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ORIGINAL RESEARCH ARTICLE

PREDICTION OF NATURAL GAS COMPRESSIBILITY FACTOR IN A SINGLE-PHASE GAS RESERVOIR: A COMPARATIVE STUDY

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ABSTRACT

Natural gas compressibility factor plays important roles in pipeline design, reserve estimation and gas metering. The aim of this study is to presents the most accurate and reliable method of computing gas compressibility factor in a single-phase gas reservoir at various reservoir pressures. In this study, the gas compositions and the specific gravity of the respective gas compounds were retrieved from literatures. This specific gravity determine the pseudo critical and the pseudo reduced properties (temperature and pressure) of the respective gas compounds being studied. The predicted methods studied are Papay correlation, Hall-Yarborough equation of state (EOS), viral EOS, Beggs and Brill and Dranchuk-Abu-Kassem correlation. The methods are expressed as functions of the pseudo-reduced temperature and pressure, thereby predicting the compressibility factor of the predicted methods. The accuracy and the performance of the methods were tested by comparing the results obtained from the methods studied with experimental z-factor values obtained from the literatures. The experimental z-factor values were set as standard for the predicted methods studied. Six (6) statistical parameters and various charts (line and column charts) were used to attest the effectiveness and the precision of the methods. The statistical tools are average absolute error (AAE), average absolute relative error (AARE), root mean square error (RMSE), residual sum of square (RSS), mean square error (MSE) and coefficient of determination (R^2). The results of the study shows that, the Papay correlation has the highest coefficient of regression, R^2 = 92%, rated as the most accurate, reliable and best method. The Hall-Yarborough equation of state has R^2 of 86%. The Viral equation of state has R^2 of 83%. The Beggs and Brill correlation has R^2 of 42%. The Dranchuk-Abu-Kassem correlation has R^2 of 10.5%. The Beggs and Brills correlation method is not suitable for application, if the pseudo-reduced pressure is less than 0.92. The Dranchuk-Abu-Kassem correlation is only applicable, if the pseudo-reduced properties are within the range of $0.2<P_{pr}<15$, $1.0<T_{pr}<3.0$. The Hall-Yarborough equation of state cannot be used if the pseudo-reduced temperature is less than one.

1.0 Introduction

Natural gas plays an important role in the global energy resources transition to a cleaner, affordable, and safer energy utilization (world energy resource, 2016). This causes the gas demand to increase globally by 1.7% to 3468.6bcm (billion cubic meter) in 2015 which was an improvement over the 2014 consumption rates. The consumption rate decreased significantly in the last decade, 2.3% average observed from 2005 to 2015 (BP Statistical Review of World Energy, 2017). Natural gas is widely used as sources of energy in power sector, transportation sector, building and industry. These sectors largely increased the consumption of natural gas by 87.3% from the 3507bcm (billion cubic meter) global consumption rate (BP Statistical Review of World Energy, 2016). The power sector is the highest consumer of the energy resources which is responsible for the continued increase in demand for natural gas (BP Statistical Review of World Energy, 2016). In 2013, the power sector represents 40.3% (1414 billion cubic meter) of the total utilization of the gas (BP Statistical Review of World Energy, 2016). Natural gas is the essential component of energy that powered the world and is the most important of all sources of energy, (Speight, 2007). Natural gas is environmental friendly compared to other fossil fuels (Speight, 2007). It availability, affordability and environmental friendly makes the world energy demand to shift natural gas.

Nigeria is renowned for its vast gas reserve which was estimated to be 202 trillion cubic feet (5.475 trillion cubic meter) of proved gas reserved in 2019, ranking 1st and 8th position in the Africa and the world respectively. The production of natural gas in Nigeria increases from about 6bcfpd (billion cubic feet per day) in 2012 to about 10bcfpd (billion cubic feet per day) (Avuru, 2013). In 2019, the production increased to 44.48bcm (billion cubic meter). The domestic consumption of gas rises from 1bcf/d (billion cubic feet per day) in 2012 to 3bcf/d (billion cubic feet per day) in 2020 with power sector being the largest consumer of the energy resources (Avuru, 2013). Nigeria is the largest exporters of natural gas via liquefied natural gas (LNG) in the world (World Energy Resources, 2016). However, the production of natural gas in Nigeria is low compared to its vast natural gas proved reserve. If this abundant gas resources could be harnessed for some years in Nigeria just as crude oil exploitation, it will go a long in diversifying Nigeria's economy by increasing its source of revenue to 15bilions US dollars (Obuba et al., 2013).

Natural gas compressibility factor is essential for the determination of gas physical properties such as gas density, viscosity, gas formation volume factor, gas expansion factor, and specific gravity of gas. These properties are necessary for the analyses and design of natural gas production and processing system (Guo and Ghalambor, 2012). Hence, the need natural gas compressibility factor become imperative in the exploitation of natural gas reserves.

Compressibility factor account for the deviation of real gas from ideal gas law (Ahmed, 2001). At low pressure most gases behave as an ideal. The gas tends to compress more than ideal at moderate pressure for temperature close to its critical values. However, the gas tends to compress less than the ideal gas at high pressure (Ikoku, 1992). To correct for the deviation of the gases from ideal behavior, a correction factor called the gas deviation factor is incorporated to the ideal gas law (Equation 1) and shown in Equation 2 (Ahmed, 2001).

$$PV=nRT \text{ (Ideal gas law)} \quad (1)$$

$$PV=ZnRT \text{ (Real gas law)} \quad (2)$$

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Where: Z is compressibility factor is defined as the ratio of the actual volume of n-moles of gas at T and P to the ideal volume of n-moles at the same temperature and pressure and is a dimensionless parameter, (Mohammed et al., 2016).

$$Z = \frac{V_{actual}}{V_{ideal}} \quad (3)$$

Compressibility factor plays a vital role in the oil and gas industry for the estimation of gas reserve, predict future gas production, gas metering, design of gas pipeline and production turbine (Elsharkawy and Elkamel, 2001).

