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A New Forecast Model and Chart for Natural Gas Compressibility Factor

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Abstract— *Gas compressibility factor for natural gas system can be determined from Standing and Katz charts using the pseudo critical gas pressures and temperatures. This chart gives accurate values for gas compressibility factor. Reservoir simulation softwares need accurate correlation to estimate the values of this natural gas property, one of the famous correlations is Beggs and Brill. This correlation gives large errors at high gas reservoir pressure. Old correlations give good estimation of gas z factor at low gas reservoir pressures below 6000psia, at high pressures the error starts to appear. In this study, a new accurate gas compressibility factor correlation has been developed which specifically addressed the limitation of other correlations. The equation was developed by regressing 645 data points of measured gas z factor data point from Niger Delta using Matlab. The developed correlation shows superiority as to compare with other evaluated correlations by the statistical parameters applied. The new developed correlation can be used to determine the gas compressibility factor at pressure ranges from 130psia to 14000pia and is a function of pseudo reduced pressure and temperature. A plot of z – factor against reduced pressure (P_r) at isothermal reduced temperature (T_r) was also developed using the equation modeled in this work which yields a chart that mimic conventional Standing and Katz chart. The proposed chart and correlation are applicable at the interval of $1.02 \leq T_r \leq 2.2$ and $0.1 \leq P_r \leq 20$. The chart developed in this research work take care of presence of non-hydrocarbon like CO_2 and N_2.*

Keywords— *Correlation, low pressure, moderate pressure, high pressure, high temperature, gas compressibilty factor.*

I. INTRODUCTION

Natural gas utilization has become an interesting topic because of significant growth of energy demand globally. Thus, natural gas is a promising energy alternative due to its availability and having similar property to petroleum [1]. As the exploration of this resource continues, it is highly essential to understand the condition and physical properties of the reservoir because they constitute a vital portion of the data required for the comprehensive knowledge and understanding of reservoirs system. These reservoir data also aid in accurate calculation of gas recovery and optimum production systems design. The estimation of reserves and the design of this equipment are obtainable when reservoir fluid (oil, condensate or gas) properties are available [2].

Gas compressibility factor is a useful thermodynamic property of a reservoir fluid that modifies the ideal gas law to account for behavior of real gases. The industry standard is to measure this property in the laboratory using reservoir samples. The procedures of acquiring experimental data are sometimes very expensive, and time consuming, hence methods such as correlations and equation of state are used to predict this property at reservoir pressure and temperature conditions [2].

Natural gas reservoirs targeted for search and development before the 1960s were less than 15,000 ft, pressure less than 10,000 psia and temperature less than 300^{o}F ([3], [4], [5]). Majority of these natural gas resources show normal pore pressure and temperature gradients. The growing demand for natural gas is driving the petroleum industry to look for new resources in previously unexplored and deeper areas, where High-Pressure and High- Temperature (HPHT) reservoirs may be encountered [4].

Several well-known correlations are used in the petroleum industry to determine the values of gas z- factor. Some of these available mathematical equations in literature are ([6], [7-9], [5], [10-14]). [3] shows the experimental capacities of gas deviation factor for HPHT conditions prevailing in reservoir. They measured gas density and z-factor for numerous dry gas sample at pressures to 20,000psia and temperatures of 300^{o}F and 400^{o}F. Laboratory data was used for evaluation with other existing correlation like [7] and [9] and mathematical model for generating pseudocritical properties. (15) with (16) outperformed (9) for the entire data studied. The correlations studied overestimated the z- factor for HPHT conditions.

[17] evaluated some selected gas deviation factor correlation using Niger-Delta data. The data comprise of 513 values acquired from gas reservoirs in Niger-Delta of Nigeria. Data employed for the analysis lies within the following range of reduced temperature and pressure of $0.5796 \leq T_r \leq 1.758$ and $0.410 \leq Pr \leq 8.985$ respectively. [8] has the best performance with rank of 2.82, an absolute percentage error (E_a) of 3.234 and the finest performance plot.

