Estimation of Natural Gas Compressibility Factors Using Mathematical Correlations For Sirte Oil Fields

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Abstract:

Knowledge of the pressure-volume-temperature (PVT) behavior of natural gases is necessary to solve many petroleum engineering problems. Gas reserves, gas metering, gas pressure gradients, pipeline flow and compression of gases are some of the problems requiring the gas compressibility factor, or Z factor. Typically, the Z factor is determined by laboratory measurement. However, laboratory data is only applicable for the conditions and condition investigated. When conditions

of interest are different from those of the laboratory studies or data is not available, correlations must be used.

This study has been conducted on four gas fields of Sirte Oil Company, namely Zeltinfield, Al Ragouba field, Al Hotayba field and Al Braiga field. The Z factor has been calculated for the different fields using mathematical correlations and charts through the calculations of pseudocritical and pseudoreducedtemperatureT_{pr} and pressureP_{pr}. The values obtained are corrected because the natural gases contain impurities(H_2S, CO_2, N_2) that caused factor deviation. The results exhibit some variation due the different constituents of gas mixture.

Key words: Natural gas, compressibilityfactor, pseudocritical temperature, pseudocriticalpressure,pseudoreduced temperature, pseudoreduced pressure, correlations, equation of state.

1. Introduction

Basically the magnitude of deviation of real gases from the conditions of the ideal gas law increases with increasing pressure and temperature and varied widely with the composition of the gas. Real gases behave differently than ideal gases. The reason for this is the perfect gas law was derived under the assumption that the volume of molecules is insignificant and no molecular attraction or repulsion exist between them. This is not the case of real gases[1].

Numerous equationsofstate have been developed in the attempt to correlate the pressure-volume-temperature variables for real gases with

experimental data. More recent equations-of-state are suggested. In order to express a more exact relationship between the variables P, V and T, a correction factor called the gas compressibility factor, gas deviation factor, or simply the Z-factor, must be introduced into the general equation of gases to account for departure gases from ideality. The compressibility factor Z is a dimensionless quantity and is defined as the ratio of actual volume of n-moles of gas at T and P to the ideal volume of the same number of moles at the same T and P.

For a perfect gas, the compressibility factor Z is equal to one. For a real gas, the Z-factor is greater or less than one depending on the pressure, temperature and the composition of the gas.

The value of Z at any given pressure and temperature can be determined experimentally by measuring the actual volume of some quantity of gas at the specified P and T.

It is commonly known that natural gas owns compressibility. When subjected to the reservoir pressure and temperature, the natural gas is in compression. However, various parameters of it undergo gradual changes at any stage of its flowing course which involves the underground percolation in formation and the wellbore flowing, resulting from the pressure drop and volume expansion. State equations are commonly used for gas to indicate its change in state (pressure P, volume V, and temperature T), and some high-pressure physical parameters which arequite practical in engineering are also introduced, for example, volume factor, isothermal compressibility, and viscosity ratio[1].

The basic methods for estimating the gas compressibility factor are well known. The principle of corresponding states, kay'spseudocritical point, and the standing and kay's chart are commonly used. If the composition of the gas is known, the pseudocritical temperature T_{pc} and pressure P_{pc} may be calculated using Kay's rules-molar averages of the critical properties of the mixture's components. Otherwise, the pseudocritical temperature and pressure may be calculated using correlation based on gas specific gravity. The pseudo reduced temperature T_{pr} and pressure P_{pr} may be calculated and the equation of state may be used to determine the Z factor.

2. Composition of Natural Gas

Generally, natural gas is flammable or inflammable gaseous mixtures of hydrocarbons and non-hydrocarbons, extracted from the underground, at normal temperature and pressure.

3. Classification of Natural Gas

Narrowly speaking, natural gas can be classified into different types:

(1) According to the essential features of the deposits: The natural gas can be ranged into two types: oil reservoir associated gas and gas from gas reservoir. The former one is dissolved in crude oil at the reservoir condition and released from oil as pressure drops. The later one, gas from gas reservoir, is in a gaseous state in the underground formations and includes two types named pure gas and condense gas, respectively. The principal constituent of the gas in pure gas reservoirs is

methane, with some others such as ethane, propane, and butane. The gas from gas-condensate reservoir, on analysis of the effluent at the oil wellhead, contains not only methane, ethane, propane and butane, but also some liquid C_{5+} hydrocarbons between C_7 and C_{11}.

