A New Correlation for Libyan Crude Oil to Estimate the Gas Solubility at Bubble-Point Pressure

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ABSTRACT

The PVT properties are ideally determined experimentally in the LAB. However, some of these experimental data is not always available; consequently, empirical correlations are used to estimate them.

These properties are the key factor of the petroleum Engineering calculations such as material balance calculation, predicting reservoir performance in the future, production facilities designing and EOR planning methods, …etc.

Many researchers have been focused on models for predicting reservoir fluid properties from the available experimental PVT data.

Our present study divided into two parts, the first part is the comparison study where we compared between some of the available empirical PVT correlations for estimating the solution gas-oil ratio at the bubble point for some Libyan crude oils based on the available 35 data point samples collected from some Libyan oil fields. The Microsoft Excel was used in the comparison study; the results showed that Standing's and Marhoun's correlations calculated the lowest and highest Absolute Average Relative Error (AARE) of 26% and 272% respectively in the range of our studied data.

In the second part of this study a new correlation was derived to predict the Gas Solubility at Bubble-Point Pressure using Eviews software, and compared the output results of this new correlation with the derived correlations used in the first part of this study using statistical analysis such as AARE, Maximum Absolute Relative Error (Max. ARE), Minimum Absolute Relative Error (Min. ARE), R2, and cross – plot analysis. The results showed good statistical analyses AARE, min ARE, max ARE and R2 of about 14%, 0.2%, 29.3% and 0.924 respectively, for our new correlation to estimate the solution gas ratio at Pb. This result was better than the values were obtained from the other evaluated empirical correlations.

Keywords: PVT properties, Empirical Correlations, Bubble point pressure, solution gas ratio.

1 Introduction

The physical and chemical properties of crude oils are varying considerably depending on the concentration of the various types of hydrocarbons and minor constituents present [1]. Therefore, an accurate description of these properties is of considerable importance in the solving of petroleum engineering problems.

Physical properties of primary interest in petroleum engineering studies include fluid gravity, specific gravity of the solution gas, gas solubility, bubble-point pressure, oil formation volume factor, isothermal compressibility coefficient of under-saturated crude oils, oil density, total formation volume factor, crude oil viscosity, and surface tension [1]. Our study will focus on the Gas Solubility, Rs at Bubble Point Pressure.

The gas solubility Rs refers to the number of standard cubic feet of gas which will dissolve in one stock-tank barrel of crude oil at certain pressure and temperature [2].

The PVT properties of crude oil are commonly measured experimentally in the laboratory from an actual reservoir fluids samples. In the absence of one of those experimentally measured data of crude oil, it is necessary for the petroleum engineer to determine, estimate or predict it from empirically derived correlations.

Those mathematically derived PVT correlations used in the oil industry are important tools in reservoir-performance calculations. In the literature, there are many of those empirically derived correlation to estimate any of those absented PVT properties.

The geological conditions are important considerations for developing a PVT correlation due to the variation of the chemical composition of crude oil from region to region. It is beneficial to analyze the available worldwide PVT correlations prior to their applicability for a certain geological region.

By reviewing many of previous studies, there were unsatisfactory in the results when applying correlations developed for a certain region to crude oil from another region, this was as a result of variation in composition.

2 Literature Review

Over the last six decades, many researchers worldwide realized that how the developing of the PVT correlations is important. Therefore, many correlations for estimating solution gas have been published in the past 60 years. In this section we focused on some Gas Solubility empirically derived correlation were used in our comparison study.

2.1 Standing’s Correlation

Standing in 1947, presented a graphical correlation for estimating the gas solubility as a function of pressure, gas specific gravity, API gravity, and system temperature. He used 105 experimentally data points to develop his correlation. The range of data used in the correlation development was as shown in Table 1. The presented correlation has an average error of 4.8%. In 1981, The Standing's proposed graphical correlation has been expressed in the following mathematical form [1, 3, 4]:

Standing recommended that for a useful use of his equation; the pressure of the crude oil should be at or below the bubble-point [3].

