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Comprehensive Evaluation of Bubble-Point and Below Bubble-Point Gas - Oil Ratio (Gor) Empirical Correlations for Niger Delta Region

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Abstract This paper presents the evaluation of some selected gas-oil ratio (GOR)empirical correlations for the Niger Delta crude. Gas-oil ratio is the ratio of the gas volume that comes from the produced oil at atmospheric pressure measured in standard cubic feet (SCF) to the volume of oil produced after the dissolved gas has evolved from it at the surface, measured in (STB). The gas-oil ratio properties considered in this study are gas-oil ratio measured at the bubble point pressure (saturated reservoir) and below bubble point pressure (two-phase reservoir). The evaluation study was done using a total number of 268 and 1473 GOR data sets for saturated and two-phase fluids respectively by implementing statistical parameters and performance plots. From the general evaluation, using Rank as the main screening criterion, Standing (1947) correlation emerges the best for bubblepoint (BP) GOR with Rank of 26.72 and a correlation coefficient of 0.93 followed by Obomanu and Okpobiri (1987) with a Rank value of 34.45 and correlation coefficient 0f 0.96. Glaso (1980) is the best correlation for predicting below bubblepoint (BBP) GOR with a Rank of 32.31 and correlation coefficient of 0.921 and Standing (1947) equation ranked second with a Rank of 33.64 and correlation coefficient of 0.835. The research results will help the reservoir engineer in selecting the most accurate Gas-Oil ratio correlation in predicting PVT properties for proper engineering design.

Keywords Bubble Point; Correlation; Evaluation; Gas-Oil Ratio; Niger- Delta; Statistical Analysis

1. Introduction

The thorough knowledge about reservoir fluid properties is the basis of every PVT calculation and screening process for different petroleum reservoir engineering procedures. Therefore, accurate measurement of fluid pressure-volume-temperature (PVT) properties such as solution gas oil ratio (Rs), dew and bubble point pressure, oil formation volume factor (OFVF) and other PVT fluid properties are essential for estimation of reserves, reservoir performance determination, recovery efficiency, production optimization and design of production systems. There are two main methods to determine these PVT parameters which are experimental measurements and empirical correlations, though recently machine learning can also be used [1]. Generally, experimental procedures for measuring PVT properties are time consuming and expensive. Also, the validity of the tests depends on the samples and is associated with the common experimental errors. Therefore, developing empirical correlations for determining the PVT properties, is essential and of great importance. The correlations are accurate within the range of data that were used to develop them [2].

Among those PVT properties is Gas-oil-Ratio (GOR) which is our focus in this study. The solution gas–oil ratio (GOR) is the quantity of gas dissolved at reservoir pressures in reservoir fluids [3]. It can also be described as the ratio of the gas volume that comes from the produced oil at atmospheric pressure measured in standard cubic feet (SCF) to the volume of oil produced after the dissolved gas has evolved from it at the surface, measured in

STB. The gas-oil ratio (GOR) serves as a dynamic indicator, providing insights on the quantity of gas that is dissolved within the oil at varying depths and pressures. According to [4], the solution gas-oil ratio is the most notable component of PVT correlations that has a very major impact on the oil viscosity, the compressibility of oil, oil formation volume factor and used also for calculating the in-situ total reservoir fluid rate. These correlations utilize basic PVT properties which are temperature, pressure, gas specific gravity, oil API and solubility that are easy to be measured experimentally in the laboratory.

Several researchers have developed correlations for determining gas- oil- ratio ([5], [6], [7], [8], [9], [10], [11], [12], [13], [14], [15], [16], [17]). [14] and [15] are the GOR correlations developed using Niger Delta data. Standing was the first author that developed GOR empirical equation in 1947. He used 105 experimentally measured data from California crude oil and natural gases. The developed correlation depends on reservoir bubble point pressure, specific Gas gravity, API gravity, and temperature. After [5] GOR correlations, several authors had tended to improve or proposed new empirical correlations for GOR. [17] presented the list of gas-oil ratio correlations and their main features as they appeared in open literature.

As more correlations are developed, researchers evaluate the previously published correlations with the new ones as to recommend the best for a particular region. Others carry out studies to select the most accurate correlation for a particular reservoir or geographical region ([18], [19], [20]). In 1985, Abdul-Majeed evaluated [5], [21] and [22] GOR correlations for their region of applicability to oil reservoirs using 630 PVT tests. The performance of each of the correlations was evaluated within pre-determined ranges of three selected variables, which are oil API gravity, gas specific gravity, and temperature. The author recommended areas of application for each correlation based on his fundings. [19] did an evaluation study of Gulf of Mexico crude oils using 285 data sets for gas-saturated oil and 134 data sets for undersaturated oil representing different crude oils and natural gas systems. The result reveals that [8] empirical equation for bubble point pressure, solution gas-oil ratio and oil formation volume factor gave the best performance for the data range evaluated. It was pointed out that [22] performed better than [8] correlation at high solution gas-oil ratio above 1400 scf/STB and bubble point pressures greater than 7000 psia. [20] published an evaluation of all reservoir properties correlations based on a large global database at Texas A&M University. [20] recommended [5] correlations for bubble point pressure and solution gas oil ratio with estimation accuracy of 15% when used with separator gas gravity and total solution gas oil ratio.