(2) According to the composition, natural gas can be described in two ways: dry gas and wet gas, or poor gas and rich gas [1].

Dry gas: The content of liquid C_{5+} heavy hydrocarbons in wellhead effluent is less than 13.5 cm^3/m^3 at standard temperature and pressure.

Wet gas: On analysis of the wellhead effluents, which are subjected to standard temperature and pressure, the content of liquid C_{5+} heavy hydrocarbons is more than 13.5 cm^3/m^3.

Poor gas: On analysis of the wellhead effluents, which are subjected to standard temperature and pressure, the content of liquid C_{3+} heavy hydrocarbons is less than94 cm^3/m^3.

Rich gas: On analysis of the wellhead effluents, which are subjected to standard temperature and pressure, the content of liquid C_{3+} heavy hydrocarbons is morethan 94 cm^3/m^3.

(3) According to the content of the acidic gases such as H_2S and CO_2:

Sour natural gas contains significant amount of acidic gases such as H_2S and CO_2. This kind of natural gases is required to be processed and clarified to reach the standards for pipeline transportation.

Clean natural gas is also named as sweet gas. This kind of natural gas contains very minor amount of acidic gases, and the cleaning (purification) treatment is not required for it.

3. Properties of Natural Gas

Properties of natural gas include gas-specific gravity, pseudocritical pressure and temperature, viscosity, compressibility factor, gas density, and gas compressibility. Knowledge of these property values is essential for designing and analyzing natural gas production and processing systems. Because natural gas is a complex mixture of light hydrocarbons with a minor amount of inorganic compounds, it is always desirable to find the composition of the gas through measurements. Once the gas composition is known, gas properties can usually be estimated using established correlations with confidence.

3.1. Specific Gravity

Gas-specific gravity (γ_g) is defined as the ratio of the apparent molecular weight of a natural gas to that of air, itself a mixture of gases. The molecular weight of air is usually taken as equal to 28.97 (approximately 79% nitrogen and 21% oxygen). Therefore the gas gravity is[2]:

$$\gamma_g = \frac{M\,W_a}{28.97} \qquad (1)$$

where

γ_g = Specific gravity of gas.

MW_g = molecular weight of gas mixture

MW_{air} = molecular weight of air (air=28.97)

Where the apparent molecular weight of gas can be calculated based on gas composition. Gas composition is usually determined in alaboratory and reported in mole fractions of components in the gas. Let y_i be the mole fraction of component *i,* the apparent molecular weight of the gas can be formulated using mixing rule as [2]:

$$MW_a = \sum_{i=1}^{N_c} y_i MW_i \qquad (2)$$

where MW_i is the molecular weight of component i, and N_c is the number of components. The molecular weights of compounds *(MW_i)* can be found in textbooks on organic chemistry or petroleum fluids such as that by McCain[2]. A light gas reservoir is one that contains primarily methane with some ethane. Pure methane would have a gravity equal to $(16.04/28.97) = 0.55$. A rich or heavy gas reservoir may have a gravity equal to 0.75 or, in some rare cases, higher than 0.9[2].

Similar to gas apparent molecular weight, the critical properties of a gas can be determined on the basis of the critical properties of compounds in the gas using the mixing rule. The gas critical properties determined in such a way are called pseudocritical properties. Gas pseudocritical pressure *(p_{pc})* and pseudocritical temperature *(T_{pc})* are, respectively, expressed as[3]:

$$P_{pc} = \sum_{i=1}^{N_c} y_i P_{ci} \qquad (3)$$

and

$$T_{pc} = \sum_{i=1}^{N_c} y_i T_{ci} \qquad (4)$$

Where: P_{ci} and T_{ci} are critical pressure and critical temperature of component i, respectively.

If the gas composition is not known but gas-specific gravity is given, the pseudocritical pressure and temperature can be determined from various charts or correlations developed based on the charts. One set of simple correlations is [3]:

$$p_{pc} = 709.604 - 58.718 (5)$$

$$T_{pc} = 170.491 - 307.344 \gamma_g \qquad (6)$$

which are valid for $H_2S < 3\%$, $N_2 < 5\%$, and total content of inorganic compounds less than 7%.

