Evaluation of Some Empirically Derived Correlations for Calculation of oil Formation Volume Factor for Libyan Crude Oils

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ABSTRACT :

Empirical PVT Correlations commonly used in the oil industry are important tools for the reservoir-performance calculations. The Oil Formation Volume Factor (OFVF) or (B_o) considered one of most important key factors in reservoir and production engineering calculations. Different OFVF correlations are proposed in the literature to estimate the OFVF in the absence of the lab measure OFVF.

Most of those correlations are depending on such properties as reservoir temperature T, gas solubility R_s, oil specific gravity γ_o, and gas specific gravity γ_g.

This study evaluated the following eight empirical correlations for estimating the oil formation volume factor B_o below the bubble point pressure:

Standing's Correlation (1947), Glaso's Correlation (1980), Marhoun's Correlation (1988), Petrosky - Farshad's Correlation (1993), Kartoatmodjo and Schmidt Correlation (1994), Almehaideb Correlation (1997), Alshammasi Correlation (1999), and Alsharkawy and Alikhan (1997).

(220) data point below the bubble point pressure from twenty-eight wells were selected from seven Libyan oilfields to perform this study.

This evaluation study adopted the calculation of the absolute average relative error AARE, regression coefficient R^2, and the standard deviation STDEV.

The results showed that Almarhoun's correlation gives the lowest Average Absolute Relative Error of **1.1%** with lowest Standard Deviation of **0.923** and the highest correlation coefficient (R^2) **0.9643**.

1. INTRODUCTION :

Crude oils' physical and chemical properties vary considerably depending on the composition and the concentration of the impurities present. An accurate description of physical properties of crude oils is a considerable importance in the fields of both applied and theoretical solving of petroleum reservoir engineering problems. Physical properties are primary interest in petroleum engineering studies, the PVT Properties of Crude Oils Include [1 - 3].

Most of the PVT fluid properties are usually determined by laboratory experiments performed on samples of actual reservoir fluids. In the absence of experimentally measured properties of crude oils, it is necessary for the petroleum engineer to determine the properties from empirically derived correlations.

1.1. Oil Formation Volume Factor (B_o)

The oil formation volume factor, B_o, is defined as the ratio of the volume of oil (plus the gas in solution) at the prevailing reservoir temperature and pressure to the volume of oil at standard conditions [1 - 3]. Evidently, B_o always is greater than or equal to unity. The oil formation volume factor can be expressed mathematically as:

$$B_o = \frac{(V_o)_{p,T}}{(V_o)_{SC}} \qquad \text{...} (1)$$

where

B_o = oil formation volume factor, bbl/STB.

$(V_o)_{P,\,T}$ = volume of oil under reservoir pressure, P, and temperature, T, bbl.

(V_o) sc = volume of oil is measured under standard conditions, STB.

The objective of this study is to compare between different imperial correlations that used to calculate and predict the Oil Formation Volume Factor (OFVF), and evaluate the applicability of these correlations for some Libyan crude. These correlations by the name are Standing's

Correlation, Glaso's correlation, Marhoun's correlation, Petrosky–Farshad's correlation, Kartomodjo and Schmidt's correlation, Almehaideb's correlation, and Alshammasi's correlation.

2. LITERATURE REVIEW:

2.1. Comparative Studies of the Oil Formation Volume Factor Correlation

The best source of oil property data is a laboratory PVT (Pressure-Volume-Temperature) analysis of reservoir fluid sample. However, in the absence of experimentally measured properties of reservoir fluid, the best source of data is the empirical derived correlations. Over the past 57 years, oil formation volume factor correlation have been extensively studied and published in the literature. Many researchers have been studied and compared most of those derived correlations and most of them yield reasonable accurate results when applied at or below bubble point pressure (P_b).