[5] developed a newer and simpler correlation using 300 data points (via linear regression function) that can predict gas z - factor at any region. The approach returned an error less than 3% associated to laboratory data. [10] also developed a model via Fourier series expansion using over 6000 data points prepared by careful laboratory measurements of natural gas mixtures and the result was found to match accuracy, without over fitting. [11] generated an equation for computing z – factor using least square support vector machine (LSSVM). 2200 data comprising of sour and sweet gas samples mixture was utilized in building the model. The

maximum pressure of 11,000 pisa and temperature of 441.80 ^oK was used to obtain the new z – factor correlation. The calculated z – factor values from the new established model did better than other correlations studied with absolute relative error of 0.19% and correlation of 0.999.

[12] developed a z-factor chart using [8] z -factor equation. 359 validated data of Niger Delta region were used in building the z-factor chart. The authors validated their new chart with [6] and observed that their chart performed well as long as the pseudo-reduced properties are within the specified range of reduced properties. The z-factor chart performed best at pseudo reduced properties ranges between 1.40 < Tr< 1.90 and 0.198 < Pr< 10.8. [18] developed a new z- factor correlation for the Niger Delta gas reservoirs. The correlation was developed using Microsoft Excel Analysis Tool and SPSS statistical software using 300 data points from the PVT analyses of 14 fluid samples from Niger Delta. The developed correlation was compared to the best performing correlations with some of the statistical parameters like percent mean relative error, percent mean absolute relative error, standard deviation and correlation coefficient. The developed correlation was found to outperform other existing correlations. The model is valid for pseudo reduced properties ranges between 1.10 < Tr< 1.65 and 0.68 < Pr< 8.2.

[19] did an evaluation work for gas compressibility factor correlation for high pressure high temperature reservoir conditions. Experiments were conducted to measure gas density and z-factor for two samples of gas mixture at high pressure of 6000psig to 14000psig and temperatures 270^oF and 370^oF. It was found from their evaluation work that majority of the existing z-factor correlations cannot be used to predict z-factor at high pressure and high temperature region. Based on the result of the measured data, some of the selected correlations performed well within certain pressure range and show a high deviation at high pressure region. The authors concluded by recommending the development of new predictive tool for gas z- factor at high pressure and temperature for a good reservoir performance.

[20] did a research on evaluation of correlations of compressibility factor of natural gas for Algeria gas reservoir. The authors experimentally study an Algeria natural gas of z factor using the relative correlation to calculate this factor. They tried to modify these with what correspond better with Algerian geographic natural gas based on statistical tools and experimental data. The authors concluded that it is possible to develop and update the correlations coefficients that correspond better with each geographic region in order to reduce the margin of error.

[14] studied five groups of high-temperature ultra-high-pressure natural gas samples collected from oilfields in northwestern China. The compressibility factors of these samples at their reservoir temperatures and different pressures are determined using a pressure-volume-temperature apparatus. The experimental results indicate that the Z-factors of these natural gases under reservoir conditions are considerably higher than those of conventional natural gases. The authors also reported that the Z-factors decrease as the pressure decreases within the high pressure ranges considered their investigation. A sample thermodynamic model based on the Soave-Redlich-Kwong equation of state and newly established binary interaction correlations was proposed to predict the Z-factors of the gas samples investigated. The evaluation was done using four Z-factor empirical correlations. It was found that the thermodynamic model proposed in their work exhibited the best prediction accuracy; with the empirical values of average absolute deviations in the calculations of the Z- factors of five natural gas samples are only 0.7%, 2.1%, 1.81%, 0.44% and 0.92%.

Recently [13] published a paper on Predictive Tool for Gas Compressibility Factor at High Pressure High Temperature. They focused on the development of predictive tool for gas compressibility factor for high pressure high temperature gas reservoirs. It was reported that the majority of the existing correlations gave large errors at high gas reservoir pressure. The 153 measured data of natural gas sample from Niger Delta region was regressed using Mat Lab. Statistical analysis and cross plots were used in the correlation comparison. The authors concluded that the new correlation outperformed other evaluated models with a mean absolute error (MAE) of 0.9262, coefficient of correlation (R) of 0.996 and Rank of 0.8919. The model matched closely to the measured data with a good performance plot. The developed correlation is a function of gas density, reduced temperature, and reduced pressure and is valid for reduced temperature of 1.7 - 3.0 and reduced pressure of 10 - 20. [21] worked on an intelligent data-driven framework to develop new correlation to predict gas deviation factor for high-temperature and high-pressure gas reservoirs using artificial neural network. They reported that the existing correlations gave high error margin and a need for high pressure high temperature gas compressibility factor correlation. They concluded that the new ANN model proposed in their work outperformed the traditional methods.

