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Calculation of Minimum Miscibility Pressure for Some Libyan Crude Oils by Using Different Correlations

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Abstract

Enhanced Oil Recovery (EOR) is defined as "the recovery of oil by injection of a fluid that is not already produced from the reservoir". There are different methods for the EOR. Among all EOR techniques, the miscible displacement process has the highest potential. It involves the injection of fluids that are capable to generate miscibility with reservoir fluid at certain conditions of pressure and reservoir temperature. The minimum miscibility pressure (MMP) is defined as the pressure required for the injection fluid to generate a miscible front that is completely miscible with the reservoir fluid. There are many available correlations in literature to calculate the MMP for a given injection and reservoir fluids and reservoir conditions. Choosing the best accurate method of calculating the MMP is very important to determine accurately the MMP value. The objective of this study is to determine the best accurate correlation to determine the MMP for Libyan oils. Six correlations were selected and used to calculate the MMP for different CO_2-Libyan oil systems. Obtained results were compared to experimental data from literature. Statistical analysis (SPSS Software) was utilized to evaluate the used correlations. Results show that Glaso's correlation is the most accurate correlation. Furthermore, the available experimental MMP measurements were utilized to develop a new empirical equation to calculate the MMP for CO_2–Libyan oil systems. Results show that the new correlation can be used for estimation of MMP with better accuracy as compared to other correlations.

Keywords: EOR; MMP; CO_2; crude oil; correlations.

1. Introduction

Enhanced oil recovery (EOR) is defined as "the recovery of oil by injection of a fluid that is not native to the reservoir." EOR means to extend the productive life of depleted and uneconomic oil fields. It is usually practiced after recovery by other, less risky and more conventional methods, such as pressure depletion (primary recovery) and water flooding (secondary recovery). When primary and secondary recoveries start depleting, reservoir should be gone towards the Enhanced Oil recoveries methods. All of currently available EOR is based on one or more of two principles: increasing the capillary number and/or lowering the mobility ratio, compared to their water flood values. Increasing the capillary number means, reducing oil-water interfacial tension. The mobility ratio may be reduced by increasing water viscosity, reducing oil viscosity, reducing water permeability or all of the above. EOR processes are divided into four categories: thermal, gas, chemical, Microbial flooding, miscible. The processes are typically defined by the nature of their injected fluid. For instance, gas EOR includes hydrocarbon miscible/immiscible and carbon dioxide miscible and immiscible processes. The miscible process can be carried out by using different methods. These involve injection of miscible hydrocarbon gases as following:

a. Hydrocarbon gas injection (miscible/immiscible)

b. Nitrogen c. Flue gas (miscible and immiscible)

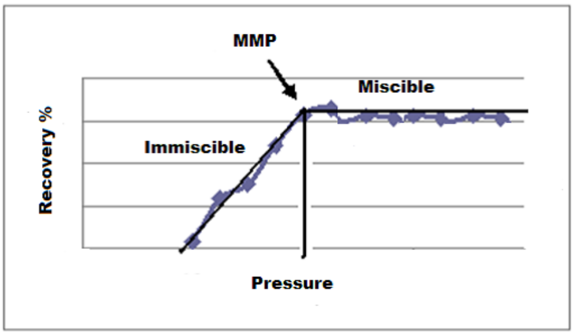
d. Carbon dioxide (CO_2) (miscible and immiscible)

The injection fluid can generate miscibility with reservoir oil either directly (direct miscibility) or through mass transfer process between the injection fluid and the reservoir oil which is known as the multiple contact process. The multiple contact process can generate miscibility only under certain conditions of pressure and temperature. The higher the pressure, the less contacts required for miscibility generation. The minimum pressure that is needed for generation of miscibility through multiple contact process is defined as the minimum miscibility pressure or MMP. There are many available correlations in literature to calculate the MMP for a given injection and reservoir fluids and reservoir conditions. These correlations include Lee, 1979 model, Yellig and Metcalfe, Cronquist, and others [1, 2, 3, 4, 5, 6, 7, 8]. Choosing the best accurate method of calculating the MMP is very important to determine accurately the MMP value. Each of the above correlations is based on some oils from different geographic locations. However, these correlations would not work very well when it applied for oils different from these used in developing the correlations i.e. these correlations need tuning to best fit oils from certain source. The objective of this work was to evaluate different correlations for the calculation of minimum miscibility pressure (MMP) for different CO_2 - Libyan oil systems. Also to develop a new empirical equation to calculate the MMP for CO_2–Libyan oil systems.

