Tree 101 block CO₂ Minimum miscibility pressure slim tube test

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Abstract: Determining the minimum miscibility pressure is the main research content of CO₂ mixed phase displacement. It is a key indicator of whether the formation fluid can reach the miscible phase. There are many ways to determine the minimum miscibility pressure. At present, the laboratory test measures the minimum miscibility pressure of CO₂-crude oil. The accepted industry standard is the slim tube test. This paper is aimed at the reservoir profile of Tree 101 block in Yushulin Oilfield. Carry out a slim tube test to determine the minimum miscibility pressure of 32.43MPa.

1. Introduction

The Block 101 of Yushulin Oilfield in the periphery of Daqing belongs to the ultra-low permeability reservoir. Most unutilized reserves have lower oil permeability. Most cracks are not developed. Water flooding development methods are difficult to use economically and effectively. Effective use of difficult-to-recover reserves, improvement of water flooding development in developed blocks, and improvement of oil recovery are urgent problems to be solved. CO₂ miscible flooding is an effective method to improve oil recovery in low permeability reservoirs. In the application of CO₂ miscible flooding, the determination of minimum miscibility pressure (MMP) is very important. At present, the laboratory test measures the minimum miscibility pressure of CO₂-crude oil. The accepted industry standard is the slim tube test.

Slim tube is the key equipment for measuring MMP in slim tube test. Slim tubes are generally 10m-30m long. Usually bent into a disk shape filled with fine sand. The purpose of using sand-filled straws is to approximate the state of porous media in reservoir rocks. In order to provide a medium for the mixing and multiple contact of the injected gas and the crude oil during the flow process. However, since the sand-filled tubules cannot be equated with the stratigraphic core, experimental data such as ultimate recovery, sweep coefficient, and transition zone length cannot be equated with actual oilfield indicators.

In order to satisfy the oil layer model with sufficient length and small enough diameter, sand filled stainless steel is used as the oil layer model. The purpose of using sand-filled tubules is not to simulate reservoir rocks, but to provide a medium for mixing and multiple contact of gas and crude oil during the flow process. The length of the pipe is generally 12-40m, the diameter is only 6.3-12.7mm, and the
filled sand is generally 160-200 mesh. The saturated oil before the experiment.

2. Experimental principle

For a given formation of crude oil and reservoir temperature, the displacement pressure and the composition of the injected gas components are the main factors affecting the miscible phase. Under the condition of porous media provided by the slim tube model, the oil displacement efficiency, gas-oil ratio and injection pore volume, and relation curve between oil displacement efficiency and displacement pressure (or note the composition of popular components) were obtained by a set of experiments that changed the displacement pressure. The pressure (or component composition) corresponding to the curve inflection point is the lowest miscibility pressure.

3. Slim tube test

3.1 Experimental condition

1) Experimental temperature: 90 ℃;
2) Experimental oil: The crude oil used in the experiment is Daqing Yushulin Oilfield Tree 101 containing natural gas simulated crude oil. The viscosity of crude oil at 90 ℃ is 3.6 mPa·s.
3) Experimental Materials: White oil (displacement medium), CO2 (purity 99%), Slim tube (Curved into a disk-shaped stainless steel tube, the inside of the slim tube is filled with pure quartz sand of about 200 mesh) Specific parameters are shown in Table 1.

| Table 1 | Experimental tube data sheet |
|---------|-----------------------------|
| length (m) | inside diameter (mm) | gas permeability (mD) | pore volume (mL) | porosity (%) | oil saturation (%) |
| 13.3 | 4 | 6000 | 62.4 | 37.35 | 76.92 |
4) Experiment apparatus: ISCO pump, back pressure valve, incubator, CO2 gas cylinder, slim tube model, vacuum pump, piston container, six-way, pressure gauge, test tube, steel pipe, valve, etc.

