Natural Gas Compressibility Factor Measurement and Evaluation for High Pressure High Temperature Gas Reservoirs

I.I. Azubuike, S. S.Ikiensikimama,O.D.Orodu

Abstract— The Natural gas compressibility factor is an important reservoir fluid property used in reservoir engineering computations either directly or indirectly in material balance calculations, well test analysis, gas reserve estimates, gas flow in lines and in numerical reservoir simulations. Existing gas compressibility factor correlations were derived using measured data at low to moderate pressures(less than 8, 000 psia) and temperatures (less than 212°F), and an extrapolation to High Pressure High temperature (HPHT) is doubtful. The need to understand and predict gas compressibility factor at HPHT has become increasingly important as exploration and production has moved to ever deeper formations where HPHT conditions are to be encountered. This paper presents laboratory measurement of gas compressibility factors at HP HT natural gas systems and the ev aluation of s ome selected gas compressibility factors correlations. Samples of gas mixtures were collected from the high pressure gas reservors from the Niger Delta region of Nigeria. Vinci PVT Cell was used to measure the gas compressibility factors for a pr essures ranging from 6,000 to 14,000 ps ia and tem peratures at 270 °F and 370°F. T he new laboratory data was compared to some of the gas compressibility factor correlations/ models used in the petr oleum industry. Results showed that majority of the correlations studied overestimated the gas compressibility factor at HPHT. Mean relative and absolute error analysis were done based on the temperature difference; it was found that the total mean relative and absolute errors for the 370°F cases are higher than those for 270°F. Among all the correlations assessed, Hall and Yarborough equation performed better than other existing correlations with a mean absolute error of 3.545 and relative error of -2.668 at 270°F. At 370°F, Beggs and Brills correlation predicted better than other correlations studied with a mean relative error of -4.77 and absolute error of 7.187.

Index Terms—Correlation, Evaluation, High Pressure, High Temperature, Gas Compressibility Factor, Gas Reservoir, Natural gas

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1. INTRODUCTION

In dealing with gases at low pressures, the ideal gas relationship is a convenient and generally satisfactory tool. At higher pressures, the use of the ideal gas equation-of-state may lead to errors as great as 500%, as compared to errors of 2–3% at atmospheric pressure [1].

- *I . I. Azubuike is currently pursuing doctoral degree program in Petroleum Engineering Department, world Bank Center of Excellence for Oil Field Chemical Research, University of Port-Harcourt, Nigeria.*
- *Dr. S. S. Ikiensikimama is currently Associate Professor in the Department of Petroleum & Gas Engineering University of Port-Harcourt, Rivers State, Nigeria.*
- *Dr. O. D. Orodo is currently Associate Professor in the Covenant University, Ota, Ogun State, Nigeria.*

Numerous equations-of-state have been developed in the attempt to correlate the pressure-volume-temperature (PVT) variables for real gases with experimental data. In order to express a more exact relationship between the variables P, V, and T, a correction factor called the gascompressibilityfactor, gas deviation factor, or simply the z-factor, must be introduced into the Ideal gas law. Its value reflects how much the real gas deviates from the ideal gas behaviour at a given pressure and temperature.

Compressibility factor is defined and expressed as:
$$Z = \frac{Vactual}{Videal} \qquad (1)$$

Introducing the z-factor to ideal gas law results to real gas equation (Equ. 2),

$$PV = ZnRT \qquad (2)$$

where n is the number of moles of gas, P is the pressure, V is the volume and T is the absolute temperature. Gas compressibility factor can be determined on the basis of measurements in PVT laboratories. At low temperature and

pressures, the ideal gas law can adequately predict the behaviour of natural gas. However at the high temperature and pressure that exist in petroleum reservoirs, the gas deviates from the ideal gas behaviour and are described as a real gases.

Prior to 1960s, the majority of natural gas resources targeted for exploration and development activities by the oil and gas industry were less than 15,000 ft. Most of these natural gas resources exhibited normal pore pressure and temperature gradients. However, the oil and gas industry has continued to extend exploration and development activities to depths much greater than 15,000 ft[2]. 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 [3].

(HPHT) gas reservoirs are defined as reservoirs having pressure greater than 10,000 psia and temperature over 300°F [3]. Accurate measurements of z-factor at HPHT conditions are both extremely difficult and expensive. Thus, this fluid property is typically estimated from published correlations that are based on laboratory data. Unfortunately, the correlations available today do not have a sufficiently broad range of applicability in terms of pressure and temperature, and so their accuracy may be doubtful for the prediction of gas compressibility factor at HPHT conditions. Therefore, this paper aimed at presenting the measurement of gas z-factor at HPHT and also to use the new experimental laboratory data to evaluate some of the existing gas compressibility correlations.

2.EXISTING CORRELATIONS

Several well-known correlations are used in the petroleum industry to determine values of gas z- factor. Some of these correlations available in literature are [4, 5, 6,7,8,9,10,11,12].

