoir. The water type of formation water is $CaCl_2$, the total salinity is 35.42 g/L, the viscosity of formation crude oil is 0.73 mPa·s, the original gas-oil ratio is 85 m^3/t, the reservoir temperature is 84 °C, the MMP (minimum miscible pressure) of formation crude oil is 16.1 MPa, and the MMP of surface crude oil is 19.3 MPa.

This experiment is matched with simulated formation water. The water type is $CaCl_2$ and the total salinity is 35.0 g/L. The oil used is degassed crude oil (high pressure condition) on the reservoir surface and simulated crude oil (atmospheric pressure condition) prepared by the laboratory. The highest temperature and displacement pressure of the experiment are 70 °C and 17.9 MPa, which fully ensure that the experimental conditions are close to the real state.

1.3 Experimental Steps

Model Preparation. The core is extracted, dried, sliced and wear down, make a real sandstone micro-model.

Evacuation and Saturated the Core for Water. This process is to simulate the state of reservoir without oil and gas entering.

Saturated the Core for Oil. This process simulates the process of oil and gas entering reservoir.

Water Flooding (or CO_2 Flooding). The real sandstone model of saturated oil directly to CO_2 flooding (or direct water flooding), increasing pressure, the occurrence status and percolation characteristics of CO_2 (or water) in the displacement process were observed. For experiments requiring alternating displacement, repeat this step.

Pressure Relief. After maintaining the maximum displacement pressure for a certain period of time, gradually reduce the displacement pressure, continue to observe and analyze the seepage path of CO_2, and use image processing software to statistics the final displacement efficiency.

The detailed experimental procedure of real sandstone CO_2 flooding micro-experiment is shown in Fig. 3 [4].

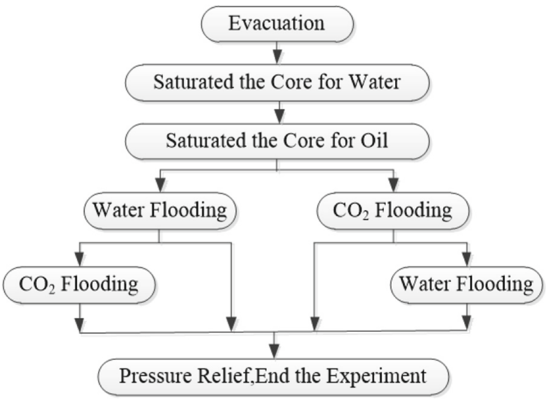

Fig. 3. Microscopic experimental steps of CO_2 flooding in real sandstone. Note: CO_2 flooding includes miscible flooding and immiscible flooding.

2 Experimental Results

2.1 Single Displacement Experiment

Water flooding, CO_2 immiscible flooding and CO_2 miscible flooding are carried out, and the sandstone used is taken from the same core. The local horizon map of water flooding experiment shows that, the direction of water flooding line is not uniform, the displacement is not complete, and the residual oil is in large clusters [5] (Fig. 4).

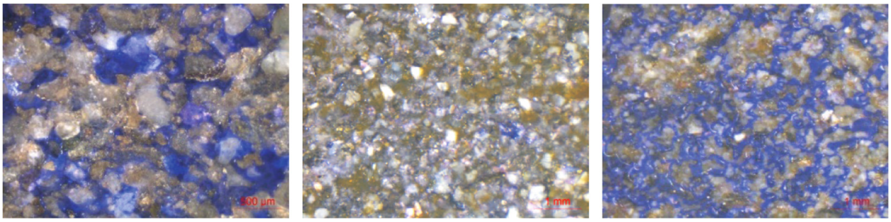

Fig. 4. Local horizon map of water flooding experiment (Saturated for Water → Saturated for Oil→ Flooding End). Note: In the experimental photos and all the photos in this paper, the blue is simulated formation water (injected water), the light yellow, yellowish brown and dark brown are crude oil. The direction of fluid displacement is from left to right. This note applies to all pictures in the full text.

