A Novel Correlation on MMP Prediction in CO2-LPG Injection System: A Case Study of Field X in Indonesia

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Abstract: In order to increase Indonesia's petroleum production, which mostly comes from the marginal field, an Enhanced Oil Recovery (EOR) method is needed. One EOR method that is proven to be able to increase large oil yield is mixed CO2 injection. In implementing EOR CO2 injection mixed, the Minimum Reliability Pressure (MMP) value is the key to success. One of the problems faced by oil fields in Indonesia in carrying out EOR of mixed CO2 injection is that the reservoir pressure has dropped due to old age making it difficult to inject with MMP pressure above the reservoir pressure. The solution that can be done to overcome this is by reducing the MMP value using Liquified Petroleum Gas (LPG).This study will determine the optimal method of LPG use to reduce CO2 injection MMP values from Field X fluid in South Sumatra. Then, the MMP value in various conditions will be determined using a slimtube simulation which will be used to make a correlation to determine the MMP value. From the results of the study, in principle mixing LPG with CO2 will reduce the MMP value optimally. In addition, the average MMP value dropped by 29.5% with an increase in the composition of LPG in the gas mixture of CO2 - LPG injection by 30%, the MMP value increased by 23% with a change in hexane plus molecular weight of 27.5% higher than before, and the MMP value increased by an average of 13.4% with an increase in temperature of 20%.The resulting correlation is formed using parameters that have a significant influence on the determination of the MMP value. The resulting correlation has R-Squared of 98.65%. The correlation is then tested with MMP values previously determined through a slimtube simulation and produces an Average Absolute Relative Error (AARE) value of 4.52%. Correlation was then re-tested against the correlations of other MMP determinations using 9 fluid MMP data from other literature. The result is the proposed correlation produces an AARE value of 10.82%.

1 INTRODUCTION

Production of crude oil and condensate in Indonesia is 803,000 barrels per day in 2017 (Statistics of the Ministry of Energy and Mineral Resources). Meanwhile, Indonesia's national oil consumption currently reaches 1.6 million barrels per day and continues to increase (Statistical Review of World Energy 2017 BP). This means that crude oil production in Indonesia is smaller than consumption of petroleum as an energy source. In addition, Indonesia's petroleum production has experienced a downward trend of 1.35% every year since 2012 (Statistics of the Ministry of Energy and Mineral Resources). Indonesia needs to make breakthroughs in order to increase its petroleum production.

One such breakthrough is Enhanced Oil Recovery (EOR). The breakthrough is a step to increase oil acquisition if a field has gone through the primary recovery stage, which is the stage where the reservoir fluid can flow by itself; and the secondary recovery stage, which is the stage where the field is injected with gas or water to maintain pressure in the reservoir so that it does not drop dramatically (Lake, 1989). EOR is the third step or tertiary recovery.

One type of EOR method that is quite well known is CO2 injection. CO2 injection is still rarely used in fields in Indonesia. There are 2 mechanisms for CO2 injection, namely: miscible injection (mixed injection) and immiscible injection (injection not mixed). From the literature study conducted, it is known that miscible injection produces oil that is greater than immiscible injection. This also underlies the research focus on the miscible CO2 injection mechanism.

In performing miscible CO2 injection, the Minimum Miscibility Pressure (MMP) value is very im-

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portant to know. MMP is the minimum pressure so that the reservoir fluid and injection fluid can mix. Unfortunately, the value for miscible CO_2 injection is quite high considering the reservoir pressure has drastically reduced because of the primary and secondary production stages. As a result, the injected CO_2 cannot mix with the oil in the reservoir and the miscible CO_2 injection mechanism can be considered a failure.

There are two methods for this problem, namely:

- Injecting another gas into the reservoir so that the intermediate component (C2-C6) of hydrocarbons in the reservoir increases before injecting CO_2, or
- Mixing the other gases with CO_2 gas on the surface then inject the mixed gas into the reservoir. Both of these methods are carried out so that the MMP value of the reservoir fluid against CO_2 can decrease and the fluid can mix at the current reservoir pressure.

The mixed gas is generally a hydrocarbon intermediate component such as propane and butane. It was also known that the biggest decrease in MMP was in mixing between CO_2 and butane with a ratio of 40:60 (Muslim dan Permadi, 2016; Permadi, 2014; Rommerskirchen and Nijssen, 2016). In this study, the gas used as a mixture of CO_2 to be injected is LPG, assuming the main constituent is propane.

