Estimation of Minimum Miscibility Pressure for CO₂ Flood Based on EOS

ABSTRACT

CO₂ Gas is considered one of the unfavorable gases and it causes great air pollution. It’s possible to decrease this pollution by injecting CO₂ gas in the oil reservoirs to provide a good miscibility and to increase the oil recovery factor. MMP was estimated by Peng Robinson equation of state (PR-EOS). South Rumila-63 (SULIAY) is involved for which the miscible displacement by CO₂ is achievable based on the standard criteria for success CO₂ EOR processes. A PVT report was available for the reservoir under study. It contains deferential liberation (DL) and constant composition expansion (CCE) tests. PVTi software is one of the (Eclipse V.2010) software’s packages, it has been used to achieve the goal. Many trials have been done to match the data of DL test by tuning some of the PR-EOS parameters through the regression analysis process, but no acceptable match was obtained especially for saturation pressure. However; splitting the mole fraction of \((\text{C}_6^+\)) to many pseudo components was carried out, and then a regression analysis process was made again to improve the matching by tuning some of the PR-EOS parameters. A good estimate of saturation pressure and a good match of PVT properties was noted. Ternary diagram has been constructed to represent the phase behavior of CO₂-Oil and to calculate MMP for the South Rumila-63 (SULIAY) oil well.

Keywords: minimum miscibility pressure, CO₂, PR-EOS, differential liberation.
1. INTRODUCTION

Paitoon, et al., 2013 declared that CO₂-oil MMP is an important parameter to be specified in CO₂ EOR processes as it plays a key role in the design of CO₂ miscible flooding.

Stalkup, 1978 confirmed that the high solubility of CO₂ in the oil causes swelling it and increases in their volume with high oil recovery rate due to a significant reduction in viscosity and interfacial tension. However, a complete miscibility between CO₂ and oil is done at a displacement pressure. Which must be greater than a specified minimum, this minimum refer to MMP (minimum miscibility pressure) and/or MME (minimum miscibility enrichment).

Abu-Khamsin, 1989 determined MMP for carbon dioxide flooding process by slim tube method for three standard Arabian stock tank crude oils: Arab Light, Medium and Heavy. He found the higher temperature or oil density causes increase in CO₂-MMP for Saudi Arabian crudes.

Hameed, 2017 estimate MMPs according to PR-EOS for selected twenty-seven Iraqi oil samples by using eclipse (v.2010)/PVTi software and finally tried to correlate MMPs with the major parameters, till to conclude MMP correlation with $R^2=0.8806$ using Statistics (v.10) software.

2. AIM OF STUDY

Determination of minimum miscibility pressure for CO₂ flood into South Rumila-63 (SULIAY) oil sample.

3. STUDY AREA

South Rumila-63 (SULIAY) oil sample has been selected from different fields and formations that are located in the southern part of Iraq based on screening criteria for CO₂ gas flooding. The selection is done on the base of EORGUI software that designed according to Martin et al. Fig.1 shows the location of South Rumila oil field

4. RESERVOIR FLUID PROPERTIES

As an example, the properties of Sulaiy reservoir fluid in South Rumila field are presented here. The oil has a light API gravity of 45.9, GOR and Saturation Pressure at reservoir temperature 252
°F, are 299.2 m³/m³ and 3506 psi, respectively and the initial pressure is 9956.3 psi and the reference depth is 4219 mRTKB.

5. FINAL PVT MODEL

Many trials have been made in order to find a match between the measured data of DL test with tuning some of the main PR-EOS parameters were: (Ωa, Ωb, P_c, T_c, acentric factor and binary interaction coefficient) that have been used in the regression process, but they didn’t give satisfactory results. Splitting techniques were used to characterize or to tune the EOS to be able to simulate the PVT experiments. This was a multi-step process that was started by splitting the heavy components (C_{6+}) as suggested by Whitson. Then, regression was done by a return to tune PR-EOS to get matched PVT properties.

