Correlations for predicting solution gas-oil ratio, bubblepoint pressure and oil formation volume factor at bubblepoint of Iran crude oils

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Abstract

Knowledge of the PVT parameters is a requirement for all types of petroleum calculations such as determination of hydrocarbon flowing properties, predicting future performance, designing production facilities and planning methods of enhanced oil recovery. Over the last decade increased attention has been focused on models for predicting reservoir fluid properties from reservoir pressure, temperature, crude oil API gravity and gas gravity. The present study develops empirical PVT correlations based on Al-Marhoun's correlations for estimating the solution gas-oil ratio, bubblepoint pressure and bubblepoint oil formation volume factor of Iran crude oils. Multiple regression analysis was used in developing these correlations. The evaluation is performed by using an unpublished data set of 55 bottomhole fluid samples collected from different locations in Iran. Based on statistical error analysis, the PVT correlations with their original coefficients and the modified coefficients were compared. The correlations developed in this study exhibit significantly lower average absolute error and deviation than the published ones.

Keywords: experimental data, PVT correlations, reservoir fluid, multiple regression

1. Introduction

Correlations on PVT which is commonly used in the oil industry are important tools in reservoir-performance calculations. The PVT properties can be obtained from a laboratory experiment using representative samples of the crude oils. However, the values of reservoir liquid and gas properties must be computed when detailed laboratory PVT data is not available. For developing a correlation, the geological condition must be considered because the chemical composition of crude oil differs from region to region [1, 2].

Because of the availability of a wide range of correlations, it is beneficial to analyze them for a given set of PVT data belonging to a certain geological region. Therefore, to account for regional characteristics, PVT correlations need to be modified prior to their application. Certain correlations, for bubblepoint pressure and other fluid properties, require use of production data such as producing GOR, oil gravity, gas gravity, and reservoir temperature. A large number of PVT correlations for estimation of solution gas-oil ratio, bubblepoint pressure and bubblepoint oil FVF of reservoir oils have been offered in the petroleum engineering literature over the last few years [1-6].

The objective of this study is to develop a set of new equations, using multiple regression analysis, based on Al-Marhoun's correlations for estimating the solution gas-oil ratio, bubblepoint pressure and bubblepoint oil formation volume factor of Iran crude oils. The validity and statistical accuracy are determined for these correlations.

2. PVT data

The PVT analyses of 55 bottomhole fluid samples collected from 55 oil reservoirs in different locations of Iran (Iranian Central Oil Fields, Iranian Southern Oil Fields and Iranian Offshore Oil Fields) were used to develop the correlations presented in this study. These data were the results of standard differential liberation tests conducted on bottomhole fluid samples accessed with cooperation by Research Institute of Petroleum Industry of Iran (IRPI).

3. Development of the PVT correlations

We developed our model based on Al-Marhoun's correlations for predicting the PVT properties for Iran crude oils. These correlations were obtained by multiple linear regression analysis using Eview's software.

3.1. Bubblepoint pressure correlation

Al-Marhoun (1988) published his correlation for determining bubblepoint pressure based on 160 data points from Middle East oil samples. The following general relation of bubblepoint pressure was proposed [3]:

$$P_b = f(R_s, \gamma_g, \gamma_o, T) \tag{1}$$

In this model, the bubblepoint pressure is predicted as a direct function of solution gas-oil ratio, specific oil and gas gravity and temperature. Best results were obtained by multiple regression analysis from the following empirical relation:

$$P_b = 1.09373 \times 10^{-4} R_s^{0.5502} \gamma_g^{-1.71956} \gamma_o^{2.5486} (T + 460)^{2.0967} \tag{2}$$

where

P_b = bubblepoint pressure (psia),

R_s = solution gas- oil ratio (scf / STB),

γ_g = dissolved gas relative density(air = 1),

γ_o = stock-tank relative density (water = 1), and

T = reservoir temperature(°F).

3.2. Solution gas-oil ratio correlation

The correlation for the solution gas-oil ratio is usually derived from bubblepoint pressure correlation. In this study, the coefficients for the solution gas-oil ratio correlation developed by Al-Marhoun (1988) were regressed through the experimentally obtained data to improve the estimation:

$$R_s = 994.3718\gamma_g^{2.113367} P_b^{1.45558} \gamma_o^{-5.48944} (T+460)^{-1.90488} \qquad (3)$$

3.3. Bubblepoint oil formation volume factor correlation

Al-Marhoun (1992) updated his earlier 1988 correlation by acquiring a large data set of 4012 data points collected from all over the world [6]. Oil FVF at bubblepoint pressure can be derived as a function of solution GOR, gas and oil relative density and temperature as follows:

$$B_{ob} = 0.99117 + 0.00021 R_s - 2.32\times10^{-6} R_s \left(\frac{\gamma_g}{\gamma_o}\right) - 4.30\times10^{-7} R_s (T-60)(1-\gamma_o) + 0.00071(T-60) \qquad (4)$$

The crossplots of estimated vs. experimental values for bubblepoint pressure, solution gas-oil ratio, and oil formation volume factor correlations are presented in Figures 1-3 respectively. The plotted data points obtained by the new correlations are quite close to the perfect correlations of the 45^o line.

