DrEngMuslim - Karya Ilmiah - Determination of optimum CO2 water alternating gas (CO2-WAG) ratio in Sumatera Light Oilfield

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Determination of optimum CO_2 water alternating gas (CO_2-WAG) ratio in Sumatera Light Oilfield

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ABSTRACT

The CO_2 Water Alternating Gas (CO_2-WAG) injection method, allows the oil to first expand and become better able to flow because of the CO_2, and then the water increases the pressure in the reservoir to flush this newly freed oil to production wells. This study is in Sarolangun District, Jambi Province which is prospect of CO_2 injection tertiary recovery project due to its abundant CO_2 reserve. The success of CO_2-WAG injection can be determined by investigating ratios between CO_2 and water. The goal of this study is to determine optimum CO_2-WAG injection ratio in Sumatera Light Oilfield. This study is done through a numerical simulation of immiscible CO_2-WAG which is conducted under three scenarios of ratio using both CMG WINPROP and GEM simulator. The CO_2/water ratios are varied from 1:1, 2:1 and 1:2. The study results show that the CO_2/water 1:2 is the best CO_2-WAG injection ratio that gives highest additional oil recovery factor of 35.24%. Additional recovery factor given by CO_2/water ratio 2:1 and 1:1 is 1.49% and 19.52% respectively. Based on this study, the effect of CO_2-WAG ratio to oil productivity is depending of amount of water injected. Lower initial oil viscosity lead to an insignificant effect of CO_2. Proper CO_2-WAG injection ratio will give an optimum oil recovery. This works will have a great use in the CO_2-Enhanced Oil Recovery (EOR) application.

1. Introduction

Sumatera Light Oilfield is in Sarolangun, Jambi province. Geologically, this field is in the northern part of the South Sumatra back arc basin. The decline in the production rate at the field occurs due to a decrease in reservoir pressure. The low oil recovery in this field is also caused by the type of driving mechanism, that is solution gas drive [1]. Based on the simulation carried out on this field, it produces primarily with initial oil saturation of 0.65. After going through the primary recovery stage, there is a residual oil saturation of 0.44. This means that there are still plenty of oil reserves and prospects for the application of advanced oil recovery methods through the enhanced oil recovery (EOR) method. In the wake of encountering a decrease in production, the amount of residual oil reserves is still sufficiently substantial to make this field prospect for the application of methods of enhanced oil recovery (EOR). Several options of enhanced oil recovery method has been proposed in the Sumatera Basin, such as Chemical Flood in Limau Field [2], Surfactant Huff and Puff in this field and Semoga Field [3,4], cyclic steam [5], low salinity water [6], and CO_2 injection as a one-month pilot trial in this field [7]. CO_2 by far was the most suitable candidate due to the accessibility of extensive CO_2 sources in the South Sumatra Basin [8]. Meanwhile, the use of chemical mainly restricted in the stimulation process [3,4]. The result did show an increased in cumulative oil production but it is unclear how the effectiveness of the surfactant used on the project [3]. The South Sumatra is positioned third in Indonesia as a basin in which has the potential to store CO_2 reserves [9,10]. Some scientific trial of CO_2-EOR has been developed to increase oil recovery in Sumatra Light Oilfield [7]. Source of CO_2 gas can be obtained from the power plant in the Bangko Tengah block area with a CO_2 production rate of 594,435 MMscfd [8]. The Bangko area is located in the same basin as the Sumatera Light Oilfield location, namely the South Sumatra Basin, Muaraenim Formation [11].