3.2. Compressibility Factor (Z)

Gas compressibility factor is also called deviation factor, or Z-factor. Its value reflects how much the real gas deviates from the ideal gas at given pressure and temperature. Definition of the compressibility factor is expressed as [4].

$$z = \frac{V_{actual}}{V_{ideal\ gas}} \qquad (7)$$

Introducing the Z-factor to the gas law for ideal gas results in the gas law for real gas as:

$$pV = nzRT \qquad\qquad (8)$$

Where *n* is the number of moles of gas. When pressure *p* is entered in psia, volume V in ft^3, and temperature in ^{0}R, the gas constant R is equal to R=10.73 psia-ft^3/Mole-°R[4]:

The gas compressibility factor can be determined on the basis of measurements in PVT laboratories. For a given amount of gas, if temperature is kept constant and volume is measured at 14.7 psia and an elevated pressure P$_1$, z-factor can then be determined with the following formula [4].

$$z = \frac{P_1}{14.7}\frac{V_1}{V_0} \qquad\qquad (9)$$

Where V$_o$ and V$_1$ are gas volumes measured at 14.7 psia and P$_l$ respectively.

Very often the Z-factor is estimated with the chart developed by Standing and Katz[5]. This chart has been set up for computer solution by a number of individuals. yield Z-factor values accurate enough for many engineering calculations. Brill and Beggs' Z-factor correlation is expressed as follows[4]:

$$A = 1.39(T_{pr} - 0.92)^{0.5} - 0.36T_{pr} - 0.10 \qquad\qquad (10)$$

$$B = (0.62 - 0.23T_{pr})P_{pr} + \left(\frac{0.066}{T_{pr} - 0.86} - 0.037\right)P_{pr}^2$$
$$+ \frac{0.32P_{pr}^6}{10^E} \qquad\qquad (11)$$

$$C = 0.132 - 032\ log(T_{pr})\ (12)$$

$$D = 10^F \tag{13}$$

$$E = 9(T_{pr} - 1) \tag{14}$$

$$F = 0.3106 - 0.49T_{pr} + 0.1824T_{pr}^2 \tag{15}$$

and

$$z = A + \frac{1 - A}{e^B} + Cp_{pr}^D \tag{16}$$

3.3. Formation Volume Factor

Formation volume factor is defined as the ratio of gas volume at reservoir condition to the gas volume at standard condition, that is:

$$B_g = \frac{V}{V_{sc}} = \frac{P_{sc}}{P} \frac{T}{T_{sc}} \frac{z}{z_{sc}} = 0.0283 \frac{z}{p} \tag{17}$$

Where the unit of formation volume factor is ft^3/scf. If expressed in rb/scf, it takes the form of:

$$B_g = 0.00504 \frac{zT}{P} \tag{18}$$

4. Effect of Non-hydrocarbon Components

Natural gases commonly contain hydrocarbon sulfide, carbon dioxide, and nitrogen. The presence of these gases does affect the Z-factor obtained by the previously described methods. Hence, limits have to be put up for the usage of those methods: The content of the non-

hydrocarbons in the studied natural gas must be less than5 % by volume (the volume content of N_2 is less than 2 % and the volume content of CO_2 is less than 1 %), and what's more, the volume content of methane should not be less than 50 %. Exceeding these limits means great error (more than 3 %). For this reason, when the non-hydrocarbon or C_{5+} components of a natural gas(e.g., condensate gas) make a comparatively high contribution, the methods should undergo a correction by referring to some other chartsand equations. To remedy this problem, methods have been developed to eliminate the error caused by non-hydrocarbons, and two of them will be introduced below.

4.1. Wichert-Aziz Correction Method

In order to get a corrected Z-factor, this method adjusts the pseudo-critical parameters and the pseudo-reduced parameters, through an adjustment of the curve on the reference chart, to account for the unusual behavior of these gases containing impurities: Firstly, bring in an adjustment factor ε, a function of the concentrations of H_2S and CO_2, to the pseudo-critical temperature T_{pr}; Secondly, correct the pseudo-critical pressure p_{pc}; thirdly, with the corrected T_{pr} and P_{pc}, calculate the T'_{pc} and P'_{pc}; and finally get the value of Z-factor on basis of T_{pr} and P_{pr}, referring to their original Z-chart. Then, we can get the compressibility factor fortheacid natural gases that contain H_2S and CO_2.