3.2 Experiment procedure

1) Experimental preparation: Thoroughly clean the tubules with petroleum ether before the experiment. When the color of the petroleum ether at the outlet end becomes clear and transparent during the cleaning process, it indicates that the washing reaches the requirements. After the rinsing is completed, the thin tube is blown dry with a suitable pressurized nitrogen gas, and then the slim tube placed in the incubator is dried for 6 hours.
2) Test air tightness: Connect the slim tube and other experimental lines, and check the tightness of the slim tube and the intermediate container with high pressure nitrogen (1 hour). The pressure drop does not exceed 0.15 MPa, and the air tightness is considered to be good.
3) Vacuum: After connecting the slim tube to the vacuum pump, evacuate the vacuum for more than 12 hours.
4) Measuring pore volume: Fill the toluene with a displacement pump and flush to the tubing inlet valve line, increase the pressure to the desired experimental pressure, and record the initial pump reading at that pressure. Then open the slim tube inlet valve, inject toluene, pressurize to the same experimental pressure, and after the pressure is fully stabilized, record the reading of the pump at this time. The difference in pump volume reading is corrected to be the pore volume of the capillary model. A similar method is used to determine the volume between the outlet valve and the back pressure valve of the slim tube model, and the sum of the volume of the slim tube model is the total pore volume of the slim tube model.
5) Saturated oil: Select the test pressure (P1 is higher than the formation pressure). At the experimental pressure and the experimental temperature, open the inlet end of the slim tube experiment and replace the toluene in the slim tube with the crude oil sample. And take oil and gas samples to analyze their composition. If the composition and gas-oil ratio of the produced sample are consistent with the formation crude oil sample, stop the displacement.
6) Gas preparation: Connect the experimental equipment as shown in Figure 1. First press the gas
of the CO2 cylinder into the two piston containers of 2 and 3, and then drive the white oil in the piston container 1 through the ISCO pump A. The CO2 gas in 2 is compressed into the piston container 3. After the displacement is completed, the CO2 pressure in the piston container 3 is recorded, and the piston container 3 valve is closed. Then open the six-way valve connecting the CO2 cylinder, press the CO2 into the piston container 2, and press the white oil at the bottom of the piston container back to the piston container 1. When the pressure in the piston container 2 is equal to the pressure of the carbon dioxide cylinder, the CO2 cylinder valve is closed. Continue to drive the white oil of the piston container 1 through the ISCO pump A, compressing the CO2 pressure in the 2-piston container to a higher pressure than in the piston container 3. Then open the valve of the piston container 3 and continue to pressurize the piston container 3. Repeat the above steps until the experimental pressure is reached.

7) CO2 displacement: Figure 1 connected experimental device diagram. Set back pressure by hand pump. The back pressure is lower than the injection pressure of 2 MPa. The injection pressure is adjusted to the experimental pressure, and inject CO2 at a rate of 0.2 ml/min. Inject 0.1PV~0.2PV to record the amount of oil produced once. Try to increase the data collection density after the gas breakthrough, when the cumulative pumping exceeds 1.2PV or no longer discharges the oil to stop the displacement.

8) After the displacement stops, the CO2 in the experimental pipeline is discharged, the slim tubes are disconnected and the experimental pipeline is connected, and the slim tubes and related accessories are cleaned and dried. Subsequently, the above steps are repeated to measure the pressure tube P2, P3, P4, P5, P6, and the tube displacement experiment.

9) Data processing: Recovery factor

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\text{Recovery factor} = \frac{\text{Produce crude oil volume} \times \text{Volume factor}}{\text{Saturated crude oil volume}} \times 100\%
\]

At least three or more test pressure points in the mixed phase and non-mixed phase. Draw a graph of each displacement pressure and oil displacement efficiency. The pressure corresponding to the intersection of the immiscible phase and the miscible curve is defined as the lowest miscible pressure point of carbon dioxide-crude oil.