Sources of the compressibility factor are experimental method, Z- factor correlation of standing and katz chart, empirical correlations (direct calculation of compressibility factor) and the corresponding state principle.

1.1 Experimentation

Experimental technique is one of the most accurate and reliable methods of predicting the compressibility factor of natural gas. This method is too expensive and is time consuming in estimating the gas compressibility factor (Ikoku, 1992). Also, the PVT data are not always available. Therefore, it is difficult to measure the compressibility factor experimentally for all composition of gas at any temperature and pressure (Obuba et al., 2013).

1.2 Z-factor Correlation of Standing and Katz Chart

This is one of the most widely used correlation method that is accepted in the oil and gas industry (Ikoku, 1992). It involves the use of chart in estimating the z-factor value. In order to make effective use of the chart, the knowledge of pseudo-critical pressure and temperature, gas specific gravity or gas composition is necessary to determine the pseudo-reduced temperature and pressure. These pseudo-reduced properties determined the compressibility factor in the chart (Ikoku, 1992). This method is widely and suitably used for computing the compressibility factor of sweet natural gas with small amount of impurities (CO_2 or H_2S) and/or natural gas which has been corrected. However, when there is significant amount of impurities in the natural gas system, the standing and Katz chart is not recommended because it will not give accurate predictions of the z-factor values.

1.3 Direct Calculation of Z-factors (empirical correlations methods)

Since the standing and Katz chart was developed based on the natural gas system that has small amount of impurities. The advent of computer calls for the demand to search for a convenient method of predicting the gas compressibility factor rather than feeding in the entire chart from which the Z-factor value can be obtained from the lookup in the table (Ikoku, 1992). These include: Hall- Yarborough EOS, Dranchuk-Abu-Kassem, Dranchuk-Purvis-Robinson.

1.3.1 Hall-Yarborough equation of state

This equation is developed based on the Sterling-Carnahan equation of state (Ahmed, 2001). Unlike the standing and Katz chart this method predicts the compressibility factor of natural irrespective of the amount of impurities in the gas composition, (Mohammed et al., 2016). However, the method cannot be used if the pseudo reduce temperature is less than one.

1.3.2 Dranchuk-Abu-Kassem correlation method

This method uses eleven constant variable which generate the analytical expression. This expression is used to determine the reduced density was developed and expressed in terms of the pseudo reduced temperature and pressure. Hence, it determined the compressibility factor of the natural gas (Ahmed, 2001). This correlation method is applicable within the range of $0.2<P_{pr}<15$, $1.0<T_{pr}<3.0$.

1.3.3 Dranchuk-Purvis-Robinson correlation method

This method is a modification of the Dranchuk-Abu-Kassem correlation methods. The correlation was developed based on the Benedict-Webb-Rubin equation of state and it uses seven constant variables (Ahmed, 2001). The correlation method is applicable within the range of $0.2<P_{pr}<3.0$, $1.05<T_{pr}<3.0$.

1.3.4 Begg and Brill (BB)

This is an explicit equation of state expressed as functions of the pseudo-reduced temperature and pressure which predict the compressibility factor of natural gas (Begg, 1973). The method is not suitable for used if the pseudo-reduced pressure is less than 0.92.

1.3.5 Papay correlation method

Papay proposed a simplify expression of compressibility factor as functions of pseudo-reduced temperature and pressure. This method is more accurate and reliable for predicting the gas compressibility factor (Baghmolaei et al., 2015).

1.4 Corresponding State Principle

This is a powerful correlation tool, it state that the physical and thermodynamic properties such as viscosity, density and vapor pressure which depend on the intermolecular forces are related to the critical properties in a universal way. The disadvantage of this concept is that it is valid partially for real fluid only (Campbell, 1992).

1.5 Third Parameter Equation of State

The thermodynamic and physical properties can be expressed as functions of their reduced properties according to the corresponding state principle

$$\text{Property} = f(Pr, Tr) \quad (4)$$

The above concept is not valid entirely. Therefore, in order to improve the accuracy and validity of the equation of state, a third parameter called the pitzer may be included to the above corresponding state principle.

$$\text{Property} = f(Pr, Tr, \text{pitzer}) \quad (5)$$

The pitzer is capale of characterizing the behavior of fluid (Campbell, 1992). For non-polar or slightly polar gases, the pitzer correlation provides a reliable result of Z- factor. The simplest form of the third parameter equation of state is the viral equation of state. The equation of state is valid for low to moderate pressures.

Determination of the gas composition through measurement is very important because complex mixtures of hydrocarbon which contained small amount of inorganic compound form the constituent of the natural gas (Guo and Ghalambor, 2012). Knowing the gas composition will make it possible to determine the gas properties using the correlations (Guo and Ghalambor, 2012).

Correlation method of predicting the gas compressibility factors are much easier and faster than the equation of state. This study intend to carry out a comparative study on various methods of predicting gas compressibility factor, thereafter evaluate the best method in terms of accuracy and reliability in the prediction of the compressibility factor.