2. Enhanced Oil Recovery (EOR)

The most important EOR processes can be grouped into three classes: thermal, chemical and miscible. The CO_2 (miscible and immiscible) is more related to the work in this research. In this method the oil displacement by CO_2 injection depends on the phase behavior of CO_2 and crude oil mixtures that are strongly dependent on reservoir temperature, pressure and crude oil composition. Different mechanisms occur ranging from oil swelling and viscosity reduction for injection of immiscible fluids (at low pressures) to completely miscible displacement in high-pressure applications. In these applications, more than half and up to two-thirds of the injected CO_2 returns with the produced oil and is usually re-injected into the reservoir by various means.

Figure 3.1: The determination of Minimum Miscibility Pressure (MMP)



3. Minimum Miscibility Pressure (MMP)

The lowest pressure at which the CO_2 containing injection fluid can develop miscibility with the reservoir crude oil at reservoir temperature is defined as minimum miscibility pressure and commonly abbreviated as MMP. Displacement of oil by injection fluid is made at successively increasing pressures and the recovery achieved is noted. It will be found that recovery increase with pressure at first, and then stabilizes as shown on Figure 3.1.
The MMP can be determined by using two different ways; experimentally by using the Slim Tube Test and mathematically by using some different correlations. Some researchers have already found some correlations to calculate the MMP. These will be illustrated in the Table 3.1.

4. Methodology and data collection

The previous equations from table 3.1 will be used to calculate the MMP and compared to MMP that were experimentally measured using slim tube apparatus. The different between the measured and calculated MMP will be investigated under the errors analysis. These errors are:
Average relative error ($ARE\%$):

$$ARE\% = \frac{100}{n}\sum_{1}^{n}\left(\frac{MMP_{Cal.} - MMP_{M.}}{MMP_{M.}}\right) \quad (4.1)$$

Table 3.1: Presents the correlation used in this study

No.	correlation	Formula
1	Lee model (1979)	$MMP = 7.3924 * 10^b$, where $b = 2.772 - \frac{1519}{(492+1.8T_R)}$ and T_R is the reservoir temperature, $^\circ$C
2	Yellig and Metcalfe (1980)	$MMP = 12.6472 + 0.015531 * (1.8T_R + 32) + 1.24192 * 10^{-4} (1.8T_R + 32)^2 - \frac{716.9427}{(1.8T_R + 32)}$
3	Cronquist (1978), (after Stalkup, 1984)	$MMP = 0.11027 * (1.8T_R + 32)^y$, where: $y = 0.744206 + 0.0011038 * MW_{C5+} + 0.0015279 * Vol$
4	Glaso's (1985) Original	$MMP == 5.58657 - 0.02347739 * MW_{C7+} + \left[1.1725 * 10^{-11} * MW_{C7+}^{3.73} e^{786.8 * MW_{C7+}^{-1.058}}\right] * (1.8T_R + 32)$
5	Alston et al. (1985)	$MMP = 6.056 * 10^{-6} * (1.8T_R + 32)^{1.06} * (MW_{C5+})^{1.78} * (\frac{Vol}{Interm.})^{0.136}$
6	Emera et al. Genetic algorithm-based model	$MMP = 5.0093 * 10^{-5} * (1.8T_R + 32)^{1.164} * (MW_{C5+})^{1.2785} * (\frac{Vol}{Interm.})^{0.1073}$

Average absolute relative error ($AARE\%$):

$$AARE = \frac{100}{n} \sum_{1}^{n} \mid \frac{(MMP_{Cal} - MMP_{M.})}{MMP_{M.}} \mid \quad (4.2)$$

Where:
$MMP_{Cal.}$=Minimum Miscibility Pressure Calculated
$MMP_{M.}$= Minimum Miscibility Pressure Measured

4.1. Method:

The MMP was calculated with six different correlations and all of the results from these correlations were compared with the experimental results that were collected from the fields. Then the best correlation that matched the field result was selected.

4.2. Tools

4.2.1. Microsoft Excel

In this calculation, a spreadsheet application developed by Microsoft for Microsoft Windows and Mac OS X. It features calculation, graphing tools, pivot tables, and a macro programming language called Visual Basic for Applications. The excel software was used to calculate the MMP by using six correlations.

