ASSESSMENT OF TWO CORRELATION METHODS IN PREDICTING THE COMPRESSIBILITY FACTOR OF NATURAL GAS IN A RETROGRADE GAS CONDENSATE RESERVOIR

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Abstract

Compressibility factor is one of the most important parameter used in the oil and gas industry for Natural gas production, processing and transmission. This study presents two different correlation methods which are theDranchuk-Abu-Kassem and theDranchuk-Purvis-Robinson method to predict the gas compressibility factor of natural gas in a retrograde gas condensate reservoir and to compare the two correlation methods to ascertain the level of their accuracy and performance. In this study,21 samples of natural gas compositions in the retrograde gas condensate reservoir were used. The Pseudo-critical temperatures and the pseudo-critical pressures of the respective gas compositions were computed using the specific gravity of the gas compositions. The pseudo-reduced temperatures and the pseudo-reduced pressures of the respective gas compositions were also computed using the above obtained pseudo-critical pressure and temperature. The reduced density terms embedded in the formula of the both methods were determined by Newton Raphson iteration. These parameters are essential for the computation of the compressibility factor in a Microsoft excel. The results of the study were compared and show that,the Dranchuk-Purvis-Robinson correlation methods give better prediction and perform well in the estimation of z-factor values in the reservoir, and have average percentage error of 17.87%, showing low deviation from the ideal gas behavior, as compared with the Dranchuk-Abu-Kassem correlation methods which have an average percentage error of 25.15% showing moderate deviation from ideal gas behavior. The results further show that the Dran chuk-Purvis-Robinson method is a modification of the Dranchuk-Abu-Kassem and is recommended for the prediction of gas compressibility factor in this reservoir.

***Key words**: Natural gas, Compressibility factor, pseudo-crtical temperature and pressure, pseudo-reduced temperature and pressure, reduced volume, Newton Raphson Iteration, Dranchuk-Abu-Kassem and Dranchuk-Purvis-Robinson correlation.*

Introduction

Gases are composed of a very large number of particles called molecules according to the kinetic theory of gases, (Ahmed, 2001, p.30). The volume of these molecules is negligible compared with the total volume occupied by the gas for an ideal gas, (Ahmed, 2001, p.30). All the collision existing between the molecules are perfectly elastic and there is no attractive or repulsive force between them, this was assumed by kinetic theory of gases, (Ahmed, 2001, p.30).

The ideal gas relationship is convenient and generally satisfactory tool when dealing with gases at a very low pressure, (Ahmed, 2001, p.36). The used of ideal gas equation of state may lead to errors as great as 500% at a higher pressure compared to the error of 2-3% at atmospheric pressure, (Ahmed, 2001, p.36). That is at high pressure the gas will deviate from the ideal gas behavior.

The relationship existing between pressure P, volume V, and temperature T for a given quantity of number of moles of gas can be derived using a mathematical relation called equation of state, based on the above kinetic theory of gas, (Ahmed, 2001, p.30). For perfect gases the relationship is called and ideal gas law and is expressed mathematically as

$$PV=nRT \tag{1}$$

P is the pressure in psia, V=volume in ft3, T is the temperature in ^{o}R, n is the number of moles in ib-mole, and R is the universal gas constant, (Ahmed, 2001, p.30).

Basically, increase in pressure and temperature varies widely with the composition of the gas lead to increase in the magnitude of the deviation of real gases from the condition of ideal gas law behaving differently with the ideal gas (Ahmed, 2001, p.37). This is because of the assumption made under which the perfect gas law was derived, that the volume is negligible and there is no repulsive or attractive forces existing between them, that is not the case for real gas (Ahmed, 2001, p.37).

For real gases with experimental data several equations of state have been developed so as to correlate the pressure, volume and temperature variables (Ahmed, 2001, p.37). To account for the deviation of gases from the condition of ideal, a correction factor called the deviation factor, gas compressibility factor or simply the z- factor must be introduced in order to express a more exact relationship between the variables P, V, and T (Ahmed,2001, p.37).

Gas compressibility factor also called “deviation factor” or “z-factor”. It values reflect the amount of the deviation of the real gas from the ideal gas at a given pressure and temperature (Guo, Lyon &Ghalambor, 2007, p.23). Incorporating the z-factor to the ideal gas law results in the real gas law (Guo et al, 2007, p.23).

