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Predictive Models for Condensate Gas Ratio (CGR) – Part 1: For Western Niger Delta Region

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Authors' contributions

Author JAA analyzed, verified and checked the quality of the data used in development of this model. Author IIA contributed in the area of literature review and development of the model. Author SSI developed and interpreted the models. He also carried out the statistical comparison analysis. This work was proofread and accepted by all the authors before submitted for publication.

Research Article

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ABSTRACT

Condensate-to-gas ratio (CGR) plays a significant role in sales potential assessment of both gas and liquid, design of the required surface processing facilities, reservoir characterization and modeling in gas-condensate reservoirs. This work aim at the use of regression method to develop Condensate gas ratio (CGR) correlations using dataset obtained from Western Niger Delta region. The formation was divided into three distinct geologic zones: Transitional Paralic, Paralic and Marine Paralic zones. The basic parameters used for the correlation development are: reservoir depth (ft), reservoir pressure (psia); reservoir temperature (^{o}F) all at (Gas – Oil – Contact (GOC) / Gas – Down – To (GDT) / Gas – Water – Contact (GWC)) and these parameters are data easily obtained from the field. A statistical assessments show that the models predicted CGR with a percent mean absolute error of 19.5640, correlation coefficient of 0.9539 and a rank of 18.15. These results show that the models are suitable for these fields.

Keywords: Condensate to gas ratio; correlation; regression; gas condensate.

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NOMENCLATURE

CGR	*Condensate to Gas Ratio, stb/mmscf*
GOC	*Gas – Oil – Contact*
GDT	*Gas – Down – To*
GWC	*Gas – Water – Contact*
PVT	*Pressure –Volume - Temperature*
D	*Reservoir Depth, ft.ss*
P	*Reservoir Pressure, Psia*
T	*Reservoir Temperature, ^{0}F*
E_r	*Percent Mean Relative Error*
E_a	*Percent Mean Absolute Error*
S_r	*Percent Standard Déviation Relative*
S_a	*Percent Standard Déviation Absolute*
R	*Corrélation Coefficient*
MPZ	*Marine Paralic Zone*
TPZ	*Transitional Paralic Zone*
PZ	*Paralic Zone*
SG_c	*Condensate Specific Gravity*
SG_g	*Gas Specific Gravity*
C7+	*Heptane plus*

1. INTRODUCTION

Gas condensate is a single phase gas in the subsurface. It produces both liquid and gas phases when it is taken to the surface and the pressure and temperature reduced to near ambient conditions. The liquid phase is known as condensate. The condensate gas ratio (CGR) is measured by metering the flows of condensate and gas at the surface. If mass units are used, it is defined as the mass of condensate produced per kg of gas. If oil field units are used, it is the volume of condensate (in barrels) produced per million scf of gas under standard conditions [1].

Condensate-to-gas ratio (CGR) plays a significant role in sales potential assessment of both gas and liquid, design of the required surface processing facilities, and reservoir characterization and modeling in gas-condensate reservoirs. Precise field and laboratory determination of the CGR is time and people intensive. Developing a rapid and inexpensive technique for accurate estimation of the CGR is inevitable [2].

CGR is very important parameter in gas condensate reservoir. With the aid of CGR, condition of phases can be predicted, and also, the economy of the reservoir can be envisaged. The knowledge of this parameter is also essential for gas reservoir performance calculation and numerical modeling [3].

Three things are essential in a successful development of gas condensate fields: (1) in the original well testing of the field, accurate values of the condensate to gas ratio (CGR) are determined for the evaluation of the initial “in place” reserves and the formation evaluation and reservoir characterization; (ii) the CGR behavior of the production wells are understood so that the history matching to early data can be accurate; (iii) the general long term behavior of the reservoir and the liquid recovery factors expected in any planned gas recycling process are realistic [4].

