Proposed Correlation for Gas Solubility at and below Bubble Point Pressure

Mohammed M. Daway
Engineering College, University of Baghdad / Baghdad.
Email: mohammed11sh@yahoo.com

Received on: 22/8/2013 & Accepted on:6/3/2014

ABSTRACT:

A study has been done to get an accurate correlation for solution gas-oil ratio (gas solubility). Two hundred and nine measured values from an Iraqi oil field have been used in this study.

Many formulas are tested to get the best correlation for gas solubility. Every formula predicts the value of gas-oil ratio at any given pressure, temperature, oil density and gas specific gravity. Based on the nonlinear regression analysis, the constants of these formulas are determined.

The formula with the minimum average absolute error among the assumed (reported an absolute average error of 4.97 % and a standard deviation of 453) is selected to be the proposed correlation for this study.

The accuracy of the proposed correlation is assessed through a statistical test and compared with those achieved for some published correlations. This test shows that the proposed correlation has the best fitting with the experimental data. Cross plot technique is also applied to check the performance of the correlation which gave the same index of the statistical criterion method.

Another method has been used to ensure the accuracy of the proposed correlation, in which a sample of external data (which is not used to develop the correlation) is tested. The results show the same index of the other methods.

Keywords: Gas solubility, Gas oil ratio, Bubble point pressure.

صيغة مقترحة لحساب ذوبانية الغاز عند وتحت ضغط نقطة الفقاعة

الخلاصة:

تم إجراء دراسة للحصول على علاقة دقيقة لذوبانية الغاز (نسبة الغاز المذاب إلى النفط). مئتان وتسع قيم مقاسة من أحد الحقول العراقية تم إستخدامها في هذه الدراسة.

تم إفتراض عدد من الصيغ لإيجاد أفضل علاقة لذوبانية الغاز، كل صيغة تعطي قيمة لذوبانية الغاز عند قيم معلومة للضغط ودرجة الحرارة وكثافة النفط والغاز. إعتماداً على طريقة تحليلات التراجع الخطية، تم حساب ثوابت الصيغ المقترحة.

الصيغة التي حصلت على أقل نسبة خطأ بين الصيغ المفترضة (4.97 %) وسجلت إنحراف معياري مقداره (453) تم إختيارها لتكون الصيغة المتبناة (أو المقترحة) في هذه الدراسة.

تم تقييم دقة الصيغة المقترحة عن طريق إختبارات إحصائية، حيث تم إجراء مقارنة لهذه الصيغة مع بعض الصيغ المنشورة سابقاً. وقد أظهرت هذه الإختبارات بأن العلاقة المقترحة أفضل من بقية الصيغ نسبة للبيانات المتوفرة. طريقة الرسم إستخدمت كذلك للتحقق من فعالية العلاقة، وقد أعطت الطريقة نفس الإنطباع الذي أعطته الطريقة السابقة.

https://doi.org/10.30684/etj.32.6A.12
2412-0758/University of Technology-Iraq, Baghdad, Iraq

طريقة أخرى إستخدمت أيضاً للتأكد من دقة العلاقة المقترحة، وهي تطبيق العلاقة على نموذج خارجي من البيانات (لم يستخدم في تطوير العلاقة)، وبمقارنته مع العلاقات الأخرى أعطت حساباته أيضاً نفس الإنطباع السابق.

INTRODUCTION:

Gas solubility or solution gas-oil ratio is defined as the volume of gas dissolved in one stock tank barrel of oil at a fixed pressure and temperature. Gas solubility in oil increases as the pressure increases, up to the bubble point pressure of the oil. Above the bubble point pressure, gas solubility stays constant (Fig. 1) and crude oil is often called undersaturated. In black-oil models, gas solubility determines the mass transfer between the liquid and gas phases [1].

A typical gas solubility curve, as a function of pressure for an undersaturated crude oil, is shown in figure (1). As the pressure is reduced from the initial reservoir pressure, p_i, to the bubble-point pressure, P_b, no gas evolves from the oil and consequently the gas solubility remains constant at its maximum value of R_{sb}. Below the bubble-point pressure, the solution gas is liberated and the value of R_s decreases with pressure[2].