Studies of the gas compressibility factors for natural gases of various compositions have shown that compressibility factors can be generalized with sufficient accuracies for mostengineering purposes when they are expressed in terms of the following two dimensionless properties:
   i.   Pseudo-reduced pressure
   ii.   Pseudo-reduced temperature
These dimensionless terms are defined by the following expressions:
$Pr = P/Pc$ (3)
$Tr = T/Tc$ (4)

Based on the concept of pseudo-reduced properties, Standing and Katz [4] presented a generalized gas compressibility factor chart (Fig. 1). The chart represents compressibility factors of

sweet natural gas as a function of Pr and Tr. This chart is generally reliable for natural gas with minor amount of non-hydrocarbons. It is one of the most widely accepted correlations in the oil and gas industry. Several attempts were made to fit the Standing and Katz [4]chart mathematically [8, 9, 13, 14, 15, 6].

Hydrocarbons are not always in there pure forms, hence there is need to correct for the presence of impurities. The gas impurities in natural gas are usually H_2S, CO_2 and N_2. Wichert and Aziz [16] and Carr *et al*. [17] developed correlations that are generally used to correct for the presence of impurities.
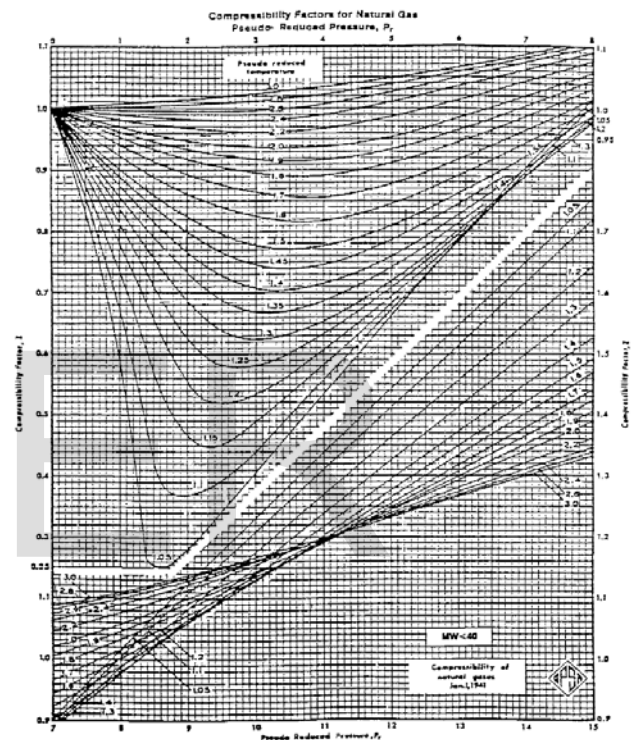

Fig. 1. Standing and Kats Compressibility Factor Chart [1]

Papay [5] proposed the following equation to calculate Z-factor

$$Z = 1 - \left(\frac{Pr}{Tr}\right)[0.36748758 - 0.04188423Pr] \qquad (5)$$

The correlation gave gas compressibility value of one when pseudoreduced pressure is zero which is consistent with the Standing and Katz [4] Chart. In addition, Papay's [5] equation is simple and has only two constants.

Hall and Yarborough [9] fitted data from the Standing and Katz [4] z-factor chart (Fig.1) into an expression based on the Starling and Carnahan equation of State. The proposed mathematical form is as follows

$$Z = \left[\frac{0.06125\,Pprt}{Y}\right]\exp[-1.2(1-t)^2] \quad (6)$$

$$f(y) = X1 + \frac{y+y^2+y^3+y^4}{(1-y)^3} - (x2)y^2 + (x3)y^{x4} = 0 \qquad (7)$$

$$x1 = -0.06125 Prt exp[-1.2(1-t)^2] \qquad (8)$$

$$x2 = (14.76t - 9.76t^2 + 4.58t^3) \qquad (9)$$

$$x3 = (90.7t - 242.2t^2 + 42.4t^{3)}) \qquad (10)$$
$$x4 = (2.18 + 2.82t) \qquad (11)$$

The above equation is a nonlinear equation and can be conveniently solvedfor the reduced density Y by using the Newton and Raphson iteration technique.They pointed out that the original data values show physically unrealistic inflections for T_r=3.0 and in the range of 1<P_r<20.