2. Materials and Methods

Seven (7) compositions of natural gas in the reservoir under study were retrieved from the literatures for the analysis. The specific gravity of the respective gas composition was used to compute the gas pseudo-critical properties such as pseudo critical temperature and the pseudo-critical pressure according to Equations 6 and 7.

$$T_{pc}=168 +325\gamma g-12.5\ \gamma^2 g \qquad (6)$$

$$P_{pc}=677-15.0\gamma g-37.5\ \gamma^2 g \qquad (7)$$

Where: γ_g = specific gravity of the gas.

The pseudo-reduced temperature and the pseudo-reduced pressure as functions of the pseudo- critical temperature and pressure were calculated using Equations 8 and 9.

$$T_{pr}=\frac{T}{T_{pc}} \qquad (8)$$

$$P_{pr}=\frac{P}{P_{pc}} \qquad (9)$$

Where: T and P are reservoir temperature (°C, K) and pressure (Pa, bar) expressed in S. I unit respectively. For a single phase reservoir, the temperature, T =149.072°C (422.222K) and the reservoir pressures are 25.511*10^6 Pa (255.11 bar), 23.442*10^6 Pa (234.42 bar), 21.374*10^6 Pa (213.74 bar) and 19.305*10^6 Pa (193.05 bar). The predicted methods under this study are expressed as functions of the pseudo-reduced temperature and pseudo-reduced pressure (T_{pr}, and P_{pr}) as shown in equation 8 and 9 above. The prediction methods considered in this study are Papay correlation, Hall-Yarborough EOS, Viral EOS, Beggs and Brill correlation and the Dranchuk-Abu-Kassem correlation method.

2.1 Papay correlation method

Papay proposed Z-factor expression as a function of the pseudo-reduced temperature and pressure as shown in Equation 10.

$$Z = 1-\left[\frac{3.53P_{pr}}{10^{0.9813T_{pr}}}\right]+\left[\frac{0.274{P^2}_{pr}}{10^{0.815T_{pr}}}\right] \qquad (10)$$

Substituting the values of T_{pr}, and P_{pr} Equations 8 and 9 into Equation 10 gives the values of Z-factors of the gas compositions studied.

2.2 Hall- Yarborough Equation of State

The generalized form of the Hall-Yarborough equation of state is expressed as functions of the pseudo-reduced temperature and pseudo-reduced pressure as shown in Equation 11.

$$Z=\left[\frac{0.06125P_{pr}t}{Y}\right]\mathrm{EXP}\left[-1.2(1-t)^2\right] \qquad (11)$$

Where: Ppr = pseudo-reduced pressure.

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t= reciprocal of the pseudo-reduced temperature= $\left[\frac{T_{pc}}{T}\right]$ and Y = reduced density terms and is expressed as:

$$F(Y) = -0.06125Ppr\ te\text{-}1.2(1\text{-}t)\ 2 + \frac{Y + Y^2 + Y^3 - Y^4}{(1-Y)^3} - (14.76t - 9.76t^2 + 4.58t^3)Y^2 - (90.7t\text{-}242.2t^2 + 42.2t^3)Y^{(2.18+2.82t)} = 0 \quad (12)$$

This can also be written as

$$F(Y) = X1 + \frac{Y + Y^2 + Y^3 - Y^4}{(1-Y)^3} - (X2)Y2 - (X3)Y^{(X4)} = 0 \quad (13)$$

Where:

$X_1 = -0.6125Pprtexp[-1.2(1-t)^2]$ (13a)

$X_2 = (14.76t-9.76t^2+4.58t^3)$ (13b)

$X_3 = (90.7t-242.2t^2+42.4t^3)$ (13c)

$X_4 = (2.18+2.82t).$ (13d)

The values of P_{pr} obtained in Equation 9 and the reciprocal of the T_{pr}, in Equation 8 were substituted in Equations 13a-13d to give the values of X_1, X_2, X_3, and X_4. The calculated values of X_1, X_2, X_3, and X_4 were substituted into Equation 13. The unknown parameter (Y), is the reduced density term which is computed using Newton Raphson iteration approach in Microsoft excel software. Initial guess value of Y is made until the function f(Y) in equation 13 converges to zero and the corresponding value of Y at which the convergence occur is the accurate value of the reduced density (Y). This value is substituted into Equation 11 to give the values of the compressibility factor of the various gas compositions.

This correlation method has high degree of confidence level with little error low encountered in this study.

2.3 Viral Equation of State

The generalized expression of viral coefficient correlation is as shown in Equation 14, below.

$$Z = 1 + \frac{BP}{RT} + \left[\frac{BP_C}{RT_C}\right]\left[\frac{P_r}{T_r}\right] \quad (14)$$

$$\frac{BP_C}{RT_C} = B^o + BI\omega \quad (15)$$

Where: $B_o = 0.083 - \frac{0.422}{T^{1.6}{}_r}$ and $BI = 0.139 - \frac{0.172}{T^{4.2}{}_r}$

The Z-factor can further be expressed as:

$$Z = 1 + B^O \frac{P_r}{T_r} + \omega B^I \frac{P_r}{T_r} \quad (16)$$

Substituting the values of ω, B^o, B^I into Equation 16, gives the values of the Z- factors of the gas compositions.

This correlation method has moderately high degree of confidence level with little error encountered in this study.

2.4 Beggs and Brill Correlation

This correlation expressed the Z-factor in terms of the pseudo-reduced and temperature and pressure as shown below.

$$Z = A + (I- A) \text{Exp}(-B) + CP^{D}_{pr} \quad (17)$$

Where: A = 1.39(Tpr-0.92)0.5 – 0.36Tpr-0.101

$$B = (0.62- 0.23T_{pr})P_{pr} + \left(\frac{0.066}{T_{pr-0.86}} - 0.037\right) P^{2}_{pr} + \left(\frac{0.32}{10^{9(T_{pr}-1)}}\right) P^{6}_{pr}$$

$$C = 0.132- 0.32\log(T_{pr})$$

$$D = 10^{(0.3106-0.49T_{pr} + 0.182T^{2}_{pr})}$$

Substituting the values of A, B. C and D into Equation 17 gives the values of the Z-factor of the respective gas compositions. The correlation method has fairly low degree of confidence level and moderately high error encountered in this study.

