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CO₂ MMP determination on L Reservoir by using CMG simulation and correlations

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Abstract. CO₂ minimum miscibility pressure (MMP) is an important parameter in CO₂ enhanced oil recovery (CO₂-EOR) process. The CO₂ injection must be conducted at the pressure equal or greater than MMP. The aim of this study is to determine CO₂ MMP by using one-dimensional CMG simulation model and CO₂ MMP correlations on L reservoir. To make an accurate simulation model and to choose the most satisfying correlation, it is necessary to validate by comparing the obtained CO₂ MMP with experiments in the laboratory on eight type oil from various fields. The result showed that Zhang's correlation is the best correlation which have -13.9% average percentage of errors while using the CMG simulation model shows the average percentage errors approximately -6.5 %. Using Zhang's correlation, CO₂ MMP on L reservoir is about 3166 psia and from CMG simulation, CO₂ MMP equals to 3219 psia.

1. Introduction

In the primary stage, oil flows to the surface due to existing reservoir pressure. During primary recovery, typically only 10 – 20 percent of original oil in place is produced. As reservoir pressure depletes, water or natural gas is injected to reservoir to increase reservoir pressure and displace oil to production well and this stage is usually called the secondary stage. In this stage, incremental recovery ranges from 15 % to 25 %. At the end of secondary recovery, a significant amount of residual oil still remains in the reservoir and becomes the target of Enhanced Oil Recovery (EOR) process.

One of the most important EOR processes is Carbon Dioxide (CO₂) flooding [1,2]. Currently, about 130 commercial CO₂ EOR operations have been conducted around the world. In designing Carbon Dioxide (CO₂) flooding, Minimum Miscibility Pressure (MMP) is key parameter to recover all the oil within the porous medium and also to obtain the maximum displacement efficiency [3-6]. MMP is the lowest pressure at which the injected gas can achieve dynamic miscibility with the oil in the reservoir. MMP can be measured accurately with experimental methods in laboratory [7-9]. However, these experimental methods are very costly and time-consuming.

E.M. Mansour et al., Ginting, M., Lai Fengpeng et al., and Metcalfe, R. S., presented a study of the effect of carbon dioxide (CO₂) injection on miscible flooding performance and focuses on designing and constructing a new miscibility lab with low cost by setup a favorable system for carbon dioxide (CO₂) injection [10-13]. Olawale Adekunle et al., Lee, J. I., and Orr Jr. et al., reported from their study provide MMP data for a range of injection fluids that can be used in planning pilot tests for miscible gas injection by using an equation of state phase-behavior program has shown similar results with the RBA MMP results [14-16].



The other methods to predict MMP not only by using empirical correlations among other developed by Alston R.B. and Yuan et al. [17,18] but also numerical simulation model by Shokir and Vulin D. [19,20]. Various empirical correlations for the estimation of MMP are available in literatures. The aim of this study is to predict CO₂ MMP of L reservoir, by using one-dimensional CMG simulation model and the best CO₂ MMP correlations on L reservoir.

2. Method

This study used two techniques in order to determine CO₂ MMP from L Reservoir, which are simulation with Computer Modelling Group (CMG) and calculation using several correlations. The correlations that are used, are correlations: Yellig-Metcalf, Holm-Josendal, Cronquist, Lee, Orr-Jensen, Alston, Yuan, Chen and Zhang correlations [6-8, 15-18,21,22].

To validate the fittest correlation for L Reservoir, we calculate MMP of eight oil samples from various literatures. After that, the results from all of this correlation are cross-checked with the real results from the laboratory. Finally, correlation technique with the smallest percentage of errors with laboratory test are used.

In second technique, CO₂ MMP simulation on L reservoir was conducted using CMG. After that, the result from this simulation was validated with the eight oil samples.

2.1. L reservoir fluid composition

L reservoir is located at a depth of 1608.5-1610.5 ft with temperature 278.5°F. The composition reservoir fluid can be seen in the Table 1.

Table 1. L reservoir composition.

