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The Research on minimum miscible pressure and prediction model of CO_2 flooding in reservoirs of Wushi Sag, Beibuwan Basin

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ABSTRACT

The low permeability reservoir in Wushi Sag of Beibuwan Basin is only about 20km away from the shore CO_2 emission source, which has a significant distance advantage as the CCUS-EOR storage point of the whole Marine process in China. The MMP(minimum miscible pressure) is an important parameter to improve the recovery and gas storage efficiency of low permeability reservoir by CO_2 injection. On the basis of laboratory PVT phase experiments, considering crude oil composition and temperature, CMG software WINPROP module was used to simulate p-x phase diagram of gas injection and simulate ternary phase diagram for multiple contacts to obtain high-precision miscible pressure results. MATLAB (Matrix Laboratory) software was used to solve the equation for miscible pressure, reservoir temperature, C_{7+}, C_{11+}. the molar fraction of volatile hydrocarbon components (N_2+CH_4), intermediate hydrocarbon components (C_2-C_4), (C_5-C_6). Compared with the traditional empirical formula, this formula improves the prediction accuracy of the minimum miscible pressure in Wushi Sag, Beibuwan Basin, and provides a simple and reliable calculation method for determining the MMP in the field.

Keywords: Offshore low permeability reservoir, Minimum miscible pressure, Prediction formula

NONMENCLATURE

Abbreviations	
MMP	minimum miscible pressure(MPa)
WN	Well name
FCMP	First Contact Miscibility Pressure(MPa)
MCMP	Multi-contact Miscibility Pressure(MPa)

Symbols	
T_R	Reservoir temperature(℃)
X_{vol}	Molar fraction of volatile components (N_2 and CH_4) in crude oil(%)
X_{Ca-Cb}	Molar fraction of crude oil (X_{Ca-Cb}) (%)
MW_{Cy+}	Molecular weight of C_{y+} component in crude oil

1. INTRODUCTION

At present, China's offshore oilfield development is dominated by water injection, and the comprehensive water cut has been more than 80%, and some have reached more than 94%. Compared with water injection, CO_2 has a large injection capacity, is not affected by salinity, and can effectively reduce the viscosity of crude oil, especially in water sensitive low permeability reservoirs. The low permeability reservoir in Wushi Sag of Beibuwan Basin has strong water sensitivity and is suitable for CO_2 injection development. The reservoir is only about 20km away from the shore CO_2 emission source, which has a significant distance advantage in China as an offshore full-process CCUS-EOR storage area.

The minimum miscible pressure is one of the most important parameters in the development of CO_2 injection. At present, there are many methods that can be used to determine MMP, which can be summed up into two main categories: experimental determination method (thin tube experiment method, interfacial tension disappearance method, bubble rising instrument method, etc.) and theoretical calculation method (chart method, empirical formula prediction method, multiple contact method, equation of state method, linear analysis calculation method, phase simulation calculation method and artificial intelligence prediction method, etc.).

The fine tube test method is a standard method to determine the MMP of CO_2 injection in the laboratory,

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which can truly reflect the multi-stage contact dynamic miscible process of CO_2 and crude oil after gas injection. It is the most widely used, but the experiment period is long and the cost is high. Among the theoretical calculation methods, chart method and empirical formula prediction method mainly use a large number of charts and empirical formulas returned by predecessors to predict the minimum miscible pressure, although the calculation is convenient and fast, but the scope of application is narrow, and the accuracy is low outside the scope of application. The multi-contact method, equation of state, linear analysis and phase simulation calculation methods are widely used and have high accuracy, but the calculation is complicated, time-consuming and inconvenient. Therefore, it is necessary to establish an improved minimum miscible pressure prediction formula suitable for target oil field when predicting the minimum miscible pressure of CO_2 flooding reservoir in Wushi Sag of Beibuwan Basin.

The improved prediction formula of minimum miscible pressure is established according to the reservoir characteristics of Wushi Sag in Beibuwan Basin, the influencing factors of minimum miscible pressure and the characteristics of existing formulas. Referring to the simulation calculation of p-x phase diagram of gas injection by CMG software and the simulation calculation data of pseudo-ternary phase diagram by multiple contacts, MATLAB (Matrix Laboratory) software was used to solve the equations of minimum miscible pressure and reservoir temperature, relative molecular weight of C_{7+} and C_{11+}, molar fraction of volatile hydrocarbon components (N_2+CH_4) and intermediate hydrocarbon components (C_2-C_4) and (C_5-C_6), and then the prediction correlation formula was obtained. It is proved that the prediction accuracy of this prediction formula is better than the existing formula for the minimum miscible pressure prediction of Wushi Sag reservoir in Beibuwan Basin.

