Research Article

Effect of Non-hydrocarbon components on Gas Compressibility Factor Values and Correlations

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Abstract

Gas compressibility factor is necessary in most natural gas engineering calculations. The most common sources of z-factor values are experimental measurements, equation of state and empirical correlations. There are more than twenty correlations available with two variables for calculating the z-factor from fitting Standing-Katz chart values in EOS or through fitting technique. The theory of corresponding states dictates that the Z-factor can be uniquely defined as function of reduced pressure and temperature. Natural gases frequently contain material other than hydrocarbon components, such as nitrogen, carbon dioxide and hydrogen sulfide. Hydrocarbon gases are classified as sweet or sour depending on the hydrogen sulfide content. Both sweet and sour gases may contain nitrogen, carbon dioxide or both. The compositions of most natural gases are hydrocarbon of the same family (paraffin hydrocarbons), so the correlation of this type is possible but containing non-hydrocarbon on the gases, make the prediction difficult. This paper focuses on evaluating the correlations which calculate gas compressibility factor for natural gas reservoirs contains non-hydrocarbon components. It is found that gas pseudo-critical temperature decreases with the increase of N_2 and H_2S. Also, it is observed that in the tested gas reservoirs which contain C_{7+} by Stewart Mixing Rules and Kay's there are some deviation on z factor between two methods that became negligible by using the correction method for non-hydrocarbon.

Introduction

Gas compressibility factor is involved in calculating gas properties such as formation volume factor, density, compressibility and viscosity. All these properties are necessary in the oil and gas industry for evaluating newly discovered gas reservoirs, calculating initial gas reserves, predicting future gas production and designing production tubing and pipelines. The accurate measurement of natural gas related fluids is difficult. The compressibility factor is a ubiquitous concept in measurement. It arises in many industry practices and standard. The industry standard is to measure gas properties, pressure-volume-temperature in the laboratory using reservoir samples. The drawback is that these isothermally measured PVT data is applicable at measures pressure and reservoir temperature. Calculation Methods such as correlations and equation of state are used to predict properties at other pressure and temperature. Also, laboratory analyses for PVT behavior are sometimes expensive and time consuming. Correlations, which are used to predict gas compressibility factor, are much easier and

faster than equation of state. Natural gases frequently contain material other than hydrocarbon components, such as nitrogen, carbon dioxide and hydrogen sulfide. Hydrocarbon gases are classified as sweet or sour depending on the hydrogen sulfide content. Both sweet and sour gases may contain nitrogen, carbon dioxide or both. Sometimes these correlations have comparable accuracy to equation of state. Predicting compressibility factor for gas containing non-hydrocarbon (impurities) is much difficult than that for sweet gas. The compositions of most natural gases are hydrocarbon of the same family (paraffin hydrocarbons), so the correlation of this type is possible but containing non-hydrocarbon on the gases, make the prediction difficult. Therefore, several attempts have been made to predict compressibility factor for sweet gases, Wichert and Aziz and Carr-Kobayashi-Burrows presented correction for the presences of hydrogen sulfide and carbon dioxide for determining the compressibility factor. The objective of this study is evaluating the pervious correlations which calculate gas compressibility factor for gases contain non-hydrocarbon component and observe the effect of these component on Z factor. [1-3]

Correlation

The most common method is to use one of the forms of the principle of corresponding states. In this form, gas compressibility factor is expressed as function of pseudo-reduced pressure and temperature (P_{pr}, T_{pr}). Compressibility factors are function of composition as well as temperature and pressure. Standing and Katz (SK) presented a chart for determining gas compressibility factor based on the principle of corresponding states. The SK chart was prepared for binary mixture of low molecular weight sweet gases. Several mathematical expressions fitting the SK chart have been proposed to calculate the gas compressibility factor. Dranchuk-Abou- Kassem (DK) correlation is the most accurate representation of SK chart. When dealing with gas mixture, the gas mixture is critical pressure (P_{pc}) and temperature (T_{pc}) are required. Critical properties of natural gas are calculated from either gas composition or gas gravity. Several Mixing rules have been proposed to calculate mixture critical properties of natural gases. Among these methods, Kay's mixing rule and stewart-Burkhardt-Voo (SBV) are the most widely used. Kay's mixing rule is simple and provides an accurate determination of gas compressibility factor for sweet gases of low molecular weight. Satter and Campbell evaluated several mixing rules for calculating properties of natural gases. They concluded that Stewart-Burkhardt-Voo rule known as SBV provided the most satisfactory results especially for gases of high molecular weight. Sutton studied the performance of several mixing rule for calculating compressibility factor for gas condensates that contain a large amount of heptanes plus fraction. Sutton modified SBV mixing rule to account for the presence of heptanes plus in the natural gases. Standard laboratory analysis gives composition of natural gases through hexane and lump components heavier than hexane in heptane plus fraction known as C_{7+} critical properties of pure components are well documents as shown table (1).

component	Molecular weight	Molecular weight	Critical Temperature (Ro)
H_2S	34.08	1300	672.45
CO_2	44.01	1071	547.45
N_2	28.01	493	227.27
C_1	16.04	667.8	343.04
C_2	30.07	707.8	549.76
C_3	44.01	616.3	665.68
i-C_4	58.12	529.1	734.65
n-C_4	58.12	550.7	765.32
i-C_5	72.15	490.4	828.77
n-C_5	72.15	488.6	845.37
C_6	86.18	436.9	913.37

Table 1: Physical Properties of defined component.