2.2 Glaso's Correlation

In 1980, Glaso presented a mathematical expression for predicting the gas solubility as a function of the gas specific gravity, oil API gravity, temperature, and pressure. This newly developed correlation was based on studying 45 data points from the North Sea crude oil samples. Glaso reported an average error of about 1.28% with a standard deviation of 6.98%. The range of data used in the correlation development was as Table 1 [4]. The proposed model has the following form [5].

2.3 Marhoun's Correlation

In 1988, Marhoun presented a mathematical model for predicting the bubblepoint pressure from 160 experimental saturation pressure data points from the Middle Eastern crude oil systems. The presented correlation rearranged and solved to estimate the gas solubility as given below [1, 2].

The range of data used in the correlation development was as Table 1 [4].

2.4 The Vasquez-Beggs Correlation

In 1980, Vasquez and Beggs published an empirical correlation to predict the gas solubility (R_S) in the absence of the experimentally measured one. About 5,008 experimentally measured gas solubility data points were used to develop the correlation. The measured data were divided into two groups based on the API oil gravity. This division was made at a value of 30°API. The presented correlation has the following form [1, 6].

For the first group of data (API $\leq$ 30) [1].

2.5 The Petrosky-Farshad Correlation

A nonlinear multiple regression software was used by Petrosky and Farshad in 1993 to develop a gas solubility correlation. 81 laboratory PVT database analyses from the Gulf of Mexico crude oil system were used by the authors to construct their correlation. They proposed the following expression [1, 3].

The range of data used in the correlation development was as Table 1 [4].

2.6 Hemmati and Kharrat Correlation

Hemmati and Kharrat in 2007 published correlation to estimate the gas solubility by collecting data from more than 50 the Middle East and Iran oil fields, about 499 laboratory PVT analyzed data points were obtained from those oil fields. The range of data used in the correlation development was as Table 1, the mathematical expression has been published was as [7].

2.7 Statistical Error Analysis calculation

The statistical analyses were used in this study are Absolute Average Relative Error (AARE), max AARE, min AARE, R-squared (R^2) and Cross-Plot Graphics Analysis.

3 Gas Solubility Correlation Development For Libyan Crude Oil

This paper presented a new derived correlation using multiple regression analysis to estimate the solution gas at the bubble point pressure for the Libyan oils based on 35 data point samples collected from different Libyan oil fields namely 103E, Ajdabiya, Aswad, Block 95/96, Bu-Attifel, Eteila, Fajar, Farigh, Gailo 59, Ghadames Basin, Ghani, Ghazzun, Majid, Nafoora, Nc98, Rimal, Saf-Saf, Sarir, Shehebat, Talah, Tibisti, Tmed, Waha, Waha Gialo, Zaggut, and Zella.

3.1 Methodology:

Two software were used to derive our new correlation; *Microsoft Excel*, and *EViews* software.

3.1.1 *Excel software:*

Microsoft Excel was used to input our data as an Excel file.

3.1.2 *EViews software:*

EViews is a statistical package software developed by Quantitative Micro Software (QMS), used for general statistical analysis and econometric analyses, such as cross-section and panel data analysis and time series estimation and forecasting [8].
In this study, *EViews* software used to correlate the different parameters to develop our new correlation of ***Rs*** predicting for the Libyan crude oils.

3.2 Correlation developing procedure

The good nonhomogeneous data correlating depends on the right input and use of the Eviews language variables and equation. The steps of how to use the Eviews software illustrated below:

- Put your data in an excel sheet vertically.
- Import data excel file
- Select quick and click on estimate equation
- Here the software asks you to input the type and basic formula by software language and form of output data.
- Now the software analyzes the data and gives you an equation.
- The mathematical method was used its least squares (LS).