M.N. Hemmati and R. Kharrat, 2007 used, 287 laboratory PVT analyses from 30 Iranian oilfields to develop the correlations. The data described in this paper was selected because they produce naturally black oil crudes and the availability of complete PVT reports that are necessary for the evaluation and development of the black oil correlations. The correlations used in this paper Standing, Glaso, Al-Marhoun, Hanafy, Dindoruk, Dokla, Petrosky correlations. Where the range of data used in this study can be describe as ($1.091 < B_o < 2.54$ bbl/STB), ($348 < P_b < 5156$ psia), ($77.5 < T < 290$ °F), ($125 < R_s < 2189.25$ Scf/STB), (18.8 < API <

48.34 °API), and (0.523 < γ_g < 1.0415, air = 1) [4]. They concluded that the minimum ARE was 0.06% with STDEV of 2.35 by Petrosky's correlation, and the maximum ARE was 8.77% with STDEV of 9.69 by Hanafy's correlation.

Mohammed Aamir Mahmood, Muhammad Ali Al-Marhoun, in 1996 used 22 bottom hole fluid samples collected from different locations in Pakistan, this unpublished data Set consists of 166 data points for evaluating the most frequently oil formation volume factor (OFVF) correlations used. The correlations used in this paper were Standing's correlation (1947), Vazquez & Beggs correlation (1980), Glaso's correlation (1980), Al-Marhoun's correlation (1988), Al-Marhoun's correlation (1992). The range of data used in this study can be describe as (1.20 < B_o < 2.916 bbl/STB), (79 < P_b < 4975 psia), (182 < T < 296 °F), (92 < R_s< 2496.25 Scf/STB), (29.0 < API < 56.5 °API), and (0.825 < γ_g < 3.445, air = 1). They found that the minimum ARE was as low as 1.23% with STDEV of 1.54 by Al- Marhoun (1992) correlation, and the maximum ARE was as high as 12.84% with STDEV of 4.37 by Vazquez & Beggs (1980) correlation [5].

Muhammad Ali Al-Marhoun 2003, the data used in this work was collected from the Middle East crude oil from PVT reports of 186 bottom hole fluid samples from different locations. This study evaluates the most frequently used pressure–volume–temperature (PVT) empirical correlations to determine reservoir–fluid properties for Middle East crudes. The correlations used in this paper Standing's (1947), Vazquez & Beggs'

(1980), Al-Marhoun's (1992) correlations. The data range used in this study was as (1.02 < B_o < 1.89 bbl/STB), (106 < P_b < 3331 psia,), (71 < T < 240 °F), (24<R_s<1453Scf/STB), (17.5 < API < 44.6 °API), and (0.753 < γ_g <1.819, air = 1). They concluded that the minimum ARE was 0.72% with STDEV of 1.28 by Al- Marhoun's (1992) correlation, on the other hand the maximum ARE was 1.60% with STDEV of 2.03 by Vazquez & Beggs' (1980) correlation [6].

Raffie Hosein, Tricia Singh, 2012 use data described below from 12 laboratory PVT reports that were available for this study generated by commercial laboratories outside of Trinidad. Standing's, Vasquez and Beggs', Glaso's, Al-Marhoun's, Petrosky-Farshad's and Velard's correlations are used in this work. The range of data used in this study can be describe as (1.148 < B_o <1.594bbl/STB), (2100 < P_b < 5600 psia), (140 < T < 216 °F), (288<R_s<1261 Scf/STB), (17.6 < API < 34.4 °API), and (0.621 < γ_g < 0.834 air = 1). They presented that the minimum average absolute error (AAE) was 0.9% by Petrosky-Farshad's and Velard's correlations, and the maximum average absolute error (AAE) was 2.7% by Almarhoun's correlation [7].

E.M. Mansour, et al. 2013, they modified Soave–Redlich–Kowng equation of state to be applicable for Egyptian crude oils using data of 43 black oil samples representing all active oil producing areas of Egypt. The equation enables to predict the oil formation volume factor and other PVT fluid properties of black oils with average relative errors ranging from 0.01% to 10.713%, the range of their used data was as (290.0 ≥ T ≥ 120.0

°F), (1.2720 ≥ γ_g ≥ 0.6777), (0.9499 ≥ γ_o ≥ 0.7908), (3500.0 ≥ P_b ≥ 3500.0), (1662.1 ≥ GOR ≥ 45.2 (SCF/STB)), and (API between 47.4 and 17.5) [19].