This case study aims to determine the optimum CO_2-Water Alternating Gas (WAG) ratio in Sumatera Light Oilfield. CO_2-WAG injection is basically applied to increase CO_2 injection sweeping, which primarily uses water to control displacement mobility and to stabilize the oil surface [12]. The CO_2-WAG injection process comprises of

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simultaneous water and CO_2 injection in several cycles with the aim of increasing sweep efficiency from waterflood and minimizing viscous fingering and gas overriding through gas injection [13,14]. This technique has been increasingly popular since 1950s and the implementation has been recorded over 90% of the CO_2 injection projects [15–17]. CO_2-WAG is the preferable method due to the fact it can give higher recovery, better sweep efficiency, and cost effective than other CO_2 injection method [18,19]. The WAG parameter consists of slug size, ratio, and cycle [20]. The WAG ratio is a comparison between the amount of water injected and the number of solvents injected, both expressed in units of reservoir volume [21]. The WAG ratio has a very significant influence on the design of the WAG process. Even so, basically the WAG ratio is very dependent on reservoir wettability and the availability of gas to be injected [22].

2. Methods

Investigation of the optimum CO_2-WAG injection ratio in Sumatera Light Oilfield was carried out using a Computer Modeling Group (CMG) reservoir simulator. The homogeneous reservoir model used in this simulation has an array of technical and geological parameters as well as characteristics of certain reservoir rocks and fluids. Not all reservoirs are suitable for the application of CO_2-EOR. The reservoir characteristics must go through a screening process to identify the right candidate based on several criteria, such as reservoir geology, minimum mixed pressure, oil density, and viscosity [23]. After screening the oil reservoir for CO_2-EOR applications, a design development should be carried out for optimal oil recovery efficiency. EOR screening has been published to identify suitable reservoir candidates for immiscible CO_2 flooding, including depth deeper than 1800 ft, oil viscosity less than 600 cp, °API Gravity more than 12 and oil saturation more than 35% [24]. This model was based on the formation characteristics of Sumatera Light Oilfield in Sarolangun, Jambi. Initial oil, water, and rock properties has been set to follow the actual condition of reservoir. All of fluid and reservoir properties has been collected and estimated before by series of lab and simulation tests [25,26]. Table 1 give the information about initial reservoir pressure, reservoir temperature, the well depth, and the water-oil-contact (WOC) depth. The composition of each component used to generate the fluid model is shown by Table 2. In this work, the WINPROP that mostly used to characterize the reservoir fluid is used first, then the reservoir fluid model will be imported to CMG GEM which is specialized for compositional simulation. Meanwhile, for fluid-rock interaction, special core analysis (SCAL) test has been done in the lab and the relative permeability curve generated from the test is used in this model [1]. Fig. 1 shows the relative permeability curve.

3. Case study

Determination of injection scenarios in this study refers to some previous simulation studies, which are commonly used ratios were carried out including 1:1, 1:2, 2:1, 1:3 [27–29]. In addition, the selection of ratios is also carried out based on the research objectives to observe the influence of water and CO_2 gas. Therefore, in this study three CO_2-WAG injection scenarios were carried out. Scenario 1 is CO_2-WAG injection with a ratio of CO_2 and water 1:1, scenario 2 with a ratio of 2:1, and scenario 3 with a ratio of 1:2. Slug size of 0.6 pore volume (PV) is used in all three scenarios, with different injection ratios. In determining the WAG ratio, it is very crucial to maintain the amount of water and gas injected. Too much water can cause water tongue in the bottom of the reservoir and macroscopic displacement. In addition, too much gas can also cause the formation of gas tongue at the top of the reservoir so that the sweep efficiency becomes weak [13]. Considering the decrease in flow rate at base case, CO_2-WAG injection in the study began from the 11th month to the 33rd month. The injection simulation consists of 4 cycles. Each cycle of time consists of two parts, the first part is the gas injection time, the second part is the water injection time. Details of the number of injection fluids for one cycle are shown in Table 3. WAG injection in this study begins with CO_2 injection. According to previous study who conducted labora-

Table 1
Formation characteristic of Sumatera Light Oilfield.

Parameter	Value
Reservoir Pressure	1267 psi
Reservoir Temperature	158.5 °F
Saturation Pressure	993 psi
Well Depth	3045 ft
Water Oil Contact (WOC)	3080 ft

Source: [Muslim & Permadi, 2015].

Table 2
Reservoir fluid composition.