Brill and Beggs [6] proposed a best-fit equation for the Standing and Katz z-factor chart and is as follow: The authors stated that their method cannot be used for reduced temperature values less than 0.92.

$$Z = A + \frac{1-A}{e^B} + CPr^D \qquad (12) \quad A = 1.39(Tr - 0.92)^{0.5} -$$
$$0.36Tr - 0.10 \qquad (13) \qquad B = (0.62 - 0.23Tr)Pr + \left(\frac{0.066}{Tr - 0.86} - \right.$$
$$0.037Pr2 + 0.32Ppr610E \qquad (14)$$

$$C = 0.132 - 0.32\log(Tr) \qquad (15) \quad D = 10^E$$
$$(16)$$
$$E = 0.3106 - 0.49Tr + 0.1824Tr^2 \quad (17)$$

Dranchuk *et al*. [13]developed a correlation based on the Benedict *et al.* [18] equation-of-state. Fitting the equation to 1,500 data points from the Standing and Katz [4] z-factor chart optimized the eight coefficients of the proposed equations. The equation has the following form:

$$1 + T1\rho_r + T2\rho_r{}^2 + T3\rho_r{}^2 + [T4\rho_r{}^2(1 + A8\rho_r{}^2)\exp(-A8\rho_r{}^2)] - \frac{T5}{\rho_r} = 0 \qquad (18)$$
$$T1 = [A1 + \frac{A2}{Tpr} + \frac{A3}{Tpr^3}] \quad (19) \qquad\qquad T2 = [A4 + \frac{A5}{Tpr}]$$
$$(20) \qquad\qquad T3 = [\frac{A5A6}{Tpr}]$$
$$(21) \qquad\qquad T4 = [\frac{A7}{Tpr^3}] \qquad (22)$$
$$T5 = [\frac{0.27Ppr}{Tpr}] \qquad\qquad (23)$$

The values for the coefficients are as follows:
A1=0.31506237; A5 =0.61232032; A2 =1.0467099; A6 =0.10488813; A3 =0.57832720
 A7 =0.68157001; A4 =0.53530771; A8 =0.68446549

The correlation is valid within the following ranges of pseudo-reduced temperature and pressure: 1.05 <Tr< 3.0 and 0.2 <Pr< 3.0.

Dranchuk and Abu-Kassem [14] derived an analytical expression for calculating the reduced gas density that can be used to estimate the gas compressibility factor. The reduced

gas density ρ_r is defined as the ratio of the gas density at a specified pressure and temperature to that of the gas at its critical pressure or temperature. The critical gas compressibility factor z_c is approximately 0.27, which leads to the following simplified expression for the reduced gas density:
$$\rho_r = \frac{0.27Pr}{ZTr} \qquad (24)$$

The authors proposed the following eleven-constant equation-of-state for calculating the reduced gas density:
$$f(\rho_r) = R1(\rho_r) - \frac{R2}{\rho_r} + (R3)\rho_r{}^2 - (R4)\rho_r{}^5 + R5(1 + A11\rho_r)\exp[-A11\rho_r{}^2] + 1 = 0$$
$$(25)$$

With the coefficients R1 through R5 as defined by the following relations:
$$R1 = [A1 + \frac{A2}{Tr} + \frac{A3}{Tr^3} + \frac{A4}{Tr^4} + \frac{A5}{Tr^5}] \qquad (26) \quad R2 = [\frac{0.27Pr}{Tr}]$$
$$(27) R3 = [A6 + \frac{A7}{Tr} + \frac{A8}{Tr^2}]$$
$$(28) \qquad\qquad R4 = A9[\frac{A7}{Tr} + \frac{A8}{Tr^2}]$$
$$(29)$$
$$R5 = \frac{A10}{Tr^3} \qquad\qquad (30)$$

The constants A1 through A11 were determined by fitting the equation, using nonlinear regression models, to 1,500 data points from the Standing and Katz [4] z-factor chart. The coefficients have the following values:

A1 = 0.3265; A2 =1.0700; A3 = 0.5339; A4 = 0.01569; A5 =0.05165; A6 = 0.5475
A7 = 0.7361; A8 = 0.1844; A9 = 0.1056; A10 = 0.6134; A11 = 0.7210

The proposed correlation was reported to duplicate compressibility factors from the Standing and Katz chart with an average absolute error of 0.585% and is applicable over the ranges of reduced pressure and temperatureof $0.2 < Pr < 15$ and $1.0 < Tr < 3.0$.

Burnett [7] developed the following formula to approximate the gas compressibility factor given by the American Gas Association (AGA):

$$Z = 1 + (Z' - 1)(sin90U)^N \qquad (31)$$
Where Z' U and N equal to:
$$Z' = 0.3379 \ln(lnTr) + 1.091 \qquad (32)$$
$$Pr' = 21.46Z' - 11.9Z'^2 - 5.9 \qquad (33)$$
$$U = \frac{Pr}{Pr'} (34)$$
$$N = [1.1 + 0.26Tr + (1.04 - 1.42Tr)U(\frac{\exp(U)}{Tr}) \qquad (35)$$

The author also, stated that the accuracy of the equation diminishes for pseudo-reduced temperatures below 1.3 and above 1.85 and for pseudo reduced pressures such that Pr>Pr'.

The correlation also gives a Z value of one when P_r is equal to zero which is consistent with the data.