3.3 Gas Solubility Correlation

Most of the researchers find that the solubility of the gas in the oil was a function of Pressure, Temperature, API gravity, and gas specific gravity, in our study we find the effect of the Oil Formation Volume Factor (B_o) as an extra parameter affecting the Rs. (P, T, API, γ_g) on Rs, but we find in Libyan crude Rs Affected by (P_b, B_{ob}, γ_g, API, T), the newly derived gas solubility equation as:

$$R_S = 7.838733515 \times 10^{-4} \times \gamma_g^{0.0313402153843} \times API^{2.27543022551} \times T^{-0.202920351523} \times P_b^{0.799049256752} \times B_{ob}^{1.11251541562} \quad (1)$$

4 Results and Discussion

This section illustrates the results of our study. The comparison study of the most known correlations used discussed in section two of this paper, and the results obtained from our new set of correlations to estimate the ***Gas Solubility***.

4.1 Compression Study

4.1.1 *Statistical Analysis*

Figure 1 shows the R^2 calculated for the R_s estimated from the six chosen empirical correlations of Gas Solubility, namely Standing, Glaso, Marhoun, Vasquez-Beggs, Petrosky-Farshad, and Hemmati and Kharrat, used to compare with our new derived Gas Solubility correlation in this study.
As we can notice from Figure 1 R^2 calculated for Petrosky-Farshad's correlation was the highest value of 0.763 and Marhoun's one has the lowest value of 0.024 this was for the old empirical correlations studied, while our new developed correlation has the highest R^2 of 0.924, this result was for the available experimental data collected in this study.

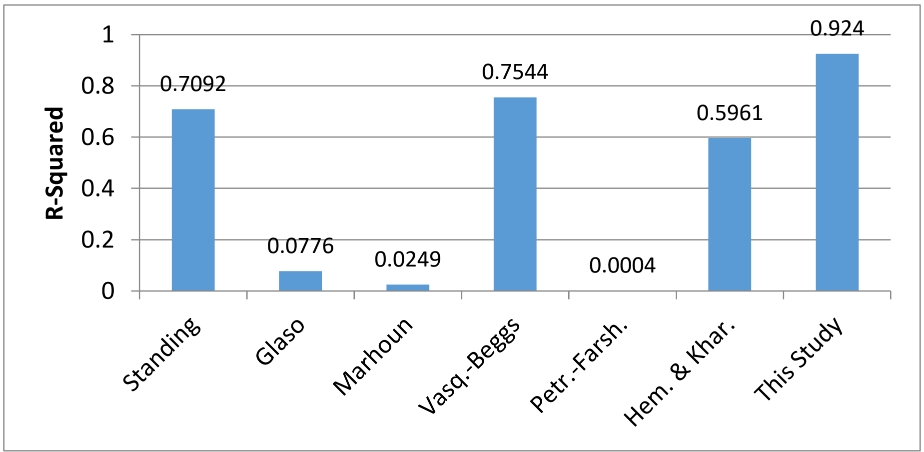

Figure1 *Statistical Analysis R-Squared Value of Gas Solubility Correlations*

Figures 2 to 4 show the ***AARE***, ***max AARE,*** and ***min AARE*** respectively, calculated for the above-mentioned correlations targeted in this paper. When we looking to the data in Figure 1 it's clearly seen that our new derived correlation has the lowest absolute average relative error (***AARE***) of about 14%

with the lowest ***min ARE*** and ***max ARE*** of 0.2% and 29.3% respectively, while the previously published correlations ranged between 26% from Standing's correlation with ***min ARE*** and ***max ARE*** of 1.1% and 60.7% to 272.5% from Marhoun's with ***min ARE*** and ***max ARE*** of 9.9% and 3964.2% respectively, these values were in the range of the experimental data collected and used in this work which about 35 data point collected from different Libyan oil fields.