Component	Mol%
CO_2	0.29
CH_4	19.66
C_2H_6	3.07
N_2	0.01
C_3H_8	3.33
IC_4	1.32
NC_4	2.02
IC_5	1.56
NC_5	1.15
NC_6	1.63
C07-C09	34.554862
C10-C11	14.994047
C12-C14	10.211792
C15+	6.1992985

Source: [Muslim & Permadi, 2015].

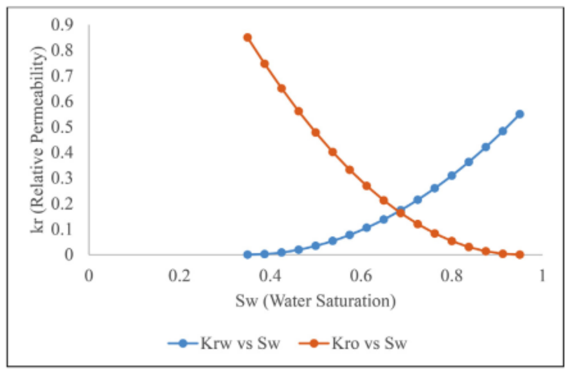

Fig. 1. Relative permeability curve of Sumatera Light Oilfield.

Table 3
Amount of injected fluid in single WAG cycle.

Scenario	CO_2 Injected (ft^3)	Water Injected (bbl.)
Base case	–	–
Ratio CO_2/Water 1:1	1747	311
Ratio CO_2/Water 2:1	2330	207
Ratio CO_2/Water 1:2	1165	414

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tory studies using two sets of cores, it is known that the WAG immiscible that starts with gas injection will provide higher oil recovery [30].

4. Results and discussion

In this study, reservoir pressure distribution during the injection period did not exceed the minimum miscibility pressure (MMP) value, so CO_2-WAG injection in this study was included in the immiscible flooding category. The effect of various CO_2-WAG injection ratios on the rate of oil production in Sumatera Light Oilfield is shown in Fig. 2. The highest production rate is achieved with a ratio of 1:2. In this scenario, an increase in the oil flow rate starts at the end of the second cycle. Meanwhile, at a 1:1 ratio, the increase in production rates occurs in the third cycle. While the new 2:1 ratio shows an increase in flow rate when entering the fourth cycle. Table 4 shows the oil recovery factor for the three scenarios.

This clearly shows that the efficiency of displacement volume in Sumatera Light Oilfield is more affected by water than the effect of CO_2 flooding. The function of water on WAG injection immiscible helps control gas mobility and helps increase sweep efficiency [20]. This happens because if only the gas phase is injected, then microscopic sweep efficiency increases. The use of gas injection can increase displacement efficiency, but under certain conditions [13]. This process usually gives sweep efficiency which is weaker because it requires more injection volume. In addition, in this study, the value of CO_2 utilization is also relatively small, sequentially from a ratio of 1:1, 2:1 and 1:2 is 0.05 MSCF/STB, 0.1 MSCF/STB and 0.02 MSCF/STB. The efficiency of oil recovery from the WAG process can be caused by one or more of the following factors: increased volumetric sweep, decreased oil viscosity, oil swelling effect, lowered interfacial tension (IFT), decreased in saturation oil residual (S_{or}) [31].

The effect of CO_2 in reducing oil viscosity in this study is almost insignificant. This is caused by initial low oil viscosity, which is only 0.39 cp. CO_2 dissolved in oil can reduce oil viscosity [32]. However, the overall decrease in viscosity depends on the viscosity of the initial oil. The decrease in oil viscosity will be greater if the initial oil viscosity is also high. Fig. 3 shows changes in oil viscosity in each scenario. At base case, oil viscosity increased around 34% from 0.39 cp to 0.521 cp. Increased oil viscosity occurs when the reservoir pressure is below the bubble point pressure. This causes the gas to escape its solubility with oil [33]. Meanwhile, oil viscosity in three CO_2-WAG scenarios initially increased to 0.524 cp, then decreased when entering the end of the first cycle. The biggest decrease in viscosity from the highest condition was obtained in the scenario with a ratio of 2:1, which decreased more than 1.5%. This ratio is a WAG injection with more CO_2. Injection with a 1:1 ratio only reduced the viscosity not more than 1% from the base case. This value is less than the decrease in viscosity given by a 2:1 ratio. This means that in a greater amount, the role of CO_2 gas in reducing viscosity in this field is also greater.

