Determination of minimum miscible pressure in CO2-crude oil system of Changqing Oilfield

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Abstract. Carbon dioxide miscible flooding in low permeability sandstone reservoir can greatly enhance the recovery, the minimum miscible pressure (MMP) is the starting point of miscible flooding. Its determination is very important for oilfield development. In this paper, the internationally widely accepted thin tube experiment method and the bubble riser method are used to compare the minimum miscible pressure. Research results show that the minimum miscibility pressure obtained by slender tube displacement experiment is 22.12 MPa. The minimum miscible pressure measured by the bubbler method is 32.33 MPa, and the error result is large.

1. Introduction
There are many methods for determining the minimum miscibility pressure of CO2-crude oil system. In this paper, the minimum miscible pressure of Changqing oil field is determined by the long thin tube displacement experiment method, and compared with the results of the widely used bubbler method to determine the minimum miscible pressure of Changqing oil field.

2. Determination of Minimum Miscibility Pressure by slender tube displacement experiment

2.1 Equipment and device diagram for experiment
(1) ISCO advection pump;
2 (2) SG-83-1 twin self-control incubator; 
(3) Direct high speed rotary vane vacuum pump; 
(4) Carbon dioxide cylinder; 
(5) Slim tube; 
(6) Hand pump; 
(7) Piston containers filled with 500 mL white oil and two empty piston containers; 
(8) A number of back pressure control valves, pressure gauges and 6-way valves; 
(9) Electronic balance; 
The experimental set-up diagram connection is shown in Figure 1 below:

![Figure 1](image)

piston container 1-white oil, piston container 2- CO2 add pressure middle container, piston container 3-CO2 Injection container 

2.2 Experimental procedure
(1) Experimental preparation: cleaning test tubes with petroleum ether, after the washing is completed, the slim tube is blown dry with a suitable pressurized nitrogen gas. The tubes are then placed in an incubator for drying.

(2) Measuring pore volume: vacuum pumping, connect the slim tube to the vacuum pump, vacuum pumping for more than 12h, saturated distilled water, calculate the porosity of the slim tube.

(3) Saturated oil: Inject 1.5PV of analog oil into the slim tube through the piston container using ISCO constant speed and pressure pump. Calculation of oil saturation based on injection rate and liquid production.

(4) CO2 displacement: Connect the experimental equipment as shown in Figure 1. Set back pressure by hand pump. When no oil is produced, the displacement is stopped and the experimental data are recorded. After the experiment is stopped, clean the correlation instruments, repeat the above steps, and carry out the next pressure displacement experiment.

(5) Data handling: There are at least three test pressure points in the miscible and immiscible phases. Draw a graph of each displacement pressure and displacement efficiency. The pressure corresponding to the intersection point of immiscible and the miscible phase curve is the lowest miscibility pressure point of carbon dioxide-crude oil.

2.3 Laboratory findings
As shown in Figure 2, the relationship between experimental pressure and crude oil recovery degree determines that the minimum miscibility pressure of Yushulin 101 block is 22.12 MPa.
3. Prediction of minimum miscible pressure by bubbler

3.1 Experimental process of bubbler method

(1) Injecting pre-prepared distilled water into the high pressure vessel and the transparent tube;

(2) The crude oil is injected into the transparent pipe to displace the residual distilled water in the pipeline. When the lower part of the transparent tube is full of crude oil, and the liquid level of the distilled water is slightly higher than the needle 12 cm, the displacement is stopped;

(3) A bubble is created in the water below the transparent tube. Observing the shape change and motion of the bubble as it rises through the oil column, and taking a picture with a micro camera to process a set of photos of the process;

(4) After two or three bubbles pass through the oil column, the distilled water is injected into the pipeline to discharge the residual crude oil in the transparent tube;

(5) Flush the transparent tube with the solvent in the container; Water is then injected into the pipeline to displace the residual solvent and discharged into the waste collection tank; Finally, a fresh crude oil sample is injected into the container for the next measurement.