2.5 Dranchuk-Abu-Kassem Correlation Method

This correlation presents an analytical expression for calculating the reduced density terms as shown below.

$$f(\rho r) = (R_1)\rho r - \frac{R_2}{\rho_r} + (R_3)\rho r_2 - (R4)\rho r_5 + (R_5)(1 + A_{11}\rho r2)\text{Exp}[-A_{11}\rho r_2] + 1 = 0 \quad (18)$$

Where: R_I, R_2, R_3, R_4 and R_5 are expressed in terms of the pseudo-reduced temperature and pressure as below.

$$R_1 = \left[A_1 + \frac{A_2}{T_{pr}} + \frac{A_3}{T^3_{pr}} + \frac{A_r}{T^4_{pr}} + \frac{A_t}{T^5_{pr}}\right] \quad (18a)$$

$$R_2 = \left[\frac{0.27P_{pr}}{T_{pr}}\right] \quad (18b)$$

$$R_3 = \left[A_6 + \frac{A_7}{T_{pr}} + \frac{A_8}{T^2_{pr}}\right] \quad (18c)$$

$$R_4 = A_9\left[\frac{A_7}{T_{pr}} + \frac{A_8}{T^2_{pr}}\right] \quad (18d)$$

$$R_5 = \left[\frac{A_{10}}{T^3_{pr}}\right] \quad (18e)$$

The constant are

A_1 = 0.3262 A_2 = -1.0700 A_3 = -0.5339 A_4 = 0.01569 A_5 = -0.05165 A_6 = 0.5475

A_7 = -0.7361 A_8 = 0.1884A9 = 0.1056 A_{10} = 0.6134 A_{11} = 0.7210 (Ahmed, 2001).

The values of R_1 to R_5 were obtained by substituting the constant terms, A_1 to A_{11} and the values of the pseudo-reduced temperature and pressure into Equations 18a-18e. The calculated values of R_1 to R_5 and the values of A_{11} were substituted into Equation 18. The reduced density (ρr) term is the unknown variable which is computed using Newton Raphson iteration in Microsoft excel environment. A value of (ρr) is guess until the function f(ρr) converges to zero. The value of ρr at which the function f(ρr) converges, is its right value. This value is substituted into Equation 14 to give the values of the compressibility factor of the various gas compositions.

$$Z = \left[\frac{0.27P_{pr}}{\rho_r T_{pr}}\right] \quad (19).$$

This correlation method has low degree of confidence level and significant errors were encountered.

In this study, six (6) statistical tools were used to evaluate the effectiveness and the accuracy of the predicted methods. The tools are average absolute error (AAE), average absolute relative error (AARE), root mean square error (RMSE), residual sum of square (RSS), mean square error (MSE) and coefficient of determination (R-square). Low values of AAE (%), AARE (%), RMSE, RSS, and MSE give high coefficient of determination (R-square). This implies better agreement between the predicted methods and the experimental methods which entails the best method.

3. Results and Discussion

Tables 1 to 4 present the results obtained from the methods studied at a reservoir temperature of 149.072°C (422.222°K) and reservoir pressures of 25.511 $\times 10^6$ Pa (255.11 bar), 23.442 $\times 10^6$ Pa (234.42 bar), 21.374 $\times 10^6$ Pa (213.74 bar) and 19.305 $\times 10^6$ Pa (193.05 bar). The methods are Papay (PP) correlation, Hall-Yarborough (HY) equation of state, viral equation of state, Beggs and Brill (BB), and Dranchuk-Abu-Kassem correlations (DA) method. The accuracy and performances of the methods could be ascertained by comparing the results obtained from the methods with experimental compressibility factor values. Because, the experimental z- factor prediction method is very accurate and reliable method. Therefore, it was set as standard or reference for validating the accuracy and performances of the compressibility factor prediction methods studied in this work.

The Tables clearly show the effect of molecular weight of the gases compositions on the pseudo-reduced properties (temperature and pressure). For hydrocarbon gases such as nC_1-nC_4, the molecular weight of the gases compound increases as the pseudo- reduced pressure increases but the pseudo- reduced temperature decreases. This causes the compressibility factor values to shift close to the standard leading to better agreement between the predicted method studied and the standard method. This is also the same for non-hydrocarbon gases such as nitrogen gas (N_2) and carbon monoxide gas (CO). However, for non-hydrocarbon gases, the compressibility factor values are highly deviated from the standard method leading to inadequate agreement between the predicted method studied and the standard method. This is because, the pseudo-reduced properties are expressed as are functions of reservoir pressures and temperatures and the z-factor methods studied are also expressed as functions of the pseudo-reduced properties. These properties along with the reservoir conditions have effect on the compressibility factor.

Furthermore, reservoir conditions such as temperature, pressure and compositions are the main factors responsible for the deviation of gases from ideal condition to real. At low temperature and pressure, all gases behave as ideal obeying the ideal gas laws. However, as the temperature and pressure increases, gases intend to deviate from ideal behavior to real. This is clearly shown in Tables 1- 4, where at a high reservoir pressure of 25.511 $\times$ 10^6 Pa (255.11 bar), the compressibility factor values obtained from the methods studied deviated highly from the standard method leading to inaccurate prediction of deficiency z-factor. Hence, significant error and least coefficient of determination occurred in the methods. While at a low reservoir pressure of 19.305 $\times 10^6$ Pa (193.05 bar), the z-factor values of the methods studied showed a slight deviation from the standard method. Therefore, least error and high coefficient of determination occurred leading better prediction of z-factor values.