Moreover, condensate liquid components have been more valuable than the gas, because of easy transportation especially in the places far from gas market or transport system [5]. As a result, understanding nonlinear and complex behavior of gas condensate reservoir is very important and also its one of the most difficult, onerous and challenging problem in petroleum reservoir engineering [6]. On the other hand behavior of gas condensate reservoir is mainly controlled by fluid properties and accurate knowledge of these PVT characteristics [7].

Gas condensates are becoming increasingly important throughout the world but the gas condensate reservoir behavior is complex and is not yet wholly understood. However, efforts have been made by Dawe and Grattoni [8] to explain gas condensate reservoir behavior through detailed mechanisms such as visualization of pore-scale phase flow mechanisms to give an insight to fluid displacements at the core scale and help the interpretation of production behavior at reservoir scale. Thomas et al. [9] also worked on optimizing production from a gas condensate reservoir and Cho et al. [10] developed a correlation to predict maximum condensation for retrograde condensation fluids and its use in pressure depletion calculations. Also, an approach for forecasting viability of gas condensate wells and predicting Condensate Gas Ratio (CGR) using reservoir volumetric balance has been developed, Olaberinjo et al. [11].

CGR can be calculated using three methods; experimental data, equation of states and correlations. By using PVT tests, CGR can be measured but reservoir fluid samples are needed. Sampling of the gas condensate reservoir has its problems. As a result obtaining CGR from experimental data is expensive, complex, energy and time consuming [2].

Some of the literature cited earlier, were directed at explaining gas condensate reservoir behavior, and noted that much work has not been done in the area of correlation development for gas condensate reservoirs. It was also clear that no correlation exist for gas condensate reservoirs for the Niger Delta in the open literature. Therefore, this work is aimed at developing Condensate Gas Ratio (CGR) correlations using datasets obtained from Western Niger Delta region via regression method. It will also be necessary to note that models using the correlating parameters of this study are not available in the (open) literature to make easy comparison and very scarce and limited data are available on this subject in the region.

2. REPORT VALIDATION/ DATA SOURCE

All the PVT reports used were validated using the basic validation techniques of Campbell plots and Material balance diagrams. 48 PVT report that met validation requirements were used.

Gas condensate reservoir PVT data from different fields in the Western Niger Delta were used. These are:- Delta State, Western Bayelsa: Bomadi, Burutu and Nun areas of oilfields operations in the region were put together. Table 1 shows the distribution of the validated PVT reports used for the study in terms of geologic zones. Table 2 shows the data distribution use for the work (see Appendix for comprehensive data).

Table 1. Distribution of PVT reports used in this study

Geologic Zones	Reservoir	Fields
Transitional Paralic	21	7
Paralic	11	8
Marine Paralic	24	5
Total	46	

Table 2. Data range used for the development of the correlations

Geologic Zones	Pressure (psia) (@GOC/GDT/GWC)	Depth, D(ft) (@GOC/GDT/GWC)	Temp (^oF) (@GOC/GDT/GWC)	CGR (stb/MMscf)
Transitional Paralic	3226 - 4284	7292 - 9802	138 - 209	1.37 - 46.39
Paralic	4387 - 4953	10074 - 11256	153 - 272	10.8 - 62.76
Marine Paralic	4861 - 8356	11541 - 12620	196 - 223	6.75 - 127.8

3. DATA ORGANIZATION AND CORRELATION PERFORMANCE EVALUATION (ZONING OF THE FORMATION)

Most of the condensate reservoirs are found in the Paralic zone [12] (much of the Agbada formation) between 6,000 and 18,000 ft. and correlating all data obtained for condensate reservoirs show some level of complexity and gave no recognizable pattern. It was then necessary to adopt a procedure of dividing this formation into three distinct geologic zones - Transitional Paralic (6,330 – 9,999 ft.ss), Paralic (10,000 – 11,499 ft.ss) and Marine Paralic (11,500 – 16,500 ft.ss) respectively.

4. CORRELATIONS/MODELS DEVELOPMENT

Fundamentally, three correlations were developed. The basic parameters used for the correlation development are (see Table 2): reservoir depth (ft), reservoir pressure (psia); reservoir temperature (ºF) (all @ GOC/GDT/GWC). These parameters are easily obtainable from the field; this gave the reason for their choice.

