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CORRELATION FOR SOLUTION GAS -OIL RATIO OF IRAQI OILS AT PRESSURES BELOW THE BUBBLE POINT PRESSURE

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ABSTRACT

The solution gas-oil ratio is an important measurement in reservoir engineering calculations. The correlations are used when experimental PVT data from particular field are missing. Additional advantages of the correlations are saving of cost and time.

This paper proposes a correlation to calculate the solution gas -oil ratio at pressures below bubble point pressure. It was obtained by multiple linear regression analysis of PVT data collected from many Iraqi fields.

In this 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.

The construction of the new correlation is depending on thirty seven PVT reports that were collected from Iraqi fields.

Statistical and graphical tools have been used to check the performance of the correlation. Correlation performance was also compared with previous published correlations.

The values of solution gas - oil ratio that were calculated from the new correlation have high accuracy when they were compared with the original laboratory data. Also, the results of the new correlation show high precision when compared with Standing [1], Vasquez and Beggs [2], Glaso [3], Al-Marhoun [4], Petrosky and Farshad [5], Kartoatmodjo and Schmidt [6], Velarde, Blasingame and McCain [7] and Mazandarani and Asghari [8] correlations.

INTRODUCTION

Solution gas-oil ratio, R_s, is defined as the number of standard cubic feet of gas that dissolve in one stock-tank barrel of crude oil at certain pressure and temperature. The solubility of a natural gas in a crude oil is

Function of the pressure, the temperature, the API gravity and the gas gravity.

For particular gas and crude oil to exist at a constant temperature, the solubility increases with pressure until the saturation pressure is reached. At the saturation pressure, all the available gases are dissolved in the oil and the gas solubility attains its maximum value.

A typical solution gas-oil ratio curve, as a function of pressure for an undersaturated crude oil, is shown in Fig. 1. As the pressure is reduced from the initial reservoir pressure, P_i, to the saturation pressure, P_b, no gas evolves from the oil and consequently the gas solubility stills constant at its maximum value R_{sb}. Below the saturation pressure, the dissolved gas is liberated and the value of R_s decreases with pressure.

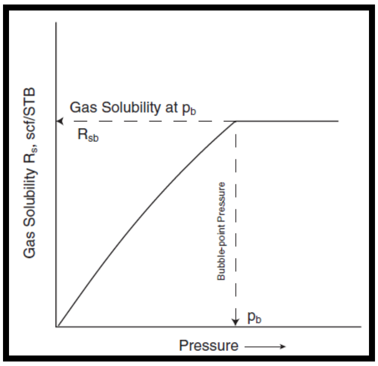

Fig. 1 Typical gas solubility/pressure relationship

In the absence of experimentally measured solution gas-oil ratio of a crude oil system, it is necessary to determine this property from empirically derived correlations.

Published Empirical Equations

Many empirical correlations for estimating the solution gas-oil ratio are presented in this paper. These correlations covered oils from USA, North Sea, Middle East, Gulf of Mexico, Iran and Libya. Further three correlations [2] [6] [7] of them depended on global data banks.

Standing [1] (1947) proposed a graphical correlation for determining the solution gas-oil ratio as a function of pressure, gas specific gravity, API gravity and system temperature. The correlation was developed from a total of 105 experimentally determined data points on 22 hydrocarbon mixtures from California crude oil and natural gases. Standing [9] (1981) expressed his proposed graphical correlation in a mathematical form.

Vasquez and Beggs [2] (1980) presented an improved empirical correlation for estimating R_s. Their correlation was obtained by regression analysis using more than five thousand measured solution gas-oil ratio data points. Based on API gravity, the measured data were separated into groups. This division was made at a value of oil gravity of 30^o API. Categorized that the value of the specific gravity of gas depends on the conditions under which it is separated from the oil, Vasquez and Beggs proposed that the value of specific gravity of gas as obtained from a separator pressure of 100 pisg is used in their correlation. This reference pressure was chosen because it represents the average field separator conditions. The authors proposed relationship for adjustment of the gas gravity to reference pressure.

Glaso [3] (1980) proposed a correlation for calculating the solution gas-oil ratio as a function of API gravity, the pressure, the temperature and the specific gravity of gas. The correlation was developed from studying a forty five samples obtained from North Sea crude.

Marhoun [4] (1988) developed an expression for calculating the saturation pressure of Middle Eastern crude oil systems. The correlation was developed by using nonlinear multiple regression analysis and a trial and error method based on more than sixty different Middle East crude oils. Marhoun's correlation can be rearranged and solved for the solution gas-oil ratio.