[17] did evaluation study on GOR and OFVF correlations on a regional basis. The region investigated include the Middle East, Central and South America, North America, Africa, and Asia. The results showed that [5] and [8] gave better performance than other GOR correlations evaluated based on AARE for the full data range utilized. The authors also developed a new universal correlation for GOR. In summary, although the above GOR correlations are applicable and accurate for certain regions and conditions, no study evaluates and compares these correlations based on laboratory measurements for their suitability and accuracy based on the type of reservoir (Bubble-point-reservoir and Two-phase reservoir) for Niger- Delta region. Therefore, this study aimed at evaluating some of the existing GOR correlations for saturated and two-phase reservoir for Niger-Delta Region.

2. Reservoir Phase Diagram

A reservoir phase diagram, also known as a Pressure-Volume-Temperature (PVT) diagram, serves as a visual depiction of the phase characteristics shown by reservoir fluids across varying pressure and temperature circumstances. The comprehension and anticipation of phase transitions and characteristics of hydrocarbons within a reservoir are essential aspects in the petroleum business. Fig. 1 shows hydrocarbon phase diagram.

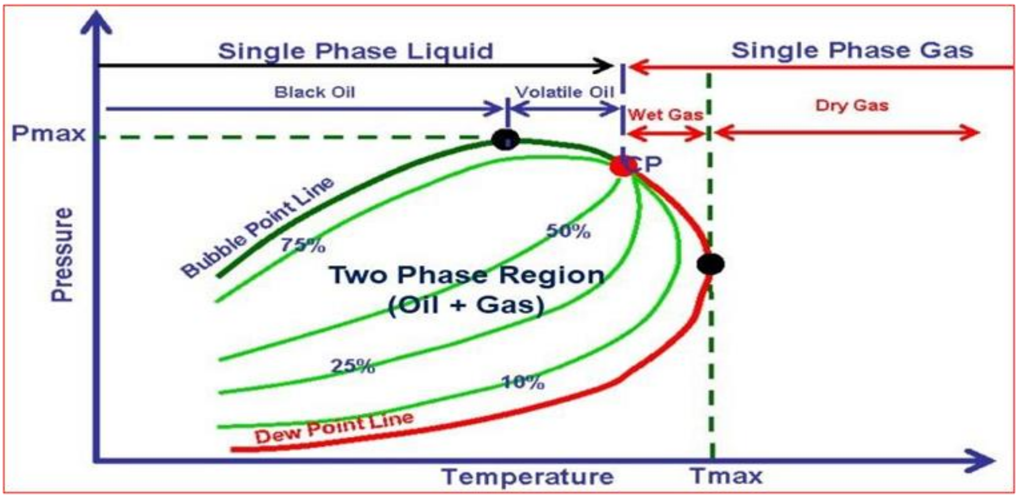

Figure 1: Hydrocarbon phase diagram [3]

The reservoir phase diagram conventionally depicts pressure along the x-axis and temperature along the y-axis. The region located above the curve of the bubble point signifies the undersaturated area, characterized by the presence of reservoir fluids in a singular liquid phase. The region below the dew point curve signifies the saturated area, whereby the reservoir fluids are present solely in a gaseous phase. The region bounded by the bubble point and dew point curves in a phase diagram signifies the coexistence of gas and liquid phases (Two-Phase). The diagram is partitioned into distinct sections that correspond to various phases of hydrocarbon fluids, encompassing: Undersaturated Region, Saturated Region, Two-Phase Region, Bubble Point Curve and Dew Point Curve. The gas-oil ratio considered in this study are those measured at Saturated and Two-Phase region.

2.1 Gas-Oil Ratio

GOR is the number of standard cubic feet of gas that dissolves in one stock-tank barrel of crude oil at certain pressure and temperature. At a constant reservoir temperature, the solubility of gas in oil will increase with increasing pressure until the bubble-point pressure is reached. At the bubble-point pressure, all the available gases are dissolved in the oil and the gas solubility attains its maximum value. In practice, the amount of gas that dissolves in reservoir oil is determined by measuring the amount of gas that comes out of stock-tank oil. This is because at stock tank condition, it is reasonably assumed that the reservoir oil will liberate all its dissolved gas. That is, the same amount of gas the oil contained in the reservoir is given out at the stock tank [10]. A typical solution GOR functional relationship with pressure for crude oil systems is shown in Fig. 2. As the pressure is reduced from the initial reservoir pressure to the bubble-point pressure, no gas evolves from the oil and consequently the gas solubility remains constant at its maximum value. Below the bubble-point pressure, the dissolved gas is liberated and the value of decreases with pressure.

Solution GOR is a volumetric ratio used to simplify petroleum engineering calculations. Precisely, it is the conversion factor that allows for the introduction of surface volumes into the material balance equations which is an inventory of underground material volumes.