4.1 Correlating Parameters

The Model as shown in Equation 1 was developed using linear and non-linear multiple regression analysis with non-linear least square curve fits via MATLAB [13] sessions with the in-built Microsoft Excel Solver functionalities in Microsoft Excel Application [14]. Regression equation as given by Equation 1 with CGR as a function of P, D and T was derived for each zone. Owing to the limited amount of data in each zone (see Table 1), the best regression equation was derived by using one condensate reservoir as a control data point while generating a regression equation from the remaining data. The regression equation so obtained is used to estimate the CGR of the control reservoir data. The estimate is then compared to the CGR of the PVT report. The regression equation who's estimated CGR for the control has the minimum deviation from the measured PVT value is selected as the best equation.

4.2 CGR as function of Dept (D), Pressure (P) and Temperature (T)

Several models were tried for the CGR correlation using only easily obtainable parameters such as depth, reservoir pressure and reservoir temperature. However, the best model was obtained using a 3-parameter correlation for CGR as a function of D, P, and T given by Equation 1. The coefficients of Equation 1 are given in Table 3 for the Transitional Paralic (TP), Paralic (P) and Marine Paralic (MP) Zones.

$$CGR = X1 + X2P + X3P^2 + X4P^3 + X5P^4 + X6D + X7D^2 + X8D^3 + X9D^4 + X10T + X11T^2 + X12T^3 + X13T^4 \quad (1)$$

Where

P = Reservoir pressure at GOC/GWC/GDT (psia)
D = Reservoir depth at GOC/GWC/GDT (ft. ss.)
T = Reservoir temperature (^{o}F)
X1 to X13 are coefficients of the model.

This model actually is similar to an in-house model use for some other studies, but the coefficients were optimized such that it gave the model flexibility to give better predictions possible. The model took the form of a fourth order polynomial for the depth (D), reservoir pressure (P) as well as reservoir temperature (T).

Table 3. Coefficients for Developed Correlation

	3 –parameter Models		
Variables	**Transitional Paralic Zone**	**Paralic Zone**	**Marine Paralic Zone**
X1	6.0870844602000 E04	1.4913197869499 E06	3.7155404208897 E08
X2	-2.8284399437000 E02	1.0167040445870 E03	-2.60320652925947 E05
X3	1.1690515217857 E-01	9.2124506870644 E02	7.5156717039050 E01
X4	-2.1373616911844 E-05	-6.9466028549798 E05	-9.63697790639015 E-03
X5	1.458371612461 E-09	6.5506494481022 E-09	4.6306880586121 E-07
X6	1.0708930138388 E02	-1.0619224161765E-03	1.7144411586871 E04
X7	-1.9393478658181 E-02	7.41248838581947 E-02	-2.4015736387775
X8	1.5524148249463 E-06	-2.77556669551227 E-07	1.4743846845262 E-04
X9	-4.6343400333374 E-11	-8.7716144942317 E-11	-3.3561612216975 E-09
X10	-6.2695708581095 E02	1.4252356335767 E03	-1.4865931268216 E06
X11	5.6162835619106	-9.9058335168366	1.0516705270328 E04
X12	-2.2157109070268 E-02	3.0472025288091 E-02	-3.3045848907682 E01
X13	3.25016027846853 E-05	-3.49387943673943 E-05	3.8915288290495 E02

5. QUANTITATIVE AND QUALITATIVE SCREENING

Different authors have used different statistical measures to choose the best correlation developed. Some have used percent Mean Relative Error (MRE), percent Relative Standard Deviation (SDR) [15] and coefficient of determination (R^2) as the criteria to choose [16] while others used percent Mean Absolute Error (MAE) and percent Absolute Standard Deviation (SDA) with or without performance plot [17,18].