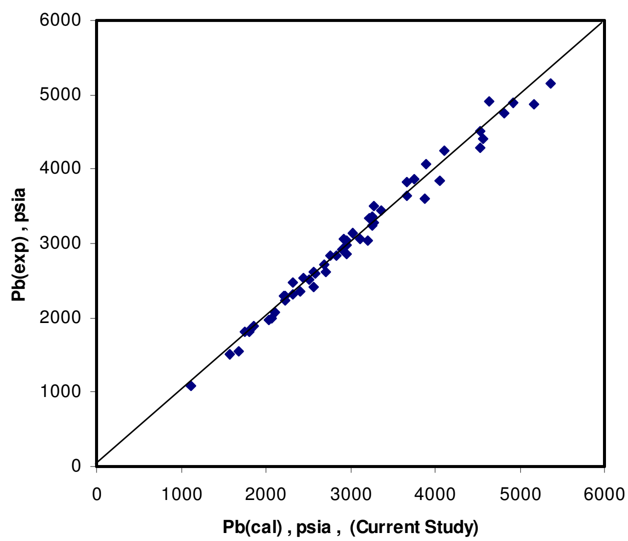


Figure 1: Crossplot for bubblepoint pressure.

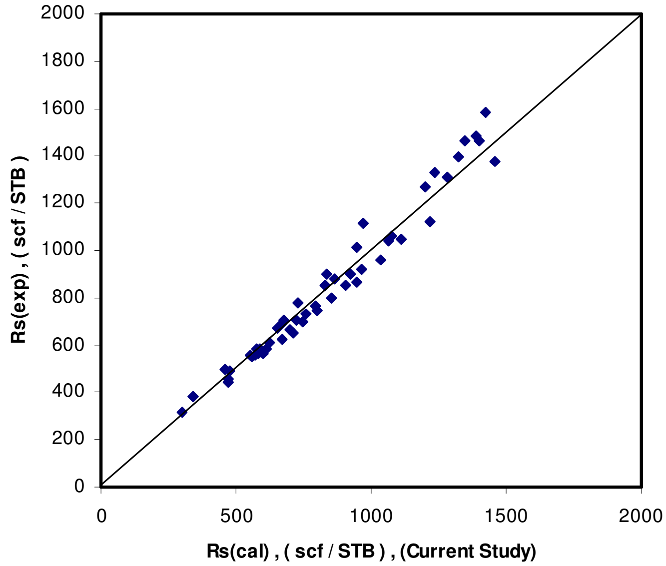


Figure 2: Crossplot for solution gas-oil ratio.

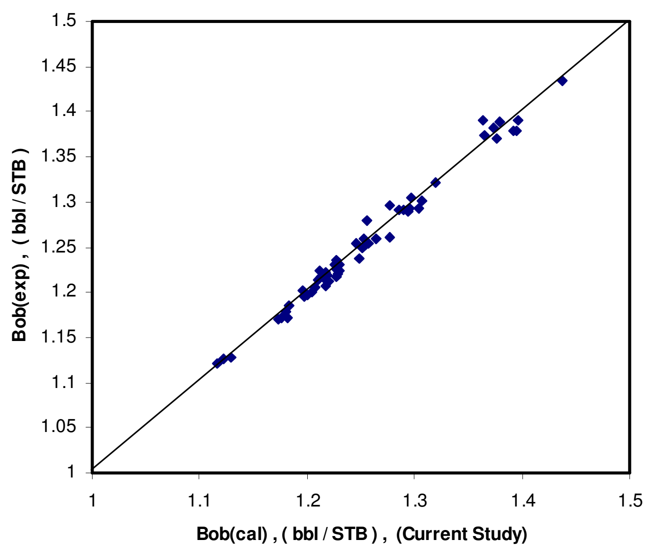


Figure 3: Crossplot for oil FVF at bubblepoint.

4. Evaluation procedure

Statistical and graphical error analyses are the criteria adopted for the evaluation in this study. Average percent relative error, average absolute percent relative error, sum squared residual, and coefficient of correlation were used as Statistical means to determine the accuracy of correlations to be evaluated. An error analysis based on oil API gravity ranges is considered an effective tool for determining the suitability of the correlation for all kinds of oil. The statistical means used to determine the accuracy of the correlations are given in Appendix A.

