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Correlation of Minimum Miscibility Pressure for Hydrocarbon Gas Injection In Southern Iraqi Oil Fields

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Abstract— One of the most important enhanced oil recoveries methods is miscible displacement. During this method preferably access to the conditions of miscibility to improve the extraction process and the most important factor in these conditions is miscibility pressure. This study focused on establishing a suitable correlation to calculate the minimum miscibility pressure (MMP) required for injecting hydrocarbon gases into southern Iraq oil reservoir. MMPs were estimated for thirty oil samples from southern Iraqi oil fields by using modified Peng and Robinson equation of state. The obtained PVT reports properties were used for tuning the equation of state parameters by making a match between the equation of state results with experimental PVT data. The values of the MMPs inputs into the statistical program to find a correlation for the value of miscibility pressure with the properties and composition of the reservoir oil and injected gas. Using a nonlinear formula, a good correlation was obtained. When comparing the present correlation with the many measured data, a superbly result of present correlation was obtained.

Keywords—Correlation, Gas injection, Minimum miscibility pressure.

1. Introduction

Injection of a mixture of hydrocarbon gases is one of the most commonly applied (EOR) processes because there was a large amount of gas usually associated with crude oil, which can be separated and reinjected into the reservoir[2]. The gas injection can be a very efficient method for improving the production of oil, especially in the case when miscibility develops during the oil displacement process[14]. The essential objective of miscible gas injection is to get better local displacement efficiency and reduce (irreducible) residual oil saturation below much that typically obtained by the immiscible process. MMP is an important design parameter used during miscible gas injection. Where MMP is the lowest pressure for which the injection gas can develop miscibility with reservoir oil at reservoir temperature. There are different methods for the MMP estimation such as experimental measurement (for example the slim tube, vanishing interfacial tension, high-pressure visual sapphire cell, rising bubble apparatus), computational methods that depending on Equation of State and there were empirical correlations [1,9,17].

The main approach for this work would be to make a semi-empirical correlation based on EOS for MMP estimation for hydrocarbon gas injection applicable in the southern Iraqi oil fields.

It was found that the independent variables for the predicated correlation are; reservoir temperature, mole fraction of intermediate component and molecular weight of C₆₊ in reservoir fluid, methane mole fraction and molecular weight of C₂-C₅ in the injected gases.

Kuo,(1985)[18] applied a new correlation for calculating MMP by enriched gas injection. This correlation can be used to determine MMP for fixed gas composition or predict C₁concentration for a given pressure. The new correlation compared with the results of the slim tube apparatus and showed a good agreement with an average prediction error on MMP of less than 4%.

Firoozabadi et al,(1986) [1] suggested a generalize correlation to predict MMP of reservoir fluids by use lean natural gas or N₂ for injection. It was considered that the influencing factors are the concentration of the intermediate component, reservoir temperature and molecular weight of C₇₊, without considering gas composition effect.

Zarenezhad,(2016)[5] developed a new correlation as a modification to the Firoozabadi and Aziz correlation. This correlation is a function of the most influencing variables such as C_2 – C_6 composition and C_{7+} molecular weight in the reservoir oil, reservoir temperature, C_{2+} mole fraction and C_{2+} molecular weight in the injected gas. Comparison of the important existing correlations with the suggested correlation shows that this correlation is more accurate than the existing correlations with (AAD = 2.61%)and ($R^2 = 0.9681$). The experimentally measured data are in excellent agreement with the predicted results. Therefore the proposed new correlation was considered a reliable correlation for prediction accurate MMP value for EOR process.

2. Area of Study.

Thirty oil samples were collected from many formations that are located in southern Iraqi oil fields, for example, Abo Grab filed/Asmari formation/well 1 as illustrated below in Table 1.

Table 1: Sources of PVT samples.