Field X in South Sumatra is one field that has been operating since 1987. The field includes the old field category (brownfield). The Feasibility Study (FS) conducted by the Bandung Institute of Technology (ITB) team on Field X showed that the EOR method that was right for the field was CO_2-EC miscible so that the value of MMP was needed. Fluid data from Field X was obtained from reservoir and fluid description data in the Final Report of Feasibility of Field X in 2009. This study will try to determine CO_2 injection MMP from Field X fluid in various conditions using a mixture of LPG on gas injection. The ultimate goal of this study is to form a correlation that can be used to determine the value of MMP injection of pure CO_2 or CO_2 - LPG on Field X and compare it with other correlations that have been formed.

2 ANALYSIS ON MINIMUM MISCIBILITY PRESSURE

Minimum Miscibility Pressure (MMP) is the lowest pressure for a gas to be mixed through a multi-contact process with reservoir oil at reservoir temperature (Elsharkawy,). MMP can actually be divided into two, namely multiple contact miscibility pressure (MCMP) and first-contact miscibility pressure (FCMP). The MCMP value must be below the FCMP value (Holm, 1987; Martin and Taber, 1992). However, as explained earlier, MMP in this study uses MCMP as the definition of MMP. This is because miscibility for EOR can be achieved at pressures below FCMP and above MCMP (Zhang et al., 2004). There are several definitions of MMP CO_2 injection mathematically, namely:

- Pressure when oil is equal to or very close to the maximum final gain when 1.2 pore volume (PV) is injected (Yellig et al., 1980).
- Pressure which causes oil acquisition as much as 80% in CO_2 breakthrough and oil yield of 94% at gas to oil ratio of 40000 SCF / stb (Holm and Josendal, 1974).
- Pressure that causes oil recovery of 90% or more at CO_2 injection of 1.2 PV (Glaso, 1985).

In this study, Glaso's definition was used to determine MMP using a slimtube simulation. Some parameters that affect the MMP value are as follows.

- Reservoir temperature. An increase in reservoir temperature will increase the MMP value.
- Oil composition. The higher the composition of the intermediate component C2 - C6 and the lower the composition of the heavy component of oil, the lower the MMP value.
- Gas injection composition. The higher the composition of the intermediate component C2 - C6 gas injection, the lower the MMP value. (Zhang et al., 2015).

These parameters will be used as the main parameter to perform sensitivity and correlation formation.

MMP Correlation and LPG Injection. There are several determinants of the MMP value of injection of pure CO_2 that has been previously formed. The correlation used as a comparison in this study is the correlation of Cronquist, Lee, Yelling-Metcalfe, Orr-Jensen, Alston, Emera-Sarma, Yuan, Shokir, Chen, Ju, and Hao Zhang (Ju et al., 2012; Al-Hinai et al., 2014; Bayagub, 2017; Bon and Sarma, 2005).

Gas injection of Liquified Petroleum Gas (LPG) has a lower MMP value than the MMP value for CO_2. The use of LPG in EOR is relatively more beneficial than the use of other light hydrocarbons (Ortega, 2017). According to a study conducted by Holm, CO_2 injection can have oil yield of up to 75% while by using LPG, oil yield can reach 95%.

LPG injection will help develop oil volume, reduce oil density, and reduce oil viscosity. In addition, LPG moves residual oil that is spread in the reservoir

(Bayat, 2015). Even so, LPG costs have an expensive price. With these conditions, it is necessary to mix CO2 with LPG so that the obtained oil is higher and the price is economical (Kumar and Von Gonten, 1973). The LPG used in this study was propane (C3H8).