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

Where z is the gas deviation factor is a dimensionless quantity and is defined as the ratio of the actual volume of number of moles of gas at pressure and temperature to the ideal volume of the same number of moles of the gas at the same pressure and temperature (Ahmed, 2001, p.37).

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

Gas compressibility factor can be obtained by the following methods: experimental, empirical correlation direct calculation methods.

Experimental method: For all composition of gas at all temperatures, this method is the most accurate method of predicting gas compressibility factor among the existing method, but occasionally the experimental data became unavailable, it is expensive and time consuming (Elsharkawy, Hashem&Elkamel, 2001).

Empirical correlation method: Standing and katz chart, the knowledge of the gas gravity or at least the gas is required in this method (Dake, 1978, p.14). It involves the use of pseudo reduced pressure and pseudo reduced temperature to predict the compressibility factor and the chart is valid when there is negligible amount of impurities (non-hydrocarbon gas) in the gas composition (Ahmed, 2001, p.38). Molecular weights in excess of 40 were not included when preparing the chart (Ahmed, 2001, p. 49).

Direct methodsthese include the following empirical correlation: Hall-Yarborough, Dranchuk-Abu-Kassem and Dranchuk-Purvis-Robinson methods.

Hall-Yarborough equation of state: this equation was developed based on sterling-carnahan equation of state (Ikoku, 1992). And are

$$Z=\left[\frac{0.06125P_{prt}}{Y}\right]EXP\left[-1.2(1-t)^2\right] \qquad (4)$$

Where Ppr = pseudo-reduced pressure, t= reciprocal of the pseudo-reduced temperature= $\left[\frac{T_{pc}}{T}\right]$ and Y=Reduced density term. This equation is not applicable for use if the pseudo reduced temperature is less than unity (Ahmed, 2001).

Dranchuk-Abu-Kassem method- is a direct empirical correlation and more convenient methodof predicting gas compressibility factor using spread sheet computer program, this correlation method fitted an equation of state to the standing and katz (Lake &Fanchi, 2006, p. I-227). These equations are not recommended for Tp=1.0 and Ppr>1.0 because it gives an unacceptable results and is only valid for 0.2<Ppr<30, 1.0<Tpr<3.0; for Ppr<1.0 with 0.7<Tpr<1.0 (Lake &Fanchi 2006, p. I-227).

Dranchuk-Purvis-Robinson method: is an eight coefficient equation developed based on the Benedict-Webb-Rubbin type equation of state (Ahmed,2001,p.59). It involves Newton Raphson iteration in a spread sheet computer package to predict the compressibility factor. It is necessary to make used of a computer in many reservoir engineering calculation when standing and katz chart become difficult to use (Craft & Hawkins, 1991, p.19). The method is applicable within the range of pseudo reduced temperature and pseudo reduced pressure: 0.2<Ppr<3.0, 1.05<Tpr<3.0 (Ahmed, 2001, p.59).

Natural gas is the most the cleanest and safest energy source which makes it environmental friendly and offers an important benefit to the environment when compared with other fossil fuels (Speight, 2007). This causes the world energy demand now to move to natural gas (Obuba, Ikiesnkimana&Ekeke, 2013, p.1). This clean energy source cannot be produce without accurate prediction of the gas compressibility factor.

Gas compressibility factor is useful and plays a vital roles in the petroleum industry for the determination of the properties of natural gas such as the gas formation volume factor, gas density, gas viscosity, gas expansion factor which are used in the estimation of gas reservoir, evaluation of newly discovered reservoirs, estimation of initial gas in place, prediction of future production of gas, designing gas pipeline and production turbing and gas metering (Elsharkawy&Elkamel, 2001, p.712).

Therefore, the need arises to exploit different methods of computing the gas compressibility factor to enhanced gas production. Owing to the fact the experimental method is expensive and time consuming, and the empirical correlation are much more easier than the equation of state (Elsharkawy&Elkamel, 2001, p.712). This study presents two different correlation methods which are Dranchuk-Abu-Kassem and Dranchuk-Purvis-Robinson method to predict the gas compressibility factor in a retrograde gas condensate reservoir and to compare the methods and recommend method that gives better performance of z-factor values