Fields	Formation
Abo Grab	Asmri
Amara	Mishrif,Yamama B1
Buzurgan	Mishrif
Halfaya	Naher Umer, Khasaib
Nasiriyah	Nuherumer,Mishrif,yamama B2,Yamama B3
Naher Umer	Zubair,Naher Umer,Yamama
Majnoon	Mishrif
Ratawi	Ratawi,Yamama,Naher Umer
Rumaila	Suliyay, Zubair
West Qurna	Mishrif
Zubair	Zubair,Mishrif,Yamama,Ratawi
Faqa	MIshrif MB21
Tuba	Zubair

3. METHODOLOGY

3.1 PVT Simulator.

In this study, a PVT model has been built by using PVTi (v.2014). A compositional PVT program base on the equation-of-state has been adopted to predict reservoir fluid properties for the reservoir samples. This simulator uses four equations of state for predicting different reservoir fluid properties. These are; Redlich–Kwong [3,8] Soave-Redlich-Kwong[19], Peng and Robinson [7]and Zudkevitch-Joffe[6] equations. also available two of three-parameter extensions of the Peng-Robinson EOS, one based on a Peneloux et al. [3] volume shift, the other being an implementation of the Schmidt-Wenzel Equation of State modified Peng-Robinson EOS[4], in addition to 2-parameter Peng-Robinson. And the Soave-Redlich-Kwong[21] Equation of State also has a three-parameter extension.

It is necessary to have a very actual physical model for a reservoir fluid samples before using them in miscibility calculation. Simulation of experiments that conducted in the laboratory on fluid samples should be done and then any observations that can be performed during a laboratory experiment can be made by theoretical predictions, in order to test the accuracy of our fluid model.

3.2 Simulation of PVT Laboratory Data by the Equations of State.

Before using the equation of state model in the experiment simulation study, the selected EOS should be able to achieve a good match between the results of EOS and the data of the PVT test. It should be noted that the EOS generally is not a good predictive without the regression process for tuning the parameters of EOS to match the experimental data. The phase behaviour models based on EOS may predict some erroneous results because the real reservoir fluids composed of thousands of components are described by a limited number of carbon groups and pure substances. The predicted compositional results of these fluids are not always very realistic and the carbon groups are not fully defined therefore the parameters of the selected equation of state must be adjusting to achieve a perfect matching between the observed laboratory PVT data and calculated by EOS. The regression method that used is **Gani and Fredenslund(1987)** [13]. The laboratory PVT data used in this study included differential liberation-expansion (DL) experiment. The main parameters that inserted into the PVTi software are components and their mole fractions, C_{7+} (sp.gr and molecular weight), DL experimental data, i.e., gas-oil ratio, compressibility factor, formation volume factor, relative volumes and gas gravity. Finally, after a well-characterized for fluid sample by EOS then we can simulate the multiple contact miscibility between crude oil and the injected gas at reservoir temperature in order to estimate the minimum

miscibility pressure. The MMPs value for all sample calculated by EOS and represented in Table 2.

4. Injection Gas Composition.

The injected gas design greatly contributes to the success of the miscible gas displacement process. Gas injection is used to improve oil recovery and the gas used for injection is typically natural gas, N₂, CO₂ and flue gases but these gases do not recover oil as well as the hydrocarbon gases[15]. So in order to achieve miscibility between the injected gas and reservoir fluid at the lowest pressure, the composition of injected gas should be close to the composition of equilibrium gas with crude oil in the reservoir. For this reason, the produced gas is a good source for gas injection and it is more economical to reinject part or all of the produced gas into the reservoir[12]. Therefore the injected gases used in this study have a composition similar to that of the gas coming out of the separator.

5. Correlation Prediction of the MMP.

The estimated formula should have an acceptable correlation coefficient (R) and less value of average absolute percent relative error (AAERR) and standard deviation(SD). Many attempts were done on correlating independent variables with MMPs by selection a form of correlation estimation. Many trials were done by changing the variables. Finally, the best correlation is found for MMP as a function of (temperature (T), the molecular weight of heptane plus (Mw_{C7+}) and mole percent of intermediate component (C₂-C₆+X_{H2S}+X_{CO2}) in reservoir oil, X_{C1} and molecular weight of (C₂-C₅) in the injected gas. The following form is selected to represent the new correlation.

$$MMP = A + (B Mw_{C7+}^{1.7}) + (J X_{C2-C6+H2S+CO2}^{-0.39851}) + (T^c)(L Mw_{C2-C5gas}^{2.5}) + (M X_{C1} + P X_{int} T^c) \quad (1)$$

where

(A,B,C,J,M,P) a suitable coefficient and exponents for this formula. After substituting the value of this coefficient the correlation it becomes.

$$MMP = 6.36779 + (0.0005 Mw_{C7+}^{1.7}) + (0.0565 X_{C2-C6+H2S+C}^{-0.39851}) (T^{0.10143}) + (0.05616 Mw_{C2-C5gas}^{2.5}) + (0.71143 X_{C1} - 0.0010887 X_{C1gas}^{1.6} X_{int} T^{-0.10143})$$

The correlation coefficient (R) of this correlation is 0.9

Mw_{C7+}: molecular weight of heptane plus, Lb mole.