2. MULTI-CONTACT MISCIBLE PRESSURE SIMULATION

Based on the PVT experimental data of multiple Wells in Wushi Sag, the p-x phase diagram simulation calculation and multi-contact miscible pressure study of CO_2 injection in multiple Wells in Wushi Sag were carried out by using the phase module WINPROP of CMG software to fit the data. The first contact miscibility pressure and the multiple contact miscibility pressure of CO_2 and crude oil system were obtained. The multiple contact miscible pressure determines the boundary between miscible flooding and immiscible flooding.

Table 1 First contact miscible Pressure Statistics (MPa)

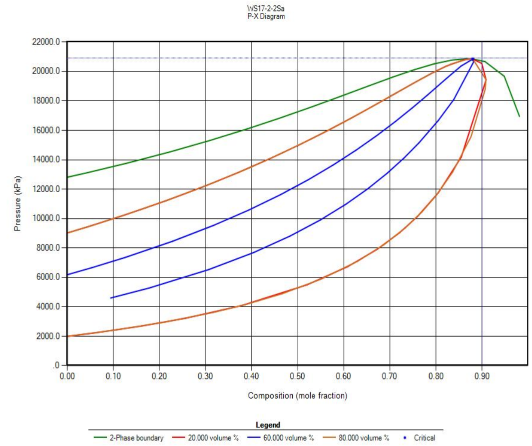

Fig. 1. P-X facies diagram of typical Wells in Wushi depression

WN	1	2	3	4	5	6	7	8	9
FCMP	24.43	23.93	21.78	22.44	17.42	25.41	18.92	20.79	21.88

Table 2 Multi-contact miscible Pressure Statistics (MPa)

WN	1	2	3	4	5	6	7	8	9
MCMP	23.32	22.94	21.03	22.20	16.31	25.19	17.54	19.28	21.77

3. EMPIRICAL FORMULA RESEARCH

Since the 1970s, many empirical formulas have been developed to predict the minimum miscible pressure of CO_2. In this study, Cronquist, Alston et al., Glass and Yaun were selected as representative calculation methods to predict the minimum miscible pressure of CO_2:

3.1 Cronquist correlation

Cronquist established a power function correlation for predicting MMP of pure CO_2 and crude oil in 1978. The correlation correlates MMP with TR, MW_{C5+}, and methane content in crude oil (C_1). The resulting model is shown in the formula:

$$MMP = 0.11027 * (1.8T_R + 32)^{0.744206+0.0011038MW_{C5+}+0.0015279C_1}$$

3.2 Alston correlation

The empirical formulas for the relationship between MMP and TR, MW_{C5+}, the volatile components (N_2 and CH_4) in crude oil (X_{vol}), and the intermediate components of C_2-C_4+CO_2+H_2S in crude oil (X_{C2-C6}) are established by Alston correlation. The prediction formula is as follows:

$$MMP = 6.0536 * 10^{-6} * (1.8T_R + 32)^{1.060} * (MW_{C5+})^{1.78}\left[\frac{X_{vol}}{X_{C2-C4}}\right]^{0.136}$$

3.3 Glass correlation

Glass believes that the multi-stage contact miscible MMP of pure CO_2 and crude oil is a function of T_R, the molecular weight of C_{7+} in crude oil MW_{C7+}, and the molar fraction of C_2-C_6 in crude oil X_{C2-C6}, and it varies with the difference of X_{C2-C6}. When X_{C2-C6}<18%, MMP is calculated as follows:

$$MMP = 20.3251 - 2.3470 * 10^{-2} * MW_{C7+} + 1.1721 * 10^{-11} * {MW_{C7+}}^{3.37} * e^{786.8*{MW_{C7+}}^{-1.058}} * (1.8T_R + 32) - 0.83564X_{C2-C6}$$

When X_{C2-C6}>18%, the expression is:

$$MMP = 5.5848 - 2.3470 * 10^{-2} * MW_{C7+} + 1.1721 * 10^{-11} * {MW_{C7+}}^{3.37} * e^{786.8*{MW_{C7+}}^{-1.058}} * (1.8T_R + 32)$$