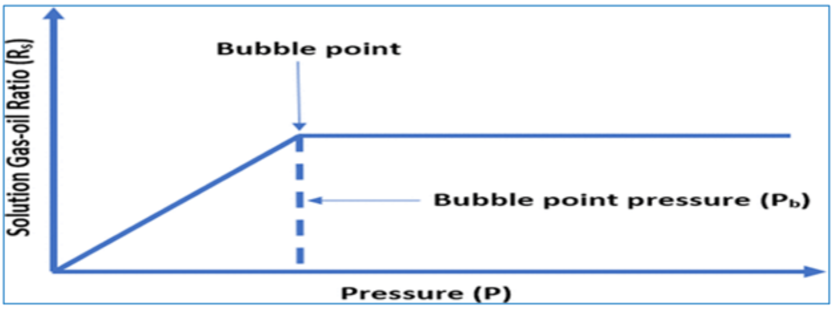

Figure 2: Typical Solution GOR relationship with Pressure [10]

3. Methodology

3.1 Data Description

Two data set were used to evaluate some of the existing GOR correlations for Niger Delta Region. The two measured data set were obtained from reservoirs at bubble point (saturated reservoir) and reservoirs below the bubble point (two-phase reservoir) from conventional PVT reports that derive the various fluid properties through liberation process from the Niger-Delta Region of Nigeria. The evaluation study was done using a total number of 1473 and 268 GOR data sets for saturated reservoir and two-phase reservoirs respectively. The data parameters include Oil relative density (γ_o), Reservoir temperature (^oF), Solution Gas-Oil Ratio (R_s) (scf/stb) and Gas gravity (γ_g). The mean, minimum and maximum values of data used for this study are shown in Tables 1 and 2.

Table 1: Summary of mean, maximum and minimum values for Below Bubble Point (BBP) GOR data

PVT Properties	Mean	Minimum	Maximum
Gas gravity	0.760	0.56	1.670
API Gravity	76.60	15.28	240.87
Reservoir Temperature (°F)	175.27	36.50	264.00
Reservoir Pressure (psia)	3065.31	67.00	6560.0
Oil Gravity	0.700	0.38	0.960
Gas-Oil Ratio R_s (scf/stb)	290.98	20.0	2046.0

Table 2: Summary of mean, maximum and minimum values for Bubble Point (BP) GOR data

PVT Properties	Mean	Minimum	Maximum
Gas gravity	0.670	0.570	1.180
API Gravity	65.73	21.80	282.24
Reservoir Temperature (°F)	172.21	128.0	255.0
Reservoir Pressure (psia)	1848.85	115.0	6015.0
Oil Gravity	0.740	0.340	0.920
R_s (scf/stb)	600.67	600.67	2606.0

3.2 Data Validation

Before any experimental PVT data are used for design or study purposes, it is necessary to ensure that there are no error or major inconsistencies that would render any subsequent work useless. Two such means of data validation are the Campbell diagram (Buckley plot) and the Mass Balance Diagram which are otherwise known as cross plot. These techniques were used to validate the data set used in this work.

3.3 Correlation Comparison

To compare the performance and accuracy of the new model to other empirical correlations, two forms of analyses were performed which are quantitative and qualitative screening. For quantitative screening method, statistical error analysis was used. The statistical parameters used for the assessment were percent mean relative error (MRE), percent mean absolute error (MAE), percent standard deviation relative (SDR), percent standard deviation absolute (SDA) and correlation coefficient (R).

For correlation comparison, a new approach of combining all the statistical parameters mentioned above (MRE, MAE, SDR, SDA and R) into a single comparable parameter called Rank was used [24]. The use of multiple combinations of statistical parameters in selecting the best correlation can be modeled as a constraint optimization problem with the function formulated as;

$$Min\ Rank = \sum_{j=1}^{m} S_{i,j} q_{1,j} \tag{1}$$

Subject to

$$\sum_{i=1}^{n} S_{i,j} \tag{2}$$

With

$$0 \le S_{ij} \le 1 \tag{3}$$

Where $S_{i,j}$ is the strength of the statistical parameter j of correlation i and q_{ij}, the statistical parameter j corresponding to correlation i. j = MRE, MAE, …. R^1, where $R^1 = (1\text{-}R)$ and Z_i is the rank, (or weight) of the desired correlation. The optimization model outlined in Equations 1 to 3 was adopted in a sensitivity analysis to obtain acceptable parameter strengths. The final acceptable parameter strengths so obtained for the quantitative screening are 0.4 for MAE, 0.2 for R, 0.15 for SDA, 0.15 for SDR, and 0.1 for MRE. Finally, Equation 3 was used for the ranking. The correlation with the lowest rank was selected as the best correlation for that fluid property. It is necessary to mention that minimum values were expected to be best for all other statistical parameters adopted in this study except R, where a maximum value of 1 was expected. Since the optimization model (equations 1 to 3) is of the minimizing sense a minimum value corresponding to R must be used. This minimum value was obtained in the form (1-R). This means the correlation that has the highest correlation coefficient (R) would have the minimum value in the form (1-R). In this form the parameter strength was also implemented to 1-R as a multiplier. Ranking of correlations was therefore made after the correlations had been evaluated against the available database.

For qualitative screening, performance plots were used. The performance plot is a graph of the predicted versus measured properties with a 45^o reference line to readily ascertain the correlation's fitness and accuracy. A perfect correlation would plot as a straight line with a slope of 45^o.

4. Results and Discussion

The evaluation of GOR measured at bubble point and below bubble point is presented using268 and 1473 data set respectively. Six predictive correlations were carefully selected, having been reported by some authors about their good performance in predicting GOR globally and at their respective regions ([19], [20]). The selected correlations are [5], [14], [12], [15], [8], [17]). Out of the six chosen predictive tool, two correlations ([14], [15]) were specially developed for Niger-Delta.