The critical properties of the C_{7+}, fraction are calculated from correlations using molecular weight and specific gravity of the heptanes plus. Standing presented correlation of pseudo critical properties to gas gravity based on low molecular weight which are:

$$P_{pc} = 706 - 51.7\gamma_g - 11.1\gamma_g^2 \qquad [1]$$

$$T_{pc} = 187 + 330\gamma_g - 71.5\gamma_g \qquad [2]$$

The previous correlation work only when there no non-hydrocarbon gases present on the gases. Sutton developed the following correlation work with high molecular weight of gases.

$$P_{pc} = 756.8 - 131.0\gamma_g - 3.6\gamma_g^2 \qquad [3]$$

$$T_{pc} = 169.2 + 349.5\gamma_g - 74.0\gamma_g^2 \qquad [4]$$

The gases which Suttton used to develop previous correlation were sweet gases with minor amount of carbon dioxide and nitrogen and no hydrogen sulfide. Then, Elsharkawy et al. developed Sutton correlation but will cover heavier hydrocarbons and minor of hydrogen sulfide.

$$P_{pc} = 787.06 - 147.34\gamma_g - 7.916\gamma_g^2 \qquad [5]$$

$$T_{pc} = 149.18 + 345.14\gamma_g - 66.976\gamma_g^2 \qquad [6]$$

Methods of Calculating the Pseudo-Critical Gas Properties

The pseudo-critical properties provide a mean to correlate the physical properties of mixtures with principle of the corresponding states. The principle of corresponding states suggests that pure but similar gases have the same gas deviation or Z factor at the same values of reduced pressure and temperature. The mixture of chemically similar gases can be correlated with reduced temperature and reduced pressure.

There are several methods which are:

1. Mixing Rules developed by Stewart et al and Kay's requires the gas composition to be known.
2. Estimating pseudo-critical properties when the gas composition is not known, developed by Sutton.

The theory corresponding states dictates that the Z-factor can be uniquely defined as function of reduced pressure and temperature. The reduce pressure and temperatures are:

$$T_{pr} = \frac{P}{P_{pc}} \text{ and } P_{pr} = \frac{T}{T_{pc}} \qquad [7]$$

The values of pseudo-critical pressure and temperature can be estimated from the following equations if the composition of the gas and the critical properties of the individual component are Known (kay):

$$T_{pc} = \sum_{i=1}^{n} P_{ci} y_i \text{ and } P_{pc} = \sum_{i=1}^{n} T_{ci} y_i \qquad [8]$$

Procedures for Stewart et al. Mixing Rules

1. Estimate the boiling temperature of the C_{7+} fraction.

$$T_{bc_{7+}} = (4.5579 M_{C_{7+}}^{0.15178} \gamma_{C_{7+}}^{0.15427})^3 \qquad [9]$$

2. Estimate the pseudo-critical pressure of the C_{7+} fraction.

$$P_{pcC_{7+}} = \exp\left[\begin{array}{l} 8.3634 - \frac{0.0566}{\gamma_{C_{7+}}} - \left(0.24244 + \frac{2.2898}{\gamma_{C_{7+}}} + \frac{0.11857}{\gamma_{C_{7+}}^2}\right)\frac{T_{bC_{7+}}}{1000} + \\ \left(1.4685 + \frac{3.648}{\gamma_{C_{7+}}} + \frac{0.47227}{\gamma_{C_{7+}}^2}\right)\frac{T_{bC_{7+}}^2}{10^7} - \left(0.42019 + \frac{1.6977}{\gamma_{C_{7+}}^2}\right)\frac{T_{bC_{7+}}^3}{10^{10}} \end{array} \right] \qquad [10]$$

3. Estimate the pseudo-critical temperature of the C_{7+} fraction.

$$T_{pcC7+} = (341.7 + 811\gamma_{C7+}) + (0.4244 + 0.1174\gamma_{C7+})T_{bC7+} + (0.4669 - 3.2623\gamma_{C7+})\frac{10^5}{T_{bC7+}}$$ [11]

4. Determine the correction factor F_j, ξ_j and ξ_k for high-molecular weight component using Sutton's method.

$$F_j = \frac{1}{3}\left(\frac{yT_c}{P_c}\right)_{C_{7+}} + \frac{2}{3}\left(\frac{y^2T_c}{P_c}\right)_{C_{7+}}$$ [12]

$$\xi_j = 0.6081F_j + 1.1325F_j^2 - 14.004F_j y_{C7+} + 64.434F_j y_{C7+}^2$$ [13]

$$\xi_\kappa = \left(\frac{T_c}{\sqrt{P_c}}\right)_{C_{7+}} (0.3129y_{C_{7+}} - 4.8156y_{C_{7+}}^2 + 27.3751y_{C_{7+}}^3)$$ [14]