Corrections for impurities in sour gases are always necessary. The corrections can be made using either charts or correlations such as the Wichert and Aziz correction by calculation acentric factor εexpressed as follows[3]:

$$A = y_{H_2S} + y_{CO_2} \quad (19)$$

$$B = y_{H_2S} \qquad\qquad\qquad\qquad\qquad (20)$$

$$\varepsilon = 120(A^{0.9} - A^{1.6}) + 15(B^{0.5} - B^{4.0}) \quad (21)$$

$$T'_{pc} = T_{pc} - \varepsilon_3 \left(corrected\ T_{pc} \right) \qquad (22)$$

$$P'_{pc} = \frac{p_{pc}T_{pc}'}{T_{pc} + B(1 - B)\varepsilon_3} \quad (corrected\ T_{pc}) \qquad (23)$$

Correlations with impurity corrections for mixture pseudocritical are also available [6].

$$P_{pc} = 678 - 50(y_g - 0.5) - 206.7y_{N_2} + 440y_{CO_2} + 606.7 \qquad (24)$$

$$T_{pc} = 326 + 315.7(y_g - 0.5) - 204y_{N_2} - 83.3y_{CO_2} + 133.3y_{H_2S} \quad (25)$$

Applications of the pseudocritical pressure and temperature are normally found in natural gas engineering through pseudo reduced pressure and temperature defined as:

$$P'_{pr} = \frac{p}{p'_{pc}} (26)$$

$$T'_{pr} = \frac{T}{T'_{pc}} \qquad\qquad (27)$$

Where

T_{pc}, P_{pc} respectively the pseudocritical temperature (˚R) and the pseudocritical pressure (psi) of the mixture of hydrocarbons.

T'_{pc}, P'_{pc} the pseudocritical temperature (˚R) and the pseudo-critical pressure(psia) after correction; n the mole fraction of the H$_2$S in natural gas;εthe adjustment factor for the pseudocritical temperature (˚R) as a function of the concentrations of H$_2$S and CO$_2$.

T'_{pr}andP$'_{pr}$ are pseudo-reduced temperature and pressure respectively.

4.2. Carr-Kobayashi-Burrows Correction Method

Carr, Kobayashi, and Burrows[7] proposed a simplified procedure to adjust the pseudocritical properties of natural gases when nonhydrocarbon components are present. The method can be used when the composition of the natural gas is not available.

$$P'_{pc} = p_{pc} - 440y_{CO_2} + 600y_{H_2S} - 170y_{N_2} \quad (28)$$

$$T'_{pc} = T_{pc} - 80y_{CO_2} + 130y_{H_2S} - 250y_{N_2} \quad (29)$$

Where

T'_{pc} = the adjusted pseudocritical temperature, ˚R

T_{pc} = the unadjusted pseudocritical temperature, ˚R

P'_{pc} = the adjusted pseudocritical pressure, psia

P_{pc} = the unadjusted pseudocritical pressure, psia

y_{CO_2} = mole fraction of CO$_2$

y_{N_2} = mole fraction of nitrogen

y_{H_2S} = mole fraction of H$_2$S in gas mixture

5. Material and Methods

5.1. Location of Study

This study has been carried out on four gas fieldsareZeltin field, Al Ragouba field, Al Hotayba field and Al BraigaterminalofSirte Oil Company. The data of chemical analysis of the investigated gas fields are obtained from central laboratory of Oil Company.

