Oil Formation Volume Factor Empirical Correlations for some Libyan Crude Oils

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Abstract—**Physical properties of reservoir fluid are necessary for different field applications. Among those properties is the Oil Formation Volume Factor (Bo). It is one of important property for both reservoir and production engineering. In many situations, laboratory measurement is not possible either because of unavailability of liquid oil samples or budget constraints, Hence, proper empirical correlations to predict formation volume factor come to rescue. The purpose of this exploration is to test the performance of the most common published Oil Formation Volume Factor correlations for selected Libyan crude oils. Statistical analysis is the criteria adopted for the evaluation in this study. Cross plot technique is also applied to check the performance of the correlation and it gave the same index of the statistical criteria method.**

Accuracy of these correlations has been confirmed by comparing the obtained results of these correlations with experimental data gathered from our labs for Libyan oil reservoirs. It was observed that, there is acceptable agreement between predicted results with experimental results.

Index Terms: **Oil formation volume factor, correlation, crude.**

I. INTRODUCTION

Oil Formation Volume Factor (Bo) is defined as the ratio of oil and dissolved gas volume at reservoir conditions to oil volume at standard condition (Ahmed,2006) . Accurate evaluation of Bo is one of prime important as it relates directly to the calculation of the petroleum reserve in the reservoir and oil in place under stock-tank conditions. The oil formation volume factor can be expressed mathematically as:

$$B0 = \frac{(V_0)_{Res}}{(V_0)_{SC}} \qquad (1)$$

where Bo = oil formation volume factor, bbl/STB, $(Vo)_{Res}$ = volume of oil under reservoir pressure p and temperature T, and $(Vo)_{sc}$ = volume of oil is measured under stock tank conditions.To estimate the oil formation volume factor, many researchers have been used different correlations. Oil formation volume factor at the bubble point pressure, can be defined as a function of solution gas oil ratio, average gas relative density, oil relative density and temperature (Hemmati et al 2007).:

$$Bo = f(Rs, \gamma g, \gamma o, T) \qquad (2)$$

The value of Bo will also depend on how is processed the fluid in surface, i.e. the separation conditions, number of stages of separation and its pressure and temperature, before reaching the stock tank oil conditions

Some of the most widely used correlations such as: Standing (1947), Glaso (1980), Al-Marhoun (1988, 1992), Mehran et al. (2006), Hemmati and Kharrat (2007) and Moradi et al. (2013) are used and presented in Table 1. A brief survey can be provided herein. Standing (1947) presented his correlation based on 105 samples from 22 different crude oil in California. Glaso (1980) considared the empirical correlation to predict the formation volume factor using 45 oil samples from North Sea hydrocarbon mixtures. Al-Marhoun (1988) developed his empirical correlations for estimating oil formation volume factor using 160 data from the Middle East oils. Based on 4012 experiment for formation volume factors data collected from worldwide origin, Al-Marhoun (1992) updated his second Al-Marhoun (1988) empirical correlation. Hemmati and Kharrat (2007) developed a new correlation based on Glaso correlation with new calculated constants. It was based on 287 data points from Iranian oil fields. Recently moradi et al. (2013) developed the new correlation to estimate B0 based on 581 data points of Middle East crude oils, ranging between 19.4 to 52 °API.

This study examines the accuracy of the common existing correlations with their original coefficients based on the data collected from some Libyan reservoirs. The statistical analysis and validity are determined for those empirical correlations and finally more adapted correlation is recommended for their application to investigated Libyan crude oils.

Received 5 May 2016; revised 3 June 2016; accepted 25 July 2016.

Available online 27 June 2016.