3.1 Statistical analysis

Tables 5 to 8 show the results of six different statistical parameters which were used to evaluate the effectiveness and the accuracy of the various methods studied in this work. The Tables clearly show that Papay correlation has the highest coefficient of regression (R-square) and the least values errors such as of AAE (%), AARE (%), RMSE, RSS, and MSE. Hence, it is the most accurate method in this work. The accuracy of the methods are arranged in descending order of magnitude ranging from the best performed to the least performed methods, these includes

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Papay correlations, Hall-Yarborough EOS, Viral EOS, Begg and Brill and Dranchuk-Abu-Kassem method correlation. The Dranchuk-Abu-Kassem method correlation is the least performed correlation because it has the least coefficient of regression (R-square) and the highest values of errors such as AAE (%), AARE (%), RMSE, RSS, and MSE in this work. The summary of the performance of the methods studied is shown in Table 9.

3.2 Graphical analysis

Figures 1 to 2 present the line and column chart which show the comparison of the various methods with the experimental values of Z-factor. It can be seen from the Figures that the values of Z-factor predicted by Papay correlation agreed closely to the standard method (experimental method). This is because it has the highest coefficient of regression and the least values of error. This is preceded in descending by the following methods such as Hall-Yarborough, Viral, and Beggs and Brill, and Dranchuk-Abu-Kassem methods in descending order of nearness of predicted values to that of the experimental method. The Dranchuk-Abu-Kassem methods is highly deviated from the standard method because it has the least coefficient of regression and the significant error is encountered in the method.

Figures 3 to 6 show the pictorial representation of the statistical analysis which present the errors encountered in the prediction methods studied.

Table 1: Comparison of experimental and predicted Z-factor methods at 149.072oC and 25.511 $\times$ 10^6 Pa (255.11 bar).

Gas comp	M wt	Tpr	P_{pr}	Z-Exp.	Z-PP	Z-HY	Z-viral	Z-BB	Z-DA
C_1	16.043	2.875	5.456	1.002	1.008	1.053	1.012	0.064	1.197
C_2	30.07	2.693	5.460	0.769	1.008	1.044	1.020	0.835	1.211
C_3	44.097	2.306	5.481	0.785	1.003	1.018	0.982	1.010	1.243
iC_4	58.124	2.190	5.492	0.898	0.998	1.003	0.968	0.992	1.254
nC_4	58.124	2.150	5.497	0.872	0.995	1.004	0.962	0.983	1.258
N_2	28.016	1.797	5.565	1.107	0.952	0.946	0.760	0.895	1.298
CO	44.01	1.786	5.568	1.109	0.949	0.946	0.842	0.892	1.300

Table 2: Comparison of experimental and predicted Z-factor methods at 149.072°C and 23.442 $\times 10^6$ Pa (234.42 bar)

Gas comp.	M wt	T_{pr}	P_{pr}	Z-Exp.	Z-PP	Z-HY	Z-Viral	Z-BB	Z-DA
C_1	16.043	2.875	5.013	1.001	1.004	1.046	1.011	0.248	1.182
C_2	30.07	2.693	5.017	0.776	1.004	1.038	1.018	0.861	1.194
C_3	44.097	2.306	5.036	0.786	0.994	1.010	0.984	1.004	1.225
iC_4	58.124	2.190	5.047	0.899	0.988	0.997	0.970	0.985	1.236
nC_4	58.124	2.150	5.051	0.883	0.985	0.993	0.966	0.977	1.240
N_2	28.016	1.797	5.114	1.104	0.934	0.932	0.779	0.886	1.280
CO	44.01	1.786	5.117	1.106	0.931	0.930	0.855	0.883	1.281

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Table 3: Comparison of experimental and predicted Z-factor at 149.072°C and 21.374 $\times 10^6$ Pa (213.74 bar)

Gas comp.	M wt	T_{pr}	P_{pr}	Z-Exp.	Z-PP	Z-HY	Z-Viral	Z-BB	Z-DA
C_1	16.043	2.875	4.571	0.9990	1.0015	1.0376	1.0104	0.4077	1.166
C_2	30.07	2.693	4.575	0.7830	0.9997	1.0297	1.0168	0.8841	1.178
C_3	44.097	2.306	4.592	0.7890	0.9875	1.0015	0.9851	0.9980	1.207
iC_4	58.124	2.190	4.601	0.9030	0.9797	0.9886	0.9731	0.9804	1.218
nC_4	58.124	2.150	4.605	0.8890	0.9762	0.9834	0.9686	0.9723	1.222
N_2	28.016	1.797	4.662	1.0870	0.9201	0.9191	0.7988	0.8794	1.262
CO	44.01	1.786	4.665	1.0930	0.9172	0.9165	0.8674	0.8760	1.263

Table 4: Comparison of experimental and predicted Z-factor at 149.072°C and 19.305 $\times 10^6$ Pa (193.05 bar).