![Figure 1](image)

**Figure 1** Connection diagram of the slim tube experimental device

Piston container 1-white oil; piston container 2-CO2 pressurized intermediate container; piston container 3-CO2 injection container

3.3 Experimental data and analysis

There are 7 pressure points in the experiment, which are 15MPa, 20 MPa, 25 MPa, 30 MPa, 35 MPa, 40 MPa. The experimental data is shown in Table 2 and Figure 2.
| displacement pressure (MPa) | 15  | 20  | 25  | 30  | 35  | 40  |
|---------------------------|-----|-----|-----|-----|-----|-----|
| 1.2PV recovery factor %   | 52.10 | 66.75 | 75.06 | 84.30 | 90.33 | 90.67 |

Figure 2 Relationship between experimental pressure and recovery factor of slim tube

It can be seen from Fig. 2 that the cumulative recovery factor increases linearly with the increase of injection pressure before 30 MPa, and this process is the CO2 immiscible phase drive stage. In the non-miscible flooding stage, the oil displacement mechanism of CO2 is mainly caused by CO2 dissolving in crude oil to expand the volume of crude oil and reduce the viscosity of crude oil, thereby increasing the fluidity of crude oil and enhancing oil recovery. The solubility of CO2 in crude oil increases with the increase of injection pressure, so the higher the injection pressure, the higher the recovery rate. When the injection pressure exceeds the miscible pressure, the injection pressure is increased, and the oil displacement efficiency is not significantly increased. After reaching the miscible flooding, the interfacial tension between CO2 and crude oil tends to zero, the capillary number becomes infinite, and the theoretical oil displacement efficiency reaches the highest. The intersection of the immiscible flooding phase and the miscible flooding phase curve is obtained, and the MMP of the tree 101 block is 32.43 MPa.

4. Conclusions
1. In the non-miscible flooding stage, as the injection pressure increases, the cumulative recovery increases linearly.
2. The main mechanism of CO2 flooding enhanced oil recovery is mixed phase effect, reducing interfacial tension, improving crude oil properties and enhancing seepage capacity. The minimum miscibility pressure of the block 101 is 32.43 MPa.

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References
[1] Kaoping Song, Xiaoyu Tian, J. Zhang & C.Guan, Remaining oil distribution rule after polymer flooding in Daqing oilfield,Underground Storage of CO2 and Energy CRC Press Taylor & Francis
Group an informa business(www.crcpress.com), pp.333-337. (Accession number: 20123215325203)

[2] Hu Wenrui, China Petroleum Enterprise Association. Current Status and Future of Low Permeability Oil and Gas in China[J]. 2009 China Low Permeability (Dense) Oil and Gas Exploration and Development Technology Seminar. 2013, 11(8): 29-37.

[3] Bai Mingxing; Sun Jianpeng; Song Kaoping. Risk assessment of abandoned wells affected by CO2, Environmental Earth Sciences, JUN 2015, 11:6827-6837.

[4] Shen Pingping, Liao Xinwei. Technology of carbon dioxide geological storage and enhanced oil recovery[M]. Beijing: Petroleum Industry Press, 2009.

[5] Mingxing Bai; Jianpeng Sun; Kaoping Song; Lili Li; Zhi Qiao. Well completion and integrity evaluation for CO2 injection wells, Renewable and Sustainable Energy Reviews, 2015, 5, (45): 556-564.

[6] Yang Yongzhi, Shen Pingping, Zhang Yunhai, et al. China CO2 enhanced oil recovery and geological storage technology research [J]. Daqing Petroleum Geology and Development, 2009, 28(6): 262-267.

[7] Zhou Dengen, Yan Meisong, Calvin W M. Optimization of a Mature CO2 Flood: from Continuous Injection to WAG[J]. SPE 154181, 2012.

[8] Mingxing Bai; Jianpeng Sun; Kaoping Song; Kurt M. Reinicke; Catalin Teodoriu, Evaluation of mechanical well integrity during CO2 underground storage, Environmental Earth Sciences, 2015, 6, 73(11): 6815-6825.

[9] Bai Mingxing; Song Kaoping; Li Yang; Sun Jianpeng; Reinicke Kurt M., Development of a novel method to evaluate well integrity during CO2 underground storage, Source: SPE Journal, v 20, n 3, p 628-641, June 1, 2015.

[10] Bai Mingxing; Sun Jianpeng; Song Kaoping; Reinicke Kurt M.; Teodoriu Catalin, Risk assessment of abandoned wells affected by CO2, Source: Environmental Earth Sciences, v 73, n 11, p 6827-6837, February 18, 2015.