Determination of CO$_2$ volume injection effect to reservoir fluid characteristic in miscible CO$_2$ displacement

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Abstract. Carbon dioxide (CO$_2$) miscible flooding is one of the Enhanced Oil Recovery (EOR) methods that has been recognized as a promising method to improve of oil recovery before abandonment. In addition, many issues related to global warming or greenhouse effect due to CO$_2$. By using CO$_2$ as either miscible or immiscible flooding to enhance oil recovery injected into reservoir, it may help reduce environmental problems. Carbon dioxide (CO$_2$) is able to improve of oil recovery effectively by important key parameter: minimum miscibility pressure (MMP), viscosity, and density. This paper aims to determine the effect of CO$_2$ volume injection to reservoir fluid characteristic in order to CO$_2$ miscible flooding for displacing the oil production. This research was carried out by some series of laboratory experiment that involve PVT test, slim tube test, and swelling test. The result from laboratory experiments were used to observe the use of CO$_2$ and its effect on reservoir fluid characteristics such as viscosity, solubility, and swelling factor. MMP obtained from slim tube test is 2805 Psi. Based on the results, all trend of parameters: viscosity, solubility, and swelling factor showed the positive impact of CO$_2$ have on liquid recovery.

1. Introduction

Most of the production of the oil fields in Indonesia have been declined and currently been recovered mostly by primary and secondary methods. Yet, there a large amount of remaining oil in the reservoir and require to be produced using Enhanced Oil Recovery (EOR) methods to improve of oil recovery before abandonment. One of the Enhanced Oil Recovery (EOR) methods that has been successfully improved oil recovery is the Carbon dioxide (CO$_2$) miscible flooding [1]. CO$_2$ flooding is also one of the most promising techniques to improve oil recovery for light and heavy oil as well [2]. In addition, many issues related to global warming or greenhouse effect due to CO$_2$ [3]. By using CO$_2$ as either miscible or immiscible flooding to enhance oil recovery injected into reservoir, it may help reduce environmental problems [4]. Carbon dioxide (CO$_2$) is able to improve oil recovery effectively by important key parameter: minimum miscibility pressure (MMP), viscosity, and density [5]. Minimum miscibility pressure (MMP) can be defined as the lowest pressure at which (90-92%) of oil has been recovered at (1.2 pore volume) of CO$_2$ injected [6] MMP is depends on composition of reservoir fluid and injection gas compositions, reservoir pressure, and temperature [7]. The greatest difference compared to other gases is that CO$_2$ can extract heavier components up to C$_{30}$ and the solubility of CO$_2$
in hydrocarbon causes the oil to swell, so due to its properties carbon dioxide (CO$_2$) can improve recovery by reducing oil viscosity and swelling the oil [8].

Understanding of CO$_2$ - fluid reservoir physical properties and its characteristic also its effect for displacing the oil is very important in miscible gas flooding [9]. The important parameters that were influenced on gas flooding EOR are solubility, swelling factor, viscosity, and density between gas injection and fluid reservoir [10]. This study was aimed to shows the effect of CO$_2$ miscible flooding for oil fields by swelling, reducing viscosity, and solubility which affecting on oil recovery that contributing to the oil production.

2. Method and data
This research was carried out by some series of laboratory experiment that involve PVT test to determine fluid composition, slim tube test to determine minimum miscibility pressure (MMP), and swelling test to determine swelling factor of miscible CO$_2$ and reservoir fluid. All these tests are performed with sample from one of oil field in Indonesia. In addition, original fluid reservoir and separator condition for sampling PVT is shown in table 1. PVT test are designed to study and quantify the phase behavior and properties of a reservoir fluid [11]. Basically, the sampling of reservoir fluid for PVT test was carried out at the surface or separator and frequently collected at separator which are then recombined to obtain a well stream fluid for full PVT analysis [12]. During the PVT test process, the bubble point pressure ($P_b$), oil formation volume factor ($B_o$), and gas to oil ratio (GOR) were measured [13]. The result of oil composition can be shown in table 2.

The slim tube test was carried out to determine the minimum miscible pressure (MMP). In addition, the prediction of MMP can be obtained from the intersection of the trend lines on oil recovery with the injection pressure [14]. The slim tube test was carried out after constant mass depletion test, where bubble point pressure of the reservoir oil was measured, because this experiment was repeated several times at different pressure above bubble point pressure [15]. MMP for this experiment yielding 2805 Psi (can be seen in Figure 1).

| Formation Characteristic       | Value  | Unit    |
|-------------------------------|--------|---------|
| Original Reservoir Pressure   | 2562   | Psi     |
| Reservoir Temperature         | 260    | °F      |
| Liquid gravity at 24°F         | 39     | API     |
| Datum                         | 6530   | ft - TVDSS |
| Separator Pressure             | 240    | Psi     |
| Separator Temperature         | 150    | °F      |