The CO_2 immiscible oil displacement line direction is uniform, and the oil displacement is thorough. The main types of residual oil are small clusters and blind hole (Fig. 5).

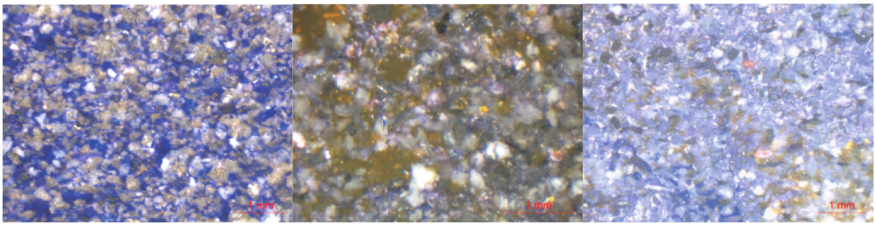

Fig. 5. Local horizon map of CO_2 immiscible oil displacement experiment (Saturated for Water → Saturated for Oil→ Flooding End)

When CO_2 is miscible/nearly miscible with crude oil, the seepage speed of fluid in pore throat is slow, and the two contacts fully, most of CO_2 is pale yellow, the type of residual oil in the small throat is mainly oil film, and there is almost no residual oil in local pore throat (Fig. 6).

It is generally believed that using CO_2 as oil displacement agent can improve oil displacement effect very well.

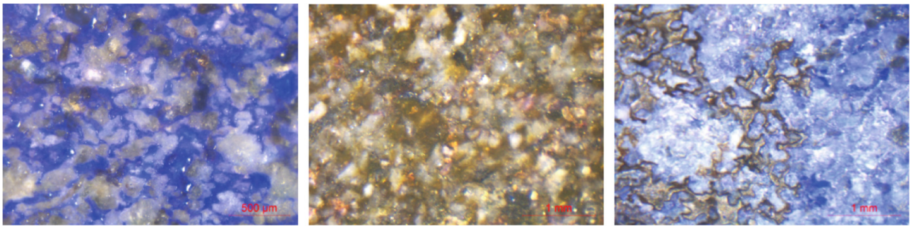

Fig. 6. Local horizon map of CO_2 miscible oil displacement experiment (Saturated for Water → Saturated for Oil→ Flooding End)

2.2 Alternate Flooding Experiments

Firstly, the water flooding experiment, when the rock is only residual oil, injection of CO_2, after the completion of CO_2 immiscible flooding, the main types of residual oil are cluster and blind end, and the effect of oil displacement is improved by gas injection (Fig. 7).

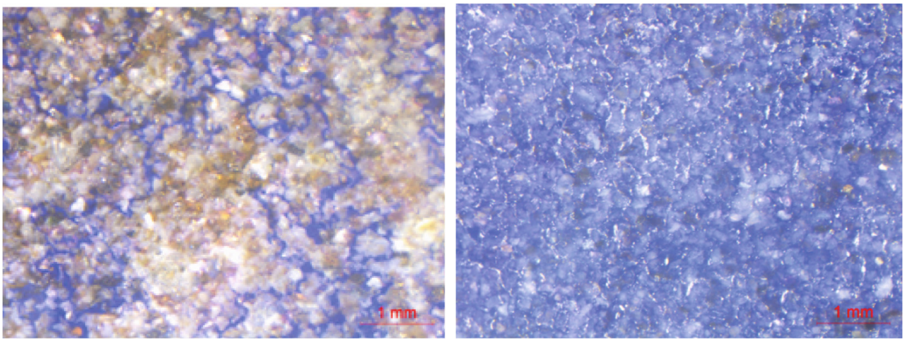

Fig. 7. Local horizon map of flooding end (water flooding end→CO_2 immiscible oil displacement end)

Firstly, the water flooding experiment, when the rock is only residual oil, injection of CO_2, after the completion of CO_2 miscible flooding. Because water flooding has displaced most of the crude oil in pore throat, it is difficult for CO_2 gas to miscible with crude oil. After the miscible flooding of CO_2, the residual oil type is mainly oil film (Fig. 8).