Papp [8] proposed the following equation to calculate the compressibility factor:

$$Z = 1 + R1Pr + R2Pr^2 - WR3Pr/(Pr^2 + R6Pr + R7) \quad (36)$$

Olajide and Ikiensikimama [19] presented a paper on evaluation of compressibility factor correlations for the Niger Delta gas reservoirs. The data base consists of 513 data points obtained from Niger Delta gas reservoirs. The Z-factors evaluated are in the ranges of reduced temperature and pressure of $0.5796 \leq Tr \leq 1.758$ and $0.410 \leq Pr \leq 8.985$ respectively. It was found from the statistical analysis that the best correlation for Niger Delta natural gas compressibility factorBeggs and Brill [6]. It had a rank of 2.82, a percentage absolute error of 3.234 and the best performance plot. They recommended Beggs and Brill [6] to be used in situations where laboratory PVT data of natural gas compressibility factor is not available for the Niger Delta gas reservoirs as well as other regions of the world where the gas composition is similar to that used for the study.

Mahmoud [10] developed a newer and simpler correlation using 300 data points (by fitting the data through a linear regression function) that can be used to determine the gas compressibility factor at any pressure range especially for high pressure. He concluded that the method returned an error less than 3% compared to measured data. Lateef [11] developed a model by way of Fourier series expansion using over 6000 data points prepared by careful laboratory measurements of natural gas mixtures and the result was found to match to a very high accuracy, without over fitting.

Recently, Elechi et al. [12] developed a z-factor chart using Beggs and Brill [6] gas compressibility factor correlation equation. 359 validated data points from Niger Delta region were used in building the z-factor chart. The authors validated their new chart with Standing and Katz [4] z-factor chart and observed that their chart performed well as long as the pseudo-reduced properties lie within the specified range of reduced properties. Their z-factor chart can perform best at pseudo reduced properties ranges between $1.40 \leq Tr \leq 1.90$ and $0.198 \leq Pr \leq 10.8$.

3.LABORATORY DETAILS

i. **Collection of Reservoir Gas Sample:** A representative bottom hole reservoir fluid samples were collected from the extreme high pressure gas reservoir and was received in the laboratory for analysis

ii. **Charging of the Gas Sample into Vinci PVT Cell:** Positive displacement pump was connected to piston bottle with a liner and the second liner was connected to PVT Vinci cell. A total volume of 77.5cc sample was charged into the PVC cell.

iii. **Gravimetric Density Measurement:** The measurement of gravimetric density was done using pycnometer. Density was determined using Equ. 37

Density (ρ) = mass/volume $\quad$ (37)

iv. **Mass Sample Calculation:** The mass was calculated using Equ. 37

v. **Measurement of Molecular Weight:** compositional analysis was carried out on the sample so as to determine the sample composition as well as its molecular weight. Table 1 shows the composition of the gas samples.

TABLE 1
GAS COMPOSITION FOR THE SAMPLES USED IN THIS STUDY

Composition	Sample 1	Sample 2
C_1	90.05	90.44
C_2	4.07	4.06
C_3	1.29	1.29
$i\text{-}C_4$	0.29	0.29
$n\text{-}C_4$	0.31	0.41
$i\text{-}C_5$	0.51	0.09
$n\text{-}C_6$	0.10	0.08
C_7+	0.25	0.14
N_2	0.13	0.14
CO_2	3.21	3.00

vi. **Calculation of Gas Z-Factor**

Finally z-factor was calculated at different pressure regimes using real gas equation.

$$Z = PM/\rho RT \quad (38)$$

where P, is the pressure in psia, M, fluid molecular weight in g/mol, ρ, fluid density at any pressure in g/cm³, R, universal gas constant 669.94 in psia g/cm³R and T, is reservoir temperature in rankine.

The sample was cooled to 270°F and the experiment was repeated for 270°F and second sample was also measured at 270°F and 370°F.