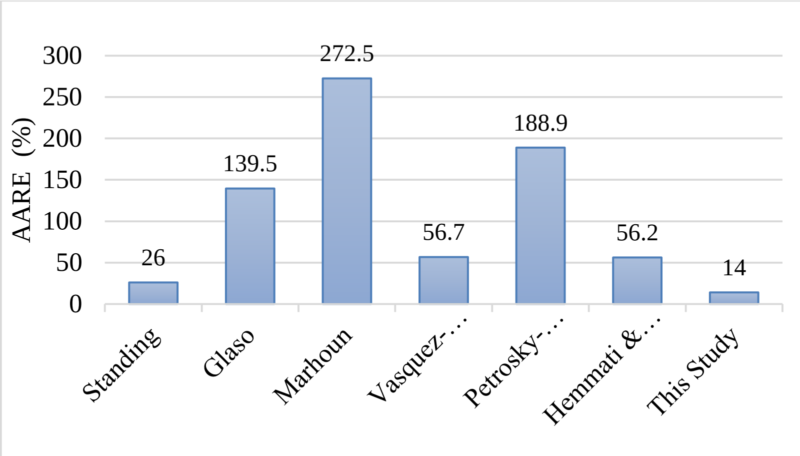

Figure 2 *AARE% Value of Rs Correlations*

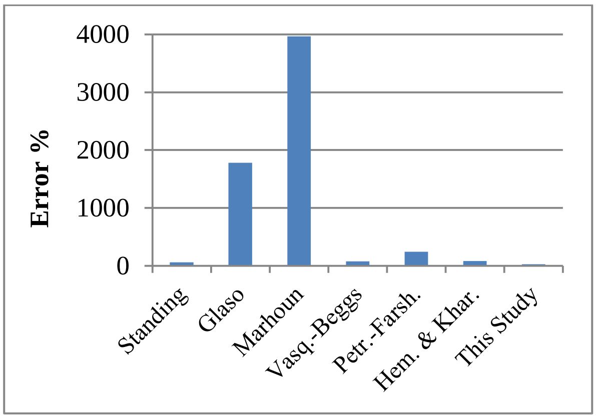

Figure 3 *Max AARE% Value of Rs Correlations*

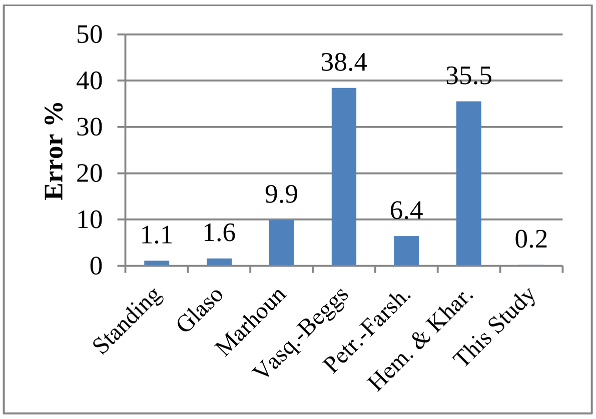

Figure 4 *Min AARE% Value of Rs Correlations*

4.1.2 ***Cross-Plot Graphics Analysis***

Figures from 5 to 11 show the cross-plot graphics analyses for the studied correlations namely *Standing's*, *Glaso*, *Marhoun*, *Vasquez-Beggs*, *Petrosky-Farshad*, and *Hemmati* and *Kharrat* correlations with comparing with ***our newly derived correlation***.

As we can see in these Figures; the estimated R_s by *Standing's* correlation was closer to the cross 45º line than the other R_s calculated from the rest of the old correlations; *Glaso*, *Marhoun*, *Vasquez-Beggs*, *Petrosky-Farshad*, and *Hemmati* and *Kharrat, while* ***Our new developed*** correlation gave estimated R_s results as shown in Figure 10 was the closest to the crossline 45º line, that means our predicted R_s more close to the reality than all correlations studied in this study, and this was in the range of the available experimental measured data we could obtain from the different Libyan oil fields.