4.1 Result for Below Bubble Point Gas - Oil Ratio (Two Phase Reservoir)

4.1.1 Statistical Analysis Result

The results of the assessed correlations using Root Mean Square Error (RMSE) and other statistical parameters are presented in Table 3. [5] gave the lowest Root Mean Square error of 318.67 followed by [14] with value of 376.52 (Table 3). [12] gave the highest RMSE of 13184.6, indicating that the equation is not suitable for predicting GOR measured below the bubble point for Niger Delta region.

Table 3: Statistical Accuracy of Below Bubble Point (BBP) GOR Using Niger-Delta Data

Correlations	RMSE	%MRE	%MAE	%SRE	%SAE	R	RANK
Glaso (1980)	516.50	-36.20	42.89	64.44	60.18	0.921	32.31
Standing (1947)	318.67	34.98	43.48	46.56	38.71	0.835	33.84
Obomanu and Okpobiri (1987)	376.57	72.95	73.32	12.80	10.48	0.921	40.19
Slieti et al., (2022)	680.52	-47.83	61.39	84.09	74.73	0.925	43.67
Ikensikimama and Ajienka, (2012)	6867.7	-203.51	217.5	537.2	531.7	0.618	227.37
Petrosky and Farshad, (1993)	13184.6	-280.45	280.7	925.9	925.8	0.427	362.56

Fig. 3 gives the graphical statistical accuracies for all the gas-oil ratio correlations examined using a superior statistical agent of Rank than Root Mean Square Error (RMSE). It was found that [8] correlation performed better than other evaluated correlations with a rank of 32.31, correlation coefficient of 0.92, followed by [5] correlation with the rank of 33.84, correlation coefficient 0.84. [14] which is GOR Niger Delta correlation performed well, and it took the third position with the rank of 40.19, correlation coefficient of 0.921. [15] did not perform well as expected because their correlation was developed specifically for bubble point solution gas-oil ratio. The findings from this research are in line with the work done by [19], [15], [24], [15], [17] that [8] and [5] are the best GOR correlations. It is recommended from this evaluation study that, [8] and [5] can predict GOR measured below bubble point from Niger Delta region in absence of an improved GOR model developed specially for Niger Delta area.

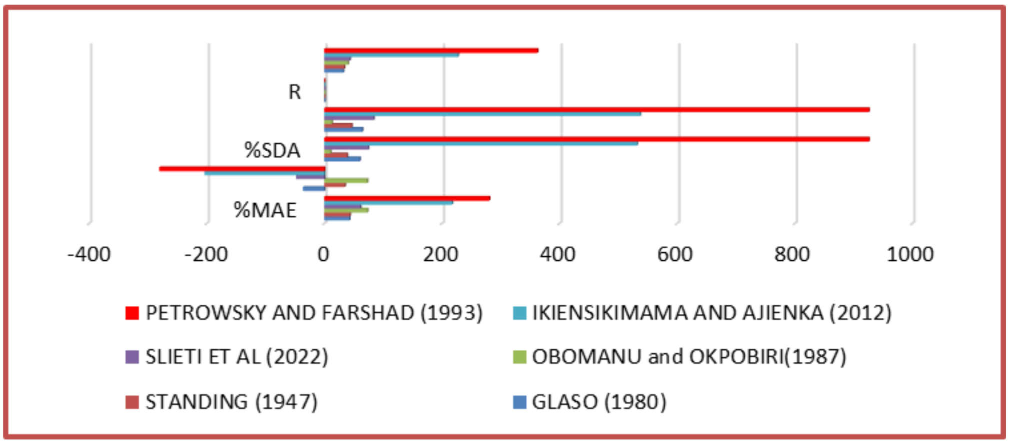

Figure 3: Statistical comparison for Different correlations using below bubble point (BBP) GOR for Niger - Delta Data

4.1.2Performance Plot Result for Below Bubble Point Gas - Oil Ratio

Figs. 4 to 7 illustrate cross plots of the predicted versus measured below bubble point (BBP) Gas-oil ratio evaluated in this study. A cross plot is graph of predicted versus measured properties with a 45° reference line to readily ascertain the correlation's fitness and accuracy. Compared to other cross plots, Figs. 5 and 7 of [8] and Standing [5] correlations show the tightest cloud of points around the 45° line with very good clusters at low band, indicating the excellent agreement between the experimental and the calculated data values when compared to Figs. 4 to 6. In addition, this indicates the superior performance of [8] and [5] in predicting gas- oil ratio below the bubble point for Niger Delta formation.

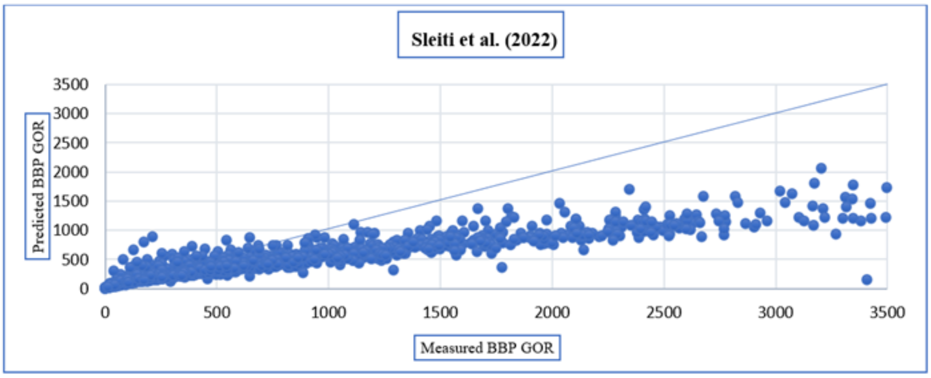

Figure 4: Cross plot of Sleiti et al (2022) correlation using BBP GOR Niger-Delta Data

