Measurement of CO₂-crude oil minimum miscible pressure in YC Oilfield by core displacement method

Li Liu¹*, Jinxin Liu¹, Yanfu Pi¹, Xuan Guo², Zhipeng Dai³, Zhihao Li¹

¹ Key Laboratory of Enhancing Oil and Gas Recovery of Ministry of Education, Northeast Petroleum University, Heilongjiang, Daqing163318, China
² China United Coalbed Methane Co, Ltd. Taiyuan030000, China
³ Sinopec Jiangsu Oilfield Petroleum Engineering Technology Research Institute 4.

*Corresponding author’s e-mail: liuliduoduo@nepu.edu.cn

Abstract: Aiming at the defect of measuring the CO₂-crude oil MMP(minimum miscible pressure) by the slim tube test, the core displacement method is established based on indoor physical simulation and homogeneous rectangular core in the low permeability block of YC oilfield. For comparison, the MMP is measured by the slim tube test in the same block. Experimental results show that the method has good repeatability and can simulate porous media and reservoir water content, which is more consistent with the actual reservoir conditions. The MMP in the target block of YC oilfield was 19.85MPa, which was 1.87MPa lower than that measured by traditional slim tube test.

1. Introduction
Whether CO₂ can be miscible with crude oil in the process of oil displacement directly affects the oil displacement effect and the oil recovery [1-3]. Therefore, it is necessary to accurately measure the MMP that determines the miscibility of CO₂ and crude oil. There is a gap between the current slim tube test and the actual reservoir conditions [4-6]. On the one hand, the porosity and permeability parameters are much higher than the actual reservoir due to the lack of cementation of the filling material [7-9]. On the other hand, the formation water is not saturated in the actual reservoir simulated by the slim tube test. In view of the above defects, this paper established a core displacement method to measure the MMP, and the results are of great significance for the formulation of CO₂ miscible displacement development plan.

2. Experiments

2.1 Materials
(1)Simulation oil is composed of crude oil of YC oilfield and aviation kerosene in a certain proportion. At reservoir temperature, the viscosity is 9.8mPa·s.
(2)About 200 mesh fine tubes of pure quartz sand are filled inside. The specific parameters are shown in the Table 1.
Table 1 Related physical parameters of slim tube

| Parameter          | Value |
|--------------------|-------|
| Length (m)         | 13.3  |
| Inner diameter (mm)| 4     |
| Permeability (mD)  | 6000  |
| Pore volume (mL)   | 62.4  |
| Porosity (%)       | 37.35 |
| Oil saturation (%) | 76.92 |

(3) CO₂ (the purity of 99%), sewage, Seven artificial cores with similar porosity and permeability parameters.

2.2 Experimental apparatus
Vacuum pump, pressure gauge, thermostat, container, back pressure valve, ISCO pump, Steel pipeline, valves etc.

![Test device connection of core displacement](image)

2.3 Experimental principle
(1) The slim tube test
Under the porous medium of the slim tube model, experiments are carried out by changing different displacement pressures to record the oil displacement efficiency. With the increase of injection pressure, CO₂ would gradually dissolve in the crude oil, resulting in the volume expansion and the decrease of the viscosity of the crude oil. When the injection pressure reaches a certain value, CO₂ and crude oil reach miscible state, and there is little change in the oil recovery with increased pressure. Draw the relationship curve between oil and recovery rate under different displacement pressures, and the pressure corresponding to the inflection point of the curve is the CO₂–crude oil MMP [9-12].

(2) The core displacement method
Several cores with similar porosity and permeability parameters were selected to carry out CO₂ core displacement experiment after saturated with formation water and oil. The minimum miscible pressure is determined by 7 pressure point. When the pressure increases, no longer increases as oil recovery. The relationship between each displacement pressure and oil recovery is plotted, and the intersection of immiscible and miscible curves is the minimum miscible pressure. So the minimum miscible pressure is obtained.