There are several ways to split the plus fraction (C_{6+}) in the PVTi software. Finally, Whitson method has been selected, which gave an appropriate split for the mole fraction of plus component. In addition, Lee Kesler correlation was selected for the critical properties correlation to demonstrate the newly defined components. Fig.2 shows the new components for South Rumila-63 (SULIAY) after splitting the heavy component (C_{6+}) into 12 pseudo-components, and the total components number of the current oil reservoirs had increased to 23 components. These 23 components were used to tune the EOS by regressions processes to match the measured data.

6. REGRESSION

Immediately after making a split for plus component mole fraction, regression was done by tuning PR-EOS parameters by changing some of them until calculated PVT properties matched the observed data in several attempts. This procedure consumes a larger time with each trial. The major regression parameters that have been changed to give the best match for different physical properties of reservoir fluid are (Ωa, Ωb, P_c, T_c). Fig.3 represents final matching of fluid physical properties. And Table 1 represents statistical parameter for the final result of D.L. test. While Table 2 illustrates average absolute percent relative error before and after splitting process for bubble point pressure.

7. TERNARY DIAGRAM AND MMP ESTIMATION

A ternary diagram is used to illustrate the occurrence of miscibility. The resulted ternary diagram from MCM (vaporizing gas displacement) after splitting and lumping process for South Rumila-63 (SULIAY) are presented in Fig.4. This diagram consists of three peaks, the upper apex
denotes the CO₂, the lower-right apex denotes the light and intermediate component (L+I): \([ C_1, N_2, C_2, C_3, C_4, C_5 ]\) and the lower-left apex denotes the heavy component \([C_{6+}]\). The green envelope represents the two-phase immiscible region (oil + gas), red point represents the oil composition at reservoir pressure and temperature and the blue point represent 100 % composition of pure CO₂ injection (without impurities), the green line represents the limiting tie line. **Green and willhit**, 2003 presented the main purpose from drawing ternary diagram is to know that the CO₂ gas is miscible or immiscible with the reservoir oil. However; when the oil composition point on the right side of the tie line, the system is miscible. While if the oil composition point on the left side of the tie line, the system is immiscible because of oil composition and the two-phase envelope region is the same side of the critical point tangent line. Finally, after obtaining a suitable matching between observed and calculated PVT properties, MMP can be calculated in the PVTi software. The MMP for South Rumila-63 (SULIAY) is 2589.443 psia.

8. CONCLUSIONS

- The equation of state is found to be a powerful tool for estimating PVT properties where a good match was shown for all experimental PVT. Accordingly, the value of MMP can be considered accurate.
- The match with the measurements was obtained after adjusting \((P_c, T_c, \Omega_a, \Omega_b)\) that effect on PR-EOS calculation.

9. REFERENCES

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10. NOMENCLATURE

AAERR=average absolute percent relative error.
CCE=constant composition expansion.
CO₂= carbon dioxide.
DL= differential liberation.
MMP= minimum miscibility pressure.
PR-EOS= peng Robinson equation of state.
SD= standard deviation.

Figure 1. The location of the South Rumila that have been considered in the present work.
Figure 2. Oil composition in mole Percent after splitting.

Figure 3. Calculated and observed oil FVF with GOR after splitting process.
Table 1. Statistical parameter for final Result of DL test (after splitting process).

| property               | AAERR % | SD % |
|------------------------|---------|------|
| Oil rel. vol. (Rb/STB) | 5.71    | 6.73 |
| Gas-Oil Ratio (Mscf/bbl)| 16.827  | 20.45|

Table 2. Average absolute percentage relative error between Observed and calculated saturation pressure.

| Method of calculation       | Measured saturation pressure (psia) | Calculated saturation pressure (psia) | AAERR% |
|----------------------------|-------------------------------------|--------------------------------------|--------|
| Before regression           | 3506.4                              | 3433.7                               | 2.071  |
| After splitting and groping | 3506.4                              | 3541.5                               | 1.001  |

Figure 4. Ternary diagram for South Rumila oil field/ Suliy formation with two phase region in CO₂/hydrocarbon system.