Component		Mole Percent	Weight Percent
Hydrogen Sulfide	H ₂ S	0.0000	0.0000
Carbon Dioxide	CO ₂	11.0672	3.9889
Nitrogen	N ₂	0.1809	0.0415
Methane	C ₁	16.0882	2.1138
Ethane	C ₂	3.3207	0.8178
Propane	C ₃	7.4013	2.6729
Iso-Butane	i-C ₄	3.1615	1.5049
n-Butane	n-C ₄	2.4822	1.1815
Iso-Pentane	i-C ₅	2.3275	1.3753
n-Pentane	n-C ₅	1.2917	0.7632
Hexanes	C ₆	3.8313	2.7040
Heptanes Plus	C ₇ ⁺	48.8475	82.8362
Total		100.0000	100.0000

2.2. Correlation analysis

Test fluid data was taken randomly from published papers. The compositions, MMP, and temperatures of experiment of the eight fluids (A to H) can be seen in Table 2. From composition and temperature known in Table 2, the MMP of each sample oil is calculated by Yellig-Metcalf, Holm-Josendal, Cronquist, Lee, Orr-Jensen, Alston, Yuan, Chen and Zhang correlations [6-8, 15-18,21,22].

Table 2. Fluid data for correlation analysis.

	A	B	C	D	E	F	G	H
H ₂ S	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CO ₂	0.06	0.12	0.06	0.58	0.00	0.00	0.02	0.05

Table 2. Cont.

O ₂	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
N ₂	0.39	0.65	0.00	0.60	0.00	0.10	0.00	0.00	0.42
C ₁	13.88	18.50	0.37	9.90	17.07	24.15	17.04	15.66	
C ₂	1.75	1.79	0.37	2.72	6.41	11.46	6.90	7.09	
C ₃	4.05	1.87	0.86	4.98	7.82	8.62	6.01	11.48	
i-C ₄	1.65	0.84	0.96	1.09	0.67	1.00	0.02	0.73	
n-C ₄	3.06	1.37	1.24	4.91	6.05	2.77	4.29	4.49	
i-C ₅	1.67	1.64	1.88	2.16	0.98	1.63	0.26	1.55	
n-C ₅	1.57	0.99	1.54	3.73	1.71	1.42	0.71	1.55	
C ₆	2.70	2.58	5.46	4.85	5.19	3.81	5.21	3.88	
C ₇ ⁺	69.22	69.65	87.26	64.48	54.10	45.04	59.54	53.10	
MMPlab (psia)	1680	1700	3160	1190	1550	1800	1300	1535	
T (F)	145	156	250	105	109	104	109	120	

2.3. Simulation model

The model will be created using parameters in the table 3.

Table 3. Parameters of the slim tube simulation model.

Parameter	Value	Unit
Porosity	0.388	
Permeability	700	mD
Lenght	20	Grid
Grid	2.04	Feet
Injection Rate	0.2	cc/min
Inside Diameter	0.45	Cm
Injected Fluid	100% CO ₂	

The model is a 2D model which presents a slim tube device in the laboratory.

3. Results and discussion

3.1. Correlation test result

The equations of correlations that is used to determine Minimum Miscibility Pressure can be seen in in reference4. The result of MMP which is calculated from correlation compares with MMP laboratory can be seen in table 4.

Table 4. Correlation analysis result.

Correlations	A	B	C	D	E	F	G	H	Error (%)	
									Range	Average
Yellig-Metcalf	1822.5	1957.5	3107.3	1279.1	1201.9	1263.6	1097.9	1297.5	-15.1-29	14.5
Holm-Josendal	1500	1800	-	1600	1800	1600	1700	1100	-34.5-28.3	19.6
Cronquist	1287.4	1481.6	4375.1	1352	1595.5	1595.1	1706.2	1121.8	-38.5-26.9	20.1
Lee	1956.7	2169.5	4600.8	1299.5	1357.3	1285.3	1357.3	1525.1	-45.6-28.6	18.1

Table 4. Cont.