Materials and methods

The Dranchuk-Abu-Kassem and the Dranchuk-Purvis-Robinson method were used to predict the compressibility factor of natural gas in the retrograde gas condensate reservoir.21 samples of the gascompositions in the retrograde gas condensate reservoir were used to achieve the results of the study. The specific gravity, Pseudo critical temperature and pressure, pseudo-reduced temperature and pressure of the gas components are essential for the computation of z-factor. The pseudo-critical temperature and pressure were determined using the specific gravity of the gas components as shown in equation 1 and 2 below (Ahmed, 2001, pp. 42-43).

$$T_{pc}=187+330\gamma_g-71.5\,\gamma^2_g \qquad (5)$$

$$P_{pc}=706-51.7\,\gamma_g-11.1\,\gamma^2_g \qquad (6)$$

From the above equation 5 and 6. The pseudo reduce temperatures (T_{pr}) and pressures (P_{pr}) were obtained as shown in the below expression

$$T_{pr}=\frac{T}{T_{pc}} \qquad (7)$$

$$P_{pr}=\frac{P}{P_{pc}} \qquad (8)$$

Where T is the reservoir temperature in^{o}R , which is 180^{o}F=640^{o}R. P is the reservoir pressure in psia which is =2700psia for this study.

From the above equation 3 and 4. The Dranchuk-Abu-Kassem method was applied. The below is the general expression (Ahmed, 2001, p.56).

$$f(\rho_r)=(R_1)\,\rho_r-\frac{R_2}{\rho_r}+(R_3)\,\rho_r^2-(R_4)\,\rho_r^5+(R_5)(1+A_{11}\,\rho_r^2)\mathrm{Exp}[-A_{11}\,\rho_r^2]+1=0 \qquad (9)$$

From equation 9above, the unknown variables R1, R2, R3, R4 and R5 were obtained from the pseudo reduced pressures and temperature expression in equation 3 and 4 above. As shown below.

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

$R_2=\left[\frac{0.27P_{pr}}{T_{pr}}\right]$

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

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

$R_5=\left[\frac{A_{10}}{T^3{}_{pr}}\right]$

Where the constants A1 through A11 were determined by fitting the equation, using nonlinear regression models, to 1,500 data point from the Standing and Katz chart (Ahmed, 2001,p.57). The coefficients have the following values:

A1 = 0.3262 A2 = -1.0700 A3 = -0.5339 A4 = 0.01569

A5 = -0.05165 A6 = 0.5475 A7 = -0.7361 A8 = 0.1884

A9 = 0.1056 A10 = 0.6134 A11 = 0.7210. (Ahmed, 2001, pp. 58-59)

Newton-Raphson iteration was applied and the reduced density term (ρ_r) in equation (9) abovewas computed in Microsoft Excel application package.

After the iteration the correct values of the reduced density terms $\rho_r$were obtained and were substituted in the equation (6) below and the compressibility factor values of the respective gas compositions were obtained.

$$z=\left[\frac{0.27P_{pr}}{\rho r T_{pr}}\right] \qquad (10)$$

For the Dranchuk-Purvis-Robinson Method. The general expression of the method is as shown below:

$$1+T_1\rho_r+T_2\rho^2{}_r+T_3\rho^5{}_r+[T_4\rho^2{}_r\,(1+A_8\rho^2{}_r)\exp(-A_8\rho^2{}_r)]-\frac{T_5}{\rho_r}=0 \qquad (11)$$

Where

$T_1=\left[A_1+\frac{A_2}{T_{pr}}+\frac{A_3}{T^3{}_{pr}}\right]$

$T_2=\left[A_4+\frac{A_5}{T_{pr}}\right]$

$T_3=\left[A_5 A_6 / T_{pr}\right]$

$T_4=\left[A_7 / T^3{}_{pr}\right]$

$T_5=\left[0.27 P_{pr} / T_{pr}\right]$

$A_1 = 0.31506237$ $A_2 = -1.0467099$ $A_3 = -0.57832720$ $A_4 = 0.53530771$

$A_5 = -0.612332032$ $A_6 = -0.10488813$ $A_7 = 0.68157001$ $A_8 = 0.68446549$

The solution procedure is similar to that of the Dranchuk and Abu- Kassem method (Ahmed 2006, pp. 58-59).