Meanwhile, in the 1:2 injection scenario, the increase in viscosity occurs again at the end of the third cycle and the end of the fourth cycle. Viscosity initially decreases due to solubility of CO_2 gas with oil. Then at the end of the third cycle, there is an increase in pressure as in Fig. 4, so that it reaches the bubble-point pressure. In this condition, CO_2 gas is released from the oil so that the viscosity increases. The same situation also occurs in the fourth cycle, so that the oil viscosity increases again. The effect of water injection in CO_2-WAG injection in this study provides a good pressure maintenance effect. In Fig. 4, it can be seen in the three scenarios where the pressure increase occurs at the end of the injection cycle, which

Table 4
Oil recovery factor for all scenarios.

Scenario	Oil Recovery Factor, %	Additional Oil Recovery Factor, %
Base case	24.27%	–
Ratio 1:1	43.79	19.52
Ratio 2:1	25.76	1.49
Ratio 1:2	60.21	35.94

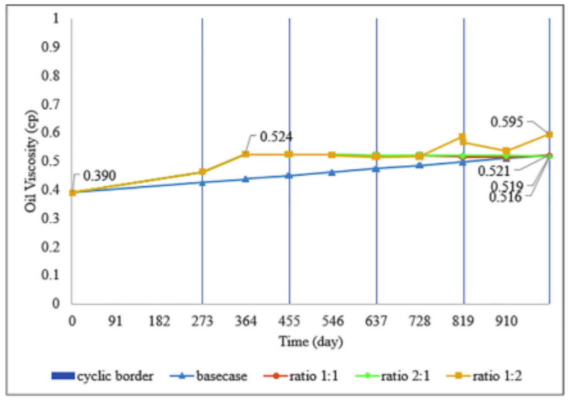

Fig. 3. Effect of CO_2-WAG injection ratio on oil viscosity.

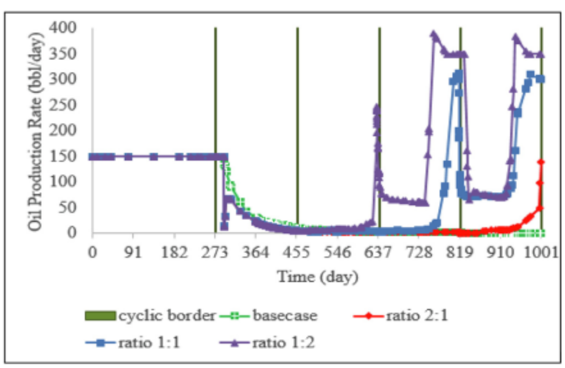

Fig. 2. Effect of CO_2-WAG injection ratio on oil production rate.

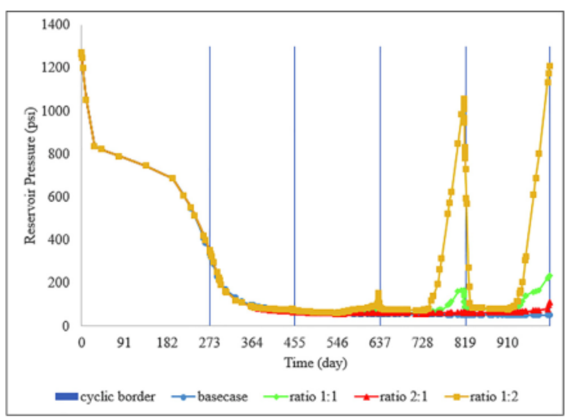

Fig. 4. Effect of CO_2-WAG injection ratio on reservoir pressure.

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is when the water injection is carried out. The amount of pressure increase that occurs is proportional to the amount of water injected. The more amount of water in the CO_2-WAG ratio, the higher the increase in reservoir pressure.