Petrosky and Farshad [5] (1993) developed new correlations for Gulf of

Mexico crudes. Standing's correlation for solution gas-oil ratio was taken as the basis for developing the new correlation coefficients. The approach that Petrosky and Farshad [5] applied to develop the correlation was to give the original correlation model maximum flexibility through nonlinear regression to achieve the best empirical relation possible with the available data set. The maximum flexibility allows each variable to have a multiplier and exponent, while the original model fixes multipliers and exponents of some of the variables to one. Ninety data sets from the Gulf of Mexico were used in developing these correlations.

Kartoatmodjo and Schmidt [6] (1994) used a global data bank to develop new correlations for all PVT properties. Standing's correlation was taken as the basis for solution gas-oil ratio correlation. In addition to the global data gathered for the study, a separate data set collected from the literature was used to verify the final results of the correlation models developed and compare them with published correlations.

Velarde, Blasingame and McCain [7] (1999) formed new correlation to calculate the solution gas-oil ratio for pressures at and below saturation pressures. In contrast to many approaches presented in the past, this correlation of solution gas-oil ratio is not derived from rearranging a saturation pressure correlation. Two sets of dimensionless functions were calculated with data from each PVT report. These functions are "reduced pressure" and "reduced gas-oil-ratio". The reduced pressure variable is defined as the pressure divided by the bubble point pressure and the reduced gas-oil-ratio variable is defined as the solution gas-oil ratio divided by the solution gas-oil ratio at the bubble point.

Mazandarani and Asghari [8] (2007) tuned Al-Marhoun 's [4] correlation to Iranian field data to get modified correlation . They took about fifty fluid samples collected from different Iranian fields.

Taghaz, Eltaeb and Alakhdar [10] (2008) tested the accuracy of PVT correlation to determine the solution gas-oil ratio of Libyan oils using about 1600 data points from different reservoirs in the Sirte basin. Authors concluded that no correlation is suitable for Libyan oils.

Experimental Data

Experimental PVT data were collected from different oil reservoirs. Thirty seven PVT reports that totally include four hundred data points represent the overall data of this paper. The ranges of data are listed in Table 1. In addition, Figs. 2, 3, 4 and 5 show the distribution details for reservoir temperature, gas relative density, bubble point pressure and oil gravity respectively.

Table 1 Physical Properties

Property	Minimum limit	Maximum limit
API	20	37
T	190	275
γ_g	0.7	0.9
P_b	1950	4000