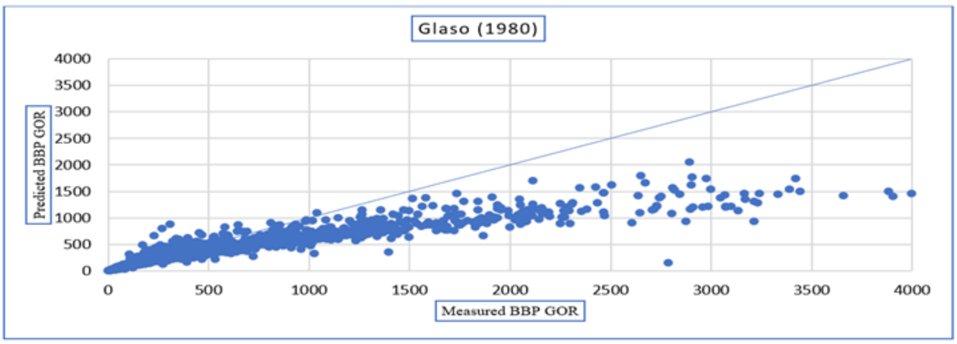

Figure 5: Cross plot of Glaso (1980) correlation using BBP GOR Niger-Delta Data

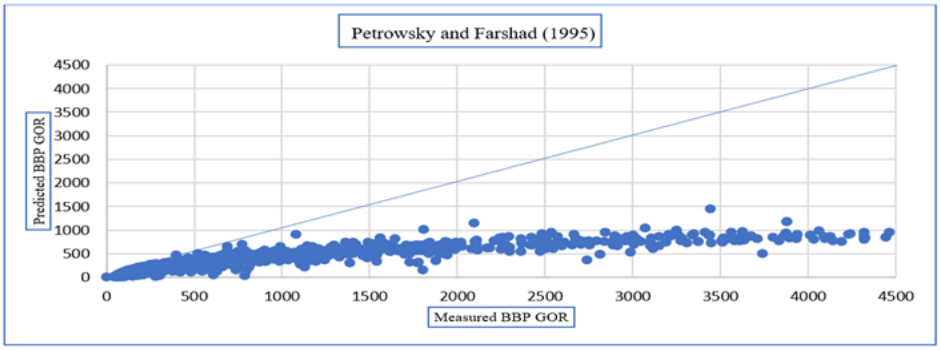

Figure 6: Cross plot of Sleiti et al (2022) correlation using BBP GOR Niger-Delta Data

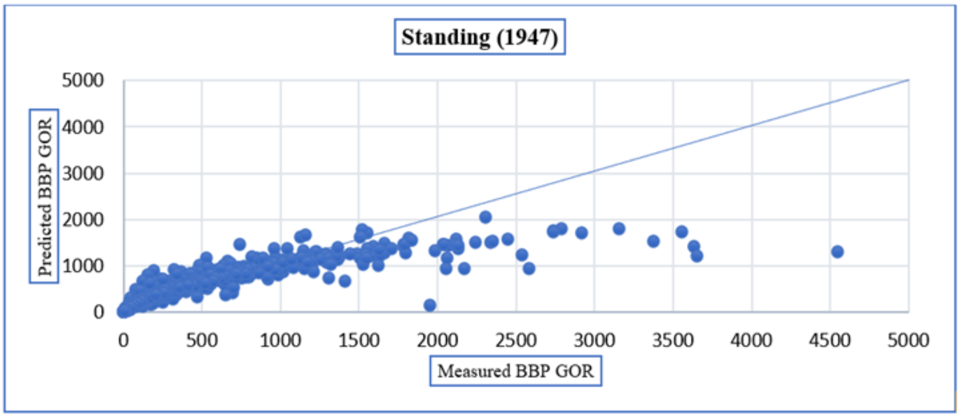

Figure 7: Cross plot of Standing (1947) correlation using BBP GOR Niger-Delta Data

4.2 Gas-Oil Ratio at Bubble Point Evaluation Result

4.2.1 Statistical Analysis Result for Bubble-Point Gas-Oil Ratio

Table 4 and Fig. 8 present the Root Mean Square Error (RMSE) and statistical analysis of all the GOR empirical equations examined using GOR data measured at bubble point (BP). [14] correlation which is an indigenous equation performed better than other evaluated correlations using RMSE yardstick. It has RMSE value of 483.3 followed by [5] correlation which the 679.2. The good performance of [14] is expected because the correlation was developed using measured GOR data from Niger-Delta area.