5. Results and comparison

Average absolute relative error is an important indicator of the accuracy of an empirical model. It is used here as a comparative criterion for testing the accuracy of correlations. Error calculations in the form of average absolute relative error, average percent relative error, sum squared residual, and coefficient of correlation for solution gas-oil ratio, bubblepoint pressure and bubblepoint oil FVF are summarized in Tables 1-3. Another effective comparison of correlations is performed through graphical representation of errors as a functional of oil API gravity ranges. Figures 4-6 represent correlation errors for six oil API gravity ranges.

Table 1: Statistical accuracy of solution gas-oil ratio

correlation	$E_r(\%)$	$E_a(\%)$	SSR	r
Al-Marhoun (1988)	10.3	10.6	1.22×10^6	
Current study	0.174	5.17	1.7×10^5	0.9880

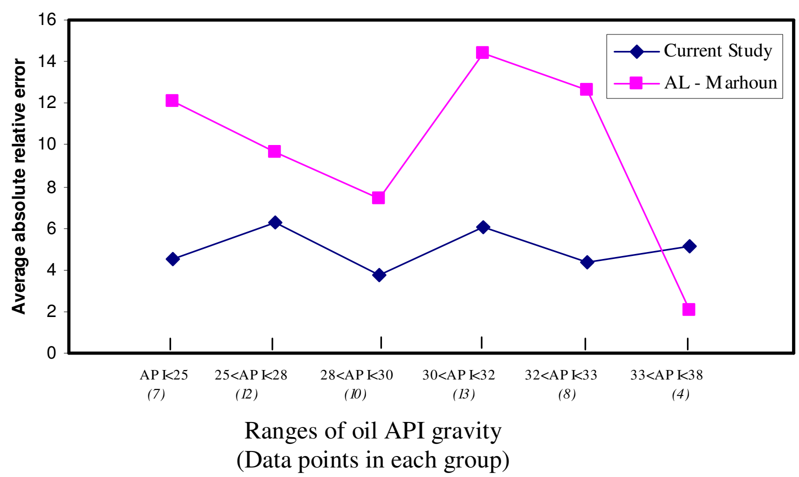
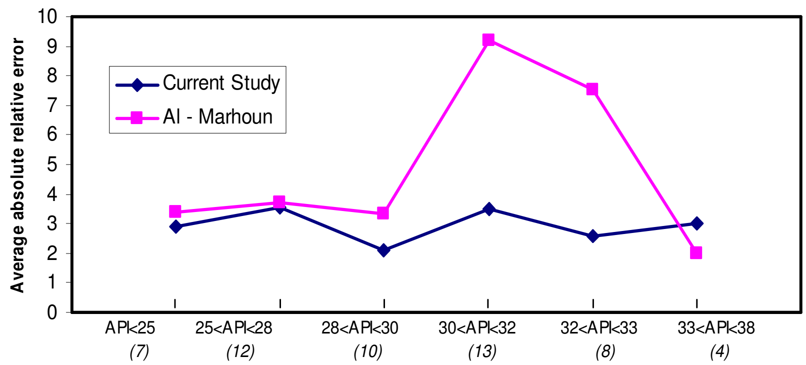


Figure 4: Statistical accuracy of solution gas-oil ratio grouped by oil API gravity.

Table 2: Statistical accuracy of bubblepoint pressure

correlation	$E_r(\%)$	$E_a(\%)$	SSR	r
Al-Marhoun (1988)	3.6	5.36	5.64×10^6	
Current study	0.066	3.002	8.04×10^5	0.9941

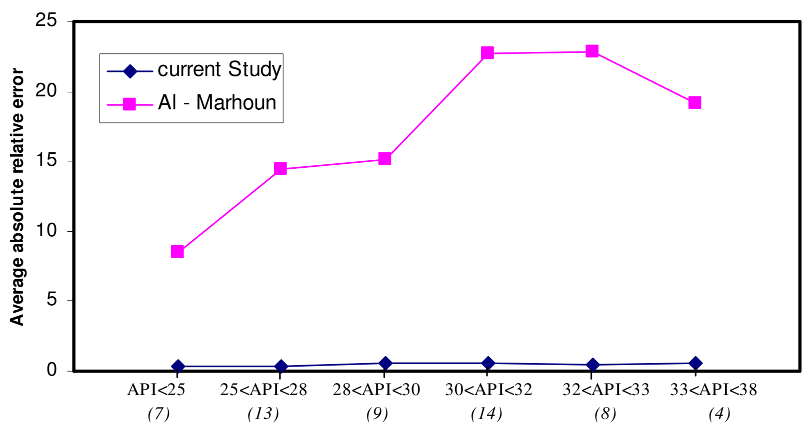


Ranges of oil API gravity
(Data points in each group)

Figure 5: Statistical accuracy of bubblepoint pressure grouped by oil API gravity.