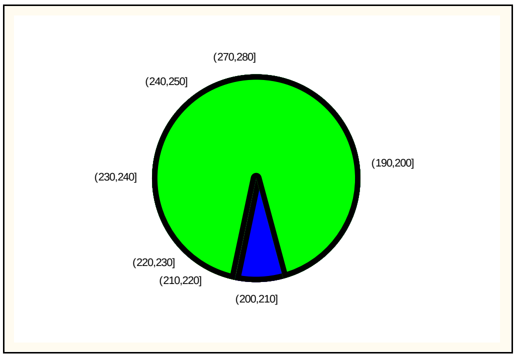

Fig. 2 The distribution of reservoir temperature for overall data

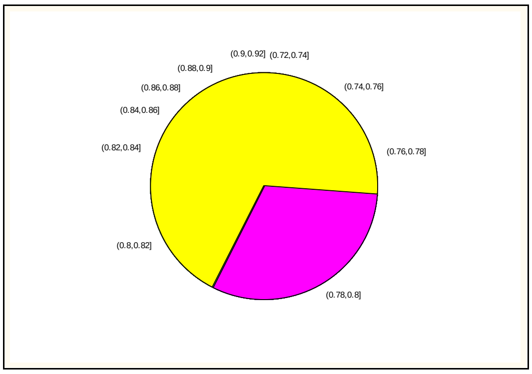

Fig. 3 The distribution of relative gas density for overall data

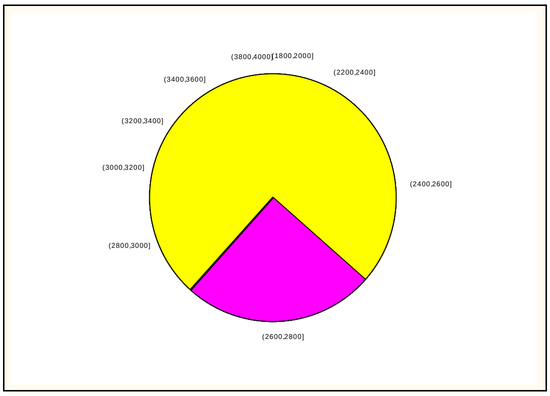

Fig. 4 The distribution of bubble point pressure for overall data

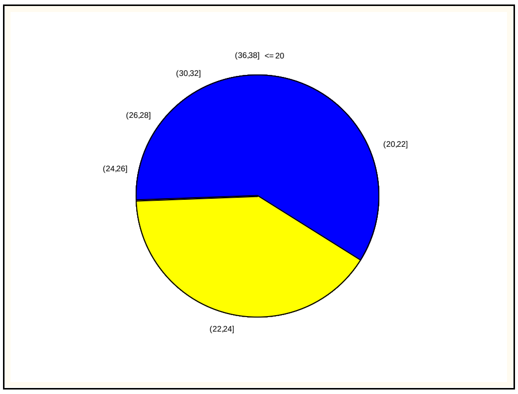

Fig. 5 The distribution of oil gravity for overall data

Formulation of Gas-Oil Ratio Correlation

The basic principle of formulation of a correlation is regression analysis that is defined as a conceptually simple method for investigating functional relationships among variables [11].

Firstly, the regression analysis usually starts with a formulation of the problem by detection of the influent variables on gas-oil ratio. Therefore the formulation of correlation includes the following properties: reservoir pressure, bubble point pressure, gas-oil ratio at bubble point pressure, oil gravity, gas specific gravity and the temperature of reservoir. The problem statement (formulation) is the first and possibly the most important step in regression analysis [11]. This step gave the following general relationship

$$R_s = f\left(P, P_b, \gamma_g, T, API, R_{sb}\right) + \varepsilon \quad \ldots\ldots\ldots (1)$$

Where the solution gas-oil ratio is the response variable and the set of predictor variables are the influent variables, while ε is assumed to be a random error representing the discrepancy in the approximation. Secondly, many mathematical forms were suggested to formulate the correlation. They were subjected to nonlinear regression for detecting the true relationship between response variable and predictor variables. Many statistical criteria were applied to select the optimum form of the correlation. Finally, the filtration processes to produce the suitable correlation were achieved after the mathematical and graphical checking were finished.

The following correlation is selected

$$R_s = A_0 \; P_b^{A_1} \gamma_g^{A_2} T^{A_3} API^{A_4} R_{sb}^{A_5} \; P^{\left(A_6 \, P_b^{A_7} \gamma_g^{A_8} T^{A_9} API^{A_{10}} R_{sb}^{A_{11}}\right)} \quad \ldots. (2)$$

Where

A_0, A_1, A_2, A_3, A_4, A_5, A_6, A_7, A_8, A_9, A_{10} and A_{11} are the constants which are estimated by application of nonlinear regression.

The values of the constants are recorded in Table 2.

Table 2 Regression Parameters

Regression Parameter	Value
A_0	0.0006
A_1	0.856
A_2	0.351
A_3	1.829
A_4	1.462
A_5	-2.116
A_6	3.867
A_7	-0.306
A_8	-0.083
A_9	-0.306
A_{10}	-0.288
A_{11}	0.525

Validation of the Correlation

The solution gas-oil ratio curves resulting from the proposed method (Eq. 2) have the correct profile. Fig. 6 clarifies the results of the correlation compared with the same laboratory data for Iraqi oil sample which was not used to achieve the new correlation. The agreement in both the shape of curves and the values is good.

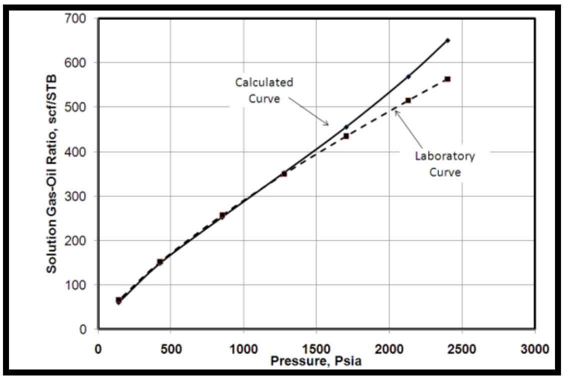

Fig. 6 Comparison of solution gas-oil ratios from New correlation with laboratory data

The evaluation of the correlation's confidence has passed through two types of test that are statistical and graphically.

All of experimental data were subjected to statistical tests that are absolute average error, standard deviation error, variance and sum of squared residuals. Table 3 shows the results of statistical tests for the new correlation, Standing [1], Vasquez and Beggs [2], Glaso [3], Al-Marhoun [4], Petrosky and Farshad [5], Kartoatmodjo and Schmidt [6], Velarde et al. [7] and Mazandarani and Asghari [8] correlations. These tests give the first kind of superiority to apply with Iraqi oils because this correlation has the best statistical criteria among them.

