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Swelling Performance of Paraffinic Crude Oil Under Carbon Dioxide Injection

Muslim Abdurrahman, Asep Kurnia Permadi, Wisup Bae, Ivan Efriza, Shabrina Sri Riswati, and Adi Novriansyah

Abstract

Paraffinic crude reservoir is one of an attractive options for co-implementation of CO_2-EOR and CO_2-storage activities. The effectiveness of oil recovery is affected by an oil swelling mechanism. The swelling performance of CO_2 in paraffinic crude is essential to be studied due to the difficulties to pursue miscible condition. This mechanism was investigated through the analysis of the swelling factor value from the swelling experiment. Moreover, the equation of state calculation (EOS) using Peng–Robinson equation was performed to predict the minimum miscibility pressure (MMP) of the crude sample for investigating swelling trends toward this point. Results from the experimental test reveal a slow process of oil swelling due to CO_2 injection, which is implied from the low swelling factor value. The EOS calculation shows a large MMP value, which was impossible to reach under reservoir condition. Extrapolating extraction-condensation trend indicates no occurring extraction which means that the main mechanisms for this crude type was dominated by viscosity and interfacial tension reduction. Although it was impossible to pursue the MMP, the utilization of CO_2 in paraffinic crude may bring a positive impact on the oil recovery process.

Keywords

CO_2 • Paraffinic oil • Immiscible displacement • Swelling factor • Minimum miscibility pressure

1 Introduction

As an alternative option to store carbon dioxide (CO_2), main component of greenhouse gas (GHG), oil reservoir is an attractive storage candidate because CO_2 can be used as an enhance oil recovery (EOR) agent, known as CO_2-EOR (Gozalpour et al. 2005). For over two decades, CO_2-EOR has successfully recovered residual light oil (Zhang et al. 2019). As CO_2 is well known to solve wax problem in production facilities (Yang et al. 2019), CO_2 capability in paraffinic crude oil reservoir should be tested. Paraffinic oil contains a large amount of wax. This oil type has gravity more than 25° API or still in the range of medium to light oil, where CO_2 flooding is still acceptable. High wax content is the reason of the time consumed by CO_2 solubilization process (Abdurrahman et al. 2019). This is similar to mechanisms of CO_2 injection in heavy oil. (Li et al. 2013). Even though the mechanism is similar, viscosity of paraffinic crude is lower than that of heavy crude in reservoir conditions. Therefore, the strategy to implement CO_2 in this type of crude should be different, including its swelling performance.

The objective of this paper was to study CO_2 swelling performance of paraffinic crude under CO_2 injection. This parameter was analyzed by interpreting CO_2-Oil swelling factor, a ratio of observed oil level at specific injection pressure to initial oil level. The swelling factor is useful in the condensation-extraction analysis and MMP estimation (Abdurrahman et al. 2015). Peng–Robinson equation of state (EOS) calculation was used to predict the MMP and analyze the possibility of an extraction mechanism to occur in miscible condition.

M. Abdurrahman (✉) · A. Novriansyah
Universitas Islam Riau, Pekanbaru, Indonesia

A. K. Permadi
Institut Teknologi Bandung, Bandung, Indonesia

W. Bae · S. S. Riswati · A. Novriansyah
Sejong University, Seoul, Republic of Korea

I. Efriza
PT SPR Langgak, Jakarta, Indonesia

S. S. Riswati
Universitas Trisakti, Jakarta, Indonesia

M. Meghraoui et al. (eds.), *Advances in Geophysics, Tectonics and Petroleum Geosciences*, Advances in Science, Technology & Innovation, https://doi.org/10.1007/978-3-030-73026-0_93

2 Methodology

This experimental study utilized a crude oil sample from central Sumatra basin. The sample has an API gravity of around 30 or included to the medium-light oil. The bubble point pressure, pour point temperature, wax, and asphaltene contents are 113 psi, 105–110 °F, 33 wt%, and 13 wt%, respectively. The percentage of heptane plus (C_7H_{1+}) was around 90 mol% at reservoir condition (Table 1). The crude was sampled at 1200 ft. depth, and the reservoir pressure was approximately 500 psi (Abdurrahman et al. 2019).

The swelling factor apparatus consists of a syringe pump for CO_2 injection, high-pressure-high-temperature (HPHT) optical cell, camera, and PC for observation. Crude oil is placed inside the optical cell which was located in the air-bath. The temperature inside the air bath was maintained constant by adjusting a heater temperature to reservoir condition (136 °F). CO_2 was injected continuously into the cell at constant pressure. Crude level inside the optical cell was recorded by using camera and recorded into numerical data by computer. The experiment was repeated for certain injection pressure, starting from 300 to 3300 psi.