5. Obtain the critical pressure and temperature of the remaining component from table (1).

6. Determine the pseudo-critical pressure and temperature of the gas

7. Calculate the parameters J and K

$$J = \frac{1}{3}\sum_{i=1}^{nc}\left(\frac{yT_c}{P_c}\right)_i + \frac{2}{3}\left[\sum_{i=1}^{nc}\left(y\sqrt{\frac{T_c}{P_c}}\right)_i\right]^2 \text{ and } K = \sum_{i=1}^{nc}\left(\frac{yT_c}{\sqrt{P_c}}\right)_i$$ [16]

8. Correct the parameters J and K for the C_{7+} fraction.

$$J' = J - \xi_j$$
$$K' = K - \xi_K$$ [17]

9. Calculated the Pseudo-reduced pressure and temperature by using equation 7.

$$T_{pc} = \frac{K'^2}{J'} \text{ and } P_{pc} = \frac{T_{pc}}{J'}$$ [18]

10. Finding z factor from Standing & Katz compressibility factors figure 1.

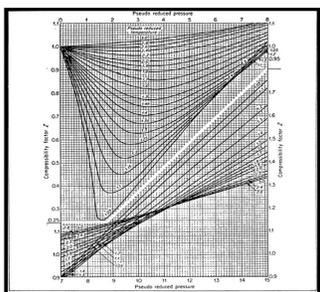11. Finding z factor from Standing & Katz compressibility factors figure 1

Figure 1: Standing and Katz Compressibility Factors Chart. [4]

Procedures for Sutton's correlations of sweet gas

1. Estimate the gas gravity of the mixture
2. Calculate the pseudo-critical pressure and temperature for the hydrocarbon component by using the following equation:

$$P_{pch} = 756.8 - 131.0\gamma_h - 3.6\gamma_h^2$$
$$T_{pch} = 169.2 + 349.5\gamma_h - 74.0\gamma_h^2$$ [16]

3. Ignore the nitrogen contamination, then

$$P_{pc} = P_{pch}$$
$$T_{pc} = T_{pch}$$ [17]

4. Calculated the Pseudo-reduced pressure and temperature from equation 7

5. Finding z factor from Standing & Katz compressibility factors chart

Procedures for Sutton's correlations of Sour gas

1. Determine the gravity of the hydrocarbon components of the Mixture

$$\gamma_h = \frac{\gamma_w - 1.1767y_{H_2S} - 1.5196y_{co_2} - 0.9672y_{N_2} - 0.6220y_{H_2O}}{1 - y_{H_2S} - y_{Co_2} - y_{N_2} - y_{H_2O}}$$

2. Calculate the pseudo-critical pressure and temperature for the hydrocarbon component by using the following equations.

$$P_{pch} = 756.8 - 131.0\gamma_h - 3.6\gamma_h^2$$
$$T_{pch} = 169.2 + 349.5\gamma_h - 74.0\gamma_h^2$$ [19]

3. Calculate the Pesudo-critical properties of the total mixture.

$$P_{pc} = (1 - y_{H_2S} - y_{CO2} - y_{N_2} - y_{H_2O})P_{pch} + 1,306y_{H_2S}$$
$$+ 1,071y_{CO_2} + 493.1y_{N_2} + 3200.1y_{H_2O}$$
$$T_{pc} = (1 - y_{H_2S} - y_{CO_2} - y_{N_2} - y_{H_2O})T_{pch} + 672.35y_{H_2S}$$
$$+ 547.58y_{CO_2} + 227.16y_{N_2} + 1164.9y_{H_2O}$$ [20]

Methods of Correction the Pseudo-Critical Gas Properties for H_2S and CO_2 contamination.

Natural gases, which contain H_2S and CO_2 frequently, exhibit different compressibility factor behavior than do sweet gases. Wichert and Aziz developed a simple, easy to use calculation procedure to account for these differences.

Wichert-Aziz Correction Method

This method permits the use of the standing-Katz chart, by using a pseudo-critical temperature adjustment factor, which is function of the concentration of CO_2 and H_2S in the sour gas. The following Wichert and Aziz correlation is also can obtain from figure 2:
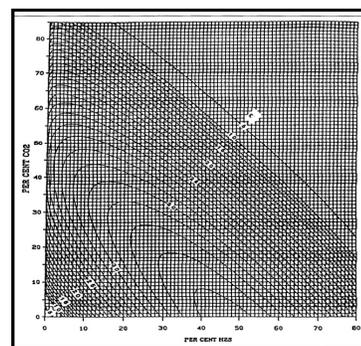

Figure 2: Show the pseudo-critical property correction for H_2S and CO_2. [4]

$$\xi = 120(A^{0.9} - A^{1.6}) + 15(B^{0.5} - B^4)$$ [20]

Where the pseudo-critical temperature, T'pc and pressure P'pc, adjusted for CO_2 and H_2S contamination are:

$$T'_{pc} = T_{pc} - \xi$$
$$P'_{pc} = \frac{T'_{pc}P_{pc}}{[T_{pc} + B(1-B)\xi]}$$ [21]

Where,

A: Sum of the mole fractions of H_2S and CO_2 in the gas mixture
B: Mole fraction of H_2S in the gas mixture.

