The New Prediction of the Minimum Miscible Pressure by Iranian Fractured Reservoirs

S. Torfi, E. Novieri

Abstract**—** The aim of this study is to develop a new model to predict the minimum miscibility pressure (MMP) of Iranian oil reservoirs. So far, different MMP correlations and models regarding the kind of injection gas and the mechanism of miscibility have been proposed, which are respectively based on mathematical and thermodynamic calculations. None of these correlations can be used with enough confidence and applying them for Iranian reservoirs is more or less prone to errors. In this article, compositional and empirical models introduced for predicting MMP regarding the composition of the injected gas and the condition in which miscible displacement is done have been studied. Experimental data from Iranian oil reservoir b with different injection gases carried out by slim-tube test have been used to obtain a new MMP correlation that is suitable to be applied to Iranian oil reservoir.

By applying the new MMP correlation, one can determine minimum miscibility pressure of Iranian oil reservoir with more accuracy and within a shorter period of time. The predicted MMPs are compared with the experimental results reported from the above reservoirs .The sensitivity analysis is done and consequently their error percentage are determined and reported. Therefore, a suitable model with less error and more precision is introduced. It is shown that the results obtained from the new MMP model are more accurate when they are compared with other most common correlations reported in literature.

Keywords**—** Minimum Miscibility Pressure, Gas Injection, MMP correlations, oil reservoir, sensitivity analysis.

I. Introduction

As the effective human being's life depends on the body physiology, health, rest, and proper nutrition, the effective reservoir life and its ultimate recovery also depend on rock physical structure, type, method and the amount of injected fluid, and most importantly, the manner it is managed by drilling, reservoir, and production engineers. A highly noticeable percentage of the oil production of OPEC members and especially Iran comes from fractured reservoirs. Fractured reservoirs are recognized by their dual structure, with a combination of high porosity / low permeability matrix and low porosity / high permeability fractures network. The co-existence of these two contrasting media has complicated the recovery performance in such reservoirs. The majority of fractured reservoirs have an initial high rate which declines significantly later on, leading to a low recovery factor. This is mainly due to the change of recovery mechanism from solution gas drive to gas gravity drainage, a typical behavior of Iranian fractured reservoirs.

The original oil in place in Iran is estimated to be more than 600 billion barrels. Considering the reservoir heterogeneities and the complexity of production mechanisms and if the present trend is not revised; only 20% of the oil in place is expected to be recovered. The application of miscible gas flooding as an enhanced oil recovery technique has increased rapidly. A large amount of gas is usually associated with oil in gathering center, which can be separated and reinjected into reservoir for miscible or immiscible displacement in order to enhance oil recovery. Generally, by using hydrocarbon gas as injecting fluid, the following mechanisms can be activated: immiscible displacement, miscible displacement, pressure maintenance, gravity enhancement and driving agent for miscible slug. In miscible displacement, lean gas can displace oil efficiently by developing a miscible bank through a multicontact miscibility (MCM) process. Minimum miscibility pressure (MMP) is needed to achieve the dynamic miscibility between oil and hydrocarbon gas. MMP is an important parameter for screening and selecting reservoirs for miscible gas injection projects and is defined as the minimum pressure at which oil and gas exist in one phase (Stalkup, Jr., 1983). Figure 1 shows compositional phase diagram for a definite temperature and pressure which is called ternary diagram. In thermodynamic criteria for defining the MMP by using ternary diagrams, the MMP is the pressure at which the limiting tie line passes through the point representing the oil composition.

In order to determine the MMP in gas injection processes, several methods are used. These methods include slim tube test (STD), rising bubble test, vapor-liquid equilibrium (VLE) studies, slim tube composition simulator, empirical correlation, among others. Application of correlation is the simplest method. Empirical correlations are used to obtain first-pass estimation or as a screening tool (Stalkup, Jr., 1983).