Slim Tube Injection Process. Slimtube simulation in IPM - PVTP vers software. 9.5 is used to determine the MMP value in various field conditions of X. The simulation of the slimtube is used because the use of the slimtube in the laboratory will take a very long time and the costs are not cheap. Slimtube modeled in this simulation has 10 cells, where each cell has a size of 2.3727 ft in the x-direction, 0.0113686 ft in the y-direction, and 0.0113686 ft in the z-direction. The porosity used for the slimtube model is taken from the average porosity of Field X, which is 0.16275. The permeability of the slimtube model is also taken from the average permeability of Field X, which is equal to 63.5 mD. The Field X reservoir depth becomes the slimtube depth input data, which is 6490 ft. To determine the MMP value, the Slimtube simulation requires a definition for the MMP value. As mentioned in the previous chapter, the MMP value is the pressure at which 90% or more oil has been obtained when injecting a gas of 1.2 pore volume into the slimtube. The results of the slimtube simulation to determine MMP under certain conditions will be displayed in the graph of recovery vs pore volume. An example of the MMP determination can be seen in Figure 1. Before determining the MMP value in various conditions, it is necessary to validate whether the fluid model to be simulated on the Slimtube in the PVTP software has the same MMP value as the fluid MMP when tested with a slimtube in the laboratory. The field X MMP oil value on the slimtube test from the laboratory test was 2820 psi. In the slimtube simulation for this validation, the CO2 injection MMP value was 2870 psi. An error of 50 psi or 1.77% is considered to be tolerable and the determination of MMP using a slimtube simulation and the fluid model in this PVTP can be started.

To do a slimtube simulation, gas injection is needed. In this study, there are 2 methods to be tested, namely injection of LPG first into the reservoir fluid and then injecting CO2 and injection of a mixture of CO2 and LPG into the reservoir fluid.

For the first method, the reservoir fluid will be injected with LPG by comparison as follows.

- 95% reservoir fluid and 5% LPG
- 90% reservoir fluid and 10% LPG
- 80% reservoir fluid and 20% LPG

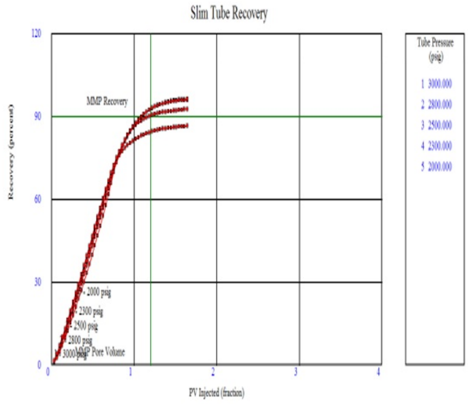

Figure 1: Example of Slimtube Simulation.

- 70% reservoir fluid and 30% LPG

Next, the value of MMP is determined by the second method. The injection gas used is as follows.

- 100% CO2
- 70% CO2 and 30% LPG
- 60% CO2 and 40% LPG
- 50% CO2 and 50% LPG

Both methods were tested with the same weight temperature and molecular weight components, namely 263,525 oF and 196,073 gr / mol. Furthermore, one method will be selected for further study by conducting sensitivity to temperature, weight of molecular weight components, and LPG composition. These parameters are selected based on literature studies that have been done before. The sensitivity for each parameter is as follows.

- Temperature (250, 263,525 and 300 oF)
- MW C6 + (196,073, 225 and 250 gr / mol)
- LPG composition (0%, 30%, 40%, and 50%)

3 RESULTS AND DISCUSSION

The next step is to form a correlation that can determine the MMP value for Field X with the constituent variables in the form of parameters that are significant to the MMP value. The formation of this correlation uses the Design of Experiment (DOE) method as described previously. The DOE feature in MINITAB 17 software with the Two-Level Factorial Design model requires 8 input data in the form of MMP values because there are 3 parameters to be tested. Each parameter requires input data in the form of maximum and minimum sensitivity values. Then, the MMP value for each pair of sensitivity values between parameters was included in MINITAB 17. The input data for this DOE can be seen in Table 7.

Table 1: DOE Input Data.

MW C6+	Co2	Temperature (°f)	MMP(psi)
196.073	100	250	2795.00
196.073	50	250	1336.33
196.073	100	300	3025.00
196.073	50	300	1788.75
250	100	250	3455.00
250	50	250	1920.00
250	100	300	3900.00
250	50	300	2122.82

The results obtained for the DOE in this study can be seen in the Pareto Chart and Normal Plots shown in Figure 2 and Figure 3. In the Pareto Chart, it can be seen that the three parameters have a significant effect on the determination of the MMP Field X value. This can be seen from 3 the parameter bar has crossed the minimum line which indicates the boundary of a parameter has a significant effect or not. From the Pareto Chart, it can be seen that the parameter with the most significant effect is the composition of CO2 - LPG, then followed by the molecular weight of C6 +, and finally the temperature. This shows that the effect of the composition of CO2 - LPG is the most important parameter in reducing MMP on case of Field X. In addition, Normal Plot also shows that all three parameters have a significant effect on MMP values and CO2 - LPG composition parameters having the farthest point from the normal line. This again confirms how the composition of CO2 - LPG has the most significant effect. The three parameters are to the right of the normal line which indicates that the higher the value of the parameter, the MMP value will also increase (positive effect). This is because in this DOE test the composition parameters of CO2 - LPG only use CO2 input as a parameter so that the increase in CO2 composition will certainly increase the MMP value.