[6] is still the correlation used widely by the petroleum industry to determine the natural gas compressibility factor. Unfortunately, the range of pressure and temperature conditions represented by the data used to generate the standing and Katz correlation are not typical of those conditions encountered in deep natural gas reservoirs. Improvements to the Standing and Katz correlation as well as extensions to higher pressures and temperatures have been made using mathematical models or equations of state (EOS), unfortunately, the [22] and [9] EOSs were matched to the same data base used to generate the [6] correlations. [7] model was not only matched to the Standing and Katz data, but was also tested against a limited set of additional data from twelve natural gas reservoirs that do not represent extreme pressure and temperature conditions. Also, these models were not compared to actual measured data to validate the new proposed correlations to estimate gas compressibility factor.

From the literature, conclusion can be drowned that the correlations of gas compressibility factor available in open access are not having a sufficiently wide collection of applicability for extraordinary pressure and temperature, and so their application and accuracy may not be reliable in predicting natural gas Z factor at higher regions and some authors has explained that this parameter works best on the

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geographical region. Monitoring the behavior of these exceptional reservoirs needs a proper knowledge of gas reservoir characteristic at extreme condition. Therefore, this paper focuses on modeling gas compressibility factor for low-moderate- high pressure high temperature conditions using Niger Delta Data for proper monitoring of gas reservoir.

II. METHODOLGY

A. Data Acquisition and Analysis

The PVT analyses of 519 reservoir fluid samples comprising of low to moderate (130 psia – 8000 psia) pressure and temperature data were collected from the Niger-Delta fields of Nigeria. The Data sets collated were obtained from conventional PVT reports that was used to derive the various reservoir fluid properties. In the report, the reservoir fluid analysis for flashed liquid, flashed gas and recombination of reservoir fluid were considered for the various components for validation. After the validation, 511 data set was found to be valid.

645 data point was used in this research gotten by adding 134 high pressure high temperature measured data from [19] and 511 low- moderate pressure temperature field data. Table 1 shows the low-moderate-high data range used in building gas compressibility factor model and chart.

TABLE 1. Range used for this Study

Parameters	Minimum	Maximum	Mean
Reservoir Temperature (°R)	600.0	830.0	669.74
Reservoir Pressure (Psia)	130	14000.0	4105.63
Specific gravity	0.5791	1.1515	0.729
Reduced Temperature	1.372	2.019	1.6944
Reduced Pressure	0.1959	20.11	6.0997
Experimental Z - factor	0.716	1.7077	0.997
C_1	89.24	91.34	90.53
C_2	5.01	4.35	4.538
C_3	1.83	2.3	1.954
$i\text{-}C_4$	0.50	0.73	0.564
$n\text{-}C_4$	0.48	0.69	0.544
$i\text{-}C_5$	0.28	0.33	0.295
$n\text{-}C_6$	0.22	0.34	0.2657
C_7^+	0.41	1.93	0.7614
CO_2	0.32	0.44	0.353
N_2	0.13	0.14	0.135

B. Correlation Development

Description of Microsoft Excel solver: The in-built MS Excel Solver is a linear and non-linear equation solver applied for curve fitting (data fitting) for a system of equations, for both constraint and unconstrained adjustment problems. It is partly add-in functions that is employed in the Excel worksheet. Microsoft Excel Solver operates on Generalized Reduced Gradient (GRG2) non-linear optimization code built by Leon Lasdon, University of Texas at Austin, and Allan Warren, Cleveland State University.