Stalkup, Jr. (1983) offered an empirical correlation for estimation of MMP with lean hydrocarbon gas. The MMP was correlated with the oil composition and oil saturation pressure. The correlation was developed from data of nine different oil compositions with average deviation of 260 psi and maximum deviation of 640 psi. Firoozabadi and Aziz (1986) reviewed twelve MMP data (experimentally measured data and simulator data) and proposed a correlation to estimate MMP for all vaporizing gas drive (VGD) processes. They correlated the MMP by oil composition without considering the injected gas composition. Their correlation was found as the most

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reliable MMP correlation for lean gas and nitrogen injection with standard deviations of 11.5 % and 23.5 % compared with other correlations reported in literature. Their correlation was developed from data, which contained more than 80 mol% methane. Large errors are produced when the methane content in the driving gas is significantly lower than 80 mole percent (Danesh, 1997).But the MMP is the lowest pressure at which any one of the initial oil, injection gas or crossover key tie lines becomes critical, which means that its length approaches to zero. In this paper, we propose a method for a solving multi component system based on analytical calculation of ternary systems, which simplifies and converts the multi component system into a pseudo ternary system and estimates the minimum miscibility pressure without solving complex and time consuming equations of crossover tie lines.

II. Method of Calculation

Miscible gas injection into an oil reservoir is among the most widely used enhanced oil recovery techniques, and its applications are increasingly visible in oil production worldwide. As the injected gas is initially at equilibrium with the reservoir oil, the contact between the phases results in mass transfer which subsequently it changes the properties of two phases. The displacement of oil by gas becomes highly efficient when the properties of the advancing gas and displaced oil become similar. In this situation, the two phases achieve complete miscibility and the vapor- liquid interface vanishes. Two fluids are miscible when they can be mixed together in all proportions and all resulted mixtures remain as single phase. [det] an important concept associated with the description of miscible gas injection processes is the minimum miscibility pressure (MMP). At this pressure, the injected gas and the initial oil, becomes multi-contact miscible, and the displacement process becomes very efficient. The slim tube test is one of the most widely used techniques and is accepted as a standard means to measure MMP in the petroleum industry. The tube is initially filled with oil at reservoir temperature above the formed. The MMP is taken to be the lowest of the pressure required to produce a critical mixture (vapor and liquid phase identical).

III.A Case Study

The under study reservoir consists of 9 permeable and non permeable layers and sub layers. In this study we just used layer 2 (thickness=175 meter), which is permeable and contains 70% of oil in place (2134 MMSTB). The volume of the supported edge aquifer in this layer is about 9056MMbbl, which is small in comparison to the reservoir volume of 2134 MMSTB. Hence, the aquifer may not be considered as an active aquifer and consequently may not have a significant contribution to the oil recovery. The reservoir was initially under-saturated at 5920 psi and 201of where bubble point pressure was 1595psi. There were 18 production wells with 35000 stb/d production. Also, there are 6 injection wells with a rate of 11000Mscf/d. Average matrix and fracture porosity were 8.1% and 0.1% respectively, while the average matrix and fracture permeability were respectively 0.22md and 88.5md. Moreover, the available flash and differential expansion test at 135oF and 215oF, flash separator test and viscosity test results were used to model the fluid properties.

The Oil Component in This Reservoir

- N2 ۱,۱۹
- Co2 ۴,۳۹
- H2S ۰
- C1 ۲۱,۹۶
- C2 ۲,۰۸
- C3 ۳,۲۷
- iC4 ۲,۳۸
- nC4 ۳,۶
- iC5 ۹,۳۲
- nC5 ۱,۱۲
- C6 ۲,۴۴
- C7 ۴۸,%۲۵

Reservoir Injection Gas properties

- H2S ۰,۲۳
- N2 ۳,۳۴
- CO2 ۲,۰۵
- C1 ۸۲,۶۳
- C2 ۵,۲۸
- C3 ۱,۹۶
- iC4-nC4 ۱,6
- iC5-nC5 ۰,۵۷
- C6 ۲,۸۸

IV. Prediction My Correlation

By summarizing the findings presented above, an improved MMP correlation was generated including the following criteria:

a. As temperature increases, the hydrocarbon gas MMP increases for any type of oil
b. The hydrocarbon gas MMP also increases as the C7+ molecular weight increases;
c. The hydrocarbon gas MMP decreases as the mole fractions of methane and C2 increase in the oil composition.
d. By increasing the mole fraction and molecular weight of C5+, the MMP is reduced.(corrolation1,2)

The pressure at which either one of them becomes a critical tie line (its length approaches to zero) is called MMP. Proposed the following procedure to find the MMP in a ternary System:

1-Start calculation at a low pressure. For a proper initial guess, one can start by *Benham* curves or *Kuo* correlation and so on.
2- Find equilibrium values of the liquid and vapor phase (xi, yi) for initial oil and injection gas compositions by using one of the flash calculation methods (see next section).