Methods of Correction the Pseudo-Critical Gas Properties for N_2 and H_2O vapor contamination

Carr-Kobayashi and Burrows developed a simple procedure to adjust the pseudo-critical properties of natural gases when non-hydrocarbon components are present. [4-7]

Carr-Kobayashi and Burrows Correction Method

The procedures to obtain the correction are following:

Known the specific gravity of the natural gas, calculate the pseudo-critical temperature and pressure from figure 3.
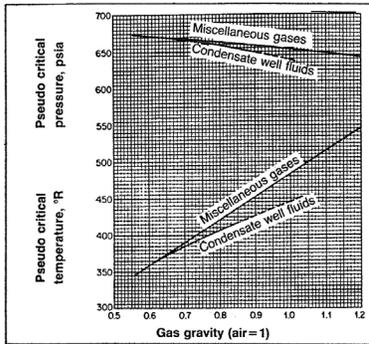

Figure 3: Show the pseudo-critical property of natural gases. [4]

1. or by the following equation:

$$T_{pc} = 168 + 325\gamma_g - 12.5\gamma_g^2$$
$$P_{pc} = 677 + 15\gamma_g - 37.5\gamma_g^2 \qquad [22]$$

2. Calculate the corrections for nitrogen and water vapor.

$$T_{pc,cor} = -246.1y_{N2} + 400y_{H2O}$$
$$P_{pc,cor} = -162.0y_{N2} + 1270y_{H2O} \qquad [23]$$

3. Calculate the pseudo-critical temperature and pressure for nitrogen and water vapor.

$$T_{pc}^{''} = \frac{T_{pc}^{'} - (227.2)y_{N2} - (1,165)y_{H2O}}{(1 - y_{N2} - y_{H2O})} + T_{pc,cor}$$

$$P_{pc}^{''} = \frac{P_{pc}^{'} - (493.1)y_{N2} - (3,200)y_{H2O}}{(1 - y_{N2} - y_{H2O})} + P_{pc,cor}$$

Where,

T'Pc and P'pc are the pseudo-critical temperature and pressure corrected for H_2S and CO_2 with wichert and Aziz correlation.

4. If there is no H_2S or CO_2 in the gas mixture, then T'p=Tpc and P'pc=Ppc.

Results and Discussion

The data are analyzed and Stewart method and Kay's mixing rules for predicting pseudo-reduce pressure and temperatures are used for these data with knowing composition. Moreover, according to present of non-hydrocarbon on the data I used the correction methods which are Wichert- Aziz and Carr-Kobayashi and Burrows

The data of three reservoirs (A,B,C) with water vapor, carbon dioxide and hydrogen sulfide but with light molecular weight while ,the others (D,E,F) have C_{7+} and without water vapor are shown in table 2.

	A	B	C	D	E	F
Pressure(psia)	6000	5200	5000	4010	2640	2748
Temperature (Ro)	673.8	657.6	657.6	711.6	672	690
C_1	59.59	69.14	57.95	57.95	61.83	40
C_2	0.02	2.27	0.1	12.59	7.7	11.93
C_3	0.01	1.96	0	7.94	7.63	14
i-C_4	0	0.46	0	1.13	1.73	4.7
n-C_4	0	1.46	0	3.16	4.38	7.37
i-C_5	0	0	0	1.42	2.38	2.38
n-C_5	0	0	0	2.01	2.6	5.6
C_6	0	0	0	2.18	4.34	7.54
C_{7+}	0	0	0	4.54	6.87	5.93
CO_2	12.59	7.9	9.05	3.9	0.3	0.34
N_2	11.95	0.1	6.35	0.2	0.24	0.21
H_2S	12.09	13.03	9.44	2.98	0	0
H_2O	3.75	3.68	3.74	0	0	0

Table 2: Six different reservoir in Abu-Dhabi.

So I used Stewart et al. Mixing Rules and Kays, The calculation and result for six reservoir are appear in tables 3 to14.