4. RESULTS AND DISCUSSION

4.1 Effect of Pressure and Temperature on Measured Z-Factors and Density

The measured data showing the effects of both high temperatures and pressure on z-factors for gas samples are discussed first. Compressibility factors at temperatures of 270oF and 370oF for pressures from 6,000 psia to 13,200psia are shown in Figs. 3 and 5 while the corresponding gas density measurements are shown in Figs. 4 and 6. The solid, colour filled points in the both plot represent the measured values, while the solid colour lines are best-fit curves through the data. From Figs. 3 to 6, the trends and magnitude of the measured z-factor and density obey the real gas law since the z-factor varies linearly with pressure and density varies inversely with pressure. It was also observed that the impact of temperature on gas compressibility factors in the high pressure and at temperature of 370oF is much lower than those at 270oF. The result indicates that as pressure and temperature increases the z-factor decreases.
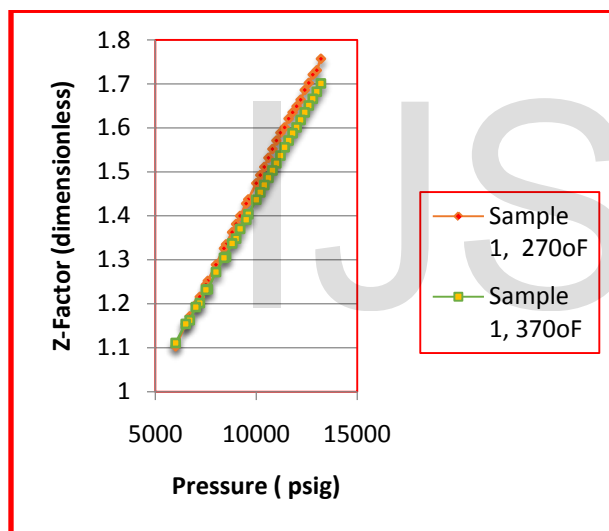
Fig. 3. Measured gas z-factor for gas Sample 1 at temperatures of 270oF and 370oF
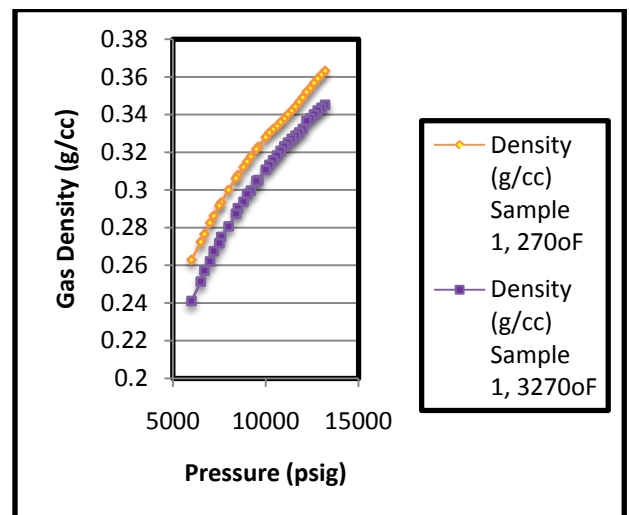

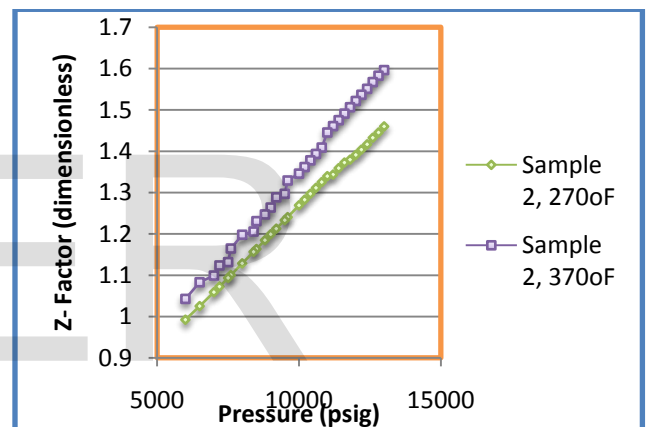Fig. 4. Measured gas density for gas Sample 1 at temperatures of 270oF and 370oF

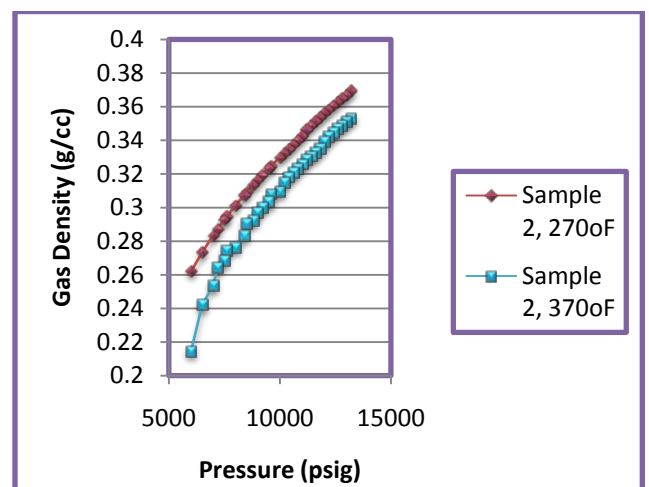Fig. 5. Measured gas z-factor for gas Sample 2 at temperatures of 270oF and 370oF

Fig. 6. Measured gas density for gas Sample 2 at temperatures of 270oF and 370oF

4.2   Comparison of New Laboratory Data with Existing Correlation

The laboratory measured z-factor data at HPHT were assessed to ascertain the accuracy of the most widely used compressibility factor correlations as applied to natural gas. The Hall and Yarborough [9] and Dranchuk and Abuo-Kassem [14] equations of state alongside Burnett [7], Papp [8], Brill and Beggs [6] and Mahmoud [10] empirical models were evaluated. These predictive correlations were carefully selected, having been developed specifically for the prediction of natural gas compressibility factor. For all the correlations evaluated, the Carr et al. [17] correlation was used to correct for the presence of impurities.