Empirical Correlations:

Several empirical correlations to determine gas solubility are presented. They assume a flash-vaporization process. Six methods of predicting the gas solubility are presented here: Standing's correlation [3], Vasquez and Beggs's correlation [4], Glaso's correlation[5], Marhoun's correlation[6], Petrosky and Farshad's correlation [7], and Omar's correlation[8]. It should be noted that all the correlations could be used at any pressure equal to or below the bubble-point pressure.

Standing's Correlation

The Standing correlation states [3]:

$$R_s = \gamma_g \left[\left(\frac{p}{18.2} + 1.4 \right) 10^x \right]^{1.2048} \quad \ldots(1)$$

with:

$$x = 0.0125\text{API} - 0.00091(T - 460) \quad \ldots(2)$$

Vasquez-Beggs's Correlation

Vazquez and Beggs [4] presented an improved empirical correlation to estimate gas solubility, which can be written as:

$$R_s = C_1 \gamma_{gs} p^{C_2} \exp\left[C_3 \left(\frac{\text{API}}{T} \right) \right] \quad \ldots(3)$$

Values for the coefficients are listed in Table (1).

with:

$$\gamma_{gs} = \gamma_g \left[1 + 5.912(10^{-5})(\text{API})(T_{scp} - 460) \log\left(\frac{p_{scp}}{114.7} \right) \right] \quad \ldots(4)$$

Glaso's Correlation

This correlation [5] is based on North Sea crude-oil data. The mathematical form is:

$$R_s = \gamma_g \left\{ \left[\frac{API^{0.989}}{(T-460)^{0.172}} \right] (A) \right\}^{1.2255} \quad \ldots(5)$$

The parameter A is a pressure-dependent coefficient defined by the following expression:

$$A = 10^X \quad \ldots(6)$$

with the exponent X as given by:

$$X = 2.8869 - [14.1811 - 3.3093 \log(p)]^{0.5} \quad \ldots(7)$$

Marhoun's Correlation

Al-Marhoun [6] presented this correlation based on Middle East crude oils. It can be expressed as:

$$R_s = \left[a \gamma_g^b \gamma_o^c T^d p \right]^e \quad \ldots(8)$$

a, b, c, d, and e: coefficients defined in the nomenclature.

Petrosky and Farshad's Correlation

Petrosky and Farshad [7] used nonlinear multiple regression software to develop a gas solubility correlation. The authors constructed a PVT database from 81 laboratory analyses from the Gulf of Mexico crude oil system. Petrosky and Farshad proposed the following expression:

$$R_s = \left[\left(\frac{p}{112.727} + 12.340 \right) \gamma_g^{0.8439} 10^x \right]^{1.73184} \quad \ldots (9)$$

with:

$$x = 7.916\,(10^{-4})(API)^{1.5410} - 4.561(10^{-5})(T-460)^{1.3911} \quad \ldots (10)$$

Omar's Correlation:

Omar [8] proposed a correlation to calculate the solution gas oil ratio at pressures below bubble point pressure. He mentioned that the equation was obtained by multiple linear regression analysis of PVT data collected from many Iraqi fields.

In his study, the solution gas-oil ratio was taken as a function of bubble point pressure, stock tank oil gravity, reservoir pressure, reservoir temperature and relative gas density.

He developed the correlation depending on thirty seven PVT reports that were collected from Iraqi fields.

He expressed his correlation as follows:

$$R_s = A_0 P_b^{A_1} \gamma_g^{A_2} T^{A_3} API^{A_4} R_{Sb}^{A_5} P^{\left(A_6 P_b^{A_7} \gamma_g^{A_8} T^{A_9} API^{A_{10}} R_{Sb}^{A_{11}}\right)} \quad \ldots(11)$$

Where: A_0 through A_{11} are constants defined in table (2).

Data of the project:

The data studied in this project were obtained from Jambour oil field one of the northern Iraqi oil fields. The data represents 209 experimental points of the gas-oil ratio with temperature, pressure, oil density and gas specific gravity.