2.2.Statistical Error Analysis:

There are four main statistical parameters that are being considered in this study. These parameters help to evaluate the accuracy of the predicted fluid properties obtained from the black oil correlations.

2.2.1 *Average Absolute Relative Error*

This Parameter is to measure the average value of the Absolute Relative deviation of the measured value from the experimental data.

The value of AARE is expressed in Percent.

The parameter can be defined as:

$$E_a = \left(\frac{1}{nd}\right) \sum_{i=1}^{nd} Ei \text{ .... } (2)$$

E_i is the relative deviation in percent of an estimated value from an experimental value and is defined by

$$Ei = \left[\frac{X_{est} - X_{exp}}{X_{exp}}\right] i \times 100 \, , \quad i = 1, 2, \ldots, n_d \text{ .... } (3)$$

Where x_{est} and x_{exp} represent the estimated and experimental values, respectively and indicate the relative absolute deviation in percent from the experimental values.

A lower value of AARE implies better agreement between the estimated and experimental values [4].

2.2.2 *Standard Deviation*

Standard deviation of the estimated values with respect to the experimental values can be calculated using the following equation:

$$S_x{}^2 = \left[\frac{1}{n_d - 1}\right] \sum_{i=1}^{n_d} E_i^2 \quad \text{(4)}$$

The symbol *x* represents the physical properties.

The accuracy of the correlation is determined by the value of the standard deviation, where a smaller value indicates higher accuracy. The value of standard deviation is usually expressed in percent [4]. A lower value of standard deviation means a smaller degree of scatterness.

2.2.3 *Cross Plot*

In this technique, all the estimated values are plotted against the experimental values, and thus a cross plot is formed. A 45° [0.79-rad] straight line is drawn on the cross plot on which the estimated value is equal to the experimental value [4].

3. THE EMPIRICAL CORRELATIONS STUDIED

3.1. Standing's Correlation (1947)

In 1947, Standing published a graphical correlation for estimating the oil formation volume factor with different PVT properties, the gas solubility, gas gravity, oil gravity, and reservoir temperature as the correlating parameters. 105 experimental data points were used to originate this graphical correlation from California hydrocarbon systems. In

1981Standing revealed that the oil formation volume factor can be estimated more conveniently by the following equation [1, 3, 8 – 10].

$$Bo = 0.972 + 0.000147 \left[Rs \left(\frac{\gamma_g}{\gamma_o} \right)^{0.5} + 1.25(T - 460) \right]^{1.175} \ldots\ldots\ldots\ldots (5)$$

Where

T = temperature, °R.

γ_o = specific gravity of the stock-tank oil, 60°/60°.

γ_g = specific gravity of the solution gas.

3.2. Glaso's Correlation (1980)

Glaso in 1980 derived the following expressions for calculating the oil formation volume factor [1, 3, 8, 11].

$$Bo = 1.0 + 10^{A} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

Where

$$A = -6.58511 + 2.91329 \log B^*{}_{ob} - 0.27683 \left(\log B^*{}_{ob}\right)^2$$

B^*_{ob}: is a correlating number defined by the following equation:

$$B^*{}_{ob} = R_s \left(\frac{\gamma_g{}^*}{\gamma_o} \right)^{0.526} + 0.968(T - 460) \ldots\ldots\ldots\ldots (7)$$

Where

T = temperature, °R.

γ_o = specific gravity of the stock-tank oil, 60°/60°.

γ_g = specific gravity of the solution gas.

This correlation originated from studying PVT data of 45 oil samples from the North Sea crude oils. In general, Glaso's correlation under predicts formation volume factor [1, 3, 8, 11].

3.3.Almarhoun's Correlation (1988)

Marhounin1988 developed a correlation for determining the oil formation volume factor as a function of the gas solubility, stock-tank oil gravity, gas gravity, and temperature [1, 3, 8, 12, 13].