X_{C2-C6+H2S+CO2}: intermediate mole fraction in oil.

X_{C7+}: mole fraction of heptane plus in oil.

X_{C1gas}: mole fraction of methane in injection gas.

Mw_{C2-C5}: intermediate molecular weight in injection gas.

Table 2 represents the independent variable for the predicted correlations, MMP estimated by EOS, MMP calculated by the predicted correlations, the difference (residual) between the observed and calculated.

The convergence of estimated MMP by EOS and MMP calculated by the new correlation is shown below in figure 1.

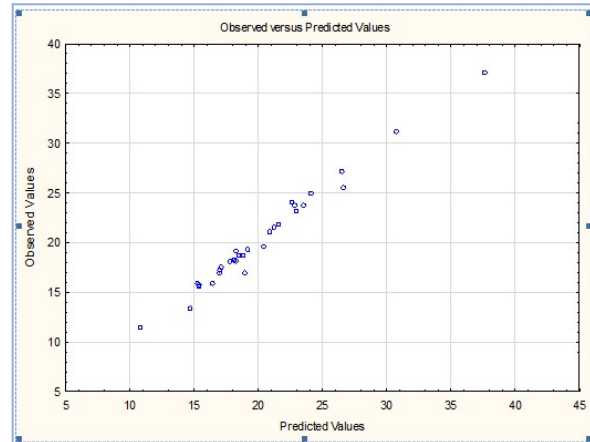


Figure 1: comparison of MMP estimated by EOS with MMP predicted by new correlation.

Figure2 illustrates the difference between MMP predicted by new correlation and MMP estimated by EOS. These point lie between (-0.5 to 0.5 Mpa) that indicate a good predicted values.