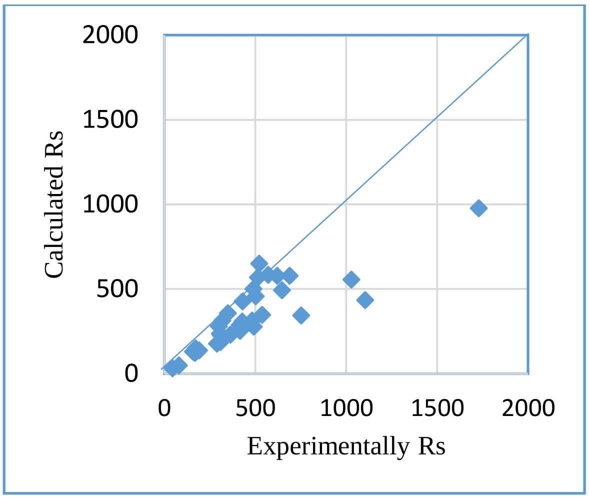

Figure 4 *Cross-Plot of Standing Correlation Data V.S Measured Data of Gas Solubility Correlation*

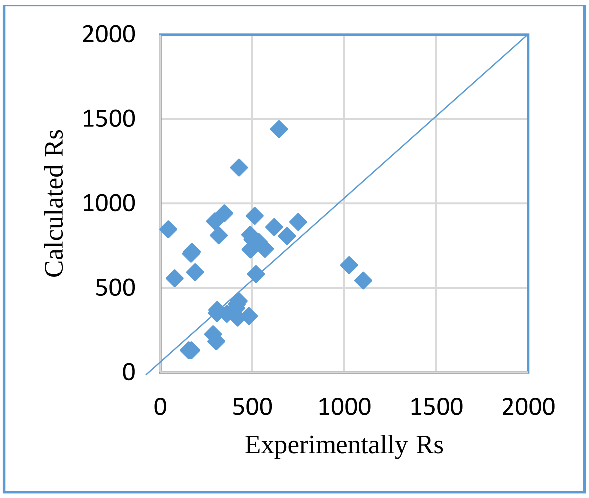

Figure 6 *Cross-Plot of Glaso Correlation Data V.S Measured Data of Gas Solubility Correlation*

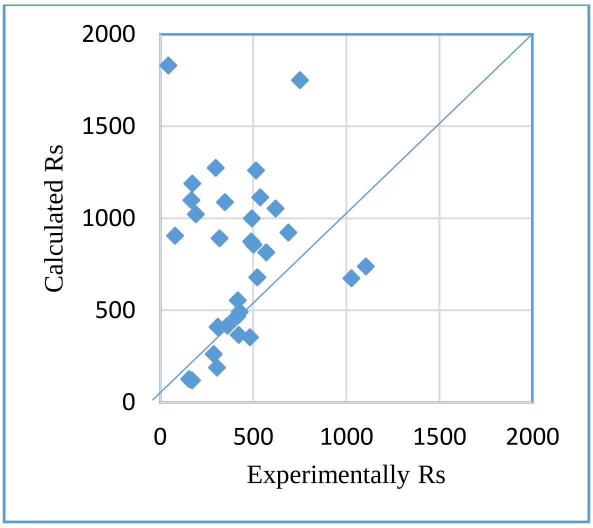

Figure 7 *Cross-Plot of Marhoun Correlation Data V.S Measured Data of Gas Solubility Correlation*

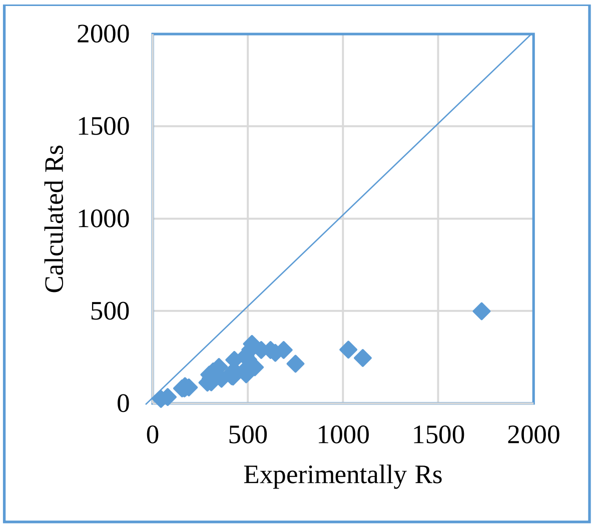

Figure 8 *Cross-Plot of Vasquez-Beggs Correlation Data V.S Measured Data of Gas Solubility Correlation*