The stages involved are as follows:

Step 1: Problem Formulation / Problem Statement

The regression analysis began with the formulation of problem by detection of the influential variables on the gas z-factor. The formulation of problem involves identifying the dependable and independent parameters. Gas compressibility factor is a function of reservoir pressure, reservoir temperature, pseudo-reduced temperature, pseudo-reduced pressure, gas gravity and gas density. Defining the problem is the major and possibly the paramount step in regression analysis [19]. The general relationship for z-factor with its dependent variable is given in Equation 1;

$$Z\ Factor = f(P_r, T_r \gamma_g) + \varepsilon \tag{1}$$

where: Gas z-factor is response or independent variable, P_r, T_r, and γ_g are set of the influent or dependent variables and ε is the assumed random error indicating the differences in the approximation.

Step 2: Suggestion of Mathematical Equations

Many mathematical equations were suggested by the software so as to establish the right relationship between response variable and predictor variables.

Step 3: Filtration Process This stage involves using many statistical criteria (Mean relative error, Mean absolute error etc.) to select the optimum form of the correlation. Finally, after statistical analysis, mathematical and graphical checking was also done to produce the suitable correlation..

C. 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;

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

Subject to

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

with

$$0 \leq Sij \leq 1 \tag{4}$$

Where Si,j is the strength of the statistical parameter j of correlation i and qij, the statistical parameter j corresponding to correlation i. j = MRE, MAE, …. R1, where R1 = (1-R) and Zi is the rank, (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 MAE, 0.2 for R, 0.15 for SDA, 0.15 for SDR, and 0.1 for MRE. Finally, equation 4 was used for the ranking. The correlation with the lowest rank

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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 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 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}.

III. Results and Discussion

Gas compressibility factor model was developed using low - moderate - high pressure and temperature data. Equations 5 and 6 are the gas z- factor models developed in this research work using 645 data points and is a function of reduced pressure and reduced temperature. The new correlation is applicable at the interval of $1.02 \le Tr \le 2.2$ and $0.1 \le Pr \le 20$.

$$z = 0.4326 + 0.2775T_r + \alpha P_r \tag{5}$$

where:

$$\alpha = 0.04984 - 0.0377T_r + 0.002971P_r \tag{6}$$

After the development of the correlation, the empirical equation was assessed alongside with some published correlations to check their performance and the degree of accuracy in approximating gas z factor for the various gas reservoirs pressure temperature conditions. The published correlations evaluated are: ([7], [9], [8] [5]). The correlations were carefully selected having reported by [19] and [12] to be the best existing gas compressibility factor equation for Niger Delta region. Percent relative error (MRE), percent absolute error (MAE), standard deviation relative error (SRE), standard deviation absolute error (SAE), correlation coefficient (R) and Rank were used for the validation. The results of the assessment as presented in Fig. 1 gives the statistical accuracies for all the gas z factor models examined. From the Fig. 1, this study which is the model developed in this work ranked best with the numerical value of 2.449, MAE of 2.6785 and correlation coefficient (R) of 0.979, while (8) ranked second with a numerical value of 3.1209, MAE of 3.6905 and correlation coefficient of 0.9421 for the entire data set studied.

[8] equation has been reported by various authors to perform well in predicting compressibility factor of gas by applying low to intermediate data range ([12], 17]) [7] and [9] were two equation of state evaluated. [9] performed well than [7] but its computation involved iteration which is one of the limitation of using equation of state models. [8] correlation is recommended to be used in predicting gas compressibility factor at entire pressure and temperature conditions for the Niger Delta region.