3.2 Determination of minimum miscibility pressure

(1) Determine the minimum miscibility pressure based on the bubble shape

Under different pressure conditions, the change of bubbles in the process of rising is not the same. Through the visual observation during the experiment and the dynamic photos of the bubbles taken with the camera, we can determine the minimum miscibility pressure of the gas-oil system at constant temperature. In this process, the dynamic changes of the bubbles may be large, and can be roughly divided into three types:

i When the pressure is far less than the minimum miscible pressure. As the gas migrates to the oil phase, the volume of the gradually rising bubbles gradually becomes smaller, but a clear outline and shape can still be observed. The upper part is closer to the sphere and the bottom is flat, and the shape is like a bullet. After a long period of contact, the bubbles shrink and eventually become almost invisible, but the shape does not change significantly, as shown in A of Figure 3 below. This situation can be divided into two types.
Figure 3 Shape characteristics of bubbles rising in oil at different pressures

① When the experimental pressure is less than the saturation pressure of the system.

The shape of the bubble as it rises through the oil column is still approximately spherical. Due to the mass transfer between gas and oil, the bubbles will gradually become smaller, but they will not disappear completely. When the pressure gradually approaches the minimum miscibility pressure, the shape of the top of the bubble does not change, and the bottom of the bubble may flatten or appear a wave.

② When the experimental pressure is greater than the saturation pressure of the system.

The change in the bubble is similar to the condition described in ①. But the difference is, after rising to a certain distance, the bubble volume gradually became smaller and eventually disappeared completely. This is more common when the gas is hydrocarbon. This is because when the system pressure is greater than the saturation pressure, the mass transfer between gas and crude oil is shown as the dissolution of gas in crude oil, which corresponds to the formation of miscible phase in the displacement process. Therefore, in the experiment, we should always pay attention to the way of bubble disappearance, so as to judge whether the mixture is achieved or not, rather than judge whether the bubble disappears as the basis.

ii When the pressure is equal to or slightly greater than the minimum miscible pressure, in the beginning, the bubble still kept bullet like contact with the crude oil. But in the subsequent rising process, it will quickly diffuse and dissolve into the crude oil and disappear. During the ascent, the shape of the bottom of the flat gas-oil interface is abrupt, and a tail shape appears, as shown by in Figure 3,B. This variation of the bubble indicates that the process is a multiple-contact miscible process rather than a single-contact miscible process.

iii When the pressure is much greater than the minimum miscible pressure. When the bubble contacts with the crude oil, the bottom shape changes abruptly, forming a tail shape rapidly and spreading continuously, as shown in Figure 3, C. This is a contact mixing process.

(2) Determine the minimum miscibility pressure based on the distance the bubble moves

In general, When the pressure is less than the minimum miscible pressure. The gas in the bubble is constantly in contact with the crude oil, and some of it is dissolved in the crude oil. At this time, the bubble slowly contracts, the volume becomes small, and the moving distance is relatively long. When the pressure is greater than the minimum miscible pressure, after the bubble contacts the crude oil, they will rapidly diffuse into the crude oil. At this time, the bubble volume becomes larger and the moving distance is relatively shorter. Therefore, it is a good strategy to measure the minimum miscible
pressure with the distance of bubble movement. The final measured minimum miscible pressure is 32.33 MPa.

4. Conclusion
The minimum miscible pressure is 22.12 MPa determined by the thin tube experiment, while the minimum miscible pressure measured by the bubbler method is 32.33 MPa, with a relative error of 46.15%. Although the bubbler method has the advantages of short experimental period, low requirements for experimental instruments and low cost, it is influenced by subjective factors, lack of quantitative analysis results and low measurement accuracy.

Acknowledgement
Project funded by National Natural Science Foundation of China (Grant No.: 51704075), and Heilongjiang Natural Science Foundation of China (Grant No.: E2018013).

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