The statistical criteria explained that New correlation followed by Velarde et al. [7] correlation. Table 3 also showed that Glaso [3] correlation and Mazandarani and Asghari [8] correlation have the highest error.

Table 3 Statistical Results

The Correlation	Average Absolute Error %	Sum of Squared Residuals	Standard Deviation Error	Variance
New	5.04	168213.4	21.123	446.189
Standing [1]	41.143	9681180	160.248	25679.52
Vazquez and Beggs [2]	42.554	11220114	172.515	29761.58
Glaso [3]	47.226	14854317	198.498	39401.37
Al-Marhoun [4]	46.398	11591464	175.3471	30746.59
Petrosky and Farshad [5]	34.71	11199518	172.36	29706.94
Kartoatmodjo and Schmidt [6]	42.105	12004490	178.44	31842.15
Velarde, Blasingame and McCain [7]	10.156	428401.8	33.71	1136.344
Mazandarani and Asghari [8]	50.142	13595883	189.9035	36063.35

Figs. 7 through 15 show the comparisons of the values of solution gas-oil ratio predicted by the correlations to that measured by experimental tests for the same sample which was not employed to complete the new correlation. New correlation gave better scattered around 45^{o} line as shown in Fig. 7. Mazandarani and Asghari [8] correlation gave worst predicted values of solution gas- oil ratio as shown in Fig. 15. These cross plots completed the confidence of the new correlation because they explain that it has the highest matching with the experimental records.

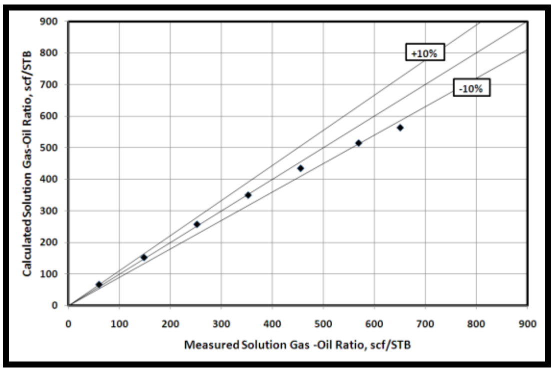

Fig. 7 Comparison of measured data and calculated solution gas-oil ratio by New correlation

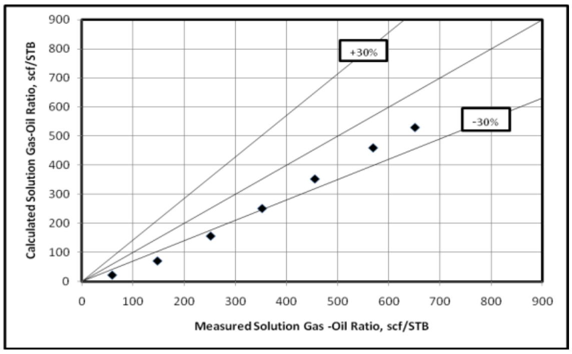

Fig. 8 Comparison of measured data and calculated solution gas-oil ratio by Standing's correlation

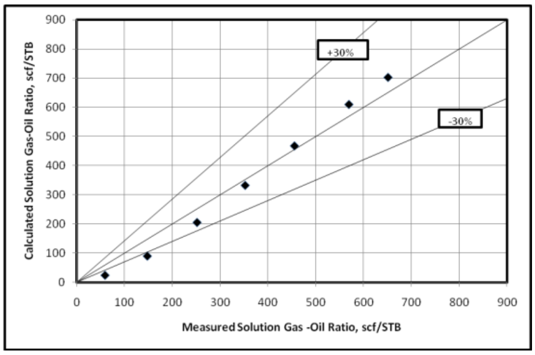

Fig. 9 Comparison of measured data and calculated solution gas-oil ratio by Vazquez and Beggs's correlation

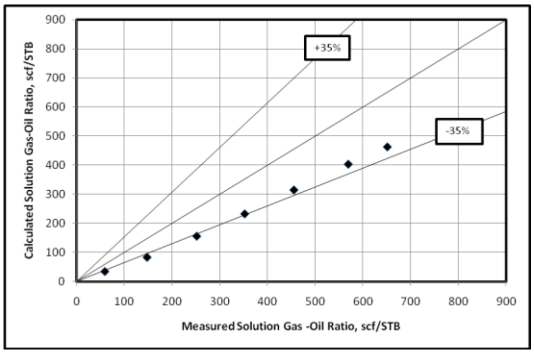

Fig. 10 Comparison of measured data and calculated solution gas-oil ratio by Glaso's correlation