Fig. 7 compares some of the selected gas compressibility factor correlations with the measured data at 370°F for gas sample 1 and Fig. 8 shows the similar chart for the temperature at 270°F. Hall and Yarborogh [9] equation of state model overestimated the measured data while the Beggs and Brill [6] correlation underestimated it,Dranchuck and Abu-Kassem [14] and Mahmoud [10] predicted the measured data at some pressure ranges as can be observed in Fig. 7. Dranchuk and Abu-Kassem [14] predicted the measured data at the pressure of 7600psia and Mahmoud, [10] match at 10800 psia and deviate at a very high pressure.

From Fig. 8, it can be observed that Beggs and Brill [6] andDranchuck and Abu-Kassem [14] models underestimated the measured data and Mahmoud, 2013 overestimated it. The Hall and Yarborogh [9] equation of state model matched the measured data at some pressure range of 10000psia to 10800psia and then deviated at higher pressure.
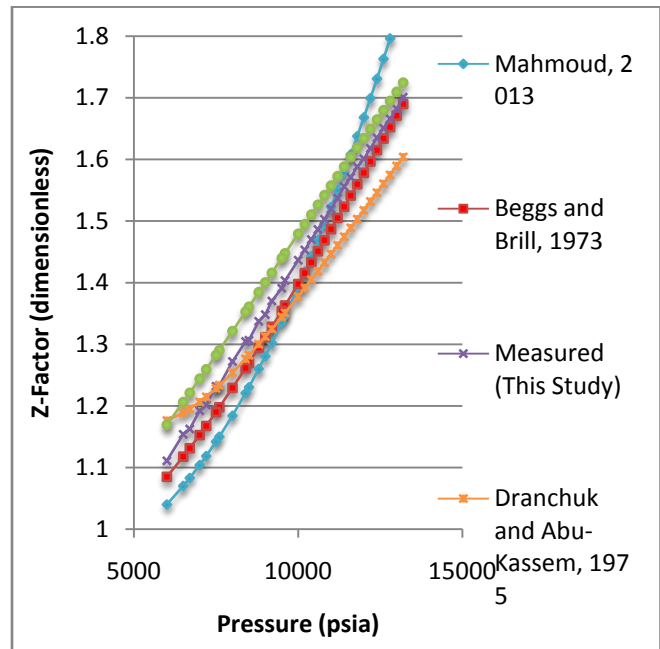

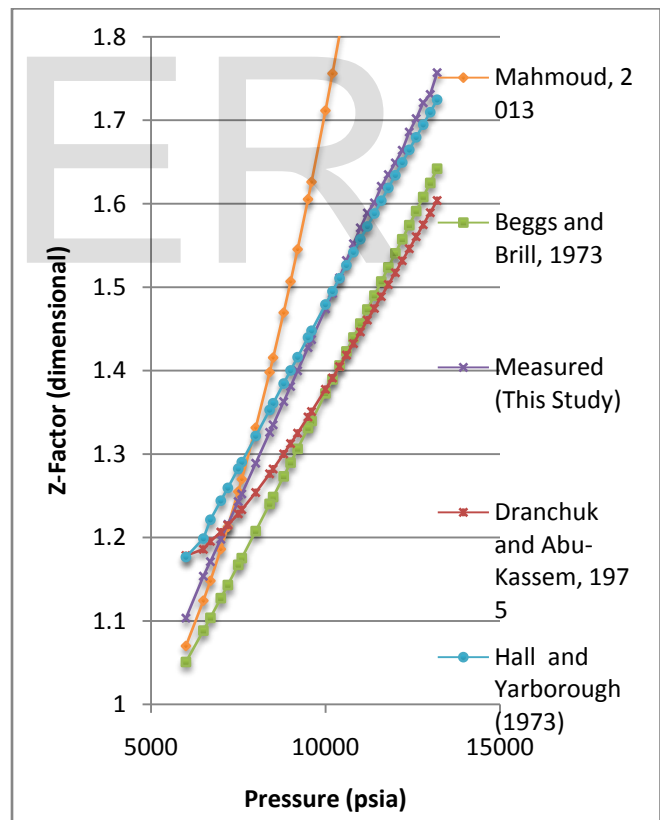Fig. 7. Gas Z-Factor against Pressure for gas Sample 1 at 370°F

Fig. 8. Gas Z-Factor against Pressure for gas Sample 1 at 270°F

Figs. 9 and 10 show the accuracy of some selected models for gas sample 2 for the temperatures of 270°F and 370°F. In fact, all models tend to overestimate the z-factors for all the

