THE INFLUENCE OF PRESSURE AND TEMPERATURE ON THE COMPRESSIBILITY FACTOR

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ABSTRACT

The natural gas compressibility factor indicates the compression and expansion characteristics of natural gas under different conditions. It is a thermodynamic property used to take into account the deviation of the behaviour of real natural gases from that of an ideal gas. Compressibility factor, Z, values of natural gases are necessary for most petroleum gas engineering calculations.

In this study, a comparison between five different calculation methods is presented to determine this critical parameter for the same natural gas at different conditions (pressure and temperature), using Canadian Association of Petroleum Producers, Azizi, Behbahani and Isazadeh, Dranchuk- Purvis- Robinson, Dranchuk-Abu-Kassem and Standing- Katz methods.

The correlations are based on the equation of state are often implicit because they require iteration. Many correlations have been derived to enhance simplicity; however, no correlation has been developed for the entire range of pseudo-reduced pressures and temperatures. Azizi, Behbahani and Isazadeh's method was found to have the biggest error as a result obtained for $T=20^{\circ}\text{C}$, and $p=20\text{ bar}$ is no longer in the field of applicability.

Keywords: gas compressibility factor; correlation; equations of state (EOSs); pressure; temperature;

INTRODUCTION

“Critical insight into the behaviour of natural gas is important to the reservoir and the chemical engineering calculations that deal with gas as one of the main phases. Among the parameters of evaluating the performance of natural gas, the compressibility is of highest importance in the determination of the natural gas phase behaviour.” [3]

The compressibility factor (Z) is a dimensionless coefficient used to modify the thermal equation of state of the ideal gas to correspond to the behaviour of a real gas. In this sense, the compressibility factor can be interpreted as a physical property of gases, its value depending on the pressure, temperature and nature of the gas. The gas compressibility factor is required for gas reservoir engineering calculations which

include the estimation of gas reserves, design of oil and gas separators and design of pipelines for the transmission of produced gas, among others.

In general, the deviation of a gas from the behaviour of the ideal gas becomes significant in the vicinity of the saturation curve (at phase change), or at low temperatures, or at high pressures. The most precise way to determine gas compressibility factor is laboratory analysis, but in the absence of laboratory data correlations are feasible alternatives for estimating the compressibility factor.

The values of the compressibility factor are calculated from the equations of state usually written in viral form, in which the constants are determined empirically. Its values for a given gas can also be extracted from a universal diagram that represents Z as a function of low pressure, having as a parameter the low temperature.

The Z factor, equation (1), is the volume occupied by the amount of gas and the same amount of ideal gas:

$$Z = \frac{V_{actual}}{V_{ideal}} \quad (1)$$

Substituting in the relation of the ideal gas, equation (2) Videal results:

$$PV_{actual} = ZnRT \quad (2)$$

Where P is the pressure, V is the volume, T is the absolute temperature, Z is the compressibility factor, n is the number of kilo-moles of the gas, and R is the gas constant. The gas deviation factor, z , is close to 1 at low pressure and high temperature, which means that the gas behaves like an ideal gas in these conditions. At standard or atmospheric conditions, the gas z factor is always approximately 1.

HISTORY OF THE Z-FACTOR CORRELATIONS

“Probably the most widely accepted correlation for natural gas mixtures is the Standing-Katz (S-K) Z-factor chart” [1]. The S-K chart was developed using data for binary mixtures of methane with propane, ethane, butane, and natural gases having a wide range of composition. Actually, the S-K chart is a continuation and modification of a generalized Z-factor chart developed by Brown and Holcomb (BH). Those two charts are identical at reduced pressures less than 4. Above this value, the BH chart was found to be consistently inaccurate. “Therefore, Standing and Katz used data from 16 natural gas mixtures, along with methane Z-factors as a guide, to extend the chart to reduced pressures of 15.” [2] Since the publication in 1941 of the S-K chart, several correlations have been developed which successfully extended the chart.