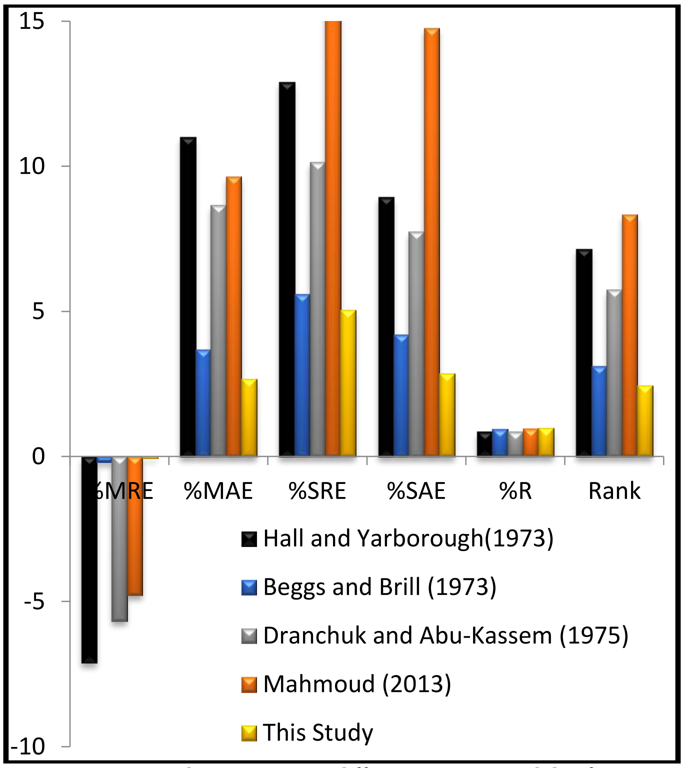

Fig. 1. Statistical Accuracy using different gas compressibility factor correlations

Figs. 2 to 5 illustrate cross plots of the new correlation and the best three performed evaluated correlations ([8], [9], [7]). A cross plot is a graph of predicted versus measured properties with a 45^{o} reference line to readily ascertain the correlation's fitness and accuracy. Compared to other cross plots, Fig. 4 shows the tightest cloud of points around the 45^{o} line with very good clusters at the low band, indicating the excellent agreement between the experimental and the calculated data values. Again, this indicates the superior performance of this model as compared to other empirical correlations evaluated.

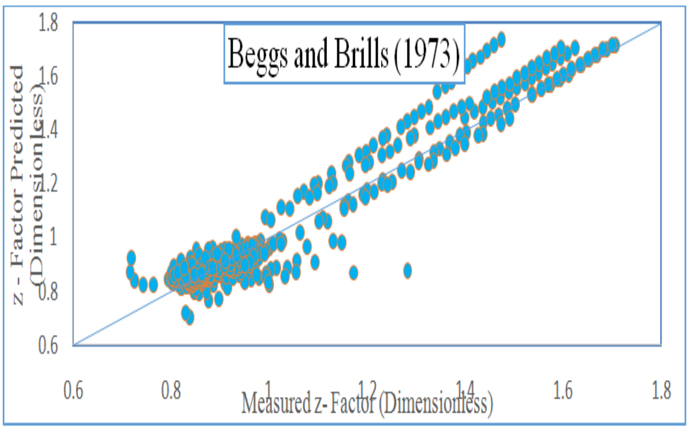

Fig. 2. Plot of predicted against Measured Compressibility Factor for Beggs and Brill (1973)

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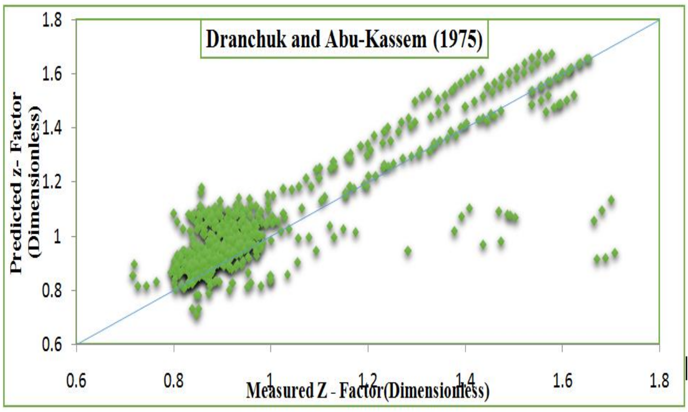

Fig. 3. Plot of Predicted against Measured Compressibility Factor for Dranchuk and Abu-kassem (1975)