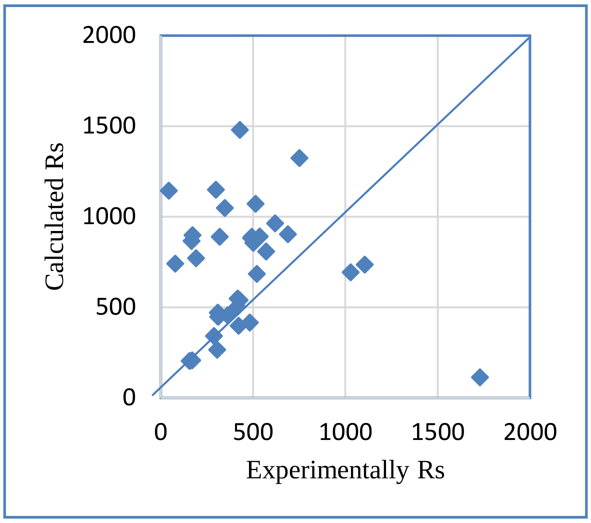

Figure 9 *Cross-Plot of Petrosky-Farshad Correlation Data V.S Measured Data of Gas Solubility Correlation*

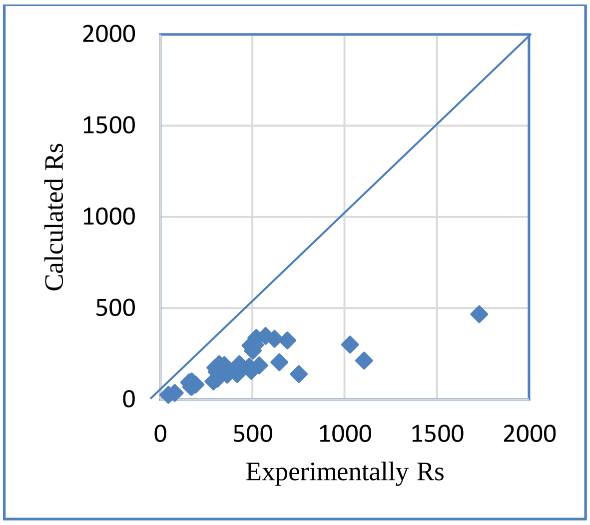

Figure 10 *Cross-Plot of Hemmati-Kharrat Correlation Data V.S Measured Data of Gas Solubility Correlation*