Firstly, the CO_2 immiscible flooding experiment is carried out, when only residual oil exists in the core, injection of water. Because CO_2 gas has the characteristics of high diffusion coefficient, easy compression and low viscosity, it is difficult for CO_2 gas to “continuously” distribute in reservoir pore throat, resulting in local residual oil enrichment. After water injection, the injected water can not only squeeze the CO_2 into smaller pore throats to displace crude oil, but also displace the island-like residual oil in the large pore channels, thus improving the oil displacement effect (Fig. 9).

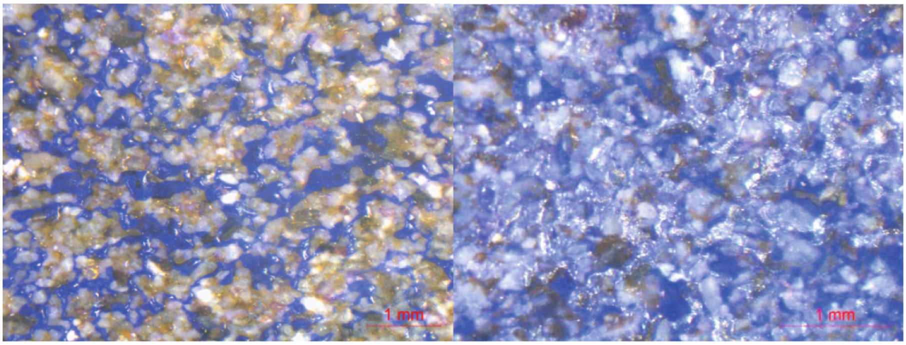

Fig. 8. Local horizon map of flooding end (water flooding end→CO_2 miscible oil displacement end)

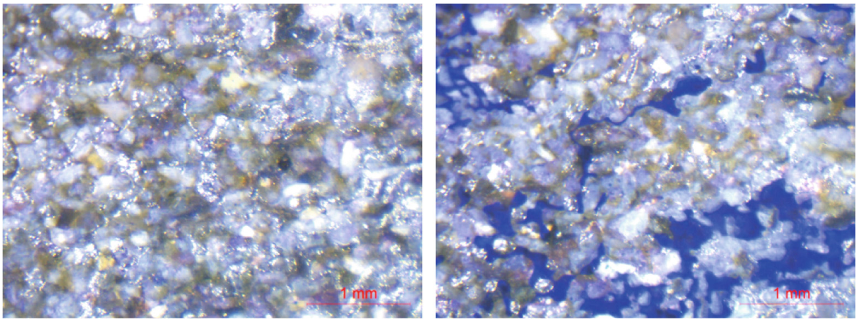

Fig. 9. Local horizon map of flooding end (CO_2 immiscible oil displacement end → water flooding end)

Firstly, the CO_2 miscible flooding experiment is carried out, when only residual oil exists in the core, injection of water. The injected water is interacted by various fluids in the pore throat. Flow and fingering phenomenon are easy to occur. Injected water can displace some of the remaining oil which was not affected in the early stage of CO_2 immiscible flooding and improve micro-displacement efficiency. The type of residual oil is blind end and small cluster (Fig. 10).

2.3 Statistics of Oil Displacement Efficiency

Statistics of displacement efficiency of different displacement modes show that compared with water flooding, the other displacement modes have higher displacement efficiency, which shows that CO_2 flooding has a strong advantage in improving displacement efficiency in ultra-low permeability reservoirs [6, 7] (Fig. 11).