Table 4: Statistical Accuracy of Bubble Point (BP) GOR Using Niger-Delta Data

Correlations	RMSE	%MRE	%MAE	%SRE	%SAE	R	RANK
Standing (1947)	679.2	-3.94	38.47	48.27	29.43	0.93	26.72
Obomanu and Okpobiri (1987)	483.3	59.04	59.04	16.63	14.52	0.96	34.45
Glaso (1980)	1411	-104.10	105.45	59.91	57.51	0.95	49.43
Slieti et al. (2022)	1777	-141.17	142.96	70.08	66.37	0.96	63.57
Ikensikimama and Ajienka (2012)	16788	-639.49	642.25	759.49	757.08	0.84	420.64
Petrosky and Farshad (1995)	25598	-742.60	743.038	1177.2	1176.9	0.74	576.34

When Rank which is a superior statistical yardstick was used, [5] equation did better than other correlations analyzed with a Rank of 26.72, Mean Absolute Error Percent (%MAE) of 38.47, Mean Relative Error Percent (%MRE) of -3.94 and coefficient of correlation (R) of 0.93 (Fig. 8). [14] correlation took second position with a Rank of 34.45, Mean Absolute Error Percent of 59, Mean Relative Error Percent of 59 and coefficient of correlation 0f 0.96. [15] equation that took the 5^{th} position is also indigenous correlation which its performance is not very impressive compared to other correlations in terms of statistical measures and cross performance. The poor performance is attributed to the data set they used in developing their correlation. This study has reveals that [5] and [14] are the best predicting equation for GOR measured at the bubble point (BP) for Niger-Delta region in absence of new improved and reliable GOR equation specially designed for Niger Delta area.

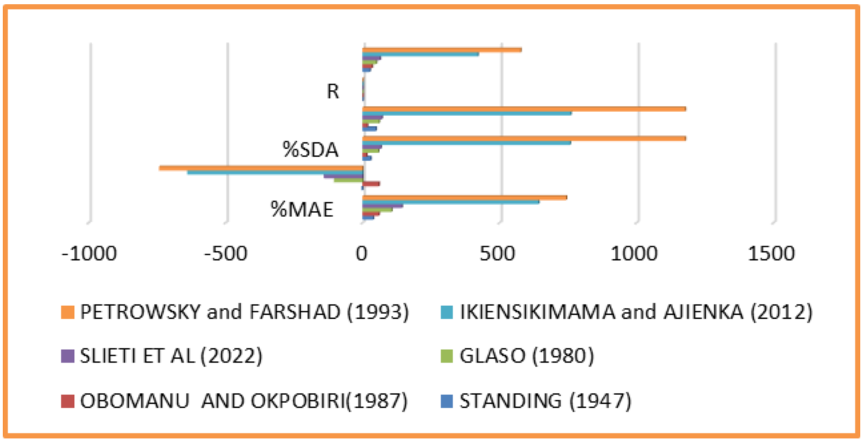

Figure 8: Statistical Accuracy of Bubble Point GOR Using Niger-Delta Data

Figures. 8 to 12 present the cross plots of the predicted versus experimental gas-oil ratio measured at bubble point. Fig. 10 which is Standing [5] equation gave the tightest cloud of points around the 45° line with very good clusters at low band, indicating the excellent agreement between the experimental and the calculated data values when compared to Figs. 8, 9 and 11. The exceptional of [5] has also been reported by [19],[24], [15], [17].