Studies of the gas compressibility factors for natural gases of various compositions have shown that compressibility factors can be generalized with sufficient accuracies for most engineering purposes when they are expressed in terms of the following two dimensionless properties:

- Pseudo- reduced pressure
- Pseudo-reduced temperature

As illustrated in Figure 1 The Standing-Katz Correlation correlates the z -factor to the Pseudo-Reduced Pressure, ppr , and Pseudo-Reduced Temperature, Tpr . The pseudo-reduced properties are defined by equations (3) and (4):

$$P_{pr} = \frac{P}{P_{pc}} \quad (3)$$

$$T_{pr} = \frac{T}{T_{pc}} \quad (4)$$

where, P= system pressure, psia

P_{pr} = pseudo- reduced pressure, dimensionless

T= system temperature, °C

T_{pr} = pseudo- reduced temperature, dimensionless

P_{pc} , T_{pc} = pseudo- critical pressure and temperature, respectively, and defined by the following relationships, equations (5)-(6):

$$P_{pc} = \sum_{i=1} y_i P_{ci} \quad (5)$$

$$T_{pc} = \sum_{i=1} y_i T_{ci} \quad (6)$$

In these equations, T_{ci} and P_{ci} provide the values for the critical temperature and pressure of component i. Also, y_i describe the mole fraction of component i.

It should be pointed out that these pseudo- critical properties, i.e., P_{pc} and T_{pc} , do not represent the actual critical properties of the gas mixture. These pseudo proprieties are used as correlating parameters in generating gas properties.

“Natural gases that contain H_2S and or CO_2 frequently exhibit different compressibility-factors behaviour than do sweet gases. Wichert and Aziz (1972) developed a simple, easy-to-use calculation procedure to account for these differences. This method permits the use of the Standing- Katz chart by using a pseudo-critical temperature adjustment factor, which is a function of the concentration of CO_2 and H_2S in the sour gas.”[4] The correction factor resulted is then used for the adjustment of the pseudo-critical parameters (temperature and pressure) according to the following expressions, equation (7) and (8):

$$T'_{pc} = T_{pc} - \varepsilon \quad (7)$$

$$P'_{pc} = \frac{P_{pc} T'_{pc}}{T_{pc} + B(1-B)\varepsilon} \quad (8)$$

where T_{pc} = pseudo- critical temperature, °R

P_{pc} = pseudo- critical pressure, psia

T'_{pc} = corrected pseudo- critical temperature, °R

P'_{pc} = corrected pseudo- critical pressure, psia

B= mole fraction of H_2S in the gas mixture

ε = pseudo-critical temperature adjustment factor and is defined mathematically by the following expression, equation (9):

$$\varepsilon = 120[A^{0.9} - A^{1.6}] + (B^{0.5} - B^{4.0}) \quad (9)$$

where the coefficient A, equation (10), is the sum of the mole fraction H_2S and CO_2 in the gas mixture, or:

$$A = y_{H_2S} + y_{CO_2} \quad (10)$$

GAS COMPRESSIBILITY FACTOR CORRELATIONS

In this present study, the compressibility factor was calculated by using five methods:

a. Canadian Association of Petroleum Producers Method

The calculation equation (11) used for this method is:

$$ZCAaI = \frac{1}{1 + \frac{527383 \cdot (P_{aI} - P_0)_{10}^{1.785 \cdot \delta T g}}{(t_{aI} + T_0)^{3.825}}} = 0.968 \quad (11)$$

b. Azizi, Behbahani and Isazadeh Method

For this method were used the coefficients according to the Table 1 and equations (12)-(17).

Table 1: The Coefficients of Azizi, Behbahani and Isazadeh Method

a	0.037314248539	b	0.014080715149
c	0.016326324539	d	0.030777647882
e	13843575480.94	f	16799138540.76
g	1624178942.65	h	13702270281.09
i	41645509.90	j	237249967625.01
k	24449114791.15	l	19357955749.33
m	-126354717916.61	n	623705678.39
o	17997651104.33	p	151211393445.06
q	139474437997.17	r	-24233012984.10
s	18938047327.52	t	-141401620722.69

$$A = a \cdot T_{pral}^{2.16} + b \cdot P_{pral}^{1.028} + c \cdot P_{pral}^{1.58} \cdot T_{pral}^{-2.1} + d \cdot \ln(T_{pral}^{-0.5}) \quad (12)$$

$$B = e + f \cdot T_{pral}^{2.4} + g \cdot P_{pral}^{1.56} + h \cdot P_{pral}^{0.124} \cdot T_{pral}^{3.033} \quad (13)$$

$$C = i \cdot \ln(T_{pral}^{-1.28}) + j \cdot \ln(T_{pral}^{1.37}) + k \cdot \ln(p_{pral}) + i \cdot \ln(P_{pral}^2) + m \cdot \ln(P_{pral}) \cdot \ln(T_{pral}) \quad (14)$$