Table 1. Empirical Correlations for Oil Formation Volume Factor Considered in This Work

Correlation	Equation
Glaso (1980)	$Bo = 1 + \left[(10^{-6.5811 + (2.91329 \times \log\alpha) - (0.27683 \times \log(\alpha)^2)}\right]$ $\alpha = (Rs \times (\frac{\gamma_g}{\gamma_o})^{0.526}) + (0.968 \times T)$
Standing (1947)	$Bo = 0.975 + \left[(12 \times 10^{-5}) \times \left(\left(Rs \times (\frac{\gamma_g}{\gamma_o})^{0.5}\right) + (1.25 \times T)\right)\right]^{1.2}$
Al-Marhoun (1988)	$Bo = 0.497069 + [0.862963 \times 10^{-3} \times T \times 0.182594 \times 10^{-2} \times \alpha] + [0.318099 \times 10^{-5} \times \alpha^2]$ $\alpha = (Rs^{0.74239} \times \gamma_g^{0.323294} \times \gamma_o^{-1.20204})$
Al-Marhoun (1992)	$Bo = 1 + a_1 * Rs + a_2 * Rs\left(\frac{\gamma_g}{\gamma_o}\right) + a_3 * Rs * (1-\gamma_o)(T-60) + a_4 * (T-60)$ a1= 0.177342E-03, a2 = 0.220163E-03, a_3 = 4.292580E-06, a4 = 0.528707E-03 Bo= 1.031-2.838(bbl/STB), T= 75-240 (F), Rs= 7-3113 (SCF/STB), API=10.4-49.2, γ_g= 0.740-1.588
Mehran et al. (2006)	Glaso(1980), New calculated constants Bo= 1 + 10A $A=a^1+ a_2 \log(B^*ob) + a_3 \log(B^*ob)^2$ $B^*ob = Rs((\frac{\gamma g}{\gamma 0})a_4) + a_5*T$ a_1 = 4.7486, a_2 = 1.587, a_3 = 0.0495, a_4 = 0.4211, a_5 = 2.035 Bo= 1.09-3.23 (bbl/STB), T=77.5-306 (F), Rs=83-3539 (SCF/STB), g= 0.335-1.872
Hemmati and Kharrat(2007)	Glaso(1980), New calculated constants $Bo = 1 + 10^{a1+a2*LOG(M)+a3*(LOG(M))2}$ $M= Rs*((\frac{\gamma g}{\gamma o})a_4) + a5*T$ a_1 = -4.6862, a_2 = 1.5959, a_3 = -0.0566, a_4 = 0.5946, a_5 = 1.7439 Bo= 1.09-3.23 (bbl/STB), T=77.5-306 (F), Rs=83-3539 (SCF/STB), g= 0.335-1.872
Babak Moradi et al. (2013)	Bo=f(Rs, g, o, T) $Bo= a_1+a_2*°API^{a_3}*\gamma g^{a_4} Rs*((\frac{\gamma g}{\gamma o})^{a_5}) + a_6*T)^{a_7}$ a_1 = 0.965278 a_2 = 0.000100512 a_3 = 0.0672605 a_4 = -0.465317 a_5 = 0.643141 a_6 = 2.27448 a_7= 1.15416

II. DATA ACQUISITION

The collected experimental data of 13 Libyan crude oil samples derived from oil reservoirs includes: oil reservoir temperature (T), oil gravity(γo), average gas gravity (γg), total solution gas oil ratio (Rs) and API gravity. Details of these data are listed in Table 2.

Table 2. Range of Statistical Experimental Data of Oil Samples

Property	Range
T(F)	28-285
□ □	0.785-1.582
API	*30-49*
□ g	0.7639-1.5863
Bo (bbl/STB)	1.1217-1.9337
R_s(SCF/STB)	90-1738

III. Statistical Analysis

The statistical parameters used for comparison are: average percent relative error, average absolute percent relative error, maximum and minimum average absolute percent relative error and sum squared deviations . They are used to evaluate the performance of the correlations and to measure the degree of accuracy. Also cross plot technique is used herein. The statistical parameters used to compare the degree of the accuracy of the correlations are described as:

Average Percent Relative Error(%AD):

$$\% AD = \frac{1}{n} \sum_{i=1}^{n} \frac{Bo^{\exp} - Bo^{cal}}{Bo^{\exp}} \times 100 \qquad (3)$$

Percentage Average Absolute Percent Relative Error (%AAD):

$$\% AAD = \frac{1}{n} \sum_{i=1}^{n} \frac{\left| Bo^{\exp} - Bo^{cal} \right|}{Bo^{\exp}} \times 100 \qquad (4)$$

Maximum average absolute percent relative error(Emax)

$$\text{Emax} = max_1^n |AAD| \qquad (5)$$

Minimum average absolute percent relative error(Emin)

$$\text{Emin} = min_1^n |AAD| \qquad (6)$$

Sum of Squared Deviations (DEVSQ):

$$\text{DEVSQ} = \sum (x - \acute{x})^2 \qquad (7)$$

Where n is the total number of data points and $B0$ exp and $B0$ cal representing the experimental and calculated Oil Formation Volume Factor values respectively.