Table 1. Reservoir formation characteristic.

| Component | Mole Percent (%) | Weight Percent (%) |
|-----------|------------------|--------------------|
| C$_1$     | 22.24            | 4.68               |
| C$_2$     | 3.04             | 1.20               |
| C$_3$     | 3.51             | 2.03               |
| i-C$_4$   | 1.61             | 1.23               |
| n-C$_4$   | 3.09             | 2.35               |
| i-C$_5$   | 2.37             | 2.24               |
| n-C$_5$   | 2.68             | 2.53               |
| C$_6$     | 4.52             | 5.10               |
| C$_7+$    | 33.01            | 65.00              |
| CO$_2$    | 23.58            | 13.60              |
| H$_2$S    | 0.2319           | 0.00               |

Table 2. Oil composition of oil field.
After minimum miscible pressure (MMP) was measured by slim tube test, the measurement of oil swelling (mixture of CO₂ and fluid reservoir) can be done. So, swelling test was the final step of laboratory experiment after PVT and Slim tube test was done. The viscosity, density, and flash test of the CO₂ and fluid reservoir mixture (swelling oil) were measured at saturation pressure were measured prior to injection and at various carbon dioxide (CO₂) injection percentage.

The fluid sample was separated to a flash separation at standard conditions (P = 14.73 psia and T = 60°F) to obtain original hydrocarbon gas and carbon dioxide (CO₂) injected. By using flashed data, the solubility of gas and fluid reservoir after injecting CO₂ and swelling factor (SF) at bubble-point pressure can be obtained.

![Figure 1. Minimum miscible pressure (MMP) result from slim tube test.](image)

3. Result and discussion
The result of CO₂ and fluid reservoir properties interaction in reservoir are key parameter to know the effect on oil recovery that is needed for carbon dioxide (CO₂) gas flooding enhanced oil recovery. The sample was taken from one of oil field in Indonesia. Oil sample was tested with variation of carbon dioxide (CO₂) gradually different percentage. Minimum miscible pressure (MMP) obtained from slim tube test of CO₂ – fluid is 2805 Psi as shown in figure 1. The result obtained from laboratory experiment are CO₂ injected stream percentage, the mixture of CO₂ - bubble point pressure, the mixture of CO₂ injection and fluid density, the mixture of CO₂ injection and oil viscosity, the swelling factor of CO₂ addition and oil, and the solubility of CO₂ and oil. Overall, the effect of CO₂ injection to fluid reservoir characteristic can be seen from phase diagram (figure 2) of fluid reservoir composition after injecting CO₂ [16]. Figure 2 shows phase diagram of original reservoir fluid and reservoir fluid after injecting CO₂. The black line is the original reservoir fluid hydrocarbon composition prior to CO₂ flooding and the red line is phase diagram of the change reservoir fluid by CO₂ injection into reservoir. Miscible CO₂ flooding into reservoir causes phase envelope shifting, then increase critical point of reservoir fluid so that saturation pressure or bubble point pressure increase as well. Phase diagram also indicate that the dew point drops, the bubble point decreases, and the two-phase envelope diagram shrinks with the increase of CO₂ composition [17]. All these trends showed the positive impact of CO₂ have on liquid recovery [18].

3.1. The swelling factor of the CO₂ and oil mixture
Figure 3 illustrates the results of the CO₂ – oil reservoir mixture by CO₂ addition at minimum miscibility pressure (MMP) and reservoir temperature. Swelling is defined as the increasing in bubble or saturated liquid phase volume compared to the initial reference volume at reservoir temperature [19]. The swelling factor can be obtained by using flashed data from swelling test. Figure 3 shows that as more CO₂ dissolve into the liquid phase, as the volume of the liquid phase and bubble pressure increase, as a result of the oil swelling is increased, so swelling factor increased as well.
3.2. The solubility of the CO$_2$ and oil mixture
The effect of CO$_2$ addition by injecting into reservoir to the solubility of CO$_2$ and oil mixture can be seen in figure 4. The solubility of CO$_2$ and oil mixture is increased by the increasing of CO$_2$ percentage at MMP. The higher dissolved gas content increases the driving force naturally to produce oil in the reservoir.
3.3. The viscosity of CO₂ and oil mixture
Figure 5 illustrates the results of the CO₂ and oil viscosity with variation of bubble point pressure at reservoir temperature. Each line in this figure represents the mixture of CO₂ - oil viscosity with different saturation pressure (bubble point pressure) from minimum miscibility pressure (MMP) till above MMP. This figure can also be observed that the mixture of CO₂ – oil reservoir was significantly reduced by carbon dioxide (CO₂) injection. The reduction of oil viscosity improved the total mobility ratio between reservoir oil and the displacing fluid, which will affect the recovery factor [20].