$$D = 1 + n \cdot T_{pral}^{5.55} + o \cdot P_{pral}^{0.68} \cdot T_{pral}^{0.33} \quad (15)$$

$$E = p \cdot \ln(T_{pral}^{1.18}) + q \cdot \ln(T_{pral}^{2.1}) + r \cdot \ln(P_{pral}) + s \cdot \ln(P_{pral}^2) + t \cdot \ln(P_{pral}) \cdot \ln(T_{pral}) \quad (16)$$

$$Z_{az} = A + \frac{B+C}{D+E} \quad (17)$$

c. Dranchuk- Purvis- Robinson Method

Dranchuk, Purvis and Robinson (1974) developed a correlation-based the Benedict-Webb-Rubin type of equation of state. The eight coefficients of the proposed equations were optimized by fitting the equation to 1,500 data points from the Standing and Katz Z-Factor chart. The general equation (18) of the method has the following form:

$$Z = 1 + \left(A_1 + \frac{A_2}{T_{pral}} + \frac{A_3}{T_{pral}^3} \right) R_a + \left(A_4 + \frac{A_5}{T_{pral}} \right) R_a^2 + \left(A_5 \cdot \frac{A_6}{T_{pral}} \right) R_a^5 + A_7 \frac{R_a^2}{T_{pral}^3} (1 + A_8 \cdot R_a^2) e^{(-A_8 \cdot R_a^2)} \quad (18)$$

where R_a = reduced gas density, equation (21) and (23)

The coefficients A1 through A8 have the following values:

Table 2 The Coefficients of Dranchuk - Purvis - Robinson Method

A	A value	A	A value
A1	0.31506237	A5	-0.61232032
A2	-1.0467099	A6	-0.10488813
A3	-0.57832729	A7	0.68157001
A4	0.53530771	A8	0.68446549

The method is valid within the following ranges of pseudo-reduced temperature (19) and pressure (20):

$$1,05 \leq T_{pral} \leq 3,0 \quad (19)$$

$$0,2 \leq P_{pral} \leq 3,0 \quad (20)$$

$$R_{a1I} = \frac{0,27 \cdot P_{pral}}{1 \cdot T_{pral}} \quad (21)$$

$$R_{a1I} = 0,059$$

$$Z_{1dprI} = \left[1 + \left[0,31506237 - \frac{1,0467099}{T_{pral}} - \left(\frac{0,57832729}{T_{pral}^3} \right) \right] \cdot R_{a1I} + \left[0,53530771 - \left(\frac{0,6123032}{T_{pral}} \right) \right] \cdot R_{a1I}^2 + \frac{(-0,6123032) \cdot 0,10488813}{T_{pral}} \cdot R_{a1I}^5 \right] + \left[\left(\frac{0,68157001 \cdot R_{a1I}^2}{T_{pral}^3} \right) \cdot (1 + 0,68116519 \cdot R_{a1I}^2) \cdot e^{-(0,68116519 \cdot R_{a1I}^2)} \right] \quad (22)$$

$$R_{a2I} = \frac{0,27 \cdot P_{pral}}{Z_{1dprI} \cdot T_{pral}} \quad (23)$$

$$R_{a2I} = 0,061$$

$$Z_{2dprI} = \left[1 + \left[0,31506237 - \frac{1,0467099}{T_{pral}} - \left(\frac{0,57832729}{T_{pral}^3} \right) \right] \cdot R_{a2I} + \left[0,53530771 - \left(\frac{0,6123032}{T_{pral}} \right) \right] \cdot R_{a2I}^2 + \frac{(-0,6123032) \cdot 0,10488813}{T_{pral}} \cdot R_{a2I}^5 \right] + \left[\left(\frac{0,68157001 \cdot R_{a2I}^2}{T_{pral}^3} \right) \cdot (1 + 0,68116519 \cdot R_{a2I}^2) \cdot e^{-(0,68116519 \cdot R_{a2I}^2)} \right] \quad (24)$$

$$Z_{dpr} = \frac{Z_{1dprI} + Z_{2dprI}}{2} \quad (25)$$

From the general expression of formula (18) resulted equations (22) and (24) and the final value taken into account is that of equation (25).

d. Equation of State, Dranchuk – Abu Kassem for Gas Z Factor calculating.

Dranchuk and Abu-Kassem (1975) derived an analytical expression for calculating the reduced gas density that can be used to estimate the gas compressibility factor.