Gas comp	M wt	T_{pr}	P_{pr}	Z-Exp.	Z-PP	Z-HY	Z-viral	Z-BB	Z-DA
C_1	16.043	2.875	4.129	1.0004	0.999	1.030	1.009	0.546	1.151
C_2	30.07	2.693	4.132	0.8230	0.997	1.022	1.015	0.905	1.161
C_3	44.097	2.306	4.148	0.8510	0.982	0.994	0.987	0.993	1.190
iC_4	58.124	2.190	4.156	0.9400	0.973	0.981	0.976	0.977	1.200
nC_4	58.124	2.150	4.160	0.9250	0.970	0.976	0.972	0.969	1.204
N_2	28.016	1.797	4.211	1.0700	0.910	0.910	0.818	0.876	1.244
CO	44.01	1.786	4.214	1.0900	0.907	0.907	0.880	0.873	1.245

Table 5: Error analysis of the predicted methods at 25.511 $\times 10^6$ Pa (255.11 bar)

EOS/correlations	AAE (%)	AARE (%)	RMSE	RSS	MSE	R-Sq.
Hall-Yarborough	16.004	18.091	0.175	0.214	0.031	0.810
Papay	14.291	16.150	0.160	0.179	0.026	0.869
Viral	16.004	18.916	0.209	0.307	0.044	0.800
Beggs and Brill	26.601	27.527	0.387	1.047	0.150	0.253
Dranchuk-Abu-k	31.715	36.252	0.336	0.792	0.113	0.100

Table 6: Error analysis of the predicted methods at 23.442 $\times 10^6$ Pa (234.42 bar)

EOS/correlations	AAE (%)	AARE (%)	RMSE	RSS	MSE	R-Sq.
Hall-Yarborough	15.536	17.847	0.170	0.203	0.029	0.830
Papay	13.922	15.997	0.157	0.173	0.025	0.899
Viral	16.864	18.573	0.199	0.278	0.040	0.828
Beggs and Brill	23.966	25.318	0.324	0.736	0.105	0.328
Dranchuk-Abu-k	29.738	34.299	0.317	0.702	0.100	0.105

Table 7: Error analysis of the predicted methods at 21.374 $\times 10^6$ Pa (213.74 bar)

EOS/correlations	AAE (%)	AARE (%)	RMSE	RSS	MSE	R-Sq.
Hall-Yarborough	14.603	14.688	0.162	0.183	0.026	0.837
Papay	13.203	16.285	0.151	0.159	0.023	0.910
Viral	15.781	17.102	0.185	0.238	0.034	0.830
Beggs and Brill	21.238	22.211	0.269	0.507	0.072	0.419
Dranchuk-Abu-k	28.171	32.003	0.299	0.628	0.090	0.102

Table 8: Error analysis of the predicted methods at 19.305 $\times 10^6$ Pa (193.05 bar)

EOS/correlations	AAE (%)	AARE (%)	RMSE	RSS	MSE	R-Sq.
Hall-Yarborough	11.543	12.243	0.133	0.125	0.018	0.866
Papay	10.382	10.959	0.125	0.109	0.016	0.917
Viral	12.577	13.111	0.154	0.166	0.024	0.803
Beggs and Brill	16.727	16.981	0.214	0.322	0.046	0.418
Dranchuk-Abu-k	24.218	26.319	0.254	0.452	0.065	0.073

Table 9: Summary of the assessments of the predicted methods at various pressures studied

Predicted methods	25.511$\times 10^6$ Pa (255.11 bar)	23.442$\times 10^6$ Pa (234.42 bar)	21.374$\times 10^6$ Pa (213.74 bar)	19.305$\times 10^6$ Pa (193.05 bar).	Average
Hall-Yarborough	2	2	2	2	2
Papay	1	1	1	1	1
Viral	3	3	3	3	3
Beggs and Brill	4	4	4	4	4
Dranchuk-Abu-k	5	5	5	5	5