The proposed correlation was developed from these ranges of data:

Pressure = 14.7 to 4894.7 psia,
Temperature = 80 to 210 ºF,
Solution gas oil ratio = 0 to 1596 scf/STB,
Gas specific gravity = 0.685 to 0.8
and oil specific gravity = 0.8175 to 0.8482.

The distribution of the values of the studied properties is expressed in figures (2) through (5).

Comparison with the published correlations:

The selected formula (having minimum AAE) is:

$$R_S = 1.0392 P^{0.8171} T^{-0.1892} \gamma_g^{\ 0.2239} \gamma_o^{\ 4.9013} - 9.6 \qquad \ldots(12)$$

The above formula (equation 12) was compared with six published correlations; these are: Standing's correlation [3], Vasquez and Beggs's correlation[4], Glaso's correlation[5], Marhoun's correlation [6], Petrosky and Farshad's correlation[7], and Omar's correlation [8].

Three methods were used for the comparison; the first one was done using the statistical criteria, the second was done using cross plot method, while the third was done using a data sample from Iraqi oil field containing 17 data point (which is not used in developing the correlation). Tables (3) and (4) and figures (6) to (11) show the comparison of the proposed correlation for this study, with the mentioned published correlations using the tested data and external sample data respectively.

Every correlation has been done in a range of data that presented in Table (5). Therefore, in the current study the points that fall out of range of each correlation are rejected from comparison. No. of points in range (which are used in comparison) for each correlation are presented in Table (3).

From the tables, it is clear that the proposed correlation is better than the other six correlations.

CONCLUSIONS:

1. Based on data from one of the northern Iraqi oil fields, many formulas to get an accurate correlation for the gas-oil ratio were assumed, and the selected formula (eq. 12) appeared to be the best one (among the assumed).
2. The proposed correlation compared with six published correlations using three methods. The three methods showed that the proposed correlation is better than all of those correlations.

Nomenclature:

ρ_o : density of the oil at the specified pressure and temperature, lb/ft^3.
a–e : coefficients of Marhoun's equation having the following values:
a = 185.843208
b = 1.877840
c = –3.1437
d = –1.32657
e = 1.39844
A_0 through A_{11} : Constants of Omar's correlation.
API : American Petroleum Institute unit, API.
P : Pressure, psi.
P_b : Bubble Point Pressure, psi.
P_{sep} : actual separator pressure, psia.
R_s : Gas-oil ratio or gas solubility, scf/STB.
R_{sb} : Gas-oil ratio at bubble point, scf/STB.

T : temperature, °R.
T_{sep} : actual separator temperature, °R.
γ_g : specific gravity of the solution gas.
γ_o : specific gravity of the stock-tank oil, 60°/60°.

REFERENCES:

[1]Brill, J.P. and Mukherjee, H. "Multiphase Flow in Wells", Monograph Vol. 17, SPE Henry L. Doherty Series, Richardson-Texas, 1999.
[2]Ahmed, T., "Equations of State and PVT Analysis: Applications for Improved Reservoir Modeling", Gulf Publishing Company, Houston, Texas, 2007.
[3]Standing, M.B.: Volumetric and Phase Behavior of Oil Field Hydrocarbon Systems, ninth edition, SPE, Richardson, Texas (1981).
[4]Vasquez, M. and Beggs, H.D.: "Correlations for Fluid Physical Property Prediction", JPT (June 1980) 968; Trans., AIME, 269.
[5]Glaso, O., "Generalized Pressure-Volume-Temperature Correlations", JPT, May 1980.
[6]Marhoun, M. A. "PVT Correlation for Middle East Crude Oils." Journal of Petroleum Technology (May 1988): 650–665.
[7]Petrosky, G. E., and F. Farshad. "Pressure-Volume-Temperature Correlations for Gulf of Mexico Crude Oils", SPE paper 26644, Houston, October 3–6, 1993.
[8]Omar, F.H. "Correlation for Solution Gas Oil Ratio of Iraqi Oils at Pressure below the Bubble Point Pressure", Iraqi Journal of Chemical and Petroleum Engineering, vol. 2, No. 2, June, 2011.