This is based on the following equations (26)-(31):

$$z = 1 + c_1 * \rho_r + c_2 * \rho_r^2 - c_3 * \rho_r^5 + c_4 \quad (26)$$

Where:

$$\rho_r = \frac{0,27 * \rho_r}{z * T_{pr}} \quad (27)$$

$$c_1 = A_1 + \frac{A_2}{T_{pr}} + \frac{A_3}{T_{pr}^3} + \frac{A_4}{T_{pr}^4} + \frac{A_5}{T_{pr}^5} \quad (28)$$

$$c_2 = A_6 + \frac{A_7}{T_{pr}} + \frac{A_8}{T_{pr}^2} \quad (29)$$

$$c_3 = A_9 * \left(\frac{A_7}{T_{pr}} + \frac{A_8}{T_{pr}^2} \right) \quad (30)$$

$$c_4 = A_{10} * (1 + A_{11} * \rho_r^2) * \left(\frac{\rho_r^2}{T_{pr}^3} \right) - \exp(-A_{11} * \rho_r^2) \quad (31)$$

Table 3 The Coefficients of Dranchuk and Abou-Kassem Method

A	A value	A	A value
A1	0.32650	A7	-0.73610
A2	-1.07000	A8	0.18440
A3	-0.53390	A9	0.10560
A4	0.01569	A10	0.61340
A5	-0.05165	A11	0.72100
A6	0.54750		

e. Standing and Katz Graphical Correlation

This relation is a function of the pseudoreduced pressure, p_r , and pseudoreduced temperature, T_r .

After calculating p_r and T_r , these values are entered in the respective axis, and at the intersection point, it is obtained the Z factor.

Fig. 1 Standing-Katz Correlation for Z-Factors of Hydrocarbon Gases [1]

Table 4 The composition of the gas analyzed

Component	Mole Fraction %
Methane	97.3359
Etan	1.2283
Propane	0.3713
Iso-butane	0.0905
N-butane	0.0902
Iso-pentane	0.0363
N-pentane	0.0241
N-hexane	0.0426
N-heptane	0.0292
N-octane	0.0133
Helium	0.0068
Azote	0.5719
Oxygen	0.0056
Carbon dioxide	0.1538

Table 5 The results obtained for the Z factor

Method	P=15 bar, T=15°C	P=15 bar, T=20°C	P=20 bar, T=20°C	P=20 bar, T=15°C
Azizi, Behbahani and Isazadeh	0.936	0.948	1.006	0.997
Canadian Association of Petroleum Producers	0.9684	0.97	0.961	0.958
Dranchuk-Purvis- Robinson	0.967	0.968	0.958	0.956
Dranchuk and Abu-Kassem	0.942	0.946	0.936	0.931
Standing and Katz Graphical Correlation	0.97	0.975	0.96	0.955

CONCLUSION

The Z-factor is an essential parameter in most petroleum engineering calculations. Accurate measurement and analysis of compressibility factor are significant. The following are the main conclusions that can be withdrawn from this study:

Determination of accurate, critical parameters of mixtures is an essential step in order to obtain precise compressibility factor value.

Following the calculations performed on the same gaseous composition at a pressure of 20 bar and a temperature of 20 °C, the Azizi, Behbahani and Isazadeh method is no longer in the field of applicability as evidenced by the result obtained.

The experimental trend of the gas compressibility factor showed that by increasing the temperature, the Z-factor also increases.

As can be seen from the results obtained, in the first method used, compressibility factor increases with pressure and in the other methods used, it is the other way around.

Regarding the Standing and Katz Graphical Correlation method, it cannot be used

considered very accurate, being a graphical method, which can significantly influence the results obtained.

It can be seen that the values obtained through the Canadian Association of Petroleum Producers, Dranchuk-Purvis-Robinson and the Standing and Katz Graphical Correlation graphical methods resulted in close values. Furthermore, comparing the results obtained with the Azizi, Behbahani and Isazadeh methods and Dranchuk and Abu-Kassem with the 3 methods mentioned above there are differences but not considerable.

The Azizi, Behbahani and Isazadeh and the Dranchuk and Abu-Kassem method have the lowest values of the Z factor at low temperature and pressure, and their results are close, but with the increase of the two factors the results are distant and we have big differences. The other 3 methods have similar results at the same pressure and temperature parameters.

These comparisons indicate the superiority of the Canadian Association of Petroleum Producers, Dranchuk-Purvis-Robinson and Dranchuk and Abu-Kassem methods over the other correlations used to calculate compressibility factor of natural gases.

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