Table 5: Statistical accuracy of bubblepoint oil FVF

correlation	$E_r(\%)$	$E_a(\%)$	SSR	r
Al-Marhoun (1988)	-17.4	17.4	3.31	
Current study	-0.0045	0.51	0.004	0.9932



Ranges of oil API gravity
(Data points in each group)

Figure 6: Statistical accuracy of oil FVF at bubblepoint grouped by oil API gravity.

As a typical example, the dependence of the bubblepoint pressure (P_b) on temperature at different solution gas-oil ratio, oil gravity and gas gravity is shown in figure 7.

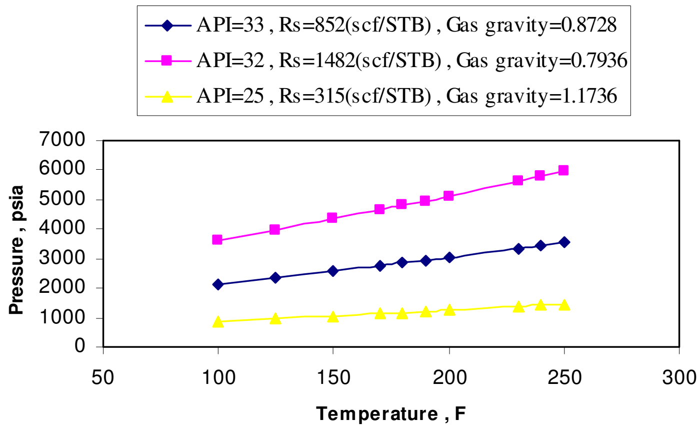


Figure 7: Effect of temperature on bubblepoint pressure at different Rs, gas and oil API gravity.

6. Conclusions

New PVT correlations for Iran crude oils were developed to predict solution gas-oil ratio, bubblepoint pressure, and bubblepoint oil FVF. The new correlations were compared with Al-Marhoun's ones and shown to be more accurate and practical.

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Notation

API	residual oil API gravity
B_{ob}	oil formation volume factor at bubblepoint pressure, bbl/STB (m^3/ m^3)
P_b	bubblepoint pressure, psia (kpa)
R_s	solution gas-oil ratio, scf/STB (m^3/ m^3)
E_a	average absolute percent relative error
E_r	average percent relative error
E_i	percent relative error
n	number of data points
SSR	sum squared residual
T	temperature, ° F (K)
X	variable representing a PVT parameter
γ_g	gas relative density (air = 1)
γ_o	Oil relative density (water = 1)

Appendix A. Statistical parameters

The following statistical means are used to determine the accuracy of the correlations.

A.1. Average percent relative error

$$E_r = \frac{1}{n}\sum_{1}^{n} E_i \tag{A-1}$$

$$E_i = \left(\frac{X_{exp} - X_{est}}{X_{exp}}\right)_i \times 100 \quad (i = 1, 2, 3, \ldots, n) \tag{A-2}$$

A.2. Average absolute percent relative error

$$E_a = \frac{1}{n}\sum_{1}^{n} |E_i| \tag{A-3}$$

A.3. Sum squared residual

$$SSR = \sum_{1}^{n} (X_{exp} - X_{est})^2 \tag{A-4}$$

A.4. Correlation coefficient

$$r = \sqrt{1 - [\sum_{1}^{n} (X_{exp} - X_{est})^2 / \sum_{1}^{n} (X_{exp} - \bar{X})^2]} \tag{A-5}$$

$$\bar{X} = \frac{1}{n}\sum_{1}^{n} (X_{exp})_i \tag{A-6}$$

References

[1] Mahmood, M. A., Al-Marhoun, M. A., (1996) *J. Pet. Science and Engineering*, 16, 275-290.
[2] Labedi, R., (1990) *J. Pet. Science and engineering*, 4, 375-390.
[3] Al-Marhoun, M.A., (1988) *J. Pet. Technol.*, 40(5), 650-666.

[4] Alikhan, A. A., (1997) *J. Pet. Science and Engineering*, 17, 291-302.

[5] Al-Marhoun, M. A., (2004) *J. Pet. Science and engineering*, 209-221.

[6] Al-Marhoun, M.A., (1992) *J. Can. Pet. Technol*, 31 (3), 22– 26.