Table (1): Coefficients of Vasquez and Beggs Correlation

Coefficient	API ≤ 30	API > 30
C_1	0.362	0.0178
C_2	1.0937	1.187
C_3	25.724	23.931

Table (2): Constants of Omar's correlation:

The Constant	Its value	The Constant	Its value
A_0	0.0006	A_6	3.867
A_1	0.856	A_7	-0.306
A_2	0.351	A_8	-0.083
A_3	1.829	A_9	-0.306
A_4	1.462	A_{10}	-0.288
A_5	-2.116	A_{11}	0.525

Table (3): Comparison of the results using tested data

Correlation	No. of points in range (which are used in comparison)	Average absolute Error, %	Sum of squared residuals	Variance	Standard Deviation
Proposed	All	0.049737	1123247	205503	453
Standing	171	0.300097	5819368	187292	433
Vasquez and Beggs	182	0.36698	10201950	160926	401
Glaso	190	0.369743	13615860	137093	370
Marhoun	115	0.459796	14728670	159927	400
Petrosky and Farshad	156	0.286482	14224470	103412	322
Omar	44	0.316269	47653140	670581	819

Table (4): comparison of the results for the external data

Correlation	Average absolute Error, %	Sum of squared residuals	Variance	Standard Deviation
Proposed	0.039387	12838	164999	406
Standing	0.209407	71795	163829	405
Vasquez and Beggs	0.289821	188936	135802	369
Glaso	0.314842	453461	108252	329
Marhoun	0.406816	516559	130946	362
Petrosky and Farshad	0.247321	394908	80969	285
Omar	0.262062	478811	201834	482

Table (5): The ranges of data used in the correlations

Correlation	P_b, psi		T, ^oF		Rs, SCF/STB		API		γ_g, dimensionless	
	Min. value	Max. value	Min. value	Max. value	Min. value	Max. value	Min. value	Max. value	Min. value	Max. value
Proposed	2010	4894	80	210	0	1596	31	43.8	0.685	0.8
Standing	130	7000	100	258	20	1425	16.5	63.8	0.59	0.95
Vasquez and Beggs	15	6055	70	295	0	2199	15.3	59.5	0.511	1.351
Glaso	165	7142	80	280	90	2637	22.3	48.1	0.65	1.273
Marhoun	130	3573	74	240	26	1602	19.4	44.6	0.752	1.367
Petrosky and Farshad	1574	6523	114	288	217	1406	16.3	45	0.578	0.871
Omar	1950	4000	190	275	---	---	20	37	0.7	0.9

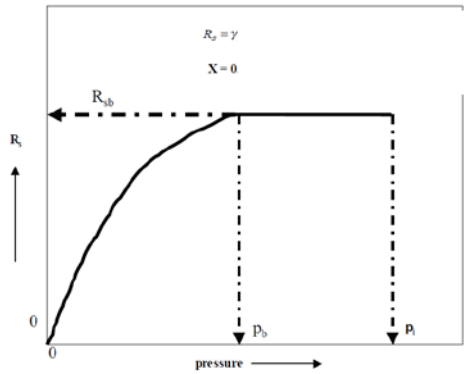

Figure (1): Typical gas solubility/pressure relationship [2].

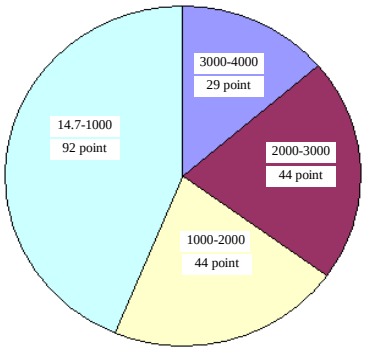

Figure (2): The distribution of Pressure for overall data (psia).

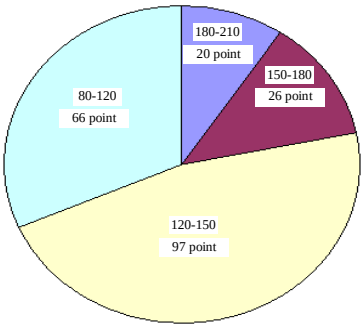

Figure (3): The distribution of Temperature for overall data (^{o}F).