The empirical equation was developed by using the nonlinear multiple regression analysis on 160 experimental data points. Those experimental data were obtained from 69 Middle Eastern oil reservoirs. The author proposed the following expression:

$$Bo = 0.497069 + 0.000862963\,T + 0.00182594\,F + 0.00000318099\,F^2 \text{……... (8)}$$

with the correlating parameter F as defined by the following equation :-

$$F = R_s^a \gamma_g^b \gamma_o^c \text{…………………………………….(9)}$$

Where

T = temperature, °R

a, b, and c are the coefficients have the following values

a = 0.742390 b = 0.323294 c = –1.202040

3.4.Petrosky - Farshad's Correlation (1993)

Petrosky and Farshad proposed a new expression for estimating Bo in 1993. This proposed relationship is similar to the equation developed by Standing however, the equation introduces three additional fitting parameters to increase the accuracy of the correlation. The authors matched the experimental crude oil data points from the Gulf of Mexico hydrocarbon system where he used total 128 experimental data points by a nonlinear regression model [1, 3, 8, 14]. Their mathematical expression has the following form:

$$B_o = 1.0113 + 7.2046\ (10^{-5})A \qquad (10)$$

Where the term A as given by

$$A = \left[R_S^{0.3738}\left(\frac{\gamma_g^{0.2914}}{\gamma_o^{0.6265}}\right) + 0.24626(T-460)^{0.5371}\right]^{3.0936} \qquad (11)$$

Where

T = temperature, °R.

γ_o = specific gravity of the stock-tank oil, 60°/60°.

γ_g = specific gravity of the solution gas.

3.5.Kartoatmodjo and Schmidt Correlation (1994)

In 1994 Kartoatmodjo and Schmidt published the most comprehensive study of oil formation volume factor correlation. They developed a new empirical correlation based on a large data collected from developed reservoirs all over the world. The authors used data were collected from 740 different crude oil samples about 5392 data pints [8,15], and their correlation has the following expression :-

$$B_o = 0.98496 + 0.0001\, F^{1.50} \quad \text{.........................(12)}$$

Where the correlating parameter F as defined below :-

$$F = R_{sb}{}^{0.755} \gamma_g{}^{0.25} \gamma_o{}^{-1.5} + 0.45\, T \quad \text{...................(13)}$$

Where

γ_o = specific gravity of the stock-tank oil, 60°/60°.

γ_g = specific gravity of the solution gas.

3.6.Almehaideb's Correlation (1997)

Almehaideb in 1997 derived PVT correlations for estimating the oil formation factor for united Arab Emirates (UAE) crude oils[8,16], this correlation considering PVT analysis on 15 reservoirs from UAE, the oil formation factor mathematical expression as :

$$B_o = 1.122018 + 1.41 \times 10^{-6} \left(\frac{R_s T}{\gamma_o{}^2}\right) \quad \text{......................(14)}$$

Where: γ_o = specific gravity of the stock-tank oil, 60°/60°.

γ_g = specific gravity of the solution gas.

3.7.Alshammasi's Correlation (1999)

Alshammasi (1999) also computed a correlation for the oil formation factor with four parameters as function of the gas solubility, gas gravity, oil gravity, and reservoir temperature [8, 18].

$$B_o = 1 + 5.53 \times 10^{-7}\big(R_s(T-60)\big) + 0.000181\left(\frac{R_s}{\gamma_o}\right) + 0.000449\left(\frac{T-60}{\gamma_o}\right) + 0.000206\left(\frac{R_s\gamma_g}{\gamma_o}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots(15)$$

Where

γ_o = specific gravity of the stock-tank oil, 60°/60°.

γ_g = specific gravity of the solution gas.

3.8.Alsharkawy and Alikhan's Correlation (1997)

Alsharkawy and Alikhan in 1997 presented PVT correlation from considered 175 analyses for estimating the oil formation factor for Kuwaiti crude oils. It was computed as function of the gas solubility, gas gravity, oil gravity, and reservoir temperature [8, 17], the oil formation factor can be expression as:

$$B_o = 1 + 40.428 \times 10^{-5}R_s + 63.802 \times 10^{-5}(T-60) + 0.780 \times 10^{-5}\left(R_S(T-60)\frac{\gamma_g}{\gamma_o}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (16)$$