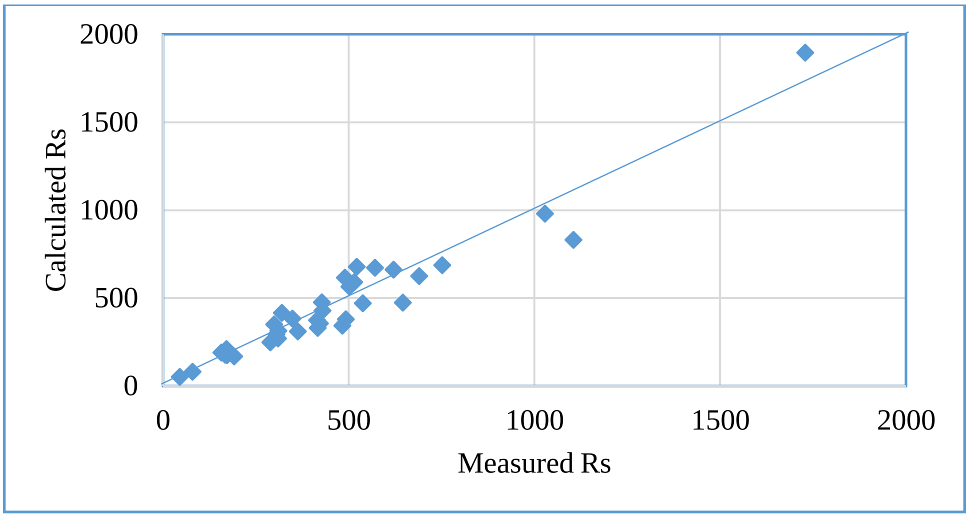

Figure 11 *Cross-Plot of* ***This Study Correlation Data*** *V.S Measured Data of Gas Solubility Correlation*

5 Conclusions

This study presented a newly developed correlation to predict the solution gas for Libyan crude oils based on data collected from different Libyan oil fields.

1. The newly developed correlation was more accurate than the old correlations, we have compared with, in this study.
2. All old correlations used in the compassion study in this paper were not applicable for the Libyan crudes in the range of our data due to the high AARE.
3. The gas solubility affected clearly by the oil formation volume factor in addition to the other parameter (Pb, γg, API, T) found in Literature.

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***Table 1** Solution gas Empirical Correlations Used in the Comparison Study and Their Parameters Range.*

Author	Correlation	Temp. °F	Rs SCF/STB	API °	P_b psia	γ_g
Standing 1947	$R_S = \gamma_g\left[\left(\frac{P}{18.2}+1.4\right)10^X\right]^{1.2048}$ x = 0.0125 API - 0.00091(T - 460)	100 - 258	20 – 1425	16.5° – 45	130 – 7000	0.59 – 0.95
Glaso 1980	$R_S = \gamma_g\left[\left(\frac{API^{0.989}}{(T-460)^{0.172}}\right)(P_b^*)\right]^{1.2255}$ $p_b^* = 10^x$ x=2.8869-$[14.1811 - 3.3093\log(P)]^{0.5}$	80 - 280	22.3 – 48.1	22.3° – 48.1	165 – 7142	0.65 – 1.276
Marhoun 1988	$R_S = [185.843208\gamma_g^{1.877840}\gamma_o^{-3.1437}T^{-1.32657}P]^{1.398441}$	74 - 240	26 – 1602	19.4° – 44.6	130 – 3573	0.752 – 1.367
Vasquez and Beggs 1980,	(API ≤ 30) $R_S = 0.0362\gamma_{gs}P^{1.0937}exp\left[25.7240\left(\frac{API}{T}\right)\right]$ (API > 30): $R_S = 0.0178\gamma_{gs}P^{1.1870}exp\left[23.931\left(\frac{API}{T}\right)\right]$ $\gamma_{gs} = \gamma_g\left[1+5.912(10^{-5})(API)(T_{sep}-460)\log\left(\frac{P_{sep}}{114.7}\right)\right]$	NA	NA	NA	NA	NA
Petrosky and Farshad 1993	$R_S = \left[\left(\frac{P}{112.727}+12.340\right)\gamma_g^{0.8439}10^x\right]^{1.73184}$ $x = 7.916\,(10^{-4})(API)^{1.5410} - 4.561(10^{-5})(T - 460)^{1.3911}$	114 – 288	217 – 1406	16 – 45	1574 – 6523	0.5781 – 0.8519
Hemmati and Kharrat 2007	$R_{sb} = [(0.095P_b + 8.6817)10^{(0.0098\gamma_o - 0.0008T)}]^{\frac{1}{K}} \times \gamma_g$ $K = 1.5897 - 0.2735B_{ob} - 0.4429\gamma_g + 0.04692B_{ob}^2 + 0.144\gamma_g^2 - \frac{0.1596}{\gamma_g \times B_{ob}}$	74 – 290	26 – 2266	18.8 – 68.5	130 – 5156	0.523 – 1.50