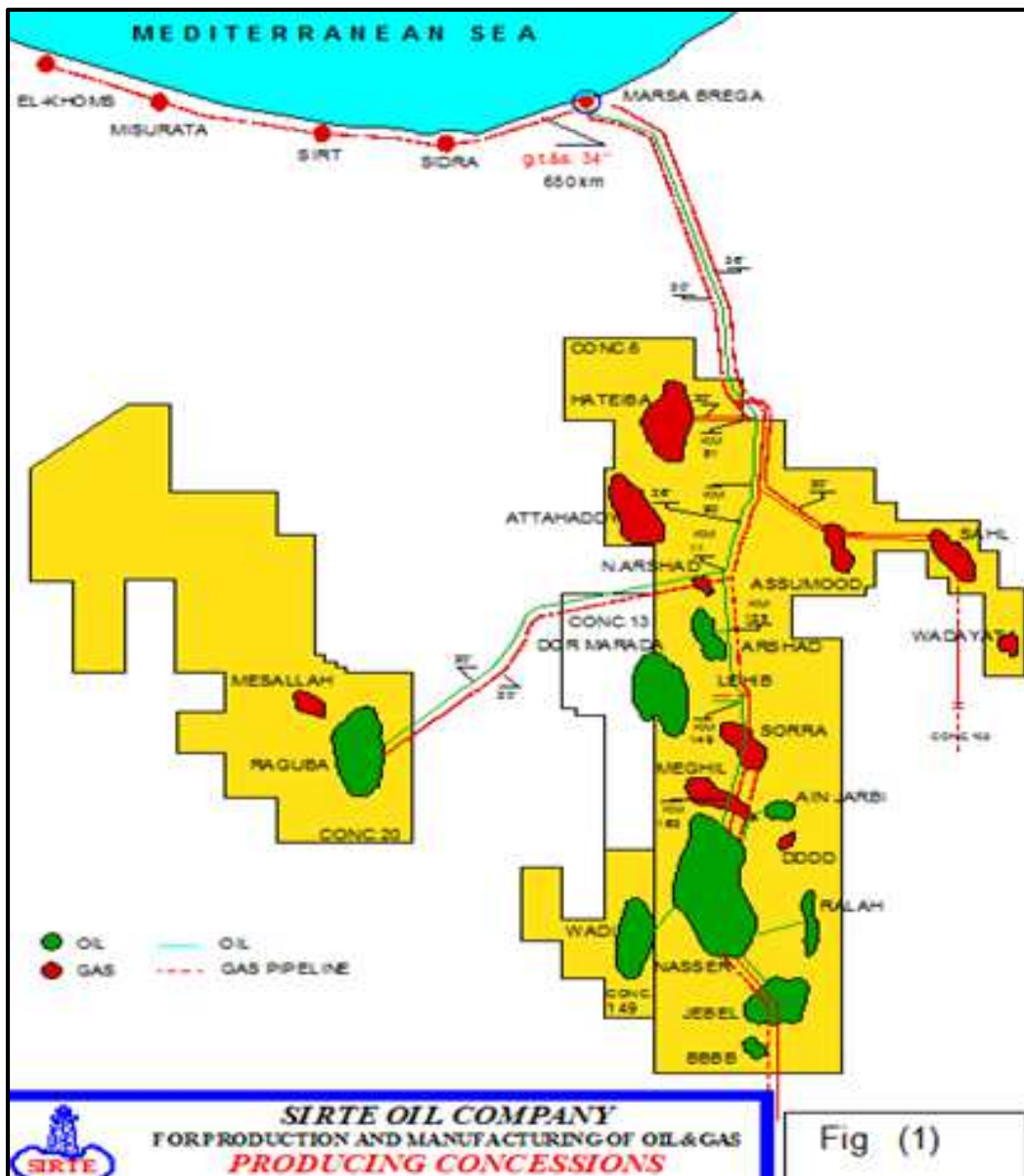The distribution of different oil and gas fields of Sirte Oil Company are illustrated in Figure 1.

Fig. 1 Distribution of different oil and gas fields of Sirte Oil Company

6. Results and Discussion

Tables 1 through 4 show the chemical composition of natural gas for the different gas fields. The pseudocritical properties, molecular weight, specific gravity, acentric factor ε and Z factor are calculated by applying the above Equations and presented in these tables.

On the other hand, from Standing-Katz chart, Fig. 2 the relationship between T_r & p_r can be used to determine the compressibility factor Z of a gases[5,8-10].