Where

T = temperature, °R

γ_o = specific gravity of the stock-tank oil, 60°/60°

γ_g = specific gravity of the solution gas

Table 1 The range of data used to develop the different correlations

Correlation	P_b "psi"		T "R"		Rs "scf/STB"		API "°API"		γg "air = 1"	
	from	to	from	to	from	to	from	to	from	to
Standing	**130**	**7000**	**100**	**258**	**20**	**1425**	**16.5**	**63.8**	**0.59**	**0.95**
Glaso	**150**	**6641**	**80**	**280**	**90**	**2637**	**22.3**	**48.1**	**0.65**	**1.276**
Almarhoun	**130**	**3573**	**74**	**240**	**26**	**1602**	**19.4**	**58.9**	**0.752**	**1.367**
Petrsky&Farshad	**1574**	**6523**	**114**	**288**	**217**	**1406**	**16.3**	**45.0**	**0.5781**	**0.8519**
Kartoatmodjo& Schmidt	**15**	**6054**	**75**	**320**	**14**	**2473**	**14.4**	**58.9**	**0.37**	**1.71**
Al-Shammasi	**31.7**	**7127**	**74**	**341.6**	**6**	**3299**	**6**	**63.7**	**.51**	**3.44**
Almehaideb	**515.7**	**4836.7**	**190**	**306**	**128**	**3871**	**30.9**	**48.6**	**0.746**	**1.116**
Alsharkawy and Alikhan	**320**	**4375**	**130**	**250**	**39**	**1586**	**14.9**	**42.76**	**0.663**	**1.268**

4. COLLECTING OF PVT DATA :

In this study the Twenty-eight wells was selected from different Libyan oil Field. 220 OFVF points were gathered from the collected Pressure – Volume – Temperature (PVT) analysis. The Input Parameters, gas solubility, oil gravity, gas gravity and reservoir Temperature, and the seven above discussed correlations were used to calculate the oil formation volume factor for the 220 points. 1540 points were computed by applying the all above mentioned correlations and compared with 220 points of the lab measured OFVF "B_o". The range of data in this study demonstrated in table 2.

Table 2 The range of data used in this study

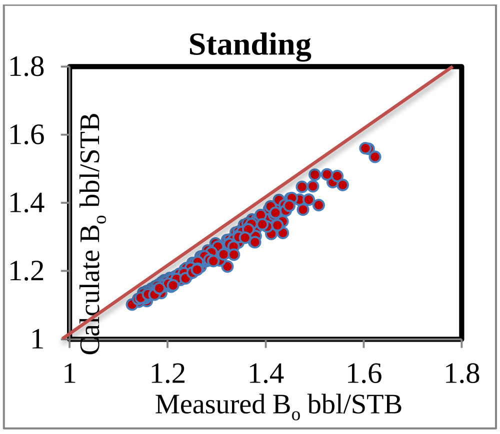
P_b "psi"		T "R"		Rs "scf/STB"		γ_o		γg "air = 1"		Bo Rbbl/STB	
from	to	from	to	from	to	from	to	from	to	from	to
62	**2196**	**148**	**261**	**64**	**858**	**0.648**	**0.7859**	**0.687**	**1.475**	**1.128**	**1.621**

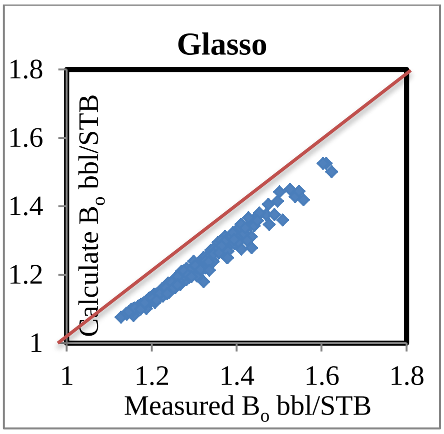
5. RESULT AND DISCUSSION:

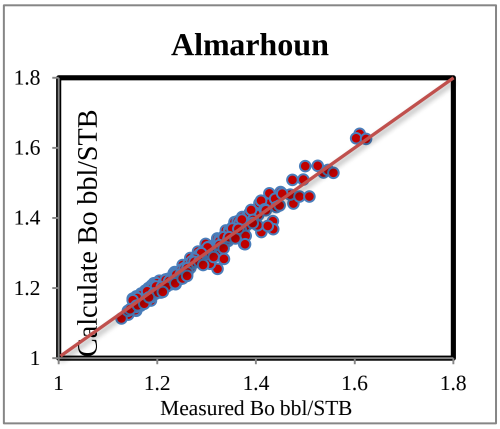
Eight empirical correlations were studied in this work, Standing correlation, Glaso correlation, Almarhoun correlation, Petrosky & Farshad correlation, Kartoatmodjo & Schmidt correlation, Al-Shammasi correlation Almehaideb correlation and Alsharkawy & Alikhan correlation.

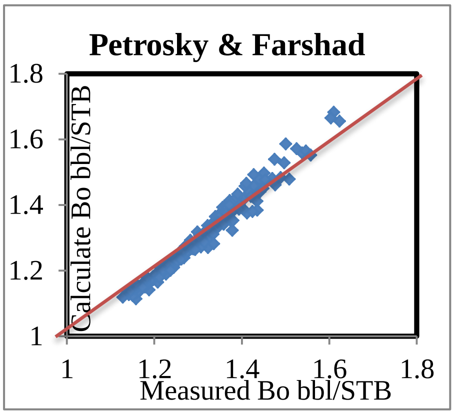
220 data point were collected from twenty eight wells from seven Libyan oil fields were used to evaluate the up mentioned correlations.

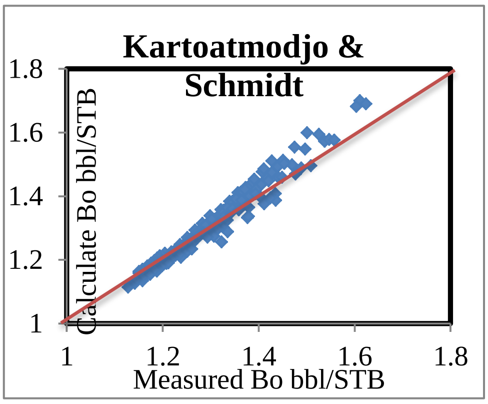
The following figure shows Cross Plot of Estimated OFVF by Different Correlations and Measured OFVF, and it clearly demonstrates Almarhoun's correlation gave the closest data to the 45° line which means it was the most accurate correlation for the studied area, followed by Al-Shammasi's correlation.

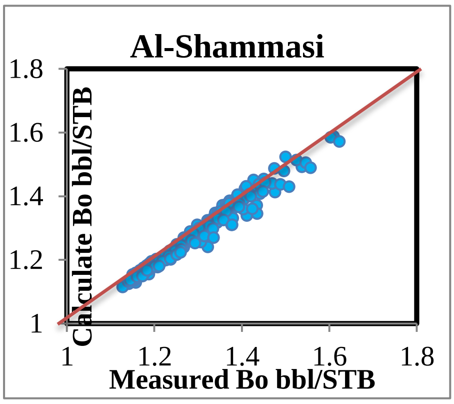

Standing
Calculate B_o bbl/STB
Measured B_o bbl/STB
1.8
1.6
1.4
1.2
1
1 1.2 1.4 1.6 1.8

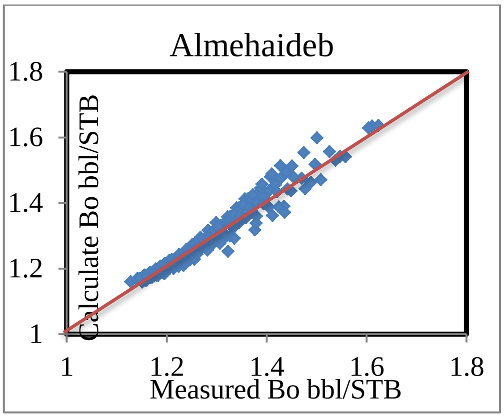

Glasso
Calculate B_o bbl/STB
Measured B_o bbl/STB
1.8
1.6
1.4
1.2
1
1 1.2 1.4 1.6 1.8