IV. CROSS PLOT METHOD

To visualize the accuracy and performance of a correlation, in general, graphical analysis employed is cross plot technique. In this technique, the predicted oil formation volume factor values are plotted versus the experimental values to create the cross plots . A 45o straight line is drawn on the cross plot which passes through the points of coincidence of experimental and calculated values. The closer the plotted data points are to this line, the better the correlation.

V. RESULTS AND DISCUSSION

To test the accuracy of selected correlations to predict the B0, the collected experimental data of 13 Libyan crude oil samples derived from oil reservoirs have been used. It should be noticed that the same database was used to test all the correlations involved. The statistical accuracy of the investigated correlations is summarized in Table 3. It includes the Average AD%, Average AAD%, Emax, Emin and DEVSQ. The Average AAD% is an important indicator of the accuracy of empirical correlations. It is used herein as a comparative criterion for the accuracy of the correlations.

The statistical analysis parameters for all correlations with original coefficients calculated for the oil Formation Volume Factor property show that Mehran et al. (2006) correlation has the least % AAD as shown in Table 3 (shown in bold and italic). it gave 4.23 % AAD when compared with another correlations in the literature. It can be concluded that most of these correlations can be used for the selected range of data (less than 5 % error).

Table 3.Statistical Error Analysis Study for all the Investigated Correlations

Correlation	Average AD%	Average AAD%	Emax	Emax	DEVSQ
Glaso (1980)	3.97	5.78	15.03	1.02	0.757
Standing (1947)	1.81	4.67	12.23	0.04	0.796
Al-Marhoun (1988)	6.28	7.60	26.15	0.246	0.456
Al-Marhoun (1992)	13.24	14.68	55.92	0.385	0.904
Mehran et al. (2006)	**1.73**	**4.23**	**10.18**	**0.18**	**0.617**
Hemmati and Kharrat(2007)	2.41	4.80	12.36	0.08	0.588
Babak Moradi et al. (2013)	3.24	4.38	12.52	0.137	0.587

Figures 1 through 7 illustrated cross plots of the predicted versus experimental Bo values. Graphical representation of the results shows that practically most of the points are very well behaved as seen in the Figures.

