Influence of permeability on the minimum miscibility pressure between CO₂ and crude oil

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Abstract: The slim tube test is the industry standard for measuring the minimum miscibility pressure at present. However, there is a huge gap between the pore parameters of the slim tube model and the actual reservoir, especially the influence of permeability on MMP is not considered. The previous studies have shown that the minimum miscibility pressure is related to the pore structure and permeability of the reservoir. It is believed that there are some theoretical defects in the MMP measured by the slim tube test. This paper aims at the defect of slim tube test, core displacement experiment is carried out by using natural core to measure the minimum miscibility pressure under different permeability, and to reveal the law of the influence of permeability on the minimum miscibility pressure.

1. Introduction

At present, there are two types of methods for determining the minimum miscibility pressure (MMP): theoretical calculation method [1,10] and experimental measurement method. However, the theoretical calculation method has large errors, the indoor experimental method of determining MMP is more accurate. Among all of them, the slim tube test method is the most widely used at present. However, the permeability of the slim tube model are about several thousand mD, which is much higher than that of the actual reservoirs, and the known studies [11,12] have suggested that there are certain theoretical defects in MMP measured by slim tube experiments. Therefore, this paper chooses core displacement method as the experimental testing method [13,14].

2. Experimental principle

Stalkup [15] defines miscibility pressure as: The ultimate recovery curve obtained through a series of displacement experiments, the pressure corresponding to the inflection point of the curve is the minimum miscibility pressure. Therefore, this paper chooses cores with different permeability to carry out carbon dioxide core displacement experiments at experimental temperature and pressure. Seven pressure points were selected and the minimum miscibility pressure was determined by successive approximation of the minimum miscibility pressure. When the displacement pressure is increased, the recovery factor is no longer increased and it is considered to reach the miscible phase. Draw a plot of each displacement pressure and recovery factor. The intersection of the non-mixed phase and the miscible curve is the MMP.

The core displacement method uses real cores for experiments and can saturate water, which can
fully represent the actual conditions of the actual reservoir. In this paper, the minimum miscible pressure under different permeability is measured through core displacement experiments with natural cores, and the influence of permeability on the minimum miscible pressure is analyzed.

![Figure 1](image)

**Figure 1.** Rock sample displacement experiment connection device diagram

### 3. Experimental condition

1) Experimental temperature: 45°C;
2) Experimental oil: a simulated oil obtained by mixing crude oil with an appropriate amount of kerosene, and having a viscosity of 9.8mPa·s at 45°C;
3) Experimental materials: Three natural cores with different permeability (length 30cm, diameter 2.5cm), See Table 1. white oil (displacement medium), CO2 (purity 99%);
4) Experimental equipment: ISCO pump, back pressure valve, incubator, CO2 cylinder, core holder, vacuum pump, piston container, six-way, pressure gauge, test tube, steel pipe, valve, etc.

### Table 1. Physical parameters of natural cores

| Sample  | Permeability ($\times 10^{-3}\mu m^2$) | Porosity (%) | Oil saturation (%) |
|---------|--------------------------------------|--------------|--------------------|
| Sample 1| 45                                   | 23.56        | 75.58              |
| Sample 2| 104                                  | 24.31        | 79.56              |
| Sample 3| 342                                  | 24.74        | 77.42              |

### 4. Experimental Results

Three kinds of natural cores with different permeability were used in the experiment for CO2 flooding experiments. The displacement pressures were 5MPa, 10MPa, 15MPa, 20MPa, 25MPa, 27MPa, 30MPa, respectively.

**Table 2.** Corresponding recovery rates of various permeability cores at various pressure points

| Displacement pressure (MPa) | Recovery ($45\times10^{-3}\mu m^2$) | Recovery ($104\times10^{-3}\mu m^2$) | Recovery ($342\times10^{-3}\mu m^2$) |
|-----------------------------|-------------------------------------|-------------------------------------|-------------------------------------|
| 5                           | 48.65                               | 53.03                               | 55.38                               |
| 10                          | 63.04                               | 66.38                               | 67.38                               |
| 15                          | 77.55                               | 76.25                               | 76.08                               |
| 20                          | 88.95                               | 87.52                               | 86.45                               |
| 25                          | 92.46                               | 90.85                               | 89.61                               |
| 27                          | 93.36                               | 91.32                               | 90.21                               |
| 30                          | 93.36                               | 91.32                               | 90.21                               |
Figure 2. Relationship between pressure and recovery

Figure 3. Relationship between core permeability and minimum miscibility pressure

As can be seen from Fig.2 to Fig.3, when the permeabilities are 45×10^{-3} \mu m^2, 104×10^{-3} \mu m^2 and 342×10^{-3} \mu m^2, those of the minimum miscibility pressures are 20.80 MPa, 21.26 MPa and 21.32 MPa.
We can see the increase of MMP with the permeability and the increase is obvious very much.
And it can be seen that in core displacement experiments, recovery increases with the increase of CO2 displacement pressure. With the increase of pressure, the solubility of CO2 in simulated oil increases, the viscosity of crude oil decreases, the volume expands, and the light hydrocarbon components in crude oil are continuously extracted and vaporized, the color of produced oil gradually becomes lighter. The fluidity of crude oil increases during CO2 displacement.

5. Conclusion
In this paper, the core-displacement method is used to measure the minimum miscibility pressure of CO2-crude in three different permeability cores, revealing the influence of permeability on MMP of CO2-crude.
(1) The minimum miscible pressure of CO2-crude oil increases with the increase of permeability. Because low permeability core has high seepage resistance, it can fully contact with crude oil and miscible.
(2) High-pressure core recovery is higher than low-permeability core during low-pressure immiscible displacement. Because capillary force is the main factor affecting oil recovery in low pressure immiscible displacement, and crude oil is easier to be displaced under low displacement pressure.
(3) Permeability has an effect on the MMP of CO2-crude oil. The lower the permeability, the greater the impact.

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