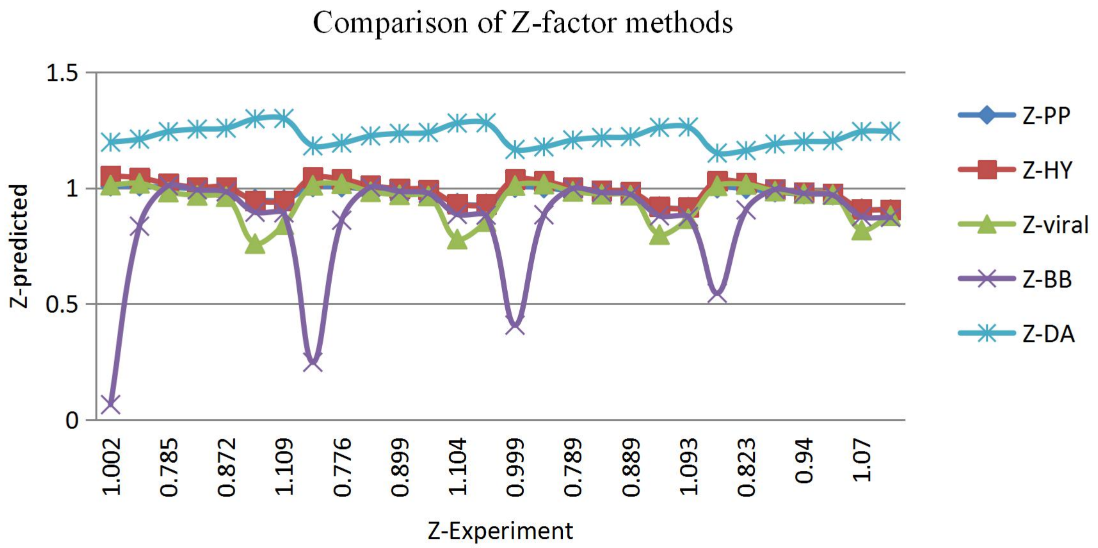

Figure 1: Comparison of the predicted method and the experimental method

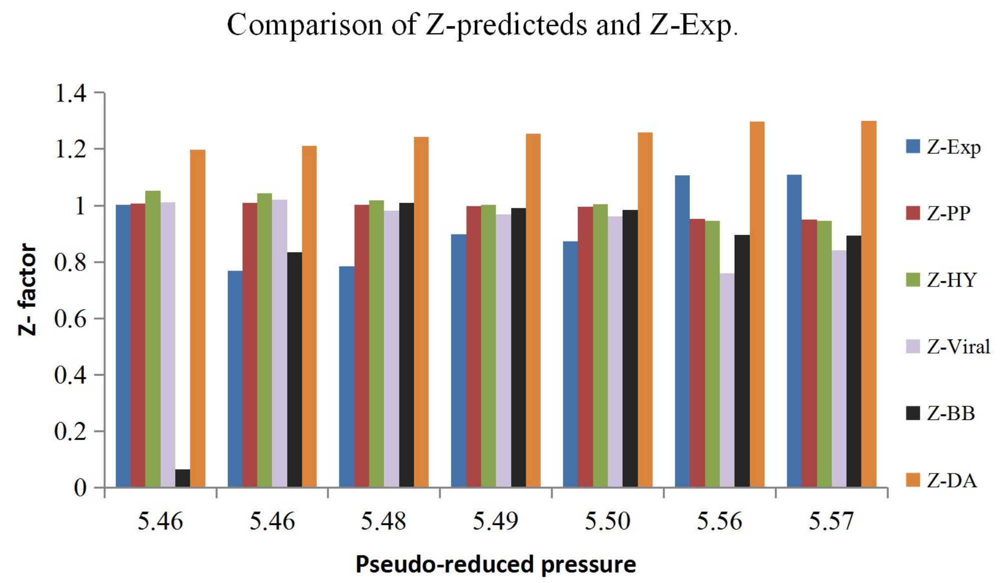

Figure 2: Comparison of predicted method with experimental method

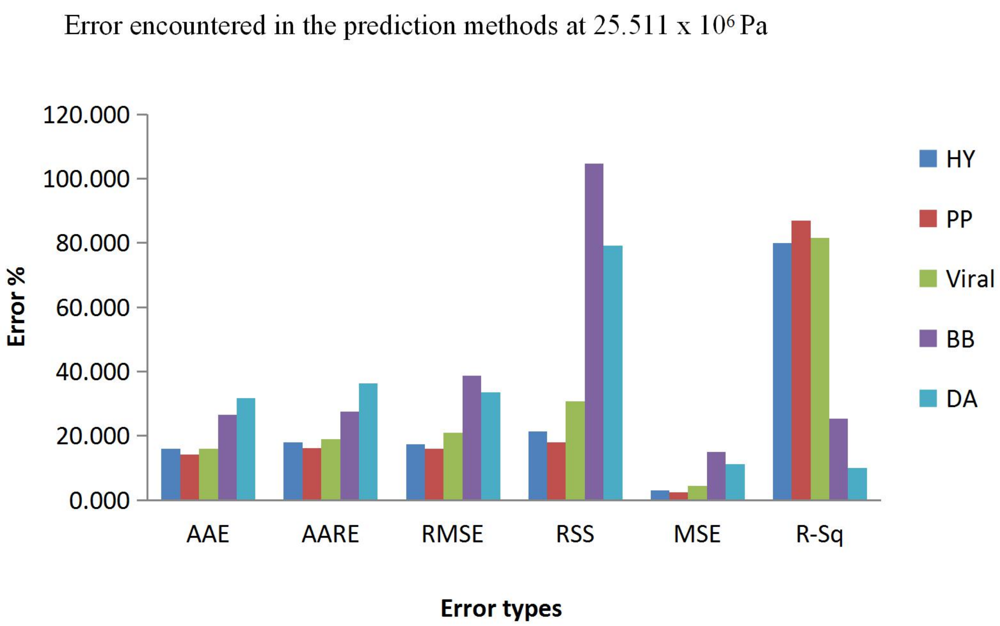

Figure 3: Summary of error in the predicted methods at 25.511 $\times$ 10^6 Pa

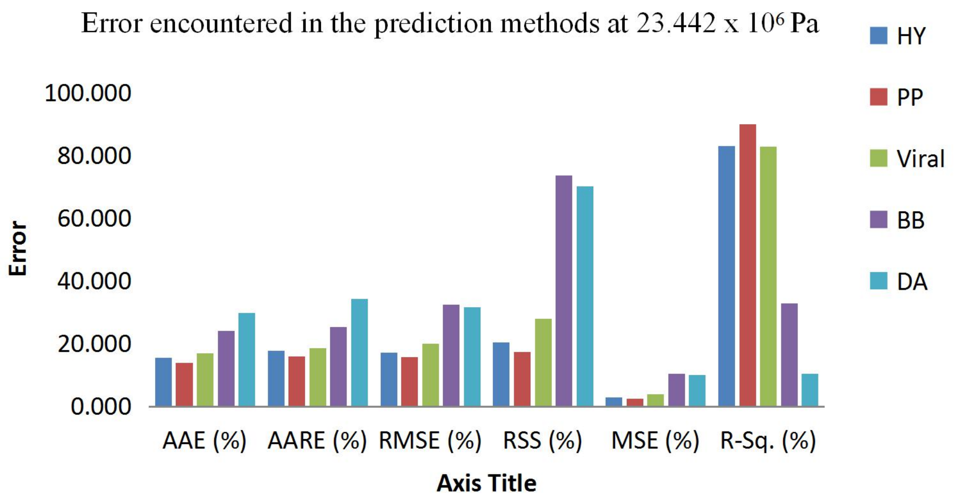

Figure 4: Summary of error in the predicted methods at 23.442 $\times 10^6$ Pa

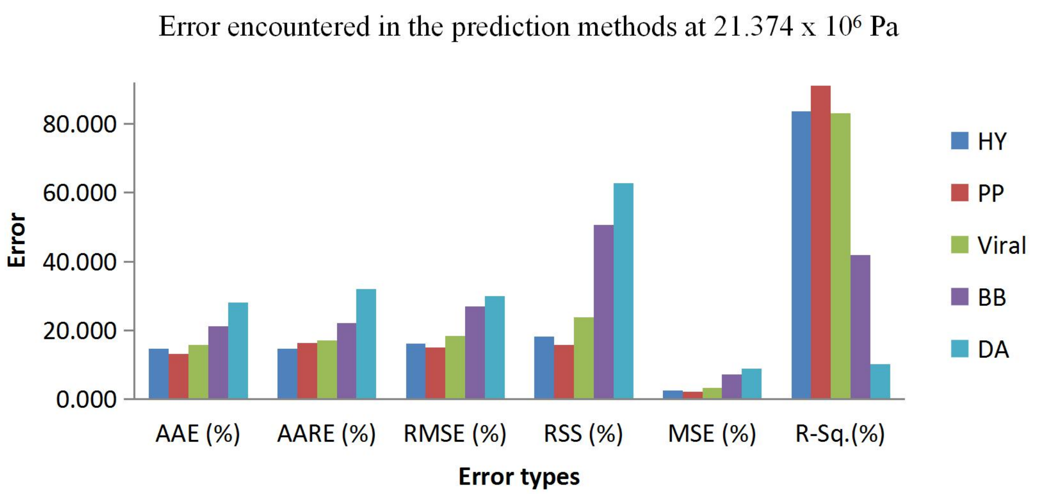

Figure 5: Summary of error in the predicted methods at 21.374*106 Pa

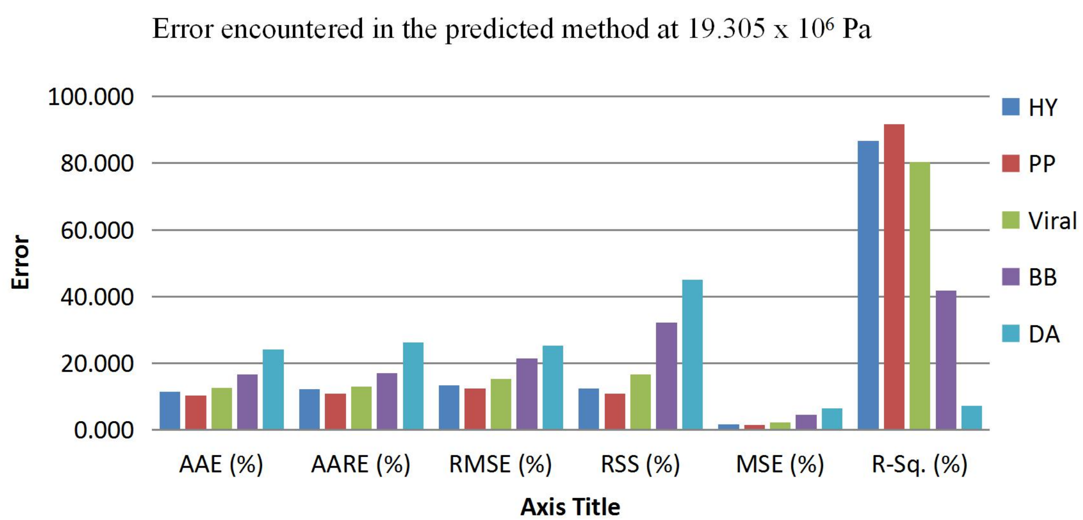

Figure 6: Summary of error in the predicted methods at 19.305*106 Pa

4. Conclusion

The important of compressibility factor can never be over emphasize as it plays vital a roles in the exploitation of natural gas. Therefore, accurate and reliable prediction of compressibility factor as well as selection of the best method is necessary. This study assessed the effectiveness and accuracy of some selected compressibility factor prediction method in a single-phase gas reservoir at a particular reservoir temperature and various reservoir pressures. The methods studied were based on empirical correlation and equation of state (EOS). The following findings were drawn from this study.

Empirical correlation methods are easier and suitable for application than the equation of state (EOS) method because the equation of state methods considered in this work are cumbersome and time consuming which may easily lead to error during computation.

The Z-factor predicted methods studied in this work are suitable and effective only for application within the range of the reservoir pressures prescribe for this study. This is due to the fact that the accuracy and performance of the various methods studied in this work increase as the reservoir pressures decrease.

The accuracy of the methods studied is rated using statistical tools which analyzed the effectiveness of the methods. If the coefficient of regression is high and least error is encountered in the method, then the method will give better performance. In this case, Papay correlation method gives the highest coefficient of regression with least error encountered in the method and hence, is the most accurate and reliable method. Dranchuk-Abu-Kassem methods gives the least performance in this work because it has the lowest coefficient of regression with highest values of errors. Therefore, the Dranchuk-Abu-Kassem methods is not suitable for application in this reservoir, it need further modification. While the other methods are suitable for application in this reservoir.

However, these methods may not be reliable and suitable in reservoirs with complex fluid compositions where polar and non-polar gases are predominantly occur in the reservoir.

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