Table 3: Reservoir A using Kay's Rule at P=6000 psi and T=673.8 R^0

component	Y_i	M_i	Y_iM_i	T_{ci}	Y_iT_{ci}	P_{ci}	Y_iP_{ci}
CO_2	0.1259	44	5.5396	547.6	68.94284	1071	134.8389
N_2	0.1198	28	3.3544	239.3	28.66814	507.5	60.7985
H_2S	0.1209	34	4.1106	672.35	81.287115	1306	157.8954
H_2S	0.0375	18	0.675	1164.85	43.681875	3200.1	120.00375
C_1	0.5956	16	9.5296	343	204.2908	666.4	396.90784
C_2	0.0002	30	0.006	549.6	0.10992	706.5	0.1413
C_3	0.0001	45	0.0045	665.7	0.06657	616	0.0616
i-C_4	0	58	0	734.1	0	527.9	0
n-C_4	0	58	0	765.3	0	550.6	0
Total	1		23.2197		427.04726		870.64729

Table 4: Reservoir B using Kay's Rule at P=5200psi and T=657.6 R^0

component	Y_i	M_i	Y_iM_i	T_{ci}	Y_iT_{ci}	P_{ci}	Y_iP_{ci}
CO_2	0.079	44	3.476	547.6	43.2604	1071	84.609
N_2	0.001	28	0.028	239.3	0.2393	507.5	0.5075
H_2S	0.1303	34	4.4302	672.35	87.607205	1306	170.1718
H_20	0.0368	18	0.6624	1164.85	42.86648	3200.1	117.76368

C_1	0.6914	16	11.0624	343	237.1502	666.4	460.74896
C_2	0.0227	30	0.681	549.6	12.47592	706.5	16.03755
C_3	0.0196	45	0.882	665.7	13.04772	616	12.0736
i-C_4	0.0046	58	0.2668	734.1	3.37686	527.9	2.42834
n-C_4	0.0146	58	0.8468	765.3	11.17338	550.6	8.03876
Total	1		22.3356		451.19747		872.37919

Table 5: Reservoir C using Kay's Rule at P=5000psi and T=657.6 R^0

component	Y_i	M_i	Y_iM_i	T_{ci}	Y_iT_{ci}	P_{ci}	Y_iP_{ci}
CO_2	0.0905	44	3.982	547.6	49.5578	1071	96.9255
N_2	0.0635	28	1.778	239.3	15.19555	507.5	32.22625
H_2S	0.0944	34	3.2096	672.35	63.46984	1306	123.2864
H_2O	0.0374	18	0.6732	1164.85	43.56539	3200.1	119.68374
C_1	0.7132	16	11.4112	343	244.6276	666.4	475.27648
C_2	0.001	30	0.03	549.6	0.5496	706.5	0.7065
C_3	0	45	0	665.7	0	616	0
i-C_4	0	58	0	734.1	0	527.9	0
C_5	0	72	0	828.77	0	490.4	0
Total	1		21.084		416.96578		848.10487

Table 6: Properties and Compressibility factor for the three Reservoirs.

	A	B	C
P_{Pc}	870.647	872.379	848.105
T_{Pc}	427.047	451.197	416.966
P_{Pr}	6.891	5.961	5.895
T_{Pr}	1.578	1.457	1.577
Z	0.928	0.848	0.872
T_{pc}'	400.563	426.246	394.149
T_p''	376.709	412.673	373.208
P_p''	778.462	774.854	756.788
T_r	1.789	1.594	1.762
P_r	7.708	6.711	6.607
z	1.004	0.920	0.946

Table 7: Reservoir D using Stewart Mixing Rules.

component	Y_i	M_i	Y_iM_i	$T_{ci}(^0R)$	P_{ci} (psia)	$\frac{Y_iT_{ci}}{P_{ci}}$	$Y_i\sqrt{T_{ci}P_{ci}}$	$\frac{Y_i}{T_{ci}/\sqrt{P_{ci}}}$
N_2	0.002	28.01	0.06	227.16	493.10	0.00	0.00	0.02
CH_4	0.5795	16.04	9.30	343.00	666.40	0.30	0.42	7.70
C_2H_6	0.1259	30.07	3.79	549.59	706.50	0.10	0.11	2.60
C_3H_8	0.0794	44.10	3.50	665.73	616.00	0.09	0.08	2.13
i-C_4H_{10}	0.0113	58.12	0.66	734.13	527.90	0.02	0.01	0.36
n-C_4H_{10}	0.0316	58.12	1.84	765.29	550.60	0.04	0.04	1.03
i-C_5H_{12}	0.0142	72.15	1.02	828.77	490.40	0.02	0.02	0.53
n-C_5H_{12}	0.0201	72.15	1.45	845.47	488.60	0.03	0.03	0.77

C_6H_{14}	0.0218	86.18	1.88	913.27	436.90	0.05	0.03	0.95
C_{7+}	0.0454	114.23	5.19	1005.30	375.50	0.12	0.07	2.36
CO_2	0.039	44.01	1.72	547.45	1071.00	0.02	0.03	0.65
H_2S	0.0298	34.00	1.01	672.35	1306.00	0.02	0.02	0.55
Σ	1		30.39			0.80	0.86	19.66

Table 8: Reservoir E using Stewart Mixing Rules.