Injection with a 1:2 ratios experienced the fastest decrease in oil saturation among other scenarios (Fig. 5). In addition, the saturation reduction value produced is also the most. That is, in this field, the more amount of water injected, the faster the decrease in oil saturation and the greater the decrease in saturation value. Fig. 6 shows the oil saturation distribution in Sumatera Light Oilfield after CO_2-WAG injection in each scenario. The 1:2 ratio gives the best sweeping effect among other scenarios. Color distribution on each grid illustrates different saturation values. The red color is the highest value and the dark blue is the lowest value. Color spread at a 1:2 ratio appears to be dominated by blue. While the 2:1 ratio is still dominated by red, meaning there are still many areas that have high oil saturation. Decreases in saturation oil residual (S_{or}) occur due to three-phase flow and the influence of hysteresis phenomena [31]. In the water wet system, the gas trapped during the imbibition cycle can cause oil mobilization at low oil saturation and lead to an effective decrease in the saturation of three-phase oil residuals. The previous study which carried out WAG immiscible in the water wet system with saturation oil initial (S_{oi}) 0.733 and 0.692 which was started with gas, decreased saturation to S_{or} 0.075 and 0.191 for 1.5 cycles [30].

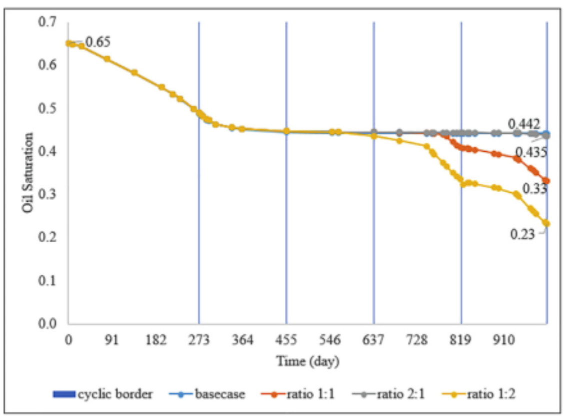

Fig. 5. Decrease of oil saturation by time.

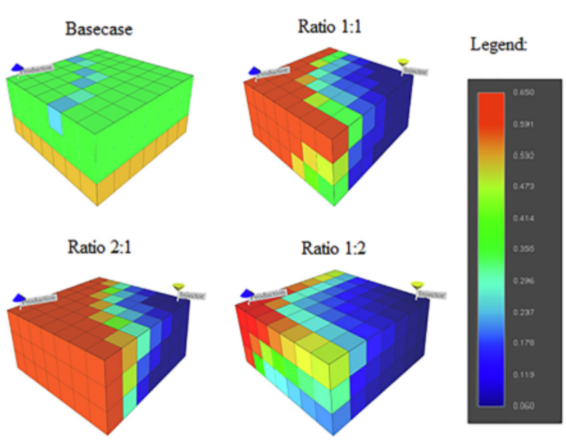

Fig. 6. Distribution of residual oil saturation.

5. Conclusion

Based on research on determining the CO_2-WAG ratio that has been carried out, it can be concluded that the optimum CO_2/water ratio at CO_2-WAG injection is 1:2 with an additional oil recovery factor of 35.94%. The results indicate that the effect of CO_2-WAG ratio to oil productivity is depending on the amount of water injected. This work also underlined the importance of initial value of oil viscosity to the effect of CO_2 viscosity reduction. Proper CO_2-WAG injection ratio will yield optimum oil recovery. The 1:2 CO_2/WAG ratio is considered as the best scenario due to the highest oil recovery and lower CO_2 volume injected.

CRediT authorship contribution statement

Muslim Abdurrahman: Conceptualization, Methodology, Supervision, Project administration, Funding acquisition. **Fiki Hidayat:** Conceptualization, Data curation, Investigation, Formal analysis, Writing - original draft, Writing - review & editing. **Ully Z. Husna:** Investigation, Resources, Software, Visualization, Writing - original draft. **Agus Arsad:** Supervision.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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