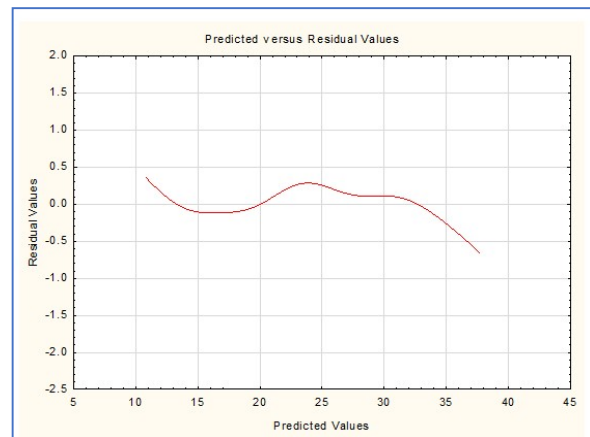


Figure 2: Residual versus predicted values

Table 2:MMPs calculated by EOS and by new correlation

Formation	Saturation pressure	MW C ₇₊	X _{C2-C6} +H ₂ S +CO ₂	X _{INC1} gas	MW(C ₂ -C ₅)gas	T(F°)	Predicted by EOS (Mpa)	predicted correlation (Mpa)	Residual (Mpa)
Abo Grab(Asmri)	16.51	370	24.75	25.64	34.8	192	16.87	16.945	-0.075
Amara 1(Mishrif)	19.09	478	29.29	18	34.80	190	19.189	19.010	0.179
Amara 2 (Yamama B1)	23.71	502	38.33	27.2	39.22	275	23.95	23.786	0.164
Amara 4 (Mishrif)	18.31	330	32.37	35.15	35.06	210	19.07	18.746	0.324
Buzurgan 6_mcl	18.14	380	28.07	23.95	25	235	18.598	18.486	0.112
Buzurgan16(Mishrif)	20.2	369	30.95	35.4	34.71	230	21.067	21.258	-0.191
Buzurgan 12 (Mishrif)	13.33	286	29.7	29.19	29.72	231	15.789	15.512	0.277
Faqa(Mishrif)	15.43	370	61.04	35.26	29.66	233	16.95	17.204	-0.254
Halfaya 1 (NaherUmr)	13.0	440	24.61	15.46	41.83	235	13.37	13.234	0.136
Halfaya 045(Khasib B2)	19.23	360	20.557	35.91	41.83	198	19.567	19.940	-0.373
HF158-N158(KHASIB)	23.41	395	24.03	32.24	29.067	201	23.623	23.211	0.412
Majnoon 5 (Mishrif)	17.67	340	26.36	27.26	26.120	379	18.056	18.326	-0.270
NaherUmer 1 (Zubair)	13.3	256	25.55	48.39	32.256	217	23.067	23.302	-0.235
NaherUmer4(NaherUmr)	9.41	180	24.09	26.6	26.683	196.0	11.356	11.121	0.235
NaherUmr 9 (Yamama)	14.19	156	24.99	40.05	33.734	240	15.534	15.744	-0.210
Nasirya 1 (Mishrif)	26.8	435	27.69	35.89	27.66	165	27.165	26.906	0.259
Nasirya1(Yamama B3)	30.79	540	20.11	29.04	31.4	217	31.134	30.524	0.610
Nasirya1(YamamaB2)	15.37	240	31.22	35	31.428	214	15.674	15.684	-0.010
Nasirya3(NuherUmer)	14.35	292	32.74	34.92	29.142	186	18.045	17.932	0.113
Ratawei 6(Yamama)	15.91	188	34.58	40.05	28.711	244	15.798	15.941	-0.143
Ratawi 12(Ratawi)	21.31	440	27.28	30.11	40.748	219	21.533	21.440	0.093
Ratawi 16 (NaherUmr)	17.35	426	35.23	20	32.163	240	17.456	17.380	0.076
Rumaila (Sulay)	23.59	410	28.85	32.53	29.561	251	23.7654	23.637	0.129
Tuba(Zubair)	24.61	460	61.8	35.6	29.89	235	24.934	22.314	2.620
Rumaila (Zubair)	18.41	370	25.41	27	29.193	210	18.643	18.976	-0.333
West qurna (Mishrif)	17.01	273	24.839	35	32.890	174	17.245	17.484	-0.239
Zubair 36 (Mishrif)	13.69	364	31.99	39.62	35.637	169	21.823	22.068	-0.245
Zubair 202 (Yamama)	35.11	560	20.63	15.553	25.569	239	25.523	25.347	0.176
Zubair 205 (Zubair)	17.94	350	28.08	24.27	14.957	235	18.243	18.157	0.086
Zubair_(Ratawi)	35.65	360	24.271	70.54	34.223	206	37.034	37.397	-0.363

6. Comparison between the predicted correlation's value with the experimental value.

In order to validate the predicted correlation in calculating the MMP value, we must compare the results of this correlation with the experimental values. This correlation was tested on published laboratory data in many literatures as (M. Kanatbayev,2016), (C. A. Hutchinson 1958), (S. S. Kuo,2007), (Williams,1980). We note that the MMP values increase with increasing (temperature, C₇₊ molecular weight in the reservoir fluid, C₁ in the injection gas). In general, miscibility pressure increases with increasing temperature because the solubility of hydrocarbons decreases with increasing temperature, which causes the size of the two-phase region to increase. MMP increase with increasing C₇₊ molecular weight because the increasing in C₇₊ molecular weight means that the oil has become heavier, so it needs a higher pressure to get miscible. The increase in methane percentage makes the gas composition significantly different from the composition of the oil. The MMP decreases with increasing (mole percent of C₂₋

C₆-H₂S in the reservoir fluid, molecular weight of C₂-C₅ in the injection gas) this is because the increase in the intermediate compounds in the gas makes its composition similar to the oil composition and the increase in the intermediate compounds in the oil makes it lighter.

Firstly AERR (absolute relative error) was calculated for each value then the AAERR (average absolute relative error) for all values was calculated. The AERR and AAERR equations were listed below eq 3 and eq 4. As shown in Table 3 the results were very close to the experimental result with AAERR=9.4%. This means that the proposed correlation has an acceptable accuracy in calculation MMP value.

$$- AERR = ((X_{exp} - X_{est})/X_{exp}) * 100\% \quad (2)$$

$$- AAERR = \left(\frac{1}{n_d}\right) \sum_{i=1}^{n_d} |AERR| \quad (3)$$

Where

X_{est} : estimated value

X_{exp} : experimental values.

Table3: Comparison between predicted correlation with the experimental value.