component	Y_i	M_i	Y_iM_i	$T_{ci}(^0R)$	P_{ci} (psia)	$\frac{Y_iT_{ci}}{P_{ci}}$	$Y_i\sqrt{T_{ci}P_{ci}}$	$\frac{Y_i}{T_{ci}/\sqrt{P_{ci}}}$
N_2	0.0024	28.01	0.07	227.16	493.10	0.00	0.00	0.02
CH_4	0.6183	16.04	9.92	343.00	666.40	0.32	0.44	8.22
C_2H_6	0.077	30.07	2.32	549.59	706.50	0.06	0.07	1.59
C_3H_8	0.0763	44.10	3.36	665.73	616.00	0.08	0.08	2.13
i-C_4H_{10}	0.0173	58.12	1.01	734.13	527.90	0.02	0.02	0.55
n-C_4H_{10}	0.0438	58.12	2.55	765.29	550.60	0.06	0.05	1.43
i-C_5H_{12}	0.0238	72.15	1.72	828.77	490.40	0.04	0.03	0.89
n-C_5H_{12}	0.026	72.15	1.88	845.47	488.60	0.04	0.03	0.99
C_6H_{14}	0.0434	86.18	3.74	913.27	436.90	0.09	0.06	1.90
C_{7+}	0.0687	114.23	7.85	1005.30	375.50	0.18	0.11	3.56
CO_2	0.003	44.01	0.13	547.45	1071.00	0.00	0.00	0.05
Σ	1		34.40			0.91	0.91	21.26

Table 9: Reservoir F using Stewart Mixing Rule.

component	Y_i	M_i	Y_iM_i	$T_{ci}(^0R)$	P_{ci} (psia)	$\frac{Y_iT_{ci}}{P_{ci}}$	$Y_i\sqrt{T_{ci}P_{ci}}$	$\frac{Y_i}{T_{ci}/\sqrt{P_{ci}}}$
N_2	0.00	28.01	0.06	227.16	493.10	0.00	0.00	0.02
CH_4	0.40	16.04	6.42	343.00	666.40	0.21	0.29	5.31
C_2H_6	0.12	30.07	3.59	549.59	706.50	0.09	0.11	2.47
C_3H_8	0.14	44.10	6.17	665.73	616.00	0.15	0.15	3.76
i-C_4H_{10}	0.05	58.12	2.73	734.13	527.90	0.07	0.06	1.50
n-C_4H_{10}	0.07	58.12	4.28	765.29	550.60	0.10	0.09	2.40
i-C_5H_{12}	0.02	72.15	1.72	828.77	490.40	0.04	0.03	0.89
n-C_5H_{12}	0.06	72.15	4.04	845.47	488.60	0.10	0.07	2.14
C_6H_{14}	0.08	86.18	6.50	913.27	436.90	0.16	0.11	3.29
C_{7+}	0.06	114.23	6.77	1005.30	375.50	0.16	0.10	3.08
CO_2	0.00	44.01	0.15	547.45	1071.00	0.00	0.00	0.06
Σ	1.00		42.43			1.07	0.99	24.92

Table 10: Properties and Compressibility factor for the three Reservoirs.

	D	E	F
F_j	0.044	0.070	0.059
E_j	0.007	0.002	0.004
E_k	0.355	0.397	0.380
J	0.762	0.851	1.017
K	19.660	21.256	24.924
J'	0.756	0.849	1.013
K'	19.305	20.859	24.544

T_{pc}	493.256	512.496	594.900
P_{pc}	652.851	603.662	587.495
T_{pc}'	481.534	511.864	594.193
P_{pc}'	636.898	602.917	586.797
T_p''	493.263	511.958	594.448

Table 11: Reservoir D using Kay's Mixing Rules.

Component	Y_i	M_i	$T_{ci}(^0R)$	$P_{ci}(psia)$	Y_iT_{ci}	Y_iP_{ci}
N_2	0.002	28.0	227.2	493.1	0.5	1.0
CH_4	0.580	16.0	343.0	666.4	198.8	386.2
C_2H_6	0.126	30.1	549.6	706.5	69.2	88.9
C_3H_8	0.079	44.1	665.7	616.0	52.9	48.9
$i-C_4H_{10}$	0.011	58.1	734.1	527.9	8.3	6.0
$n-C_4H_{10}$	0.032	58.1	765.3	550.6	24.2	17.4
$i-C_5H_{12}$	0.014	72.2	828.8	490.4	11.8	7.0
$n-C_5H_{12}$	0.020	72.2	845.47	488.6	17.0	9.8
C_6H_{14}	0.022	86.2	913.3	436.9	19.9	9.5
C_{7+}	0.045	114.2	1005.3	375.5	45.6	17.0
CO_2	0.039	44.0	547.5	1071.0	21.4	41.8
H_2S	0.030	34.0	672.4	1306.0	20.0	38.9
$\sum$	1.000		8097.5	7728.9	489.5	672.4

Table 12: Reservoir E using Kay's Mixing Rules.