Results and Discussion

The results of the compressibility factor predicted by the Dranchuk-Abu-Kassem and the Dranchuk-Purvis-Robinson correlation methods from the Microsoft Excel were analysed to ascertain the level of their accuracy and performance. The table 1 below shows the values of z-factor obtained in the retrograde gas condensate reservoir at reservoir temperature of 640^{o}R and pressure of 2700psia using theDranchuk-Abu-kassem and the Dranchuk-Purvis-Robinson correlation methods.The table1 reveals that, at high value of pseudo-reduced pressure of 2.2893 and low value of pseudo-reduced temperature of 3.9159, the Dranchuk-Abu-Kassemcorrelation methodgives low value of z-factorof 1.1828 showing high deviation of 0.1828 from the ideal gas behavior as compared with theDranchuk-Purvis-Robinson correlation method which gives high value of z-factor of 0.9412 close to ideal, showing low deviation of 0.0588 from the ideal gas behavior. The Dranchuk-Purvis-Robinson an absolute percentage difference of 7.28% improvementover the Dranchuk-Abu-Kassem correlation methods. The average deviation of compressibility factor values predicted by the Dranchuk-Purvis-Robinson method is 0.8213 which gives an average percentage error of 17.87% which is less as compared with the Dranchuk-Abu-Kassem method which has an average deviation of 1.2515 and average percentage error of 25.15%.

Table 1: z-factor values obtained in the reservoir using both correlation methods.

Natural Gas Compositions	T_{pc}	P_{pc}	T_{pr}	P_{pr}	Z-Drank-Abu-kassem	Deviation of Z-Drank.-Abu-kassem	Z-Drank.-P.-Robin.	Deviation of Z-Drank.-P-Robin.
Pentadecane	399.1911	659.4584	1.6032	4.0943	1.2659	0.2659	0.7947	0.2053
Tetradecane	397.2312	660.0702	1.6112	4.0905	1.2640	0.2640	0.7991	0.2009
Tridecane	396.8776	660.18	1.6126	4.0898	1.2638	0.2638	0.7998	0.2002
Dodecane	394.8822	660.7966	1.6207	4.0860	1.2625	0.2625	0.8039	0.1961
Undecane	393.054	661.3568	1.6283	4.0825	1.2613	0.2613	0.8076	0.1924
Decane	390.744	662.0584	1.6379	4.0782	1.2598	0.2598	0.8122	0.1878
Nonane	387.9655	662.8931	1.6496	4.0731	1.2580	0.2580	0.8175	0.1825
Octane	384.5708	663.8998	1.6642	4.0669	1.2558	0.2558	0.8238	0.1762
Heptane	380.2422	665.1629	1.6831	4.0592	1.2529	0.2529	0.8316	0.1684
Hexane	374.5489	666.7905	1.7087	4.0492	1.2492	0.2492	0.8413	0.1587
n-Pentane	366.7855	668.9511	1.7449	4.0362	1.2444	0.2444	0.8544	0.1456
i-pentane	365.2481	669.3712	1.7522	4.0336	1.2433	0.2433	0.8567	0.1433
Nitrogen	407.2603	656.8821	1.5715	4.1103	1.2704	0.2704	0.7773	0.2227
Carbonmonoxide	487.7813	624.0313	1.3121	4.3267	1.3111	0.3111	0.5943	0.4057
i-Butane	350.1018	673.381	1.8280	4.0096	1.2327	0.2327	0.8773	0.1227
n-Butane	355.3345	672.0215	1.8011	4.0177	1.2364	0.2364	0.8705	0.1295
Propane	335.931	676.9349	1.9052	3.9886	1.2228	0.2228	0.8942	0.1058
Methane	279.565	689.491	2.2893	3.9159	1.1828	0.1828	0.9412	0.0588
Ethane	295.4742	686.1761	2.1660	3.9348	1.1943	0.1943	0.9305	0.0695
Benzene	422.6219	651.7015	1.5144	4.1430	1.2802	0.2802	0.7384	0.2616
Hydrogen sulfide	405.5417	657.4387	1.5781	4.1068	1.2693	0.2693	0.7812	0.2188
Average						0.2515		0.1787