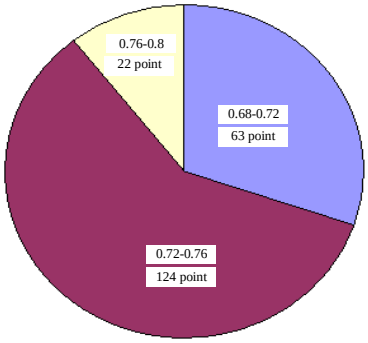

Figure (4): The distribution of gas specific gravity for overall data.

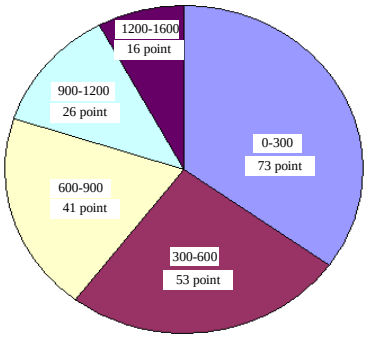

Figure (5): The distribution of gas oil ratio for overall data (scf/STB).

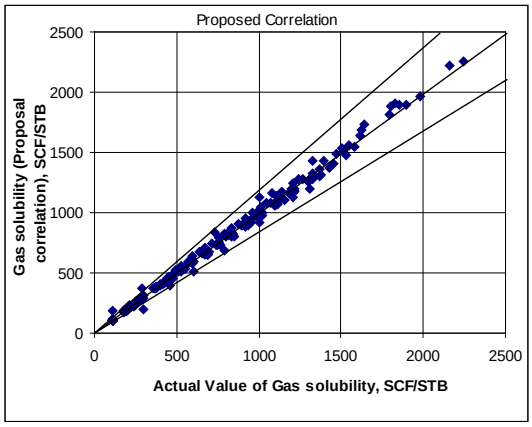

Figure (6): Cross Plot of Gas-oil ratio (Experimental data Versace the calculated data of Proposed Correlation)

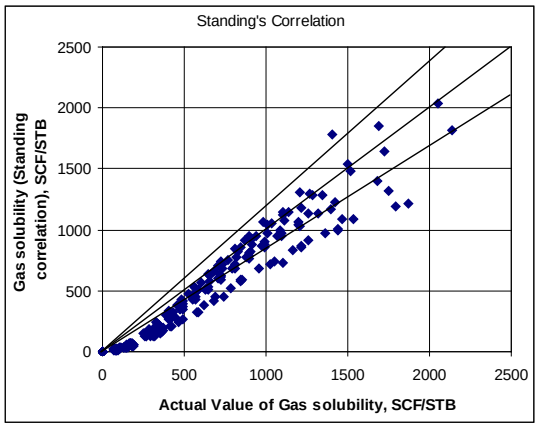

Figure (7): Cross Plot of Gas-oil ratio (Experimental data Versace the calculated data of Standing's Correlation)

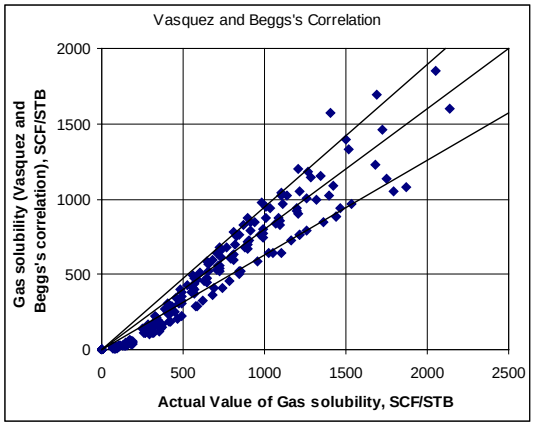

Figure (8): Cross Plot of Gas-oil ratio (Experimental data Versace the calculated data of Vasquez and Beggs's Correlation)