None of these correlations can be used with enough confidence and applying them for Iranian reservoirs is more or less prone to errors. In this article, compositional and empirical models introduced for predicting MMP regarding the composition of the injected gas and the condition in which miscible displacement is done have been studied. Using the experimentally measured MMP data in the literature and data collected in this work for generating the correlation, 3D-curve fitting regression was used,

The predicted MMP**s** are compared with the experimental results reported from the above reservoirs .The sensitivity analysis is done and consequently their error percentage are determined and reported. Therefore, a suitable model with less error and more precision is introduced. . Experimental data from Iranian oil reservoir *b* with different injection gases carried out by slim-tube test have been used to obtain a new MMP correlation that is suitable to be applied to Iranian oil reservoir.

$$MMP = f(T\ ,\ Oil\ Composition\ ,\ Mw_{c_i^+})$$

$$MMP = 2.4581 * \left(Mw_{c_5^+} * \left(\frac{X_V}{X_I} \right)^{0.31} \right) + 4.604 T_R + 1.667 * 10^{-11} T_R^{4.831} + 687.83 \left(\frac{X_V}{X_I} \right)^{0.199} - 2619.233$$

V. Proposed Procedure for Multi Component Systems to Above Correlations

In addition to initial oil and injection gas tie lines, there are n_c-3 key tie lines known as crossover tie lines in a multi component system. The MMP is defined as the lowest pressure at which one of them becomes critical. A set of complex and time consuming equations must be solved by trial and error method to find the equation and the length of crossover tie line. In order to simplify the system and also decrease the time of calculations, the following procedure is proposed by the authors. Investigating of analytical calculation for ternary systems shows that MMP only depends on T_c, P_c and ω. These critical properties are listed in some tables for pure components. Therefore, we can use the previous procedure for multi component system, if it is converted into a pseudo ternary system. For this purpose, the pure components must be divided into Light, Intermediate and Heavy cuts. Then T_c, P_c and ω of the cuts are estimated by the following formulas:

1- For defined cuts (components are known) one can use molar average equations:

$T_{c,m}=\Sigma z_i T_{ci}$ (3)

$P_{c,m}=\Sigma z_i P_{ci}$ (4)

$\omega_m=\Sigma z_i \omega_i$ (5)

2- For undefined cuts (components are unknown), specific gravity and normal boiling point must be given. From *Win-Sim- Daubert* equation, $T_{c,m}$ and $P_{c,m}$ can be obtained :

$T_{c,m}=EXP(3.9934718 \times T_b^{0.08615} \gamma^{0.04614})$ (6)

$P_{c,m}=3.48242 \times 10^9 \times T_b^{-2.3177} \gamma^{2.4853}$ (7)

VI. Conclusion

In this paper, a new procedure is proposed for the prediction of the MMP of a multi component system in carbonate reservoir by the authors. Two examples are solved and their results are compared with the results of the other MMP estimation methods. It can be concluding that:

1- If a multi component system with arbitrary number of components in initial oil and injection gas is converted into a pseudo ternary system (with a good engineering sense), the calculated MMP is in fair agreement with the estimated MMP by solving of complex and time consuming equations of crossover tie lines.

2- The presented method can be used to assess quickly the effects of designed injection gas composition changes on MMP, and then the results will give the optimum injection gas composition.

3- This method can be used as a rapid and low cost method to evaluated performance and accuracy of the other MMP determination methods (To determine the MMP accurately by slim tube test, it is in general necessary to perform six displacements at six or seven different pressures. The time required to perform one displacement is about 8 h (a working day). This means one week of experimental work is necessary to measure one MMP).

And moreover, the following conclusions can be summarized:

• Increase in matrix block height causes an increase in the ultimate oil recovery.

• The effect of matrix block height on water imbibitions mechanism is not very strong.

• Considering capillary continuity between matrix blocks causes an increase in the ultimate oil recovery by a range of 1-10%.

• Reinfiltration of oil in matrix blocks causes a decrease in the ultimate oil recovery.

• Applying gas injection is a reasonable scenario for improving oil recovery. Our case study has shown that it can increase oil recovery by 5.2%, depending on the matrix block heights.

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