Al-Marhoun [19], pointed out that the most important indicator of the accuracy of an empirical correlation is the percent MAE; having assessed different combinations of available criteria found in the literature, it became clear that no one parameter is outstanding to be used in making the choice and that these different independent assessments are not sufficient to make an excellent choice. Therefore, to make a brilliant selection multiple combinations of these statistical parameters should be adopted in the selection criteria of the developed correlations. To compare the performance and accuracy of the new models, two forms of analysis were performed which include quantitative and qualitative. For quantitative screening method, statistical error analysis was used. The statistical parameters used for the assessment were percent mean relative error (E_r), percent mean absolute error (E_a), percent standard deviation relative (S_r), percent standard deviation absolute (S_a) and correlation coefficient (R).

The new approach, combines all the statistical parameters mentioned earlier (E_r, E_a, S_r, S_a and R) into a single comparable parameter called Rank [20,21,22]. 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;

$$Min\ Z_i = \sum_{j=1}^{m} S_{i,j} q_{i,j} \tag{2}$$

Subject to

$$\sum_{i=1}^{n} S_{i,j} = 1 \tag{3}$$

With $$0 \le S_{i,j} \le 1 \tag{4}$$

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 ij = E_r, E_a, …. R^1, where R^1 = (1-R) and Z_i is the rank, RK (or weight) of the desired correlation. The optimization model outlined in Equations 2 to 4 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 E_a, 0.2 for R, 0.15 for S_a, 0.15 for S_r, and 0.1 for E_r. Finally, Equation 2 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 work except R, where a maximum value of 1 was expected. Since the optimization model (Equations 2 to 4) 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 correlation had been evaluated against the available database. For qualitative screening, performance plots were used (Figs. 1, 2 and 3). The performance plot is a graph of the predicted versus measured properties with a 45º reference line to readily ascertain the correlation's fitness and accuracy. A perfect correlation would plot as a straight line with a slope of 45º. It should be noted that the 45º is not a line of best fit. Also bar charts were used to show quick comparison of the measured and the developed correlations (see Figs. 4, 5, 6).

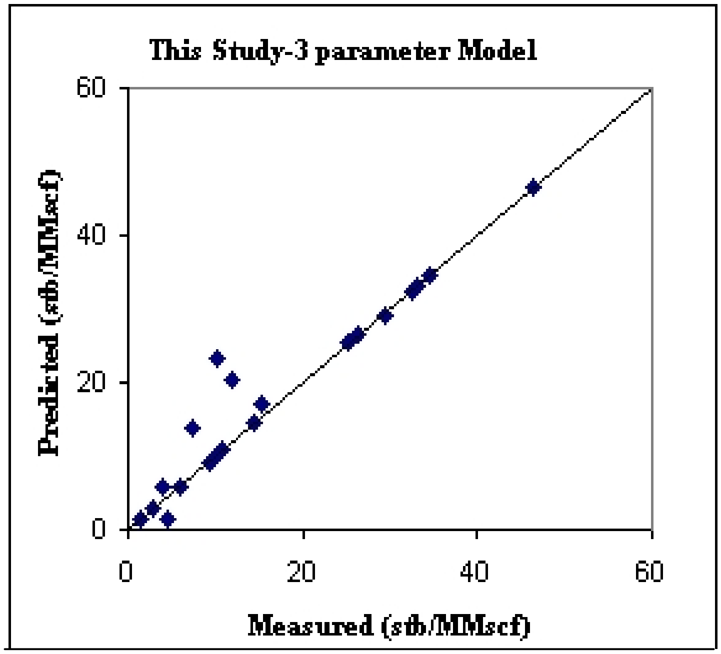

Fig. 1. Performance Plot for CGR (TPZ)