Component	Y_i	M_i	$T_{ci}(^0R)$	$P_{ci}(psia)$	Y_iT_{ci}	Y_iP_{ci}
N_2	0.0024	28.0	227.2	493.1	0.5	1.2
CH_4	0.6183	16.0	343.0	666.4	212.1	412.0
C_2H_6	0.077	30.1	549.6	706.5	42.3	54.4
C_3H_8	0.0763	44.1	665.7	616.0	50.8	47.0
$i-C_4H_{10}$	0.0173	58.1	734.1	527.9	12.7	9.1
$n-C_4H_{10}$	0.0438	58.1	765.3	550.6	33.5	24.1
$i-C_5H_{12}$	0.0238	72.2	828.8	490.4	19.7	11.7
$n-C_5H_{12}$	0.026	72.2	845.5	488.6	22.0	12.7
C_6H_{14}	0.0434	86.2	913.3	436.9	39.6	19.0
C_{7+}	0.0687	114.2	1005.3	375.5	69.1	25.8
CO_2	0.003	44.0	547.5	1071.0	1.6	3.2
$\sum$	1		7425.2	6422.9	504.0	620.2

Table 13: Reservoir F using Kay's Mixing Rules.

Component	Y_i	M_i	$T_{ci}(^0R)$	$P_{ci}(psia)$	Y_iT_{ci}	Y_iP_{ci}
N_2	0.0021	28.0	227.2	493.1	0.5	1.0
CH_4	0.4	16.0	343.0	666.4	137.2	266.6
C_2H_6	0.1193	30.1	549.6	706.5	65.6	84.3
C_3H_8	0.14	44.1	665.7	616.0	93.2	86.2
$i-C_4H_{10}$	0.047	58.1	734.1	527.9	34.5	24.8
$n-C_4H_{10}$	0.0737	58.1	765.3	550.6	56.4	40.6
$i-C_5H_{12}$	0.0238	72.2	828.8	490.4	19.7	11.7

$n-C_5H_{12}$	0.056	72.2	845.5	488.6	47.3	27.4
C_6H_{14}	0.0754	86.2	913.3	436.9	68.9	32.9
C_{7+}	0.0593	114.2	1005.3	375.5	59.6	22.3
CO_2	0.0034	44.0	547.5	1071.0	1.9	3.6
$\sum$	1		6877.7	5351.9	584.8	601.4

Table 14: Properties and Compressibility factor for the three Reservoirs.

From calculation, it is found that gas pseudo-critical temperature decrease with increase of N_2 as shown in figure 4.
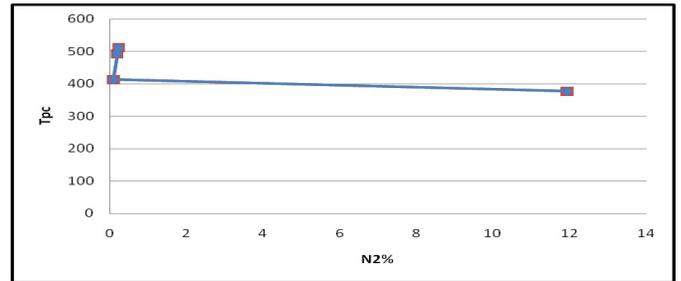

Figure 4: show the mole percent of nitrogen verses pseudo-critical temperature.
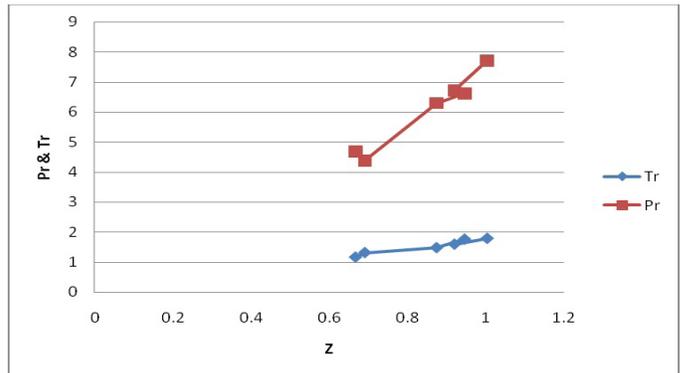

Figure 6: show the Z-factor verses pseudo-reduce temperature & pressure.

Moreover, pseudo-critical temperature with increasing H_2S is decreases with limitation as shown in figure 7.
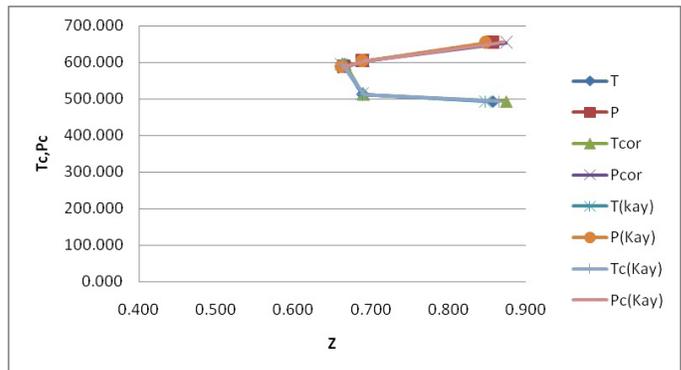

Figure 7: show the mole percent of H_2S verses pseudo-critical temperature.