Furthermore, MINITAB 17 software forms a correlation consisting of these parameters. The correlation formed is a linear correlation. The correlation is as follows.

$$\boldsymbol{MMP = -4075 + 11.37 \times (MW\ C6) + 30.04 \times (CO2) + 6.65 \times (T)}$$

From the correlation, the R-Squared value is 98.65%, with the Standard Error of Regression (S) of 136,754. The correlation summary model is shown in Table 2. This shows that the resulting correlation is very good and has a high match with the input data.

Furthermore, a feasibility test for the correlation

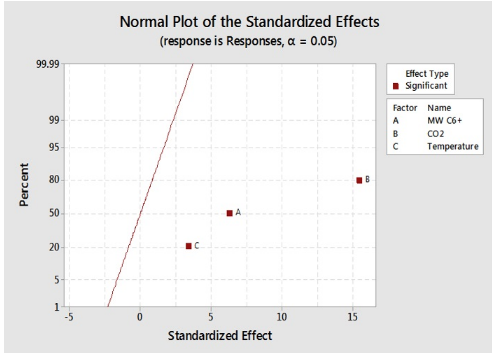

Figure 2: Normal Plot of Parameter Effects.

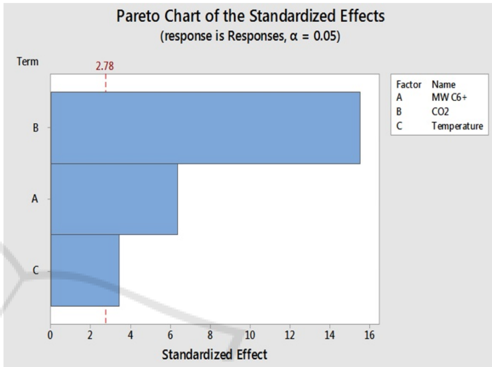

Figure 3: Pareto Chart of The Correlation.

that has been formed is carried out by calculating the previous MMP value. From the results, it can be seen that the Average Absolute Relative Error (AARE) value is 4.52% with Maximum Absolute Relative Error (MARE) of 13.22%. In addition, a graph plot was carried out between the slimtube MMP value and the MMP value calculated using correlation. The results can be seen in Figure 4. The R-Squared generated in this graph is 96.47% which means that this correlation is considered to determine the MMP value for Field X.

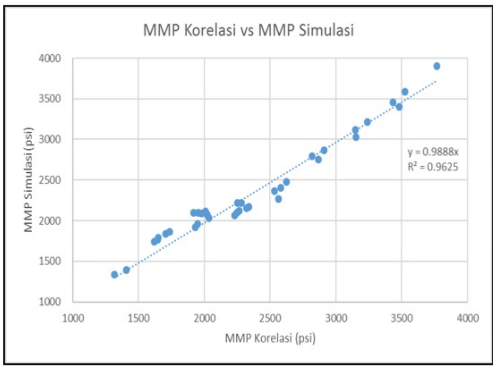

Figure 4: Accuracy of the New MMP Correlation.

Table 2: Correlation Summary.

S	*R-sq*	*R-sq(adj)*	*R-sq(pred)*
136.754	98.65%	97.64%	94.62%

Correlations that have been formed will then be compared with various other correlations. There are 12 correlations that will be used to test the feasibility of the correlations that have been formed. The 12 correlations were the correlations of Cronquist, Lee, Yelling-Metcalfe, Orr-Jensen, Alston, Emera-Sarma, Yuan, Shokir, Chen, Ju, and Hao Zhang. This correlation will be used to calculate MMP values in various oil conditions. There are 9 oil data with various compositions and temperatures obtained from various literature. The oil data will be used as input data for calculating MMP values with the correlations mentioned above. Comparison between MMP correlation values and literature MMP is shown in Figure 5. In addition, the AARE value of each correlation is shown in Figure 6.