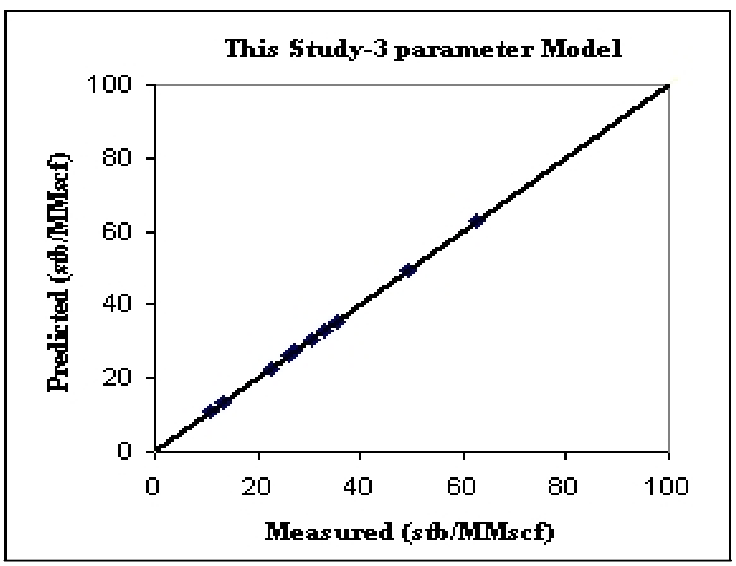

Fig. 2. Performance Plot for CGR (PZ)

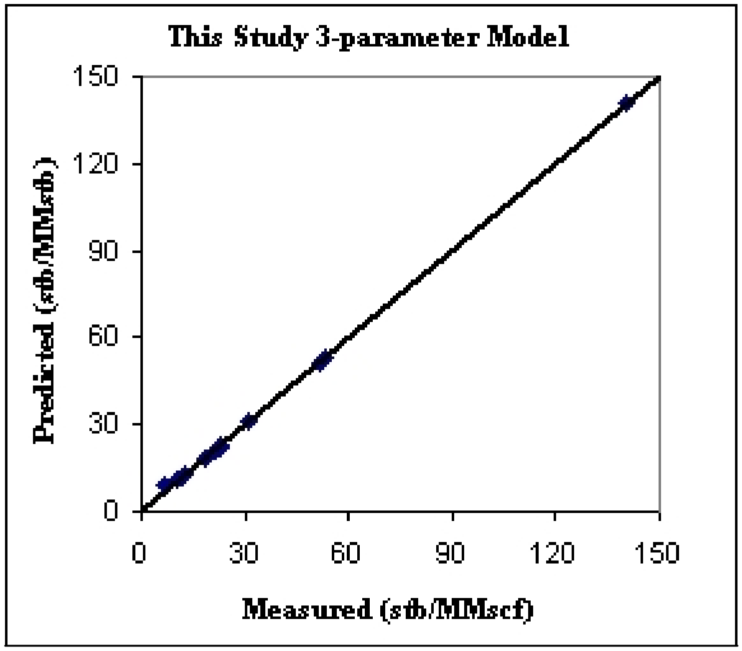

Fig. 3. Performance plot for CGR (MPZ)