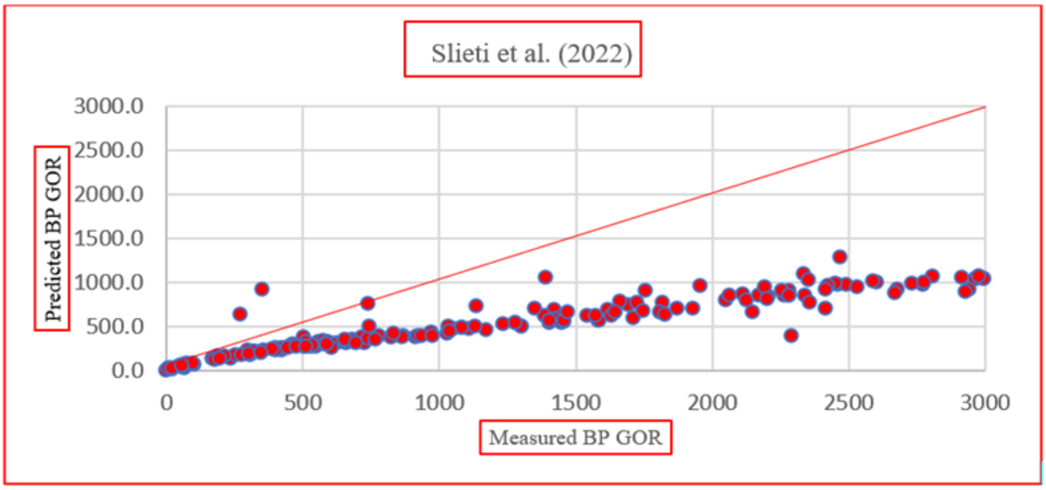

Figure 9: Cross plot of Slieti (2022) correlation using BP GOR Niger-Delta Data

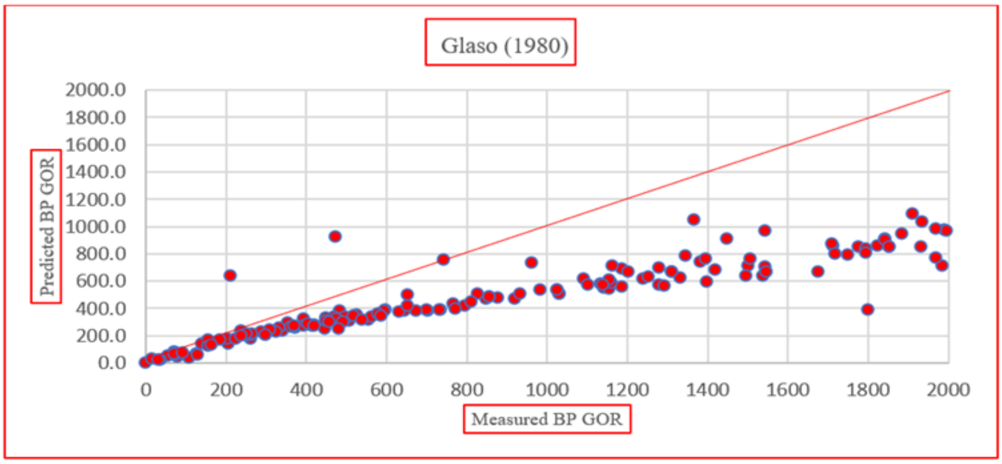

Figure 10: Cross plot of Glaso (1980) correlation using BP GOR Niger-Delta Data

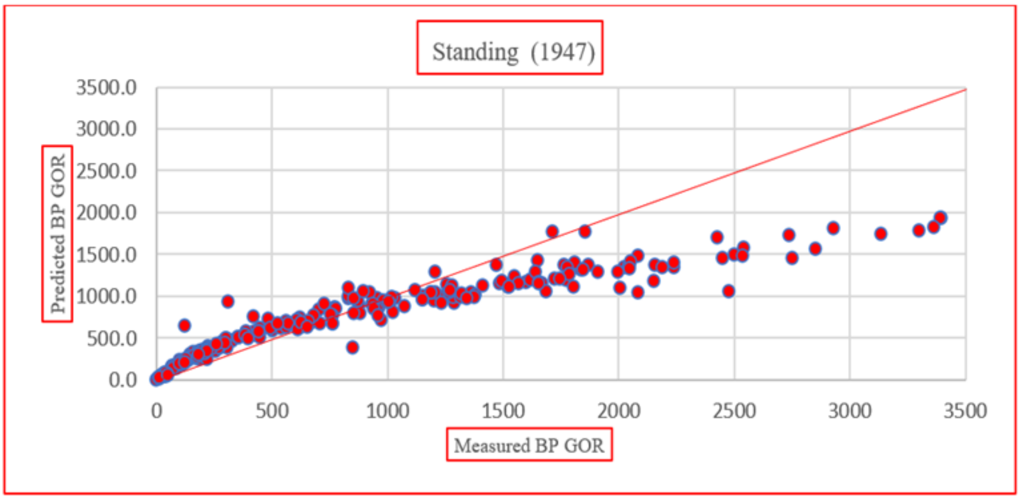

Figure 11: Cross plot of Standing (1947) correlation using BP GOR Niger-Delta Data

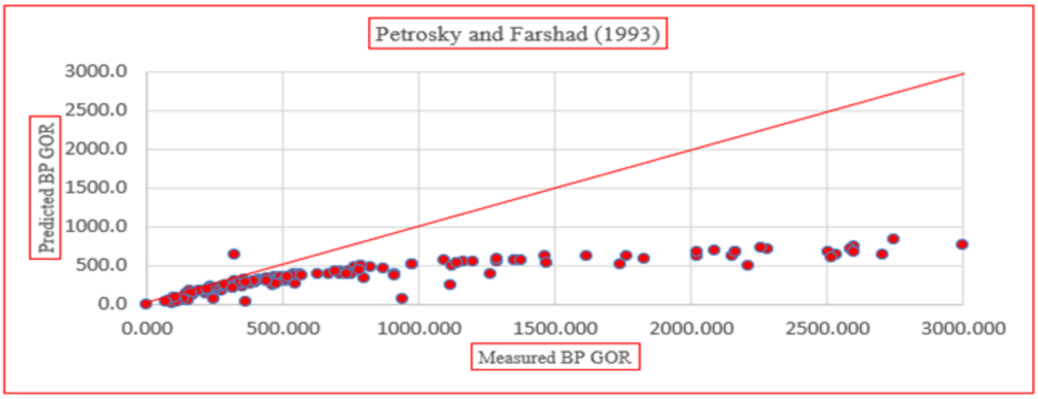

Figure 12: Cross plot of Petrosky and Farshad (1993) correlation using BP GOR Niger-Delta Data

5. Conclusion

The assessment of some existing solution gas-oil ratio (GOR) correlations was done using measured data GOR from Niger Delta region. The correlations were used to predict the GOR measured at bubble point and below bubble point. Both quantitative and qualitative analytical methods were being implemented through statistical parameters and performance plots respectively. From the analysis using Rank as the major screening criterion shows that Standing and Glaso correlations are the best predictive tool for GOR measured at bubble point and below bubblepoint GOR with a Rank of 26.72 and 32.31 respectively. Therefore, these correlations are recommended for GOR properties prediction for the Niger Delta crude in the absence of new or improved correlations.

References

[1]. Anadu, F. and Mbachu, I. I. (2023). Gas Compressibility Factor Prediction Using Machining Learning Algorithmic Protocol for Niger – Delta Gas Reservoir, International Journal of Current Science Research and Review, https://doi.org/10.1016/j.molliq.2015.12.103.