4.2.2. SPSS Statistics

In this research, the SPSS is used to calculate the deviation between measured and calculated MMP from six different correlations. In this work, six measured MMP were utilized to develop a new correlation for MMP calculations.

5. Results and Discussion

5.1. Calculation of MMP using the six correlations

Using the six correlations that previously presented, the MMP was calculated for different 23 oils from different fields and its values were compared to the experimentally measured using slim tube apparatus [9]. Table 5.1 shows an example of these calculations by using Glaso' correlation. As it can be seen from these results, the MMP calculated are close enough to the MMP measured.

5.2. Calculations of MMP for CO_2 - Libyan Oil Systems

This section presents the results of CO_2 - minimum miscibility pressure calculated for different CO_2-Libyan oil systems and utilizing different correlations. The data used in this study (Table 5.2) are from the reference [10] (Screening of Libyan EOR Candidates). It includes the physical properties of

Table 5.1: . Experimental MMP and Calculated MMP Values from Glaso's Correlation

Oil	MW_{C7+}	$(C_2\text{-}C_6)\%$	MW_{C5+}	Interm.	Vol.%	T, C	Measured MMP, Mpa	Calculated MMP, Mpa
1	210	23	203.81	22.9	31	67.8	16.9	13.595
2	220	28	213.5	28.1	32.7	112.2	24.15	20.308
3	195	3	190.7	2.95	40.14	99	30.28	18.313
4	185	36	180.6	35.64	32.51	110	20.21	19.976
5	227	7	221	6.99	41.27	71.1	23.45	14.094
6	210	10	205	9.84	51.28	102.2	28.17	18.796
7	242	9	240.7	8.6	53.36	80	26.76	15.44
8	227.9	24.68	207.9	13.9	4.4	71.1	15.52	14.094
9	197.4	40.05	171.2	31.82	29.48	54.4	11	11.569
10	221	33.12	196.1	26.8	19.35	42.8	10.62	9.815
11	192	28.58	171.1	28.6	34.2	118.3	23.45	21.231
12	206	24.44	187.77	14.28	10.5	32.2	6.9	8.213
13	206	24.44	187.77	14.28	10.5	40.6	8.28	9.483
14	206	24.44	187.77	14.28	10.5	57.2	11.86	11.993
15	200	26.39	187.25	22.82	34.34	49	11.04	10.753
16	200	26.39	187.25	22.82	34.34	65.6	13.45	13.263
17	196	11	182.6	3.48	31.88	57.2	13.79	11.993
18	222	28.83	204.1	20.95	17.07	42.8	10.35	9.815
19	223	26.83	199.7	21.81	27.84	39.4	13.79	9.301
20	268	13.4	247.8	18.34	44.53	85.6	34.49	16.287
21	220	18.93	205	11.35	5.45	59	12.8	12.265
22	227	17.7	212.56	10.76	16.78	34.4	10	8.545
23	227	31	205.1	22.62	12.5	48.9	10.49	10.738

Table 5.2: Reservoir Fluid Compositions and Properties of Libyan EOR Candidates

Oil	MW_{C7+}	T, C	Measured MMP, Mpa	Calculated MMP, Mpa
SARIR C-MAIN	290	107.222	21.45641	27.22992
SARIR C-NORTH	208	110	21.40125	19.87384
SARIR L	210	115.556	21.29783	20.81571
MESSLA	230	114.444	21.49778	21.99967
N.A.U (TBG)	310	110	27.0963	30.96079
NASSER NORTH	214	76.667	20.95999	15.07335
NASSER S-E	222	80	15.56831	15.92221
JEBEL	227	96.667	26.13104	18.87356
WAHW NORTH	226	82.222	17.23683	16.47241
WAHW SOUTH	227	82.222	18.22967	16.52393
DEFA	257	68.889	14.23762	15.95812
GIALO PALE	222	98.333	15.96131	18.83738
AMAL N	262	115	23.53862	25.25941
GAHNI L-FARRUD	201	76.667	19.99473	14.6829
BU-ATTIFEL MAIN	244	148.889	42.91282	29.32249
KOTLA	281	73.33	24.4763	18.68938