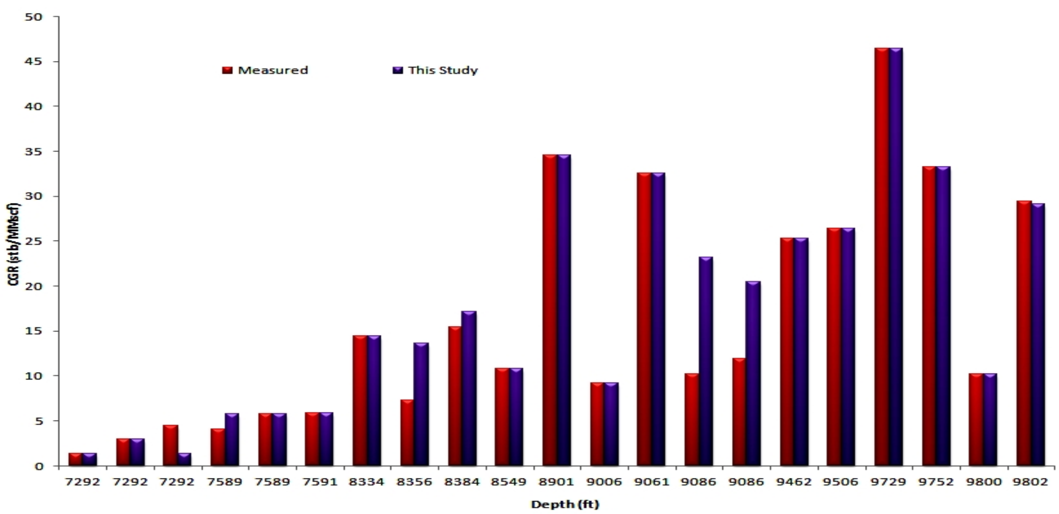

Fig. 4. Performance plot of CGR versus Depth (3-p Correlations) – (TPZ)

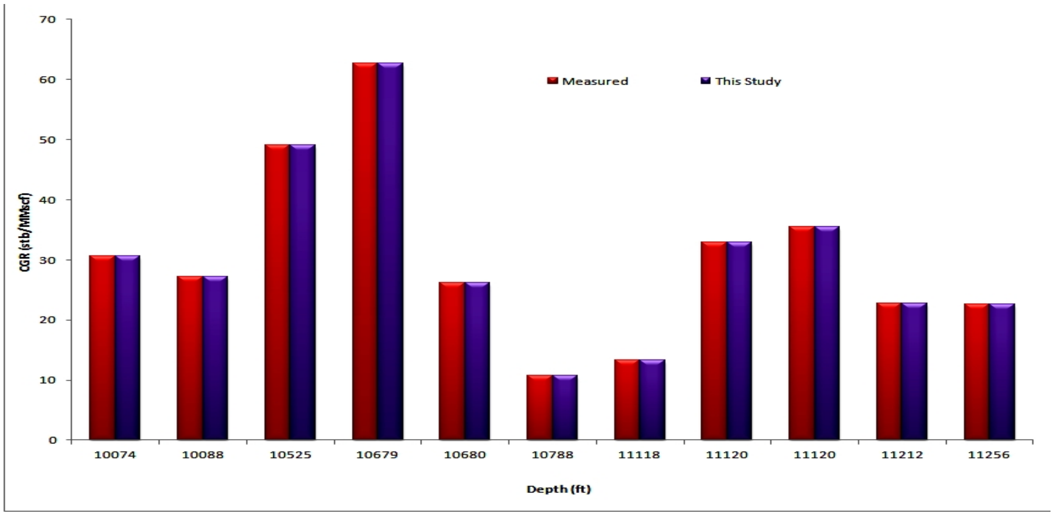

Fig. 5. Performance plot of CGR versus Depth (3-p Correlations) – (PZ)

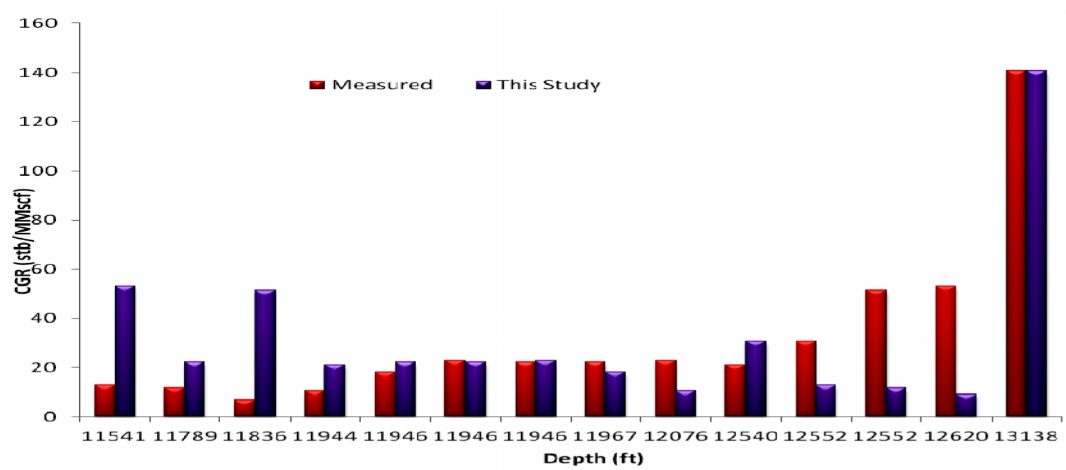

Fig. 6. Performance plot of CGR versus Depth (3-p Correlations) – (MPZ)