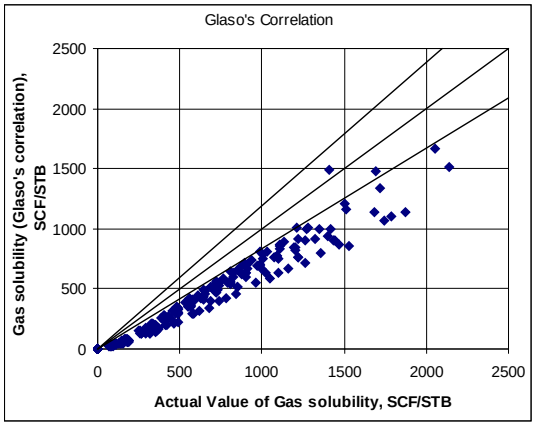

Figure (9): Cross Plot of Gas-oil ratio (Experimental data Versace the calculated data of Glaso's Correlation)

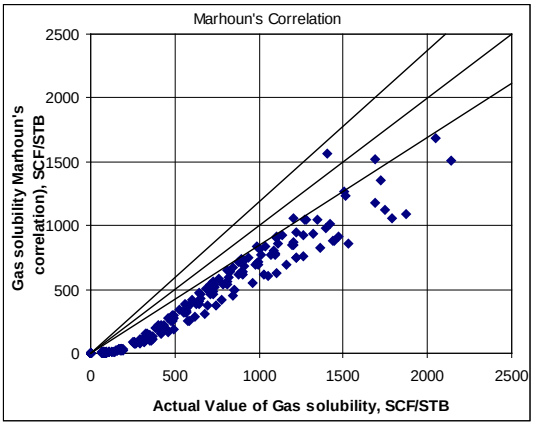

Figure (10): Cross Plot of Gas-oil ratio (Experimental data Versace the calculated data of Marhoun's Correlation)

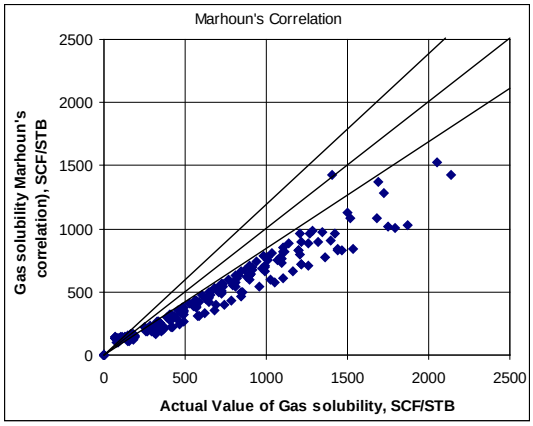

Figure (11): Cross Plot of Gas-oil ratio (Experimental data Versace the calculated data of Petrosky and Farshad's Correlation)

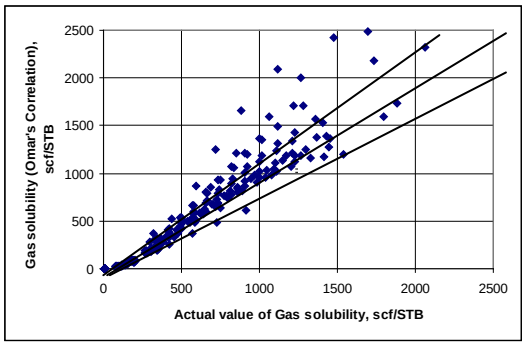

Figure (12): Cross Plot of Gas-oil ratio (Experimental data vs. the calculated data of Omar's Correlation)

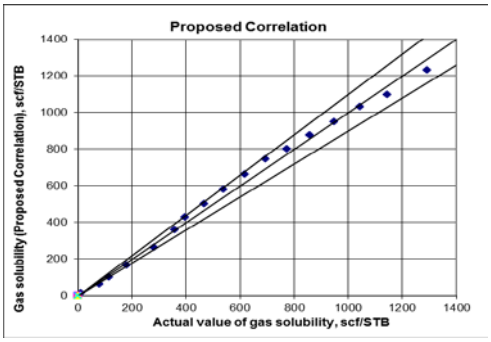

Figure (13): Cross Plot of Gas-oil ratio (Experimental data vs. the calculated data of proposed Correlation) for the external data.