[2]. Mohammed, M. B. A., Alakbani, F. S., and Nathan, C. P. (2022). Determination of the Gas-Oil-Ratio Below the Bubble Point Pressure Using the Adaptive Neutro- Fuzzy Inference System (ANFIS), American Chemical Society Publishers, https://doi.org/10.1021/acsomega.2c01496.

[3]. Ahmed, T. (2013). Equations of State and PVT Analysis; Gulf Publishing Company: Houston, TX, USA.

[4]. Whitson, C. H. and Brulé M. R. (2000). Phase Behaviors, Monograph Series, Society of Petroleum Engineers, SPE Monograph Series Vol. 20.

[5]. Standing, M.B. (1947). A Pressure Volume Temperature Correlation for Mixture of California Oils and Gases. Drill. & Prod. Prac. API, Dallas, 275–287.
[6]. Vazquez, M., and Beggs, H.D. (1977). Correlations for fluid physical property prediction. In: Proc. - SPE Annu. Tech. Conf. Exhib. 1977-Octob. https://doi.org/10.2118/6719- ms.
[7]. Elsharkawy, A.M. and Alikhan, A.A. (1997). Correlation for Predicting Solution Gas/Oil Ratio, Oil Formation Volume Factor, and Undersaturated Oil Compressibility", J. Petrol. Sci. Eng. (17), 291–302. https://doi.org/10.1016/S0920-4105(96)00075-7.
[8]. Glaso, O. (1980). "Generalized Pressure-Volume-Temperature Correlations." J. Petrol. Technol. (32), 785–795. https://doi.org/10.2118/8016-pa.
[9]. Al-Marhoun, M.A. (1988). Pvt Correlations for Middle East Crude Oils. JPT, J. Pet. Technol. 40, 650–666. https://doi.org/10.2118/13718-PA.
[10]. Dokla, M.E. and Osman, M.E. (1992). Correlation of PVT Properties for UAE Crudes. SPE Form. Evaluation (7), 41–46. https://doi.org/10.2118/20989-pa.
[11]. Omar, M.I. and Todd, A.C. (1993). Development of New Modified Black Oil Correlations for Malaysian Crudes. Proc. Asia Pacific Oil Gas Conf, 211–219. https://doi.org/ 10.2523/25338-ms
[12]. Petrosky, J., Farshad, F., (1993). Pressure Volume Temperature Correlation for the Gulf of Mexico. 68th Soc. Pet. Eng. Anna. Tech. Con. Houston, TX, SPE 26644.
[13]. Dindoruk, B. And Christman, P.G., (2004). PVT Properties and Viscosity Correlations for Gulf of Mexico oils. SPE Reservoir Eval. Eng. (7), 427–437. https://doi.org/10.2118/89030- PA
[14]. Obomanu, D.A. and Okpobori, G.A. 1987. Correlating the PVT Properties of Nigerian Crudes. Trans. ASME 109, 214–224.
[15]. Ikiensikimama, S. S. and Ajienka, J. A. (2012). Impact of PVT Correlation Development on Hydrocarbon Accounting: The Case of the Niger Delta, Journal of Petroleum Science and Engineering, (81) 80 -85. Doi: 10.1016/j.petrol.2011,12.017
[16]. Fattah, K.A. and Lashin, A. (2018). Improved Oil Formation Volume Factor (Bo) Correlation for Volatile Oil Reservoirs: an Integrated non-linear Regression and Genetic Programming Approach". J. King Saud Univ. - Eng. Sci. 30, 398–404. https://doi.org/10.1016/j. jksues.2016.05.002.
[17]. Sleiti, A. K., Wahib A. Al-Ammari, W. A, Abdelrazeq M., El-Naas, M., Rahman, M. A., Barooah, A., Hasan, R. and Manikonda, K (2021). Comprehensive Assessment and Evaluation of Correlations for gas-oil Ratio, Oil Formation Volume Factor, Gas Viscosity, and Gas Density Utilized in Gas Kick Detection, Journal of Petroleum Science and Engineering, https://doi.org/10.1016/j.petrol.2021.109135
[18]. Abdul-Majeed, G. H., (1985). Evaluation of PVT Correlation, SPE 14478, Society of Petroleum Engineers, Dallas, Texas, 1985.
[19]. Sutton, R. P. and Farshad, F. (1990). Evaluation of Empirically Derived PVT Properties for Gulf of Mexico Crude Oils, SPE Reservoir Engineering, 79-86, SPE 13172.
[20]. McCain, W. D. (1991). Reservoir fluid property correlations- State of the Art, SPE Reservoir Engineering, (May 1991), pp 266-272.
[21]. Lasater, J. A. (1958). Bubble point Pressure Correlation, Trans., AIME 213, 379-81.
[22]. Zhoa, C. Y., Zhang, H. X., Liu, M.C, Hua, Z. D., and Fan B.T, (2006). Application of Support Vector Machine (SVN) for Prediction Toxic Activity of Different Data Sets, Toxicology 217, p. 105-119
[23]. Danesh, A. (1998). PVT and Phase Behavoiur of Petroleum Reservoir Fluids, Elsevier Science B. V., Amsterdam.
[24]. Ikiensikimama, S. S. (2009). Reservoir Fluid Property Correlations, (Chi Ikoku Petroleum Engineering Series, IPS Publications, Port Harcourt.