6. RESULTS AND DISCUSSION

6.1 Transitional Paralic Zone (TPZ)

The best regression equation for this zone is given by the model of Equation 1; see Table 3 for the coefficients. In terms of statistical accuracies (Table 4), the model predicted CGR with percent mean absolute error of 19.5640, correlation coefficient of 0.9539 and a rank of 18.15. Fig. 1 is a performance plot for the Transitional Paralic zone. This plot shows that the correlation can predict CGR correctly between 1stb/MMscf to that of 55stb/MMscf. However, between 10stb/MMscf and 18stb/MMscf, there could be some over estimations of the CGR values. Fig. 1 is the bar chart quick performance comparison of the correlation. This Fig. 4 shows a depth versus CGR plot given a visual representation of the accuracy of the model to estimate CGR at different depths. The figure shows a good match except the following depths 7292ft, 7589ft, 8356ft and 9086ft respectively.

6.2 Paralic Zone (PZ)

The best regression equation for this zone is given by the model of Equation 1; see Table 3 for the coefficients. In terms of statistical accuracies (see Table 4), the model predicted CGR with percent mean absolute error of 5.1912E-06, correlation coefficient of 1.000 and a rank of 6.6E-06. Fig. 2 is a performance plot for the Paralic zone. This plot shows that the correlation can predict CGR correctly between 10stb/MMscf to that of 70stb/MMscf. Fig. 5 is the bar chart quick performance comparison of the correlation. This figure shows a depth versus CGR plot given a visual representation of the accuracy of the model to estimate CGR at different depths. The figure shows a good match for all depths considered.

6.3 Marine Paralic Zone (MPZ)

The best regression equation for this zone is given by the model of Equation 1; see Table 3 for the coefficients. In terms of statistical accuracies (see Table 4), the model predicted CGR with percent mean absolute error of 2.6266, correlation coefficient of 0.9998 and a rank of 3.62. Fig. 3 is a performance plot for the Marine Paralic zone. This plot shows that the correlation can predict CGR of gas condensate reservoir correctly between 5stb/MMscf to that of 145stb/MMscf. Fig. 6 is the bar chart quick performance comparison of the correlation. This figure shows a depth versus CGR plot given a visual representation of the accuracy of the model to estimate CGR at different depths. The figure shows a good match except that there could be some over estimations between the depths of 11541 and 11944ft; and under estimations between the depths of 12067 and 12620ft respectively.

Generally, the models developed performed better for the Paralic zone than the Transitional and Marine Paralic zones. Table 4 shows that while the Paralic zone had a rank of 6.6E-06 that of the Transitional and Marine Paralic zones had ranks of 18.15 and 3.62 respectively. This trend is also noticed at a glance from Figs. 4, 5 and 6. It will be necessary to mention that caution should be exercise for the use of these models beyond the range of data used for their development.

Table 4. CGR as function of D, P, and T - Statistical Accuracies of the Correlations

Models	Correlating Parameters	E_r	E_a	S_r	S_a	r	Rank	Comments
3- Parameter	P, T, D	-12.8078	19.5640	40.1423	37.1721	0.9539	18.15	TPZ
3- Parameter	P, T, D	-5.1264E-06	5.1912E-06	1.6800E-05	1.6778E-05	1.0000	6.6E-06	PZ
3- Parameter	P, T, D	-2.3575	2.6266	9.3765	9.2992	0.9998	3.62	MPZ

7. CONCLUSIONS

Predictive CGR models have been developed for the Niger Delta for the Western operations of oilfields in the region using different models for three predefined geological zones– the Transitional Paralic, Paralic and Marine Paralic zones with easily available field data. Both quantitative and qualitative assessments show that the models are very impressive with good statistical parameters, good ranks and better performance plots.