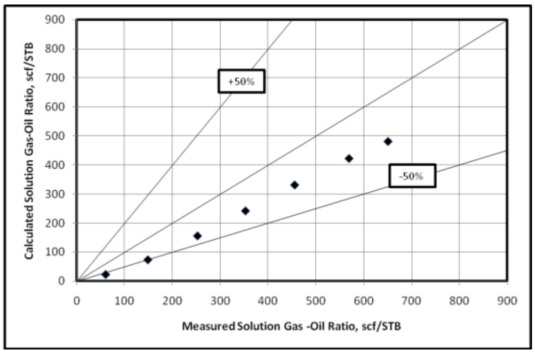

Fig. 13 Comparison of measured data and calculated solution gas-oil ratio by Kartoatmodjo and Schmidt 's correlation

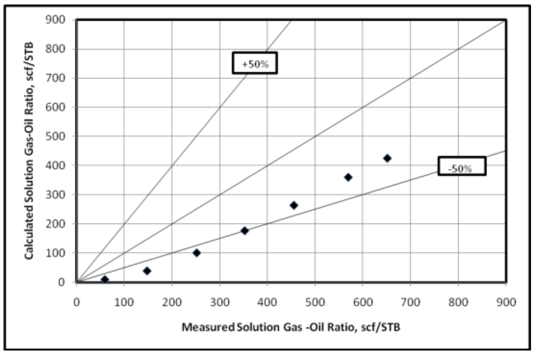

Fig. 11 Comparison of measured data and calculated solution gas-oil ratio by Al-Marhoun's correlation

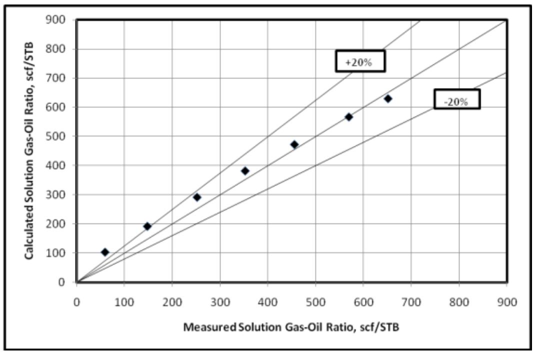

Fig. 14 Comparison of measured data and calculated solution gas-oil ratio by Velarde et al. correlation

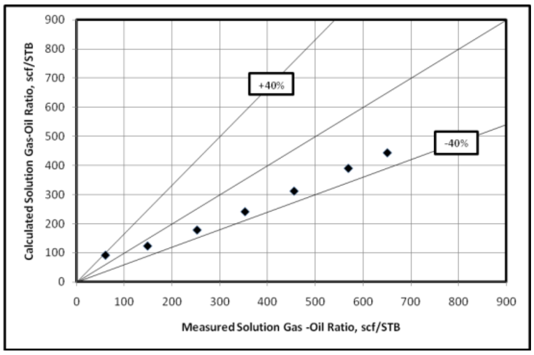

Fig. 12 Comparison of measured data and calculated solution gas-oil ratio by Petrosky and Farshad 's correlation

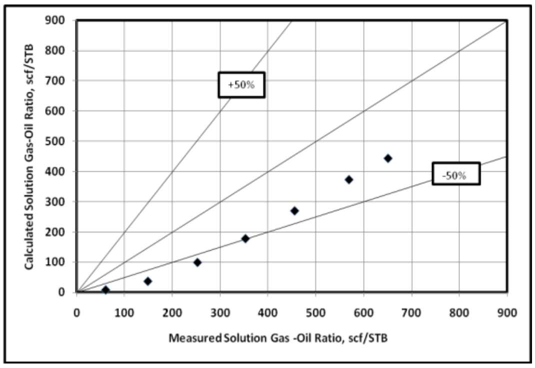

Fig. 15 Comparison of measured data and calculated solution gas-oil ratio by Mazandarani and Asghari's correlation

CONCLUSIONS

The new correlation is accurate, flexible and reliable tool for calculating solution gas-oil ratio for Iraqi oils at pressures below bubble point pressure for the range of data that have been illustrated in this paper.

Nomenclature

API: API gravity
PVT: Pressure-Volume-Temperature
P: Pressure, psi
R_s : Solution gas-oil ratio, scf/STB
R_{sb} : Solution gas-oil ratio at bubble point pressure, scf/STB
T : Reservoir Temperature, ^oF
γ_g : Specific gravity of gas
γ_o : Specific gravity of oil
ε : random error, scf / STB

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