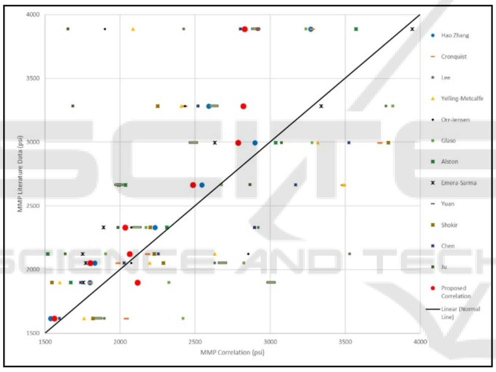

Figure 5: Comparison of MMP Calculation Correlation.

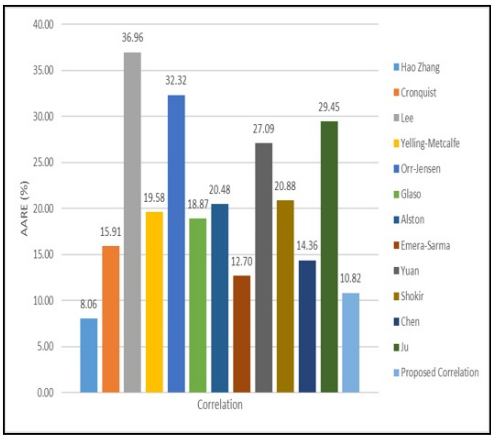

Figure 6: AARE Comparison of MMP Correlations.

From the results of calculations that have been made, it can be seen that the correlation proposed in this study has AARE and MARE values of 10.82% and 27.18%. Meanwhile, the correlations of Cronquist, Lee, Yelling-Metcalfe, Orr-Jensen, Alston, Emera-Sarma, Yuan, Shokir, Chen, Ju, and Hao Zhang produced an AARE score of 15.91%, 36.96%, 19.58%, 32.32% respectively. , 18.87%, 20.48%, 12.70%, 27.09%, 20.88%, 14.36%, 29.45%, and 8.06%. This means that the correlation formed has quite good results because other correlations have a greater AARE value, except for the correlation of Hao Zhang who has AARE of 8.06%. This can occur because the correlation formed in this study uses C6 + heavy components while the input data is C7 +. In addition, the parameters for the formation of correlation in this study have not been checked with a broader value. Even so, the results of calculating the MMP value using the correlation formed from this study can be said to be better than some of the existing correlations.

4 CONCLUSIONS

Based on the studies that have been done, the obtained conclusion as follows.

- The method of reducing CO2 injection MMP by mixing LPG and CO2 first successfully reduces MMP significantly more than the CO2 injection MMP reduction method by mixing LPG into Field X oil. Thus, the mixing method of LPG and CO2 is the most optimal method to reduce CO2 injection MMP in Field X.
- In Field X, the composition of CO2 - LPG, C6 + molecular weight, and temperature are parameters that significantly influence the CO2 injection MMP value. The average MMP value decreased by 29.5% with an increase in the composition of LPG in the gas mixture of CO2 - LPG injection by 30%, the MMP value increased by an average of 23% with a change in molecular weight of hexane plus of 27.5% higher than before, and the MMP value increased by an average of 13.4% with an increase in temperature of 20%.
- The resulting correlation to determine the value of MMP of CO2 injection in Field X is as follows. MMP = - 4075 + 11.37 x (MW $C6$) + 30.04 x (CO2) + 6.65 x (T). The correlation has R-Squared of 98.65% and AARE between the MMT results of the slimtube simulation and the correlation is 4.52%.
- The resulting correlation has AARE of 10.82% and MARE of 27.18% when tested using data

from other literature. Correlations of Cronquist, Lee, Yelling-Metcalfe, Orr-Jensen, Alston, Emera-Sarma, Yuan, Shokir, Chen, Ju, and Hao Zhang produced AARE values in a sequence of 15.91%, 36.96%, 19.58%, 32.32%, 18.87% , 20.48%, 12.70%, 27.09%, 20.88%, 14.36%, 29.45%, and 8.06%. Compared to other correlations, the correlation formed in this study resulted in a fairly good MMP value because it has a smaller AARE value, except the Hao Zhang correlation which has an AARE value of 8.06%.

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