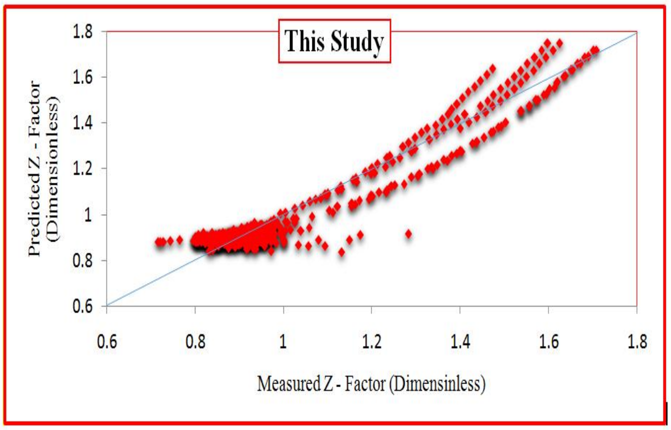

Fig. 4. Plot of Predicted against Measured Gas Compressibility Factor for this Study

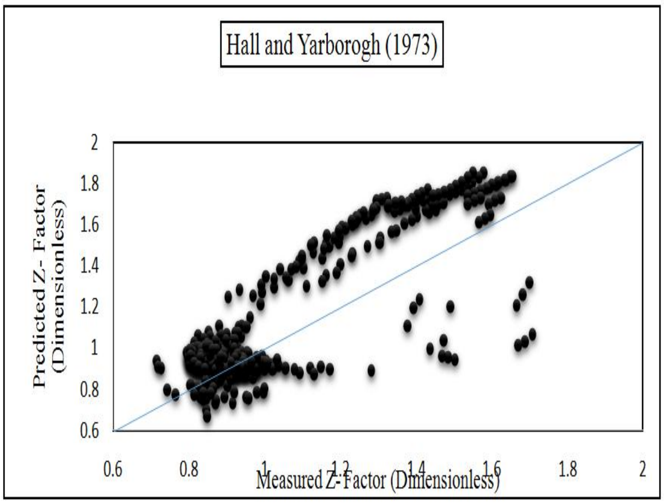

Fig. 5. Plot of predicted against measured compressibility factor for Hall and Yarbrough (1973).

IV. Z FACTOR CHART DEVELOPMENT

After the development of z-factor correlation using low-medium-high measured data from the Niger-Delta region of Nigeria, gas compressibility factor chart was developed using Excel Visual basic. Figs. 6a and 6b gave the z – factor chart developed in this study. A plot of z – factor against reduced pressure (P_r) at isothermal reduced temperature (T_r) yields a chart which mimic conventional Standing and Katz (1942) chart. The intervals of applicability of the proposed chart are $1.02 \le T_r \le 2.2$ and $0.1 \le P_r \le 20$. The chart developed in this research work take care of presence of non-hydrocarbon like CO_2 and N_2 and also extended the reduced pressure from fifteen (15) to twenty (20) where the [6] stopped.

The z - factor chart developed in this study was validated with Standing and Katz chart and measured data at T_r of 1.79 and P_r of 14.3 and also, at T_r of 1.7 and P_r of 19.0 respectively. Table 2 shows the validation results using mean absolute error. Standing and Katz chart gave a mean absolute error of 1.408% and the z –factor chart of this study gave 0.8% as to compare to the measured data. The result of the analysis at T_r of 1.7 and P_r of 19 as compared to the measured data gave percentage mean absolute error of 0.59, Standing and Katz was not considered for these values because , the authors stopped at the P_r of 15.