![Figure 5](image)

Figure 5. The viscosity of CO₂ and oil mixture with bubble point pressure.

4. Conclusion and recommendation
Throughout this research, the following conclusions and recommendations can be concluded based on the discussion and results:

- CO₂ flooding is one of the promising enhanced oil recovery method that require to gas and oil properties for oil displacement process.
- CO₂ addition into reservoir by injecting at minimum miscible pressure (MMP) give the leverage on the changes of reservoir fluid characteristic, such as viscosity, swelling factor, solubility, even the composition of hydrocarbon which can be seen from the mixture of CO₂ and oil phase behaviour.
- The increasing of CO₂ volume injection percentage at minimum miscible pressure lead to decreasing of viscosity whereas the reduction of viscosity improved the total mobility ratio between reservoir oil and the displacing fluid, which will affect the recovery factor.
- By increasing of CO₂ volume injection at minimum miscible pressure lead to increasing of the solubility and swelling factor as well.

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References

[1] Mansour E M, Al-Sabagh A M, Desouky S M, Zawawy F M and Ramzi M 2019 A laboratory investigation of carbon dioxide-enhanced oil recovery by focusing on CO 2 -oil physical properties Egypt. J. Pet. 28 21–6

[2] Huang T, Zhou X, Yang H, Liao G and Zeng F 2017 CO 2 flooding strategy to enhance heavy oil recovery 3 68–78

[3] Lashgari H R, Sun A, Zhang T, Pope G A and Lake L W 2019 Evaluation of carbon dioxide storage and miscible gas EOR in shale oil reservoirs Fuel 241 1223–35

[4] Mathiassen O M 2003 CO2 as injection gas for enhanced oil recovery and estimation of the potential on the Norwegian continental shelf Nor. Univ. Sci. ...

[5] Ahmadi K 2011 Advances in Calculation of Minimum Miscibility Pressure PhD thesis 267

[6] Desouky S M, Ramzi M, Al-Sabagh A M, Mansour E M and Zawawy F M 2017 A new estimating method of minimum miscibility pressure as a key parameter in designing CO2 gas injection process Egypt. J. Pet.

[7] Hamdi Z, Awang M and Zamani A 2016 Evaluating Liquid CO2 Injection Technique for Oil Recovery Using Core Flood Experiments

[8] Atia A and Mohammedi K 2018 A Review on the Application of Enhanced Oil/Gas Recovery through CO2 Sequestration Carbon Dioxide Chem. Capture Oil Recover.

[9] Yu W, Lashgari H R, Wu K and Sepehmoori K 2015 CO2 injection for enhanced oil recovery in Bakken tight oil reservoirs Fuel 159 354–63

[10] Jia B, Tsau J S and Barati R 2019 A review of the current progress of CO2 injection EOR and carbon storage in shale oil reservoirs Fuel 236 404–27

[11] Nnabuo N N, Okafor I S and Ubani C E 2014 Interpretation of Laboratory PVT Analysis Result (A Case Study of a Niger Delta Field)

[12] Sylvester O 2017 PVT Analysis Reports of Akpet GT9 and GT12 Reservoirs Am. J. Manag. Sci. Eng. 2 132

[13] Elmabrouk S, Zekri A, Arab U and Shirif E 2010 SPE 137368 Prediction of Bubblepoint Pressure and Bubblepoint Oil Formation Volume Factor in the Absence of PVT Analysis Soc. Pet. Eng. This

[14] Vulin D, Gaćina M and Biličić V 2018 Slim-Tube Simulation Model for Co2 Injection Eor Rud. Zb. 33 37–48

[15] Al-Hinai K, Al-Bemani A and Vakili-Nezhaad G 2013 Experimental and Theoretical Investigation of the CO2 Minimum Miscibility Pressurefor the Omani Oils for CO2 Injection EOR Method Int. J. Environ. Sci. Dev. 5 142–6

[16] Bhatti A A, Raza A, Mahmood S M and Gholami R 2019 Assessing the application of miscible CO2 flooding in oil reservoirs: a case study from Pakistan J. Pet. Explor. Prod. Technol. 9 685–701

[17] Jia Y, Shi Y, Huang L, Yan J, Zheng R and Sun L 2018 The Vapour-Vapour Interface Observation and Appraisement of a Gas-Condensate/Supercritical CO 2 System Sci. Rep. 8 1–13

[18] Curtis H and Processes G 2019 or of the i posi g t x of x locus defi behavi ning MMP composi tion from diagram

[19] Perera M S A, Garnage R P, Rathnaweera T D, Ranathunga A S, Koay A and Choi X 2016 A Review of CO2 -Enhanced oil recovery with a simulated sensitivity analysis Energies 9

[20] Jr. W D M, Spivey J P and Lenn C P 2010 Petroleum Reservoir Fluid Property Correlations