Table 5.3: Compassion between the accuracy of *MMP* Correlations

Correlation	*ARE%*	*AARE%*	ST. DEV.
Alston	11.4	34.7	16.93
Emera	8.77	27.93	13.34
Conqust	502.11	28.17	17.17
Glaso'	-4.86	15.26	5.19
Yelling	-16.21	17.71	8.35
Lee	9.4	19.48	7.45

different fields from Libyan, including the Molecular weight (MWt.) of C7+, Molecular weight of C5+, Intermediate percent volume percent, temperature and the corresponding *MMP* value, determined experimentally. The *MMP* were calculated using Glaso's correlation as an example is presented in the last column of table 5.2. It can be seen from these results that are close enough to the already measured experimentally. Therefore, the Glaso's is vallied to calculate the *MMP* for the selected Libyan oils.

Using last two columns in this table, the *ARE%* and *AARE%* can be calculated by using Equation 4.1 and 4.2. Similar calculations were done by using other five correlations (not presented). Average relative error, Absolute average relative error and the standard deviations for each of the six correlations were calculated and presented in Table 4. It can be seen from this table and by reviewing the results of all methods, it can be concluded that Glaso's method is the best method for determining the *MMP* because it gives the minimum value of *ARE*, *AARE%* and St. Deviation.

5.3. Development of New Correlation for *MMP* Calculations for Libyan Oil- CO_2 Systems

SPSS statistical package is one of the most popular statistical packages which can perform highly complex data manipulation and analysis with simple instructions. It is frequently used in the social science and some of applied science. SPSS has four windows, Data editor; Output viewer; Syntax editor; Script window. Many tasks can be performed with the menus and dialog boxes but some very powerful features are available only with command syntax. Graphs command is used exclusively in SPSS to make graphs. SPSS usually creates commonly used graphics in the fields of social science, such as histograms, scatter plots, and regression line, etc. Multiple regressions are statistical technique that allows us to predict someone's score on one variable on the basis of their scores on several other variables. The beta value is a measure of how strongly each predictor variable influences the criterion variable. The beta is measured in units of standard deviation.

The SPSS was used to generate empirical equation of the new equation by using the from table 5. Then new equation was used to calculate the MMP as it is shown also in table 5. It is resulted from the program (SPSS) and a function of (Temp.°C, Vol.%) as follows:

$$MMP = \beta_o + \beta_1 Vol. + \beta_2 Temp. + \varepsilon \qquad (5.1)$$

Where: β_o is the constant of the equation, β_1 is the coefficient of $Vol.$, β_2 is the coefficient of temperature and ε is the random error assumed to be a standard normal distribution. The estimators are listed below:

$\beta_o = 1.52$, $\beta_1 = 0.22$, $\beta_2 = 0.183$

To validate this equation, its results were compared to the experimental data and presented in Table 5. The errors also were calculated as:

ARE%=0.3%, AARE%=4.9%, ST.DEV.=0.882. It can be seen that the results show good fit for the new equation and that the errors are low in comparison for previously presented six correlations.

Table 5.4: Experimental MMP and Calculated MMP Value from new equation Correlation

Field	Temp. °C	Vol.%	MMP measured, Mpa	MMP calculated, MPa
SARIR C-MAIN	107.222	11.87	21.4564	20.7130
SARIR C-NORTH	110	6.32	21.4012	20.000
SARIR L	115.556	5.35	21.2978	20.80375
MESSLA	114.444	19.47	21.4977	23.70665
N.A.U (TBG)	110	38.81	27.0963	27.1482
NASSER NORTH	76.667	30.44	20.9599	19.20686
NASSER S-E	80	19.17	15.5683	17.3374
JEBEL	96.667	42.31	26.131	25.47826
WAHW NORTH	82.222	17.9	17.2368	17.46463
WAHW SOUTH	82.222	23.57	18.2296	18.71203

6. Conclusion

1. The six correlations to find MMP were used in this research and it was found that the Glaso's method is the best one to determine MMP for Libyan oil field due to the statistical variables were the lowest one in comparison with the other correlations. ($ARE\%$ = - 4.86, $AARE\%$ =15.26 and Std. Dev = 5.19).

2. A new equation was developed to calculate the MMP for Libyan crude oils. The new equation shows better statistical performance as compared to other correlations; Error =-0.167%, Average Error =16.16% and Standard devastation. = 0.894.

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