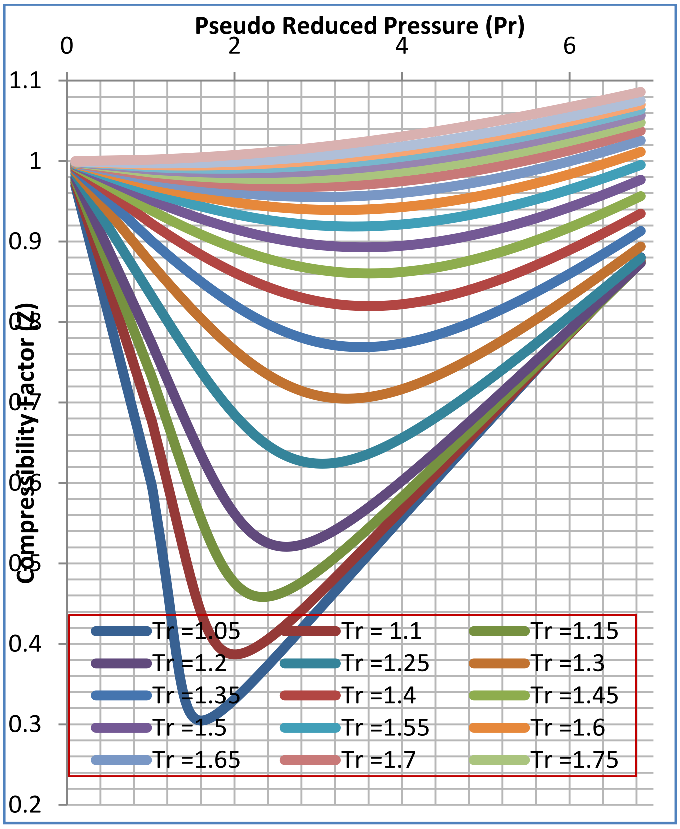

Fig. 6a. Z – Factor for this Study

TABLE 2. Shows the validation results using mean absolute error

	Z – Factor Experimental	Standing & Katz (1942)	This Study
$T_r = 1.79$ $P_r = 14.3$	1.42	1.4	1.408
%MAE	-	1.408	0.80
$T_r = 1.7$ $P_r = 19.0$	1.68	-	1.67
%MAE	-	-	0.59

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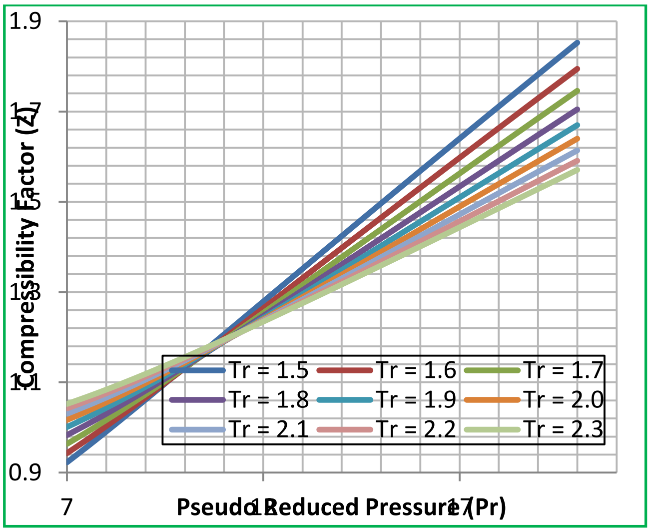

Fig. 6b. Z – Factor for this Study

V. Conclusion

The gas compressibility factor is an extremely important parameter in gas engineering. It is very important to determine the gas density, gas viscosity, and other reservoir fluid properties. New predictive tool was generated for computing gas z factor for low- moderate -high pressure high temperature conditions. The correlations of gas z- factor accessible in the literature are not having a sufficiently wide collection of applicability for the accommodation of higher conditions, and so their accuracy may not be reliable in predicting this parameter. The new model outperformed the other correlations by the statistical parameters used. It also shows the best rank of 2.4490 and better performance plot as compared to the existing empirical correlations.

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References

[1] O. M Anyiador,S. S. Ikiensikimama, and I. I Azubuike, Evaluation of Viscosity Correlation for Niger Delta Gas Reservoir, *International Journal of Science and Engineering Investigations*, Vol. 4, Issue 46.

[2] T. Ahmed, *reservoir engineering hand book* (Copyright, Elsevier Inc. Gulf Publishing, 30 Corporate Drive. Suite 400. Burlington, MA 01803, USA, 2006)

[3] J. A. Rushing, K. E. Newshan, S. A. Van Fraassen, Mehta, and G. R Moore. Natural Gas Z-Factors at HP/HT Conditions: Comparing Laboratory Measurements with Industry-Standard Correlations for a Dry Gas. *SPE-114518*.2008.

[4] K. Ling, E. C. Davani, Teodoriu, J. McCain and G. Falcone G. Measurement of Gas Viscosity at High Pressures and High Temperatures. *International Petroleum Technology Conference held in Doha, Qatar, IPTC 13528*, 2009.