Almarhoun
Calculate Bo bbl/STB
Measured Bo bbl/STB
1.8
1.6
1.4
1.2
1
1 1.2 1.4 1.6 1.8


Petrosky & Farshad
Calculate Bo bbl/STB
Measured Bo bbl/STB
1.8
1.6
1.4
1.2
1
1 1.2 1.4 1.6 1.8


Kartoatmodjo & Schmidt
Calculate Bo bbl/STB
Measured Bo bbl/STB
1.8
1.6
1.4
1.2
1
1 1.2 1.4 1.6 1.8


Al-Shammasi
Calculate Bo bbl/STB
Measured Bo bbl/STB
1.8
1.6
1.4
1.2
1
1 1.2 1.4 1.6 1.8



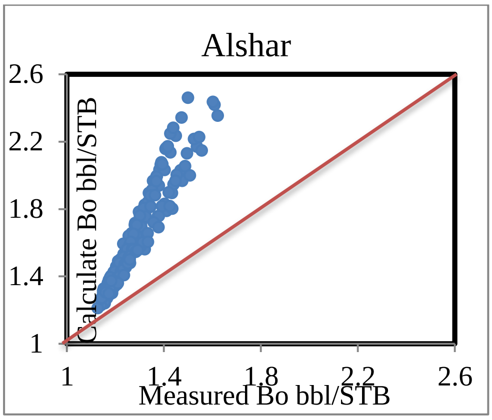


Figure 1 Cross Plot of Estimated OFVF by Different Correlations and Measured OFVF

On the other hand Alsharkawy, Glaso , and Standing correlations are deviated widely from the 45° line which means those correlations have higher AARE than Almarhoun Al-Shammasi's correlations. Also the Statistical analysis were performed for the eight different studied correlations, Table 2 shows the values of the regression factor (R^2), absolute average error (AARE) and the Standard Deviation (STDEV) for each correlation.

Table 1 Statistical analysis to select the best correlation

Correlations	**R^2**	**Average Absolute Relative Error (AARE %)**	**Standard Deviation**
Standing correlation	0.7543	3.4	1.276
Glaso correlation	0.2558	6.3	1.178
Almarhoun correlation	0.9643	1.1	0.923
Petrosky-Farshad correlation	0.9356	1.6	1.018
Kartoatmodjo & Schmidt	0.9235	1.5	1.332

Correlations	R^2	Average Absolute Relative Error (AARE %)	Standard Deviation
correlation			
Al-Shammasi correlation	0.9335	1.5	1.167
Almehaideb correlation	0.9281	1.5	1.261
Alsharkawy & Alikhan's correlation	0.7856	26.7	11.924

Results illustrated in Table 2 shows that Almarhoun's correlation have the highest regression factor R^2 of 0.9642 with lowest AARE of 1.1% and standard division of 0.92, therefore Almarhoun's correlation the most applicable correlation for estimating the oil formation volume factor for the selected Libyan oilfields in this study.

6. CONCLUSIONS :

Twenty Eight (28) wells were selected from seven different oilfields located field, in Sirte Basin to utilize in this study. A total of 220 point of laboratory (OFVF) measured at pressures below the bubble point pressure was used in this study with seven correlations to estimate the oil formation volume factor (OFVF), Standing's correlation, Glaso's correlation, Almarhoun's correlation, Petrosky & Farshad's correlation, Kartoatmodjo& Schmidt's correlation, Al-Shammasi's correlation Almehaideb's correlation and Alsharkawy and Alikhan's correlation (1997).

The Statistical result showed that Almarhoun's correlation which gives lowest an Absolute Average Relative Error of 1.06% with STDEV of 0.92 and showed the highest regression factor R^2 of 0.9643%. On the other hand Glaso's correlation showed the vice versa that means the highest an Absolute Average Relative Error of 6.3%and showed the lowest regression factor R^2 of 0.2558% therefore the best correlation to apply for Libyan oil field studied is Almarhoun's correlation. In general all the studied correlation can be considered as the applicable correlations as a result of the high regression coefficients, low absolute relative error and a small standard deviation.

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