Refr-ences	MWC ₇₊	X C ₂ -C ₆ +H ₂ S +CO ₂	X _{INC1}	MW(C ₂ - C ₅)	T(f)	MMP (EXP)	Predicted Correlation (Mpa)	AERR%
[18]	300	1.43	65	44	132	23.30	25.717	10.352
[18]	300	1.43	62.4	44	132	25.17	23.915	4.972
[18]	300	1.43	54.3	44	132	18.96	18.293	3.520
[18]	191	23.57	52.88	39.9	170	16.55	20.931	26.492
[18]	191	23.57	52.88	39.9	206	18.48	21.203	14.748
[20]	183	32.17	68.5	35	130	23.44	23.861	1.787
[10]	217	25.84	65	30	140	24.13	28.414	17.744
[16]	258	31.92	65.9	12.2	249.8	27.40	30.427	11.049
[16]	275	23.6	80.78	6.12	282	46.60	41.738	10.433
[16]	274	31.25	76.22	9.22	196	32.60	34.262	5.098
[16]	296	28.61	66.09	11.96	249.8	30.00	33.826	12.754
[16]	255	24.03	77.41	6.77	285.8	37.20	39.302	5.651
[16]	280	23.69	82.03	5.77	195.8	39.72	41.747	5.104
[16]	283	27.1	82.03	5.77	194	37.25	39.354	5.648
[16]	280	26.13	82.03	5.77	194	37.72	39.936	5.874
[16]	273	31.91	76.17	8.71	193.82	31.00	33.767	8.926

[16]	260	27.63	64.5	11.27	225.5	29.50	32.044	8.624
[16]	197.6	36.06	70.49	10.57	222	29.80	27.064	9.180
[16]	266	28.89	70.64	10.3	194	28.4	33.597	18.299
[16]	316	23.79	62.39	13.82	180.5	31.8	35.131	10.476
[16]	320	23.53	62.63	13.8	180.5	31.4	35.549	13.213
[16]	250	27.7	70.97	10.95	208.4	33.4	33.826	1.276
[16]	250	27.7	76.17	8.71	208.4	34.2	35.686	4.346
							AAERR=	9.4

7. Conclusions

1- A new correlation for accurate prediction of the MMP in southern Iraqi oil filed have been proposed regarding hydrocarbon gas injection.

2-The proposed correlation is a function of the most influencing variables that are (reservoir temperature, $C_{2-6}+H_2S+CO_2$ composition in the oil, the molecular

weight of C_{6+} in the oil, C_1 composition in the gas, and injected gas C_{2-5} molecular weight.

3- The predicted results are in good agreement with MMPs estimated by EOS and experimentally measured data suggesting that the new proposed correlation is reliable for MMP prediction.

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معادلة لحساب أقل ضغط للامتزاج عند حقن الغازات الهيدروكربونية في حقول جنوب العراق

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الخلاصة – إحدى أهم الطرق الإنتاج بطرق الثانوية هي طريقة الحقن بالغاز وخلال هذه الطريقة يفضل الوصول الى ظروف الامتزاج لتحسين عملية الاستخلاص والعامل الأكثر الأهمية في هذه الظروف هو (ضغط الامتزاج). لقد ركزت هذه الدراسة على تكوين علاقة مناسبة لحساب أدنى ضغط للامتزاج بين النفط المكمني و الغازات الهيدروكربونية المحقونة (لحقول جنوب العراق). تم حساب قيمة ضغط الامتزاج باستخدام معادلة الحالة ل (modified Peng and Robinson) لثلاثين نموذج من جنوب العراق. تقارير التجارب المختبرية لل (PVT) المستحصلة استخدمت لتحسين معاملات معادلة الحالة وذلك بعمل تطابق بين نتائجها ونتائج التقارير. بعد ذلك ادخلت قيم ضغوط الامتزاج الى البرنامج الاحصائي لأيجاد علاقة تربط قيمة ضغط الامتزاج مع خواص وتركيبية النفط المكمني والغاز المحقون. وباستخدام صيغة التخمين الغير خطي تم الحصول على علاقة جيدة وبمقارنة نتائج المعادلة المستنتجة مع القيم المقاسة بواسطة التجارب وجد بان نتائج المعادلة المستنتجة كانت رائعة.

الكلمات الرئيسية – ضغط الامتزاج، معادلة لحساب ضغط الامتزاج، حقن الغازات الهيدروكربونية.