In two groups of experiments of water flooding to CO_2 flooding, the average displacement efficiency after water flooding is 48.1% and 44.9%, the displacement efficiency of CO_2 immiscible/miscible flooding is 60.3% and 67.5%, oil displacement

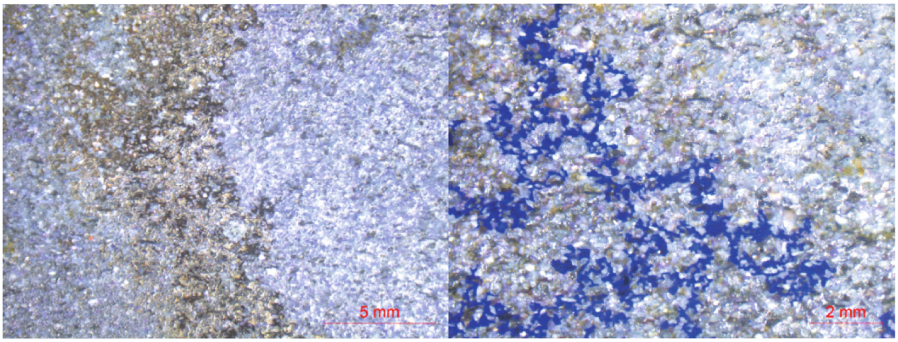

Fig. 10. Local horizon map of flooding end (CO_2 miscible oil displacement end → water flooding end)

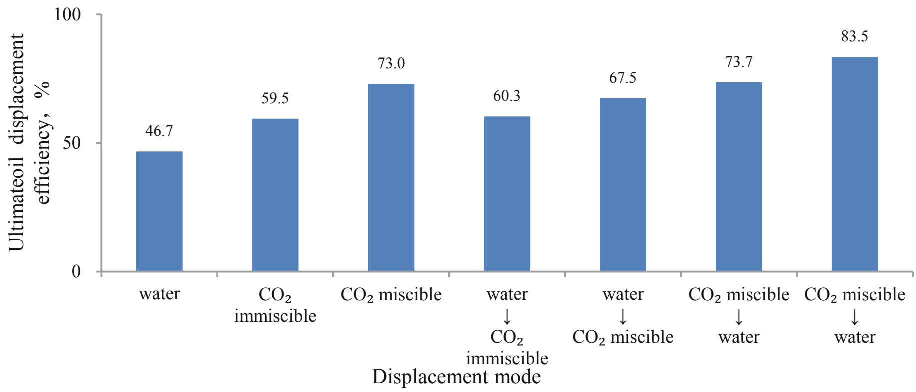

Fig. 11. Contrast Diagram of Oil Displacement Efficiency of Different Displacement Modes

efficiency increased by 12.2% and 22.5%. It is considered that the CO_2 miscible flooding after water flooding can greatly improve the oil displacement effect of reservoirs (Fig. 12).

In two groups of experiments of CO_2 flooding to water flooding, the average displacement efficiency after CO_2 immiscible/miscible is 57.6% and 76.1%, after water flooding, the average oil displacement efficiency is 73.7% and 83.5%, oil displacement efficiency increased by 16.0% and 7.3%. The displacement mode of water flooding after CO_2 miscible flooding is a reasonable way to improve oil displacement efficiency in extra low permeability reservoirs (Fig. 13).

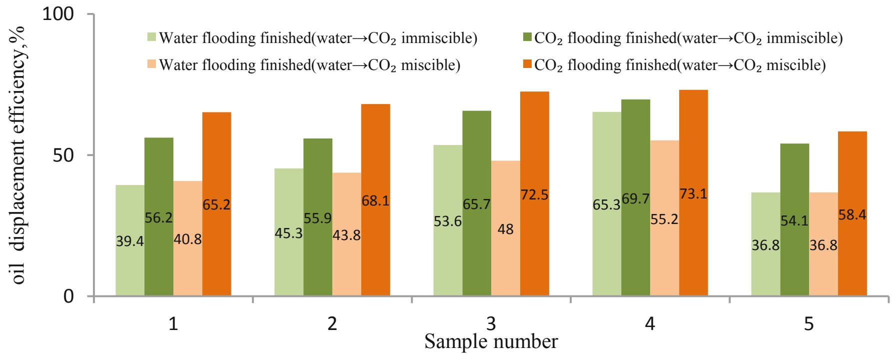

Fig. 12. Statistical Chart of Oil Displacement Efficiency (water flooding→CO_2 flooding)

