Yushulin Oilfield CO₂- Comparison of minimum miscibility pressure test results for crude oil system

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Abstract. Miscible displacement of carbon dioxide in low permeability sandstone reservoirs can greatly improve oil recovery. The minimum miscible pressure is the starting point of miscible flooding. Its determination is very important for oilfield development. In this paper, the error analysis of the results measured by empirical formulas is carried out by the internationally accepted slim tube experiment method. Research results show that the minimum miscibility pressure obtained by slender tube displacement experiment is 22.12 MPa. The maximum, minimum and average miscibility pressures predicted by empirical formula method are 32.33 MPa, 7.85 MPa and 19.76 MPa, respectively. The relative error of the average minimum miscibility pressure predicted by all empirical formulas is 10.67%. The least relative error is the Yelling and Metcalfe correlation method, the relative error is 8.82%.

1. Introduction
The application of CO₂ in oilfield flooding is increasing, and it has become an important and mature method for enhancing oil recovery at home and abroad. The minimum miscible pressure of CO₂ is an important parameter for CO₂ injection development. There are three methods to determine the miscibility pressure: experimental method, empirical formula method and equation of state method. This paper mainly applies the empirical formula method. There are many empirical formulas for the minimum miscibility pressure of CO₂-crude oil system. The results of their calculations are quite different from each other. In this paper, the minimum miscible pressure of Yushulin Oilfield is measured by using slender tube displacement test method, and the error analysis of the prediction results by the empirical formula method is carried out. Finally, a method suitable for predicting the minimum miscibility pressure in similar blocks is selected.

2. Prediction of Minimum Miscibility Pressure by Empirical Formula Method
The oil-gas ratio of Yushulin Oilfield is 25.25m³/m³, the density of crude oil is 0.782g/cm³, the volume coefficient is 1.1175, and the viscosity is 2.8 mPa·s. The following are common prediction formulas:
(1) Natl.Petroleum Council Method
This method first determines the minimum miscible pressure corresponding to the crude oil density table, and then corrects the results according to formation temperature.
(2) The second part of Cronquist correlation
\[ P_{mm} = 15.988T^{0.54206+0.0011038\text{M}_{C_{1+y}}+0.0015279\text{MPCI}} \]

(3) Yelling and Metcalfe correlation
\[ \text{MMP} = 1.5832 + 0.19038T - 0.00031986T^2 \]

(4) Glaso correlation
On the basis of Benham et al's prediction chart, Glaso considers the influence of intermediate component on the measurement of miscibility pressure, and takes the molar fraction of intermediate component up to 18% as the limit, gives the following two relations:
  ① When the molar content of intermediate components in crude oil is less than 18%:
  \[ P_{mm} = 20.3214 - 0.0235M_{C_{1+y}} + \left(1.6673 \times 10^{-9} M_{C_{1+y}} e^{-786.8M_{C_{1+y}}} + 1.0582\right) \times (0.0127T + 0.225) - 0.8356f_{GR} \]
  ② When the molar content of intermediate components in crude oil is more than 18%:
  \[ P_{mm} = 5.5805 - 0.0235M_{C_{1+y}} + \left(1.6673 \times 10^{-9} M_{C_{1+y}} e^{3.7378M_{C_{1+y}}} - 1.0582\right) \times (0.0127T + 0.225) \]

(5) The correlation of Alston et al.
For the injected gas to be pure CO2:
\[ P_{mm} = 6.5036 \times 10^{-6} \times (1.8T + 32)^{0.06} M_{C_{1+y}}^{1.78} \left(n_{vol} + n_{minit}\right)^{0.136} \]

(6) Silva prediction method
  ① Analysis of the composition of crude oil by gas chromatography, and normalized weight fractions of C2- C_{31} fractions were calculated by the following formula \( W_{iC_2} \):
  \[ W_{iC_2} = W_i + \sum_{i=2}^{31} K_i W_{i} \]
  \[ F = \sum_{i=2}^{31} K_i W_{iC_2} \]

  (1) When \( F<1.467 \), \( \rho_{MMP} = 0.542F + 1.189 \)
  (2) When \( F \geq 1.467 \), \( \rho_{MMP} = 0.42 \)

(7) Sebastian correlation
In 1985, Sebastia considered the effect of impurities on the measurement of miscible pressure and proposed a correlation of carbon dioxide flooding with impurities.
\[ P_{mm}^{imp} = P_{mm}^{pure} \times \left[1 - 0.0213(T_{cm} - 304.2) + 2.51 \times 10^{-4} \times (T_{cm} - 304.2)^2 - 2.35 \times 10^{-7} \times (T_{cm} - 304.2)^3 \right] \]
\[ T_{cm} = \sum_i x_i T_{ci} \]

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

3.1 Equipment and device diagram for experiment
  (1) ISCO advection pump;
  (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;
3.2 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.

3.3 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.
4. Comparison of Minimum Miscible Pressure Prediction Results

The minimum miscibility pressure predicted by the generally accepted long slim tube displacement experimental method is compared to the minimum miscibility pressure predicted by each empirical formula method (Table 1). It can be seen that the minimum miscibility pressure obtained by long slim tube displacement experiment is 22.12 MPa; The minimum miscible pressure predicted by the empirical formula method, the minimum value is 32.33 MPa, the minimum value is 7.85 MPa, and the average value is 19.76 MPa; The relative error of the average minimum miscibility pressure predicted by all empirical formulas is 10.67%. Among them, the least relative error is the Yelling and Metcalfe correlation, the relative error is 8.82%; followed by the Sebastian correlation, the relative error is 12.01%. The prediction results of other empirical formula methods are relatively large.

Table 1 Comparison of minimum miscibility pressure prediction results

| Forecasting Methods              | Minimum miscible pressure /MPa | Fractional error /% |
|----------------------------------|--------------------------------|---------------------|
| NPC method                       | 7.85                           | 64.52               |
| Cronquist correlation             | 15.83                          | 28.44               |
| Yelling and Metcalfe correlation  | 24.07                          | 8.82                |
| Glaso correlation                 | 32.33                          | 46.15               |
| Alston et al’s correlation        | 16.65                          | 24.71               |
| Silva Prediction method           | 16.78                          | 24.14               |
| Sebastian correlation             | 24.78                          | 12.01               |
| long tube displacement experiment | 22.12                          | /                   |

5. Conclusion

The error results of the empirical formulas determined by the slim tube experiment are as follows: The NPC method error is as high as 64.52%, the Glaso correlation method error is 46.15%, the Alston et al. correlation and the Silva prediction method between 24% and 25%, and only the Sebastian correlation and the Yelling and Metcalfe correlation errors between 8% and 12%. The comprehensive
comparison shows that the difference between the Yelling and Metcalfe correlations and the actual test results in the empirical formula is the smallest.

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