3.4 Yuan correlation

Yuan et al. adopted an analytical theory derived from the equation of state to establish the correlation between MMP and TR, MW_{C7+} and X_{C2-C6}. The specific expression is as follows:

$$MMP = -10.09014 + 0.04559 * MW_{C7+} - 0.31031 * X_{C2-C6} + \left[0.014748 + 8.0443 * 10^{-4} * MW_{C7+} + 56.3053 * \frac{X_{C2-C6}}{{MW_{C7+}}^2}\right] * (18T_R + 32) + \left(-8.4519 * 10^{-4} + 8.8828 * 10^{-6} * MW_{C7+} - 2.7685 * 10^{-8} * {MW_{C7+}}^2 - 6.383 * 10^{-6} * X_{C2-C6}\right) * (18T_R + 32)^2$$

4. NEW PREDICTIVE CORRELATION OF MINIMUM MISCIBLE PRESSURE

The correlation formula is mainly based on the following points:

(1) The exponential function is used as the basic format to investigate the effects of temperature and crude oil composition on MMP;

(2) Use the forms $[1+X_{vol}/X_{C2-C4}]$ and $[1+X_{vol}/X_{C5-C6}]$ to explore the correlation between X_{vol}, X_{C2-C4} and X_{C2-C6} and their influence on MMP, and use the form of ratio to accurately describe the interaction between these parameters. The "1" added in front is to avoid the deviation of MMP when the ratio of two parameters is close to 0 as much as possible;

(3) PVT data all contain MW_{C11+}. Because X_{C2-C4}, X_{C5-C6} and MW_{C11+} have different effects on MMP in different reservoirs, in order to more accurately describe the effects of their interactions on MMP, We combine the terms $X_{C5-C6}/(MW_{C11+})$^2 and X_{C2-C4}/X_{C5-C6} into the improved association. Based on the above points, the final correlation expression can be written as:

$$MMP = a_1 {T_R}^{a_2} * (MW_{C7+})^{a_3} * \left[1 + \frac{X_{vol}}{X_{C2-C4}}\right]^{a_4} * \left[1 + \frac{X_{vol}}{X_{C5-C6}}\right]^{a_5} + \left[a_6 * \frac{X_{C5-C6}}{(MW_{C11+})^2} + a_7 * \left(\frac{X_{C2-C4}}{X_{C5-C6}}\right)^{a_8}\right] * {T_R}^2$$

a1-8 is the fitting parameter value in the above formula, which is mainly obtained by fitting the multi-contact miscible pressure during CO_2 injection.

Based on the simulation data of multiple contact miscible pressure between CO_2 and crude oil system in Wushi Sag, it is calculated as follows: (a1, a2, a3, a4, a5, a6, a7, a8) = (0.1898, -1.9218, -1.3265, -1.2480, -1.0578, 0.0003, 0.0017, -0.0116).

5. MMP RELATIONAL RESULT ANALYSIS

The prediction effect of the new correlation is measured by comparing the numerical correlation with the numerical simulation of the miscible pressure of multiple contacts. You get:

Table 3 Compares the predictive performance of the new association with the four existing associations

The correlation	Fractional Error %
This Work	6.31
Cronquist	10.43
Alston	24.63
Glaso	6.89
Yuan	6.45

6. CONCLUSION

The correlation formula has good accuracy in predicting the minimum miscible pressure of the reservoir in Wushi Sag of Beibuwan Basin, and is better than the existing correlation formula. It can provide reference for the development of reservoir CO_2 injection in Wushi Sag of Beibuwan Basin.

REFERENCE

[1] Guangying, C., Simulation Prediction and Experimental Determination of CO_2-Oil Minimum Miscibility Pressure, 2016, Hunan University. 136.

[2] Cronquist C. Carbon dioxide dynamic miscibility with light reservoir oils. Proc. Fourth Annual US DOE Symposium, Tulsa, 1978, pp 28-30.

[3] Alston R, Kokolis G,James C. CO_2 minimum miscibility pressure: A correlation for impure CO_2 streams and live oil systems. Society of Petroleum Engineers Journal, 1985, 25(02): 268-274.

[4] Glass O. Generalized Minimum Miscibility Pressure Correlation (includes associated papers 15845 and

16287). Society of Petroleum Engineers Journal, 1985, 25 (06): 927-934.
[5] Yuan H, Johns R T, Egwuenu A M, et al. Improved MMP correlation for CO_2 floods using analytical theory. SPE Reservoir Evaluation & Engineering, 2005, 8 (05): 418-425.