Before predicting the MMP under EOS calculation, the fluid should be modeled and verified by matching the bubble point pressure and reservoir temperature with the previously reported data (113 psi; 136 °F). A simulation study was performed to estimate the sample MMP. EOS by Peng–Robinson was used under WINPROP module in CMG software. (CMG software 2014). Hydrocarbon composition in Table 1 and reservoir temperature were needed as an input parameter for this module. The MMP determination was performed by selecting multiple contact miscibility modules in the software. For a designated solvent, i.e., pure CO_2 and range of pressure, the MMP was determined at a certain temperature. In MMP, no mix envelope was found in the ternary diagram.

3 Results and Discussion

Figure 1 shows the swelling factor plot over the injection pressure where two trends of swelling factor data were recorded in this test, i.e., the swelling factor tends to increase with 0.14% per 1000 psi at low pressure region (300–1900 psi) and to decrease with 6.5% per 1000 psi in the range of 2000–3300 psi, which is lower than light crude oil swelling factor (Abdurrahman et al. 2015). These trends are similar to condensation and extraction-condensation phenomena (Wang 1986). The MMP was not achieved in this experiment based on definition by Abdurrahman et al. (2015).

Figure 2 displays the bubble point pressure of the crude sample in the fluid model phase envelope from the WIN-PROP module, where the generated fluid model was

Table 1 Hydrocarbon composition of the crude sample in this study

Component	Mole%	Component	Mole%
Hydrogen sulfide (H_2S)	0.00	Iso-Butane (i-C_4H_{10})	0.90
Carbon dioxide (CO_2)	0.56	n-Butane (n-C_4H_{10})	1.57
Nitrogen (N_2)	0.00	Iso-Pentane (i-C_5H_{12})	1.56
Methane (CH_4)	0.67	n-Pentane (n-C_5H_{12})	1.50
Ethane (C_2H_6)	0.67	Hexanes (C_6H_{14})	0.35
Propane (C_3H_8)	1.51	Heptane plus (C_7H_{1+})	90.71