[5] M. A. Mahmoud, Development of a new correlation of Gas Compressibility Factor for High Pressure Gas Reservoirs, SPE paper 164587 presented at the North Africa Technical Conference and Exhibition held in Cairo, Egypt.(2013):

[6] M. B Standing. And D. L. Katz. (): Density of Natural Gases, Trans. *AIME*, Vol. 146, pp. 140-149, 1942

[7] K. R Hall, and L. J. Yarborough. "A new equation-of-State for Z-factor Calculations" Oil and Gas Journal, 1973pp 82-9

[8] H. Beggs, andJ. Brill. Two-phase flow in Pipes, Tusla, OK; The University of Tusla.1973.

[9] Dranchuk, P. M. and Abu-Kassem, J. H. (1975): "Calculation of Z-factors for Natural Gases Using Equation-of-State", Journal of Canadian Petroleum Technology, pp 34-36

[10] A. K Lateef Explicit Half Range Fourier Series Expansion For Z factor, SPE Paper 167579 presented at Nigeria Annual International Conference and Exhibition held in Lagos, Nigeria, 2014.

[11] Fayazi, A., Arabioo, M. and Mohammadi, A. H. "Efficient Estimation of Natural Gas Compressibility Factor Using a Rigorous Method" Journal of Natural Gas Science and Engineering, vol. 16, pp. 8-17, 2014.

[12] Elechi V. U. Ikiensikimama S. S. and Azubuike, I. I. "A Correlation for estimating Gas Compressibility Factor in the Niger Delta", Festschrift for J. A. Ajienka, pp. 137-148. 2015.

[13] I. I. Azubuike, S. s. Ikiensikimama and O. D. Orodu, Predictive Tool for Gas Compressibility Factor at High Pressure High Temperature, Americacn Journal of Engineering Research Volume 8, Issue 2, pp. 149-157, 2019.

[14] L. Huang, W. Yiming, G. Ping, L. Zhiling and H. Zhaoting, Compressibility Factor Measurement and simulation of five high – temperature Ultra- High – pressure dry and wet gases. Elsevier, ScienceDirect, Volume 500, 112256. 2019.

[15] Yarborough, L. and Hall, K. R. (1974): "How to Solve Equation-of-State for Z-factors", Oil and Gas Journal, pp 86-88.

[16] Sutton, R. P. "Fundamental PVT Calculations for associated and Gas/Condensate Natural Gas System," Paper SPE 97099 presented at the 2005 SPE Annual Technical Conference and Exhibition held in Dallas, Texas, USA,2005.

[17] Olajide, O. F. and Ikiensikimama, S. S., "Evaluation of Compressibility Factor Correlations for Niger Delta Gas Reservoirs". Paper SPE 136967, presented at the 34th Annual SPE International Conference and Exhibition, 2010.

[18] Mounagor, C. M. and Ikiensikimama, S. S., "Compressibility Factor Correlation for the Niger Delta Gas". SPE-184287, 2016.

[19] Azubuike, I. I., Ikiensikimama, S. S. and Orodu, O. D. Natural Gas Compressibility Factor Measurement and evaluation for high pressure high temperature gas reservoirs international journal of scientific & engineering research, volume 7, issue 7. July-2016.

[20] H. M. Sidrouhou, M. Korichi and S. Dada, Evaluation of correlation of compressibility factor of natural gas for Algerian Gas Reservior, ScienceDirect, Energy Procedia 157, 655-669. 2018.

[21] T. Zeeshan, W. Yiming, G. Ping, L. Zhiling and A. Abdul ,An Intelligent Data- Driven Framework to Develop New Correlation to predict gas deviations factor for high – temperatuire and high pressure gas Reservoirs using Artificial Neural Network, SPE Middle East Oil and Gas Show and Conference DOI: 10. 2118/194715. MS.

[22] Dranchuk, P. M., Purvis, R. A. and Robinson, D. B. "Computer Calculations of Natural Gas compressibility factors Using the Standing and Katz Correction", Inst. of Petroleum Technical Series, No. IP 74-008, 1974.

[23] Ikensikimama, S. S. "Reservoir Fluid Property Correlations" Advances in Petroleum Engineering, Chi Ikoku Petroleum Engineering Series, IPS Publications, Port Harcourt, 2009.