3. Experimental results and analysis
Seven injection pressures (5MPa, 10MPa, 15MPa, 20MPa, 25MPa, 27MPa and 30MPa) were selected for the slim tube test. The method of successive approximation to the minimum miscible pressure was adopted for CO₂ displacement. During the experiment, each injection pressure was recorded, and the relationship diagram between each injection pressure and corresponding final oil recovery was drawn (Fig. 2). The intersection point of immiscibility stage and miscibility stage was the CO₂–crude oil MMP measured in the slim tube test.
As can be seen from Figure 2, when the displacement pressure was before 21.72 MPa, the oil recovery increased linearly with the increase of injection pressure, which was in the CO₂ immiscible flooding stage. With the increase of injection pressure, the amount of CO₂ dissolved per unit volume of crude oil increased, so the oil recovery increased rapidly. When the injection pressure exceeded 21.72 MPa, the oil recovery did not increase significantly. As CO₂ and crude oil reach miscible state, interfacial tension disappears and seepage resistance minimizes. As the pressure increases, the amount of dissolved CO₂ per unit volume is smaller than that in immiscible flooding stage, so the enhanced oil recovery amplitude decreases. According to the results of thin tube experiment and miscibility criteria, the minimum miscibility pressure can be determined as 21.72 MPa by intersecting the curves of miscibility flooding stage and immiscibility flooding stage.

In the experiment, artificial cores were used for CO₂ displacement experiment. The displacement pressures were 5 MPa, 10 MPa, 15 MPa, 18 MPa, 20 MPa, 25 MPa, 27 MPa and 30 MPa, respectively. The experimental results are shown in Figure 3. As can be seen from Fig. 3, the curve of the relationship between oil recovery and displacement pressure presents a mutation turning point when the pressure is equal to 19.85 MPa. When the displacement pressure is less than 19.85 MPa, the oil recovery increases with the increase of displacement pressure. This stage is in the CO₂ immiscible flooding stage, and the recovery factor is relatively low. The oil recovery is very high, and this stage is CO₂ miscible flooding stage. When the displacement pressure continues to increase, the oil recovery only increases slightly and the curve tends to be gentle. According to the core displacement experimental results and miscible judgment criteria, the minimum miscible pressure measured in the core displacement experiment is 19.85 MPa.

4. Conclusion
A core displacement method for determining the minimum miscible pressure of CO₂-crude oil is...
established. The results show that the minimum miscible pressure of low permeability core measured by core displacement method (19.85 MPa) is 1.87MPa lower than that measured by thin tube experiment (21.72 MPa).

Acknowledgments

This work was supported by the National Natural Foundation of China (Project No. 51704075), and the Natural Science Foundation of Heilongjiang Province of China (Project No. E2018013)

References

[1] Wang Qian, Yang Shenglai, Bai Jie, et al. (2010) Effect of pore-throat structure on petrophysical properties of reservoir during CO2 flooding. Acta Petrolei Sinica, 42(05):654-668.
[2] Kuang Nianjie, Yang Shenglai, Wang Mengyu, et al. (2021) Methods for promoting miscibility of carbon dioxide and crude oil and their application. Journal of Guangdong Institute of Petrochemical Technology, 31(01):19-23.
[3] Liu Li, Wan Xue, Yang Kun, et al. (2021) Screening and performance evaluation of CO2 foam system in low permeability reservoir. Journal of Petrochemical Universities, 29(04):62-71.
[4] Zhou Feng, Gao Wei, Li Xiao Ming, et al. (2021) Mass concentration distribution of CO2 miscible flooding in two-dimensional porous media. Fault-block oil & gas field, 28(01):120-123+128.
[5] Tian Wei. (2020) Discussion on miscibility and miscibility flooding of CO2/crude oil. Report of science and technology, 36(12):8-18.
[6] Chi Jie. (2020) Analytical method of limiting well Spacing and oil displacement characteristics in CO2 miscible flooding. Journal of Northwest University (Natural Science Edition), 50(06):996-1004.
[7] Han Bo, Ren Shaoran, Li Wei, et al. (2020) Study on minimum miscible pressure and its dynamic change in CO2 flooding. Unconventional oil and gas, 7(02):75-82.
[8] Li Chenglong, Chi Bo. (2020) Establishment and application of a new carbon dioxide flooding characteristic curve. Special Oil & Gas Reservoirs, 27(02):98-102.
[9] Zhang Hailong. (2020) Practice and understanding of enhanced oil recovery by CO2 miscible flooding. Petroleum Geology & Oilfield Development in Daqing, 39(02):114-119.
[10] Chen Zhihao, Hao Yongmao, Ji Yingchun et al. (2020) Formation mechanism and characterization method of CO2-crude oil miscible zone [J]. Petroleum Geology and Recovery Efficiency, 2020, 27(01):57-61.
[11] Liu Li, Ma Yingxue, Pi Yanfu, et al. (2020) Effect of CO2 flooding on rock properties under different salinity of formation water. Oilfield Chemistry, 37(04):665-690.
[12] Liu Li, Song Kaoping, Wang Yu, et al. (2014) Study on P-V Characteristics of CO2-foam system at high temperature. Science Technology and Engineering, 14(30):135-139.