pressure range studied but the deviation is more for the higher region.
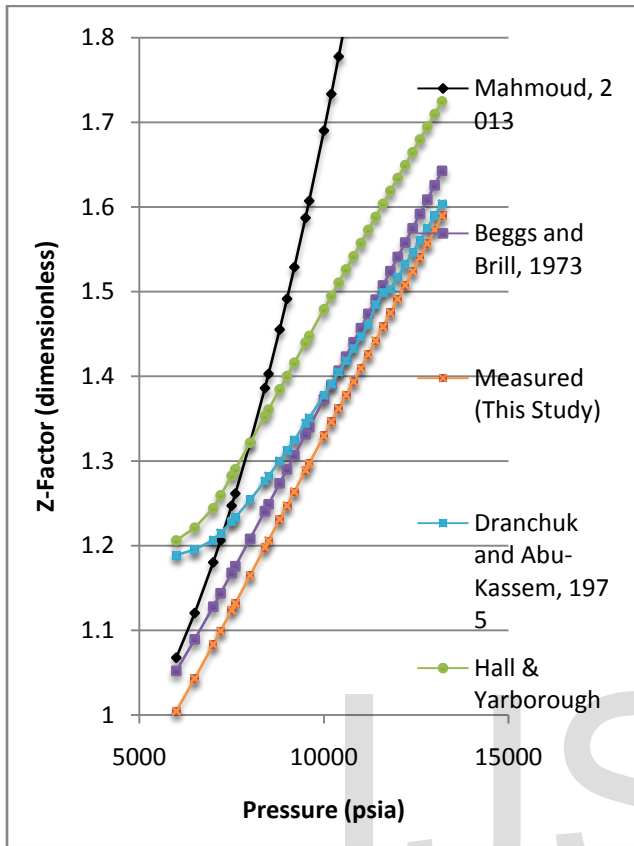

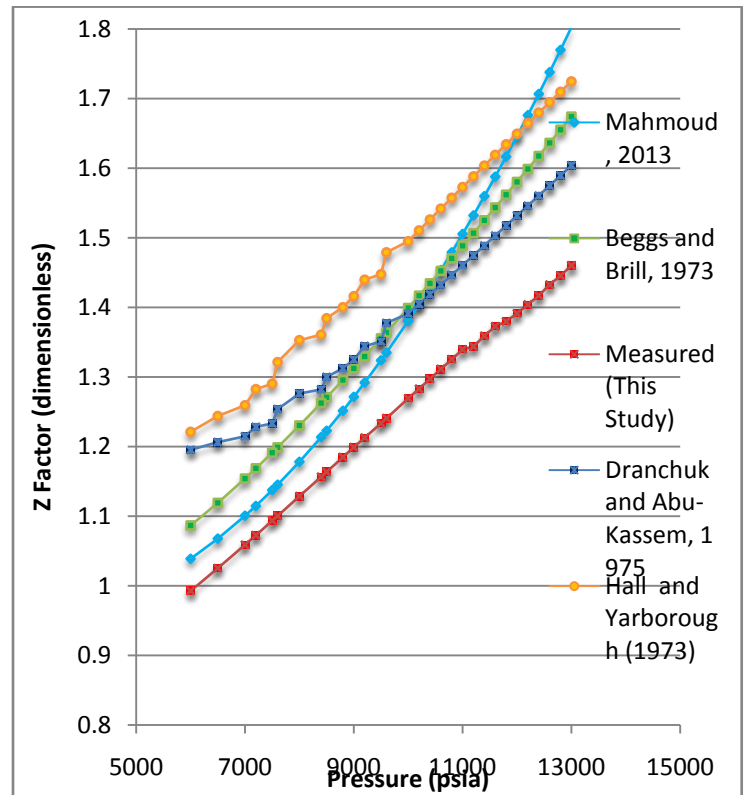Fig. 9. Gas Z-Factor against Pressure for gas Sample 2 at 270°F

Fig. 10. Gas Z-Factor against Pressure for gas Sample 2 at 370°F

4.3   Statistical Comparison

Figs. 11 and 12 are plots of mean relative and absolute error for natural gas z- factor measured at 270°F and 370°F respectively. The total absolute mean error plotted suggested that the Hall and Yarborogh [9] equation of state model is more accurate at temperature of 370°F and Beggs and Brill [6] correlation for temperature of 370°F for all the correlations evaluated in this study (see Fig. 11).