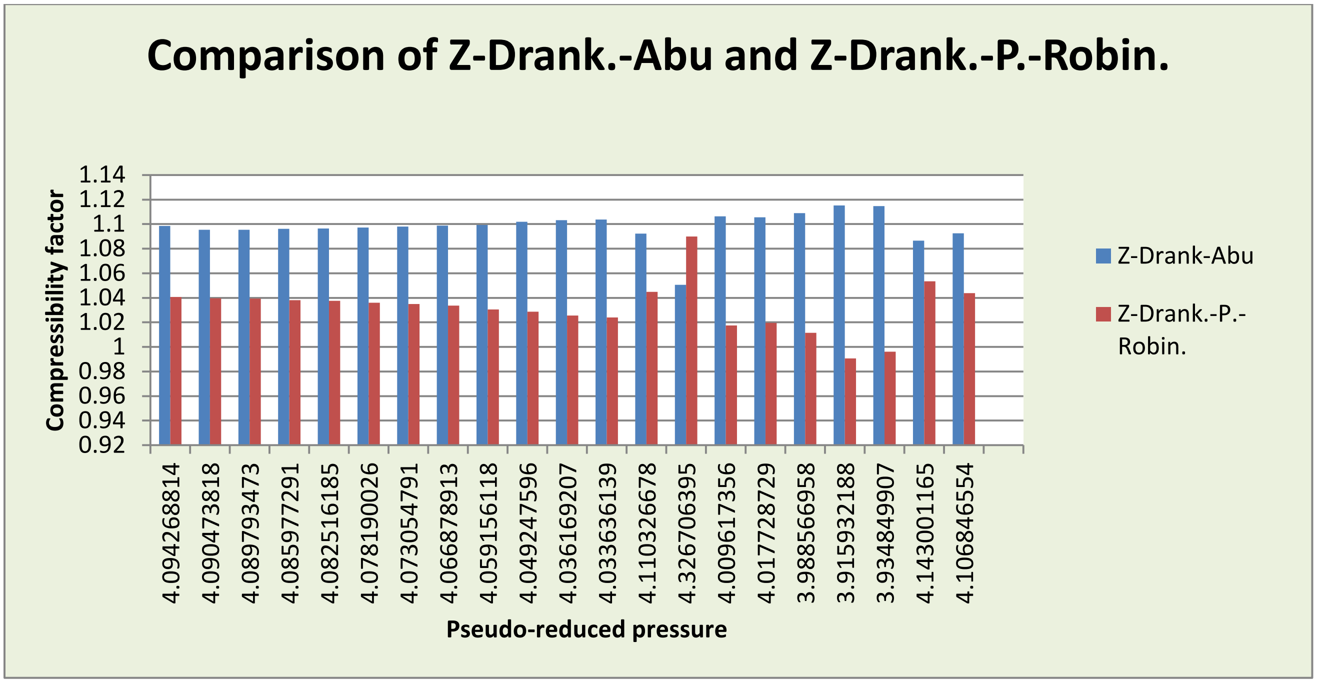

Figure 1: Comparison of the Dranchuk-Abu and the Dranchuk-Purvis-Robinson methods.

Figure 1 above compared the two correlation methods. The comparison shows that the values of compressibility factor predicted by theDranchuk-Purvis-Robinson methods are close to the ideal gas condition (unity) as compared with the values of compressibility factor predicted by the Dranchuk-Abu-Kassem methodswhich show high deviation from ideal condition.

Conclusion

The compressibility factor of natural gas was determined using two different correlation methods which are the Dranchuk-Abu-Kassem and the Dranchuk-Purvis-Robinson correlation method and the results of the study were compared. The correlation methods of predicting gas compressibility factor are easier to use as to compare with the equation of state. Apart from the Dranchuk-Purvis-Robinson correlation methods,the Dranchuk-Abu-Kassem correlation method is more accurate to handle complex fluid among the existing methods. The results show that the Dranchuk-Purvis-Robinson correlation methods give better prediction of compressibility factor values and performed well in the reservoir with an average error percentage of 17.87% as compared with the Dranchuk-Abu-Kassem correlation method with an average error percentage of 25.15% showing high deviation from the ideal gas behavior. The Dranchuk-Purvis-Robinson correlation methods achieved an improvement of 7.28% and give better prediction of the compressibility factor values over the Dranchuk-Abu-Kassem correlation method. This shows that the Dranchuk-Purvis-Robinson method is a modification of the Dranchuk-Abu-Kassem correlation method.

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Nomenclature	
Z	Compressibility factor
P_{pr}	Pseudo-reduced pressure
T_{pr}	Pseudo-reduced temperature
t	Reciprocal of the pseudo-reduced temperature
γ_g	Specific gravity of gas
T_{pc}	Pseudo-critical temperature
P_{pc}	Pseudo-critical pressure