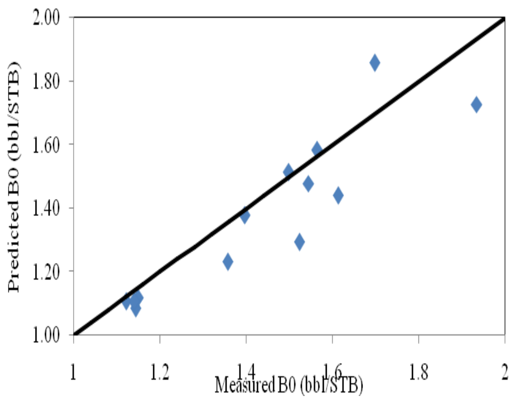

Figure 1. Cross Plot of Glaso (1980) Correlation

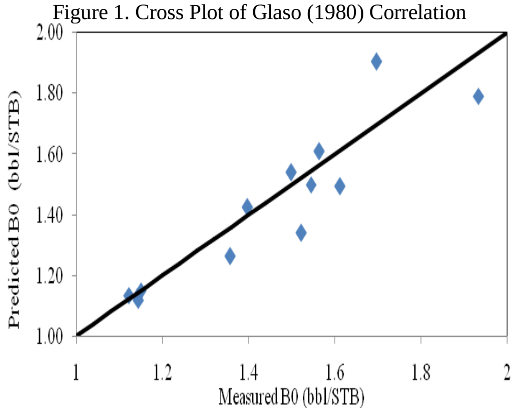

Figure 2. Cross Plot of Standing (1947)Correlation

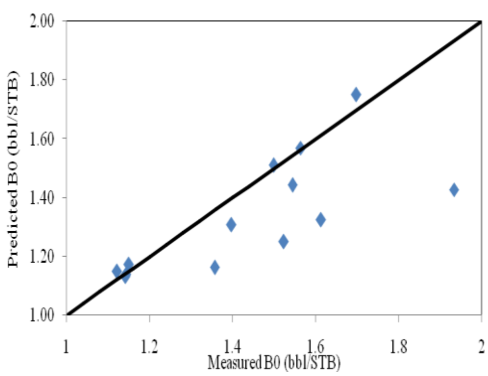

Figure 3. Cross Plot of Al-Marhoun (1988) Correlation

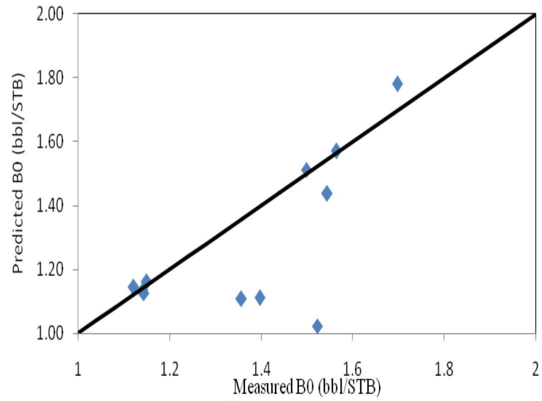

Figure 4. Cross Plot of Al-Marhoun (1992) Correlation

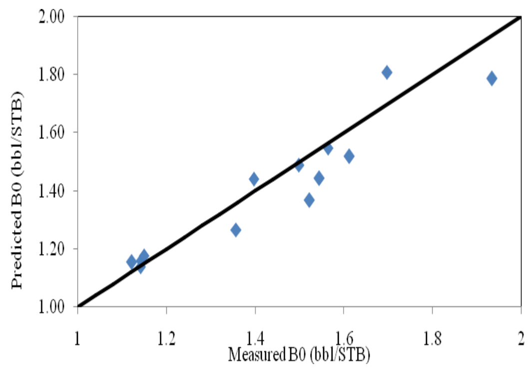

Figure 5. Cross Plot of Mehran et al. (2006) Correlation

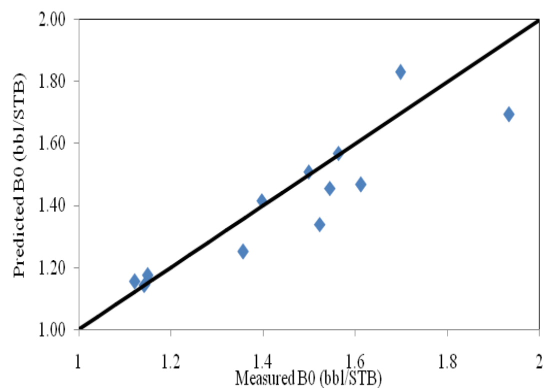

Figure 6. Cross Plot of Hemmati and Kharrat (2007) Correlation

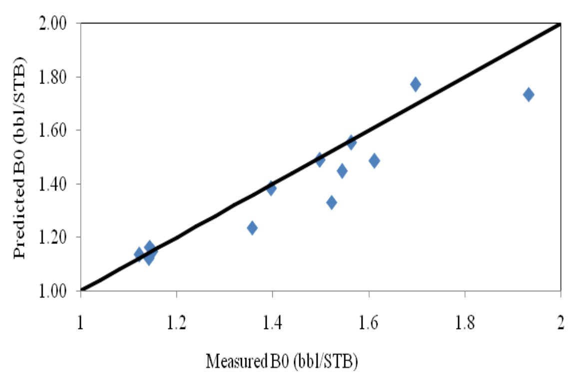

Figure 7. Cross Plot of Moradi et al. (2013) Correlation

VI. CONCLUSION

The performance of some empirical correlations reported in the literature to predict oil formation volume factor (Bo) of crude oils were examined with own experimental data. Thirteen crude oil samples with wide range of API gravity (30-49API) are used for comparison of correlations. The precision that presents each correlation was analyzed by means of the average absolute deviation. Results indicated that the correlation developed by Mehran et al. (2006) has the lowest value of % AAD 4.23%). So it resulted to be more accurate for calculating Bo compared to other existing correlations.

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