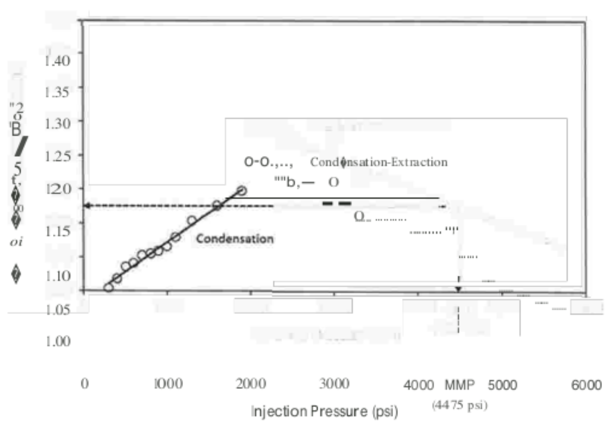

Fig. 1 Oil swelling factor at various injection pressure values

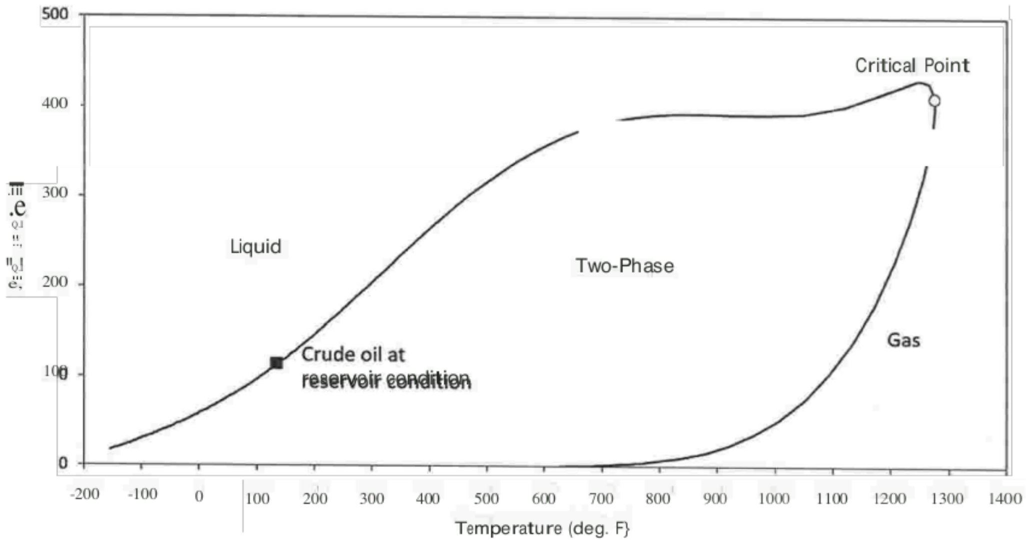

Fig. 2 Pressure–temperature diagram of crude oil sample

matched with the crude oil sample. The MMP calculation by Peng–Robinson EOS in WINPROP module yielded a large value (4475 psi), which means a displacement scenario is under immiscible condition with its reduction of oil viscosity and oil swelling due CO_2 dissolution mechanisms (Li et al. 2013). The ternary diagram in Fig. 3a indicates the change of the liquid line toward a vapor line by increasing the injection pressure. High pressure improves CO_2 solubility into oil, resulting high swelling factor (Abedini and Torabi 2014). In MMP condition (Fig. 3b), the vapor and liquid lines vanished, indicating miscibility already achieved, leaving a small portion of heavy component (represented as black dot in the ternary component) and Oil-CO_2 mixture (red dot in ternary diagram).

By referring to the swelling test result, the crude has a long extraction-condensation stage to pursue the MMP condition. Extrapolating the extraction-condensation trends to the expected MMP value from EOS calculation (Fig. 1)

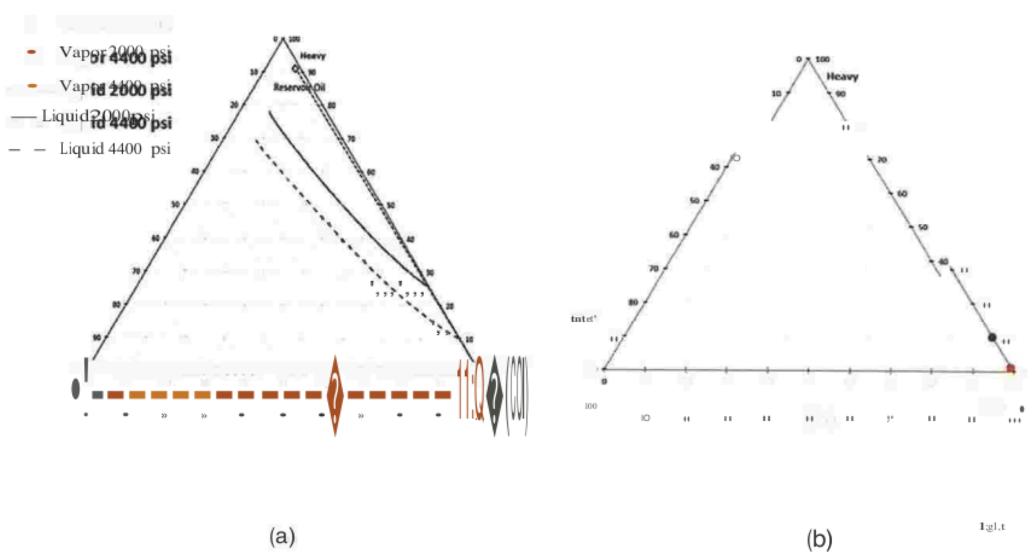

Fig. 3 Ternary diagram of fluid model at a 2000 and 4400 psi; b 4475 psi

results, the oil swelling factor was reduced from 1.24 to 1.12 (around 10% declined), which is still higher than the initial condition (1.00). Hence, the hydrocarbon extraction might not happen during CO_2 injection until the estimated MMP, and as a result, a CO_2 gas dissolves into oil, inducing the oil volume to increase. This phenomenon reduces the interfacial tension and viscosity, and the crude flows easier in porous medium (Li et al. 2013).

4 Conclusions

This paper combines the experimental and simulation work to study the swelling performance of paraffinic oil CO_2 injection. The swelling test led to two kinds of swelling factor trends which describe condensation and extraction-condensation phenomena. Both trends reveal low oil swelling factor, indicating the low capability of CO_2 dissolution. The MMP calculation by Peng–Robinson EOS limits the displacement process into immiscible scenario if the reservoir constraints are concerned. Long stages of extraction-condensation stage may have happened in the sample if the MMP from simulation was considered as MMP from the experiment. The CO_2 injection into this paraffinic crude may have ended in a CO_2 dissolution phenomenon.

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