Then slightly increase with increase temperature maybe it related to the behavior of H_2S in reservoir.

In addition, gas pseudo-critical pressure increase with increase N_2 and H_2S as shown in figure 5,8. Also, it is observed that in the tested gas reservoirs which contain C_{7+} by Stewart Mixing Rules and Kay's there are some deviation on z factor between two methods that became negligible by using the correction method for non-hydrocarbon as shown in figure 8 and table 10,14.
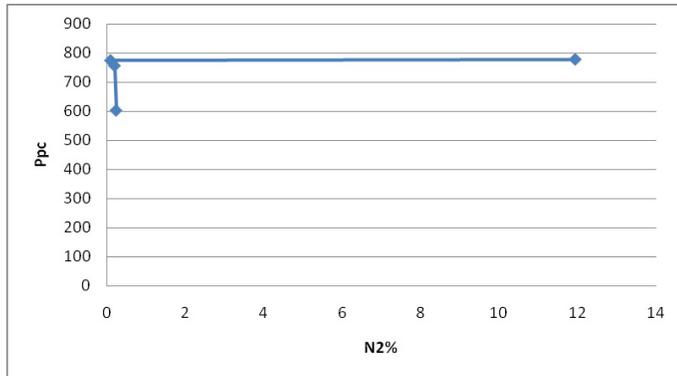

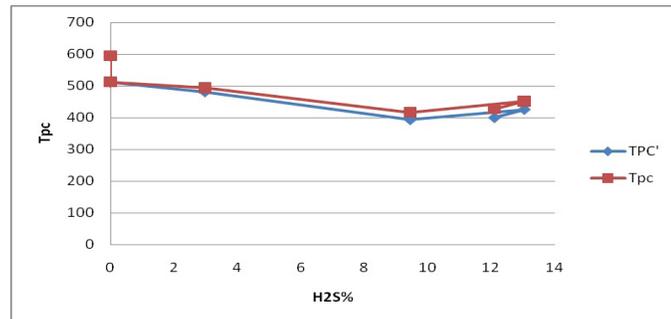**Figure 5:** show the mole percent of nitrogen verses pseudo-critical Pressure.

Figure 8: Z-factor obtained from Stewart & Kay and correction with impurities verses pseudo-critical temperature& pressure.

	D	E	F
F_j	0.044	0.070	0.059
E_j	0.007	0.002	0.004
E_k	0.355	0.397	0.380
J	0.762	0.851	1.017
K	19.660	21.256	24.924
J'	0.756	0.849	1.013
K'	19.305	20.859	24.544
T_{pc}	493.256	512.496	594.900
P_{pc}	652.851	603.662	587.495
T_{pc}	481.534	511.864	594.193
P_{pc}	636.898	602.917	586.797
T_p"	493.263	511.958	594.448
P_P"	653.206	602.792	586.654

T_r	1.478	1.313	1.161
P_r	6.296	4.379	4.684
Z	0.874	0.690	0.666

Table 10: Properties and Compressibility factor for the three Reservoirs.

	D	E	F
T_{pc}	489.453	504.005	584.759
P_{pc}	672.432	620.215	601.395
T_{pc}	477.731	503.373	584.052
P_{pc}	655.874	619.437	600.668
T_p"	477.741	503.446	584.759
P_P"	655.876	619.352	601.395
T_r	1.490	1.335	1.181
P_r	6.114	4.263	4.576
Z	0.865	0.691	0.663

Table 14: Properties and Compressibility factor for the three Reservoirs.

Conclusion

Natural gases, which contain H_2S and CO_2 frequently, exhibit different compressibility factor behavior than do sweet gases. Wichert and Aziz & Carr-Kobayashi and Burrows developed a simple procedure to account for these differences and adjust the pseudo-critical properties of natural gases. During this study, I observe that pseudo-critical temperature decreases if the mole percent of N_2 increase. While, pseudo-critical pressure was increase with increasing the percentage of nitrogen. Also, the z factor increases with increasing pseudo- reduce pressure and temperature. In addition, pseudo-critical temperature decreases if the mole percent of H_2S increase. I also notice that when I calculate the z-factor for reservoirs which contain C_{7+} by Stewart Mixing Rules and Kay's there are some deviation on z factor between two methods but it reduces when I used the correction method for non-hydrocarbon.

Nomenclature

A: Mole fraction (H_2S+CO_2)

B: Mole fraction of H_2S

P: pressure, psia

P_c: critical pressure, psia

P_{pr}: pseudo-reduced pressure

P_{pc}: pseudo-critical pressure, psia

P_{pc}': corrected pseudo- critical pressure, psia

T: Temperature, R^0

T_c: critical temperature, R^0

T_{pr}: pseudo-reduced temperature, R^0

T_{pc}: Pseudo-critical temperature, R^0

T_{pc}': corrected pseudo-critical temperature, R^0

ε: pseudo-critical temperature adjustment factor

CO_2: Carbon Dioxide

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