Orr-Jensen	1528.5	1709.6	3863.1	980.6	1028	969	1028	1166.6	-22.3-46.2	21.8
Alston	853	1116	4061	1149.2	1416.8	1376.3	1635.4	1045	-28.5-49.1	25.7
Yuan	1102.3	1491.2	4652.9	1576.9	1945.5	1757.4	2144.5	812.1	-65-47.1	33.3
Chen	1787	2150.4	3293.7	1322.3	1455.1	1402.3	1574.4	1236.4	-26.5-22.1	14.6
Zhang	1567.8	1833.4	3348.8	1499.8	1654.4	1617.8	1737.5	1316.3	-33.7-14.2	13.9
MMP Experimental (psia)	1680	1700	3160	1190	1550	1800	1300	1535		

From Table 4, it can be seen that the range of error of all correlation is quite high. The Zhang correlation has a smallest average percentage of error, which is equal to 13.9%. The large of percentage of error means that none of correlations accurately to predict Minimum Miscibility Pressure (MMP) as each correlation relates to a unique reservoir and fluid conditions. This makes the Zhang correlation is the best correlation among the eight correlations that have been provided. Later the L well data will use the Zhang correlation to determine the MMP size.

3.2. CMG model simulation result

The CMG simulation model was run several times for the eight test composition fluids data used as composition fluid model. The results of the MMP value and the percentage of errors from this simulation model can be seen in table 5.

Table 5. Model simulation result.

Oil Samples	Minimum Miscibility Pressure, psia			% Error
	CMG Simulation	Laboratory		
A	1718	1680		-2.3
B	1733	1700		-1.9
C	2980	3160		5.7
D	1160	1190		2.5
E	1450	1550		6.5
F	1870	1800		-3.9
G	1370	1300		-5.4
H	1493	1535		2.7

Overall MMP prediction is good enough, giving the percentage of error of MMP between -5.4 % to 6.5 %. The least percentage of errors is -1.9 % or calculated MMP is greater 1.9 % than laboratory MMP.

3.3. MMP calculation of L reservoir

Calculation of MMP of L Reservoir will be carried out using the Zhang correlation and CMG simulation model. Using Zhang's correlation, the MMP of L reservoir is obtained as 3166 psia.

The CMG simulation model has been made and was run with difference CO₂ injection pressure. The percentage oil recovery calculated at 1.2 PV of CO₂ injected each pressure is plotted as a function of pressure. Oil recovery increases rapidly with increasing pressure then flattens out when MMP is reached as shown in Figure 1.

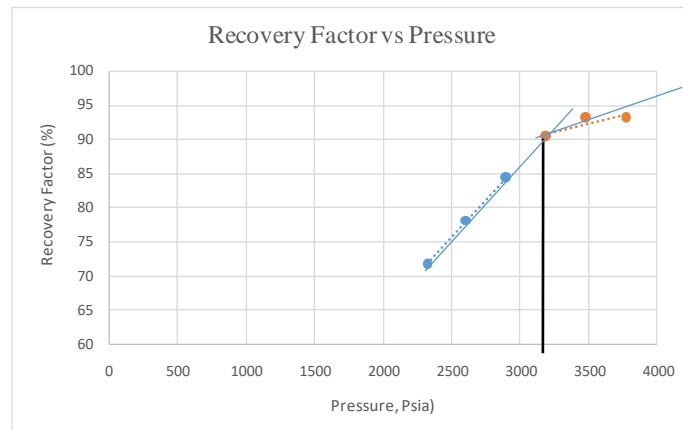


Figure 1. The plot of the CMG simulation results on L well fluid data.

In figure 1, it can be seen that the MMP plot results show MMP from L reservoir is 3219 psia.

The percentage of error of CMG model simulation is smaller than Zhang correlation, which is 13.9 %, hence its recommended to used CMG simulation model to predicted Minimum Miscibility Pressure of L Reservoir. This determination is based on the error percentage between the comparison of the MMP value from the simulation and the laboratory which is 5%.

4. Conclusion

Based on the eight-sample used in this study, the Zhang correlation is better than others correlation. Actually, The CO₂ MMP of L reservoir is about 3200 psia. By Zhang correlation obtained the CO₂ MMP value of L reservoir is about 3166 psia, while based on CMG model obtained the CO₂ MMP value of L reservoir is about 3219 psia. So, the percentage of error of CMG model simulation is smaller than Zhang correlation, which is 13.9 %, hence its recommended to used CMG simulation model is better than Zhang Correlation to predicted Minimum Miscibility Pressure of L Reservoir.

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