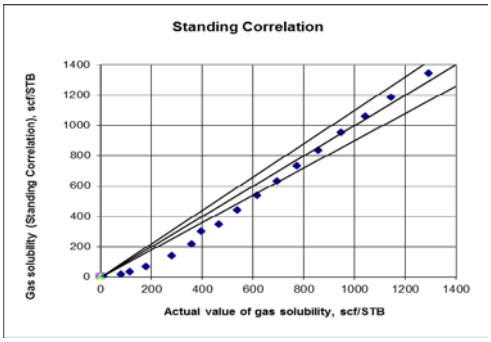

Figure (14): Cross Plot of Gas-oil ratio (Experimental data vs. the calculated data of Standing's Correlation) for the external data.

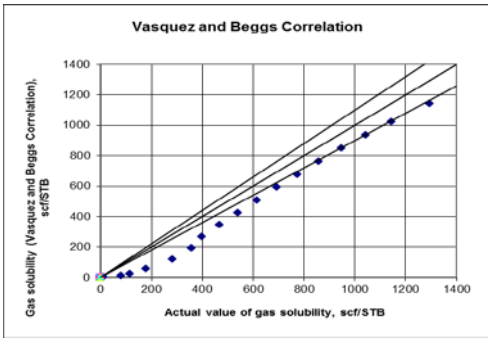

Figure (15): Cross Plot of Gas-oil ratio (Experimental data vs. the calculated data of Vasques and Beggs Correlation) for the external data.

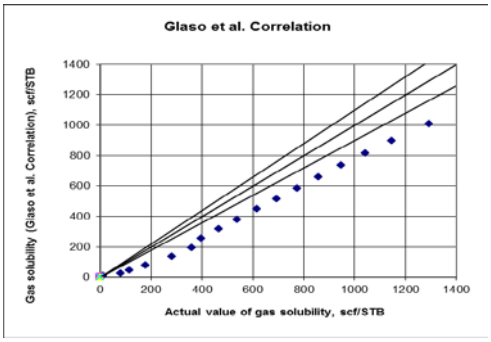

Figure (16): Cross Plot of Gas-oil ratio (Experimental data vs. the calculated data of Glaso's Correlation) for the external data.

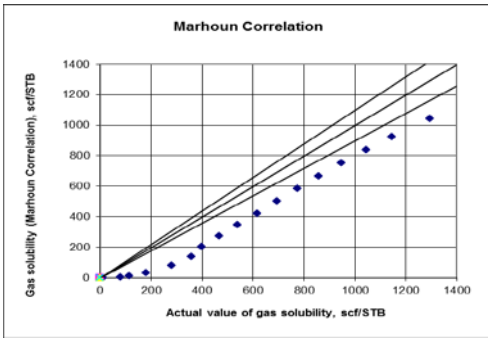

Figure (17): Cross Plot of Gas-oil ratio (Experimental data vs. the calculated data of Marhoun's Correlation) for the external data.

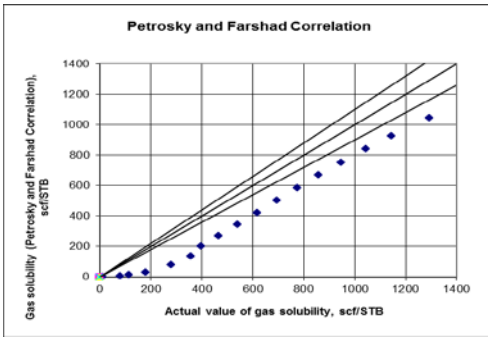

Figure (18): Cross Plot of Gas-oil ratio (Experimental data vs. the calculated data of Petrosky and Farshad's Correlation) for the external data.

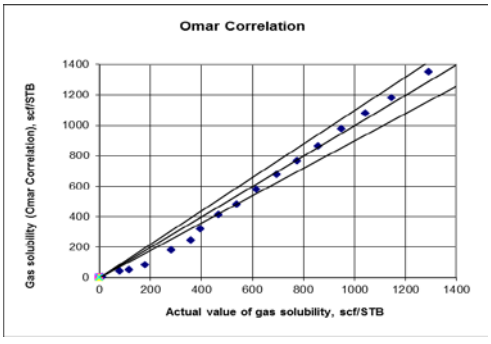

Figure (19): Cross Plot of Gas-oil ratio (Experimental data vs. the calculated data of Omar's Correlation) for the external data.