COMPETING INTERESTS

Authors declare that there are no competing interests.

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Appendix

Correlation development Data

	TRANSITIONAL ZONE		PARALIC			
FIELD	**Area**	**SGg**	**P**	**D**	**T**	**CGR**
			Psia	ft.ss	^{o}F	Stb/mmscf
			at GOC/GDT/GWC			
TRANS 1	W	0.572	3240	7292	140	1.37
TRANS 2	W	0.595	3238	7292	138	2.94
TRANS 3	W	0.582	3935	9006	155	9.24
TRANS 4	W	0.578	3240	7292	140	4.47
TRANS 5	W	0.620	3369	7589	147	4.07
TRANS 6	W	0.608	3370	7591	147	5.86
TRANS 7	W	0.620	3369	7589	147	5.81
TRANS 8	W	0.641	3932	9800	151	10.22
TRANS 9	W	0.671	3916	9086	156	10.22
TRANS 10	W	0.603	3928	9086	156	11.90
TRANS 11	W	0.695	3675	8356	162	7.29
TRANS 12	W	0.630	3570	8384	179	15.41
TRANS 13	W	0.664	3549	8549	156	10.81
TRANS 14	W	0.680	3226	9061	178	32.50
TRANS 15	W	0.600	4142	9506	163	26.40
TRANS 16	W	0.693	3673	8334	163	14.46
TRANS 17	W	0.680	3827	8901	177	34.50
TRANS 18	W	0.630	4102	9462	204	25.29
TRANS 19	W	0.650	4284	9802	151	29.41
TRANS 20	W	0.667	4241	9752	206	33.19
TRANS 21	W	0.670	4240	9729	209	46.39

PARALIC ZONE						
FIELD	**Area**	**SGg**	**P**	**D**	**T**	**CGR**
			Psia	ft.ss	^oF	stb/mmscf
			at GOC/GDT/GWC			
PARA 1	W	0.650	4671	10788	189	10.80
PARA 2	W	0.665	4844	11118	200	13.35
PARA 3	W	0.640	4915	11256	194	22.65
PARA 4	W	0.640	4883	11212	193	22.70
PARA 5	W	0.650	4652	10680	185	26.17
PARA 6	W	0.666	4387	10088	212	27.14
PARA 7	W	0.680	4402	10074	153	30.62
PARA 8	W	0.700	4866	11120	272	32.99
PARA 9	W	0.652	4953	11120	255	35.43
PARA 10	W	0.660	4570	10525	222	49.17
PARA 11	W	0.650	4684	10679	186	62.76

MARINE PARALIC ZONE						
FIELD	**Area**	**SGg**	**P**	**D**	**T**	**CGR**
			Psia	ft.ss	^oF	stb/mmscf
			at GOC/GDT/GWC			
	W	0.698	5372	12552	223	12.90
MAR PARA 1	W	0.701	5381	12552	217	11.87
MAR PARA 2	W	0.697	5501	12620	217	6.75
MAR PARA 3	W	0.705	5315	12076	208	10.67
MAR PARA 4	W	0.653	4861	11967	198	18.22
MAR PARA 5	W	0.690	5161	11946	214	22.83
MAR PARA 6	W	0.695	5161	11946	214	22.40
MAR PARA 7	W	0.696	5156	11789	214	22.40
MAR PARA 8	W	0.690	5133	11946	198	22.83
MAR PARA 9	W	0.700	5177	11944	209	21.23
MAR PARA 10	W	0.740	5450	12540	214	30.78
MAR PARA 11	W	0.650	5071	11836	196	51.37
MAR PARA 12	W	0.663	5002	11541	214	53.20
MAR PARA 13	W	0.666	5690	13138	223	140.72

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