Comparing Figs. 7 and 8, it can be found that the total mean relative and absolute error for the 370°F cases are more than two times greater than those for 270°F, except for Mahmoud [10] which was developed specifically for high region. These differences suggest neither these correlations has been matched or turned to data at higher temperatures and seem to validate our concerns about extending the Standing and Katz [4] correlation numerically to higher pressures and temperatures.
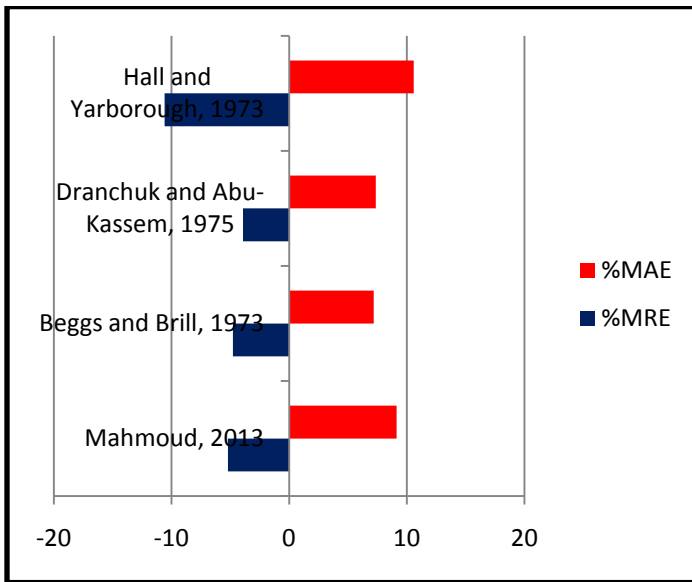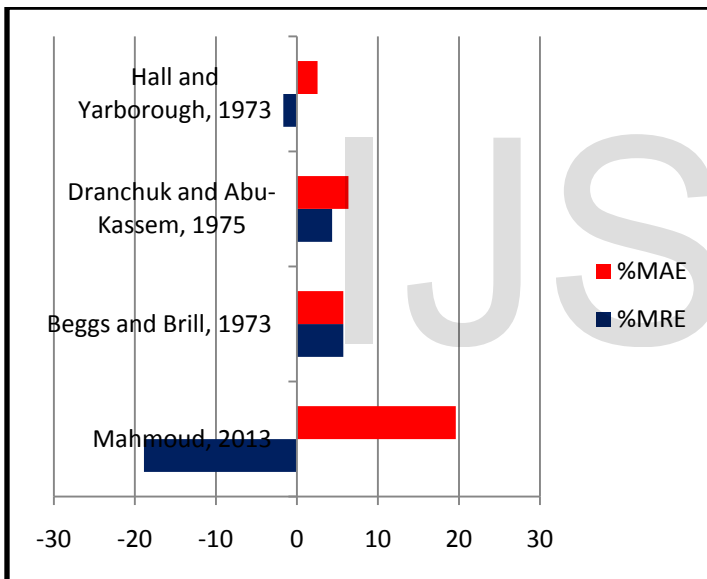
Fig. 11. Mean Relative and Absolute Error at 370°F

Fig. 12. Mean Relative and Absolute Error at 270°F

5. CONCLUSION

Prediction of gas z-factor is required for fundamental petroleum engineering calculations that allow one to monitor the management of HPHT gas field and to better estimate reserves. A laboratory measurement of the natural gas z-factor at high-pressure, high-temperature (HP/HP) reservoir conditions and evaluation of some selected correlations has been presented. 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°F and 370°F. Some of the existing z-factor correlations cannot be used to predict z-factor at high pressure. 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.

ACKNOWLEDGEMENT

REFERENCES

[1]   T. Ahmed, "Reservoir Engineering Hand Book" Copyright, Elsevier Inc. Gulf Publishing, 30 Corporate Drive. Suite 400. Burlington, MA 01803, USA, pp 7-13, 2006.

[2]   E. Davani, K. Ling, C. Teodoriu, J. McCain and G. Falcone, "Inaccurate Gas Viscosity at HP/HT Conditions and its Effects on Unconventional Gas Reserves Estimation", SPE 122827,2009.

[3]   L. Kegang,T. Catalin, D. Ehsan and F. Gioia "Measurement of Gas Viscosity at High Pressures and High Temperatures" International Petroleum Technology Conference held in Doha, Qatar, IPTC 13528, 2009.

[4]   M. B. Standing and D. L. Katz "Density of Natural Gases", Trans. AIME, Vol. 146, pp 140-149, 1942.

[5]J.Papay"ATermelestechnologiaiParameterekVoltoZasaGaJle lepKMuveleseSoran", OGIL MUSZ, Tud, KUZL, Budapest, pp 267-273, 1968.

[6]   H. Beggs and J. Brill "Two-phase flow in Pipes", Tusla, OK; The University of Tusla. 1978.

[7]   R. R. Burnett, "Calculator gives Compressibility factors", The Oil and Gas Journal, pp70-74, 1979.

[8]I.PappUjmodsZerfoldgazkelteresitenyeZojeneksZamitasara, ''KodajesFoldgaz 12 (112) evfolyam 11. Szam, pp. 337-345, 1979.

[9]   K. R. Hall, and L. J. Yarborough, "A new equation-of-State for z-factor Calculations" Oil and Gas Journal, pp 82-92, 1973.

[10]   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.

[11]   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, 2013.

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

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

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

[15]   R.W. Hankinson, L. K. Thomas andK. A, Phillips "Predict Natural Gas Properties", Hydrocarbon Processing, pp. 106-108, 1969.

[16]   E. Wichert, and K.Aziz "Calculations of Z's for Sour Gases", Hydrocarbon Processing, Vol. 51. No 5, pp 119-122, 1972.

[17]   N.Carr, R. KobayashiandD. Burrows "Visco
sity of Hydrocarbon Gases under Pressure", Trans, AIME, Vol. 201, pp 270-275,1954.

[18]   M. Benedict, G. B. Webb and L. C.Rubin "An Empirical Equation for Thermodynamics Properties of Light Hydrocarbons and Their Mixtures, Methane, Ethane, Propane, and n-Butane," J. Chem. Phys., 8, 334. 1940.

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