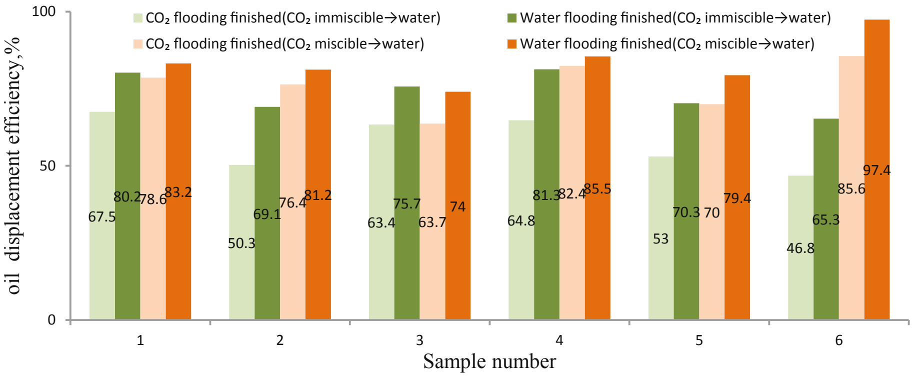

Fig. 13. Statistical Chart of Oil Displacement Efficiency (CO_2 flooding →water flooding)

3 Conclusion

On the premise of fully considering the difference of samples, through the analysis and summary of the experimental results, the important understanding that can provide guidance for mineral experiment is obtained: Different displacement modes lead to different swept area of the corresponding displacement agent and the occurrence state of residual oil, which leads to different micro-displacement efficiency. Compared with water flooding, CO_2 flooding can greatly improve micro-displacement efficiency. In the alternative displacement mode, the conversion of CO_2 miscible flooding after water flooding can greatly improve the oil displacement effect of reservoir. For the water flooding after CO_2 flooding, the injection water can greatly increase the sweep area and improve the micro-displacement efficiency of reservoir.

Acknowledgments. The project is supported by Major National Science and Technology Projects—Large Oil and Gas Field and Coalbed Methane Development (2016ZX05016-003).

References

1. Du, J., Chen, J., Li, Q., et al.: Experimental study on micro-displacement oil for different CO_2 displacement mechanism. J. Southwest Petrol. Univ. Sci. Technol. Ed. **34**(6), 131–135 (2012)
2. Hao, Y.-M., Wei, X.-L., Dong, C.-S.: Research on the microscopic distribution characteristics and storage capacity of CO_2 with different displacement methods. Nat. Gas Geosci. **28**(6), 846–851 (2017)
3. Li, N., Tian, J., Tan, X., et al.: Microscopic sweeping characteristics of CO_2 flooding in low permeability reservoirs. Fault-Block Oil Gas Field **22**(2), 237–239 (2015)
4. Lü, C., Wang, R., Cui, M., et al.: Displacement experiment of CO_2 miscible flooding under high water condition. Acta Petrolei Sinica **38**(11), 1393–1398 (2017)
5. Wang, M., Du, L., Nie, F., et al.: Microscopic visualization simulation of CO_2/water alternating flooding. Sci. Technol. Rev. **32**(36), 80–85 (2014)
6. Hu, W., Lü, C., Wang, R., et al.: Mechanism of CO_2 immiscible flooding and distribution of remaining oil in water drive oil reservoir. Petrol. Geol. Recovery Effi. **24**(5), 99–105 (2017)
7. Cui, M., Wang, R., Lü, C., et al.: Research on microcosmic oil displacement mechanism of CO_2 flooding in extra-high water cut reservoirs. J. China Univ. Petrol. **42**(1), 119–125 (2018)