Theadjusted (corrected)pseudocritical temperature, T'_{pc} and the adjusted pseudocritical pressure T'_{pc} are calculated from Equations 26 and 27 using Wichert-Aziz correction method, as well as Equations 28 and 29 of Carr-Kobayashi-Burrows correction method.
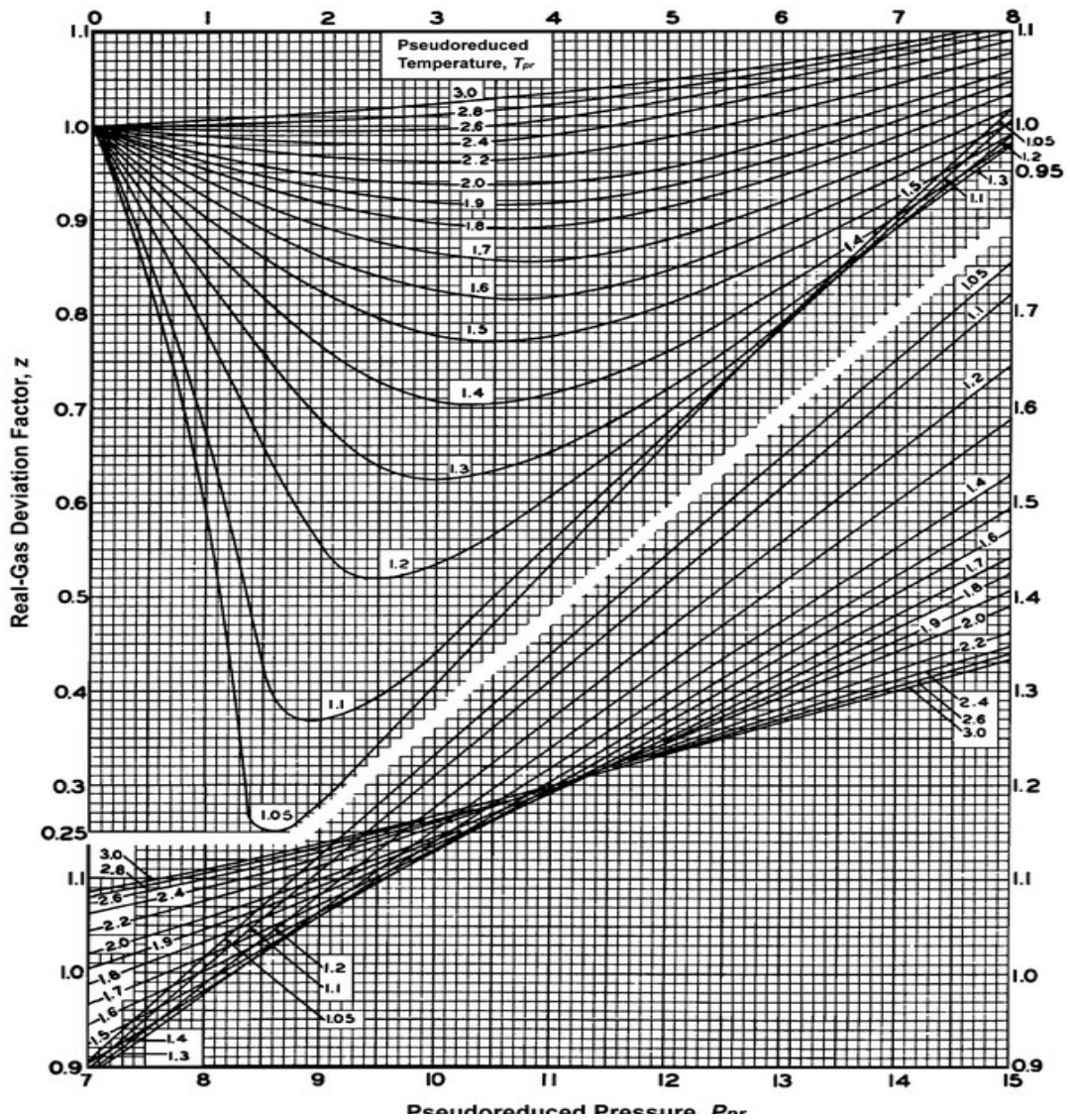
Fig.2Compressibilityfactorchart [4]

6.1. Zeltin Gas Field

Table 1. Chemical composition and critical properties of Zeltin gas field.

Components	y_i	p_{ci} (psi)	T_{ci} (°R)	Mol.Wt. M_i	$y_i p_{ci}$	$y_i T_{ci}$	$y_i M_i$
CH_4	0.690	673.1	343.0	16.043	464.44	236.67	11.07
C_2H_6	0.111	708.3	549.6	30.070	78.62	61.01	3.43
C_3H_8	0.074	617.4	665.6	44.097	45.69	49.25	3.26
C_4H_{10}	0.012	550.7	765.3	58.123	6.61	9.18	0.70
C_5H_{12}	0.024	489.0	845.6	72.150	11.74	20.29	1.73
C_6H_{14}	0.001	439.7	914.2	86.177	0.44	0.914	0.086
$C_7H_{16}^{+}$	-	-	-	-	-	-	-
CO_2	0.061	1071.1	547.6	44.010	65.34	33.40	2.68
N_2	0.013	187.5	227.2	**28.013**	2.44	2.95	0.36
H_2S	0.011	493.1	672.4	34.08	5.43	7.40	0.37
Σ	1.000				$p_{pc}=$ 680.74	$T_{pc}=$ 421.06	$Mw=$ 23.69
Specific gravity	$SG = Mw/29 = 23.69/29 = 0.82$						
Z factor	0.92						
Corrected Z	0.90						

6.2. Al RagoubaGas Field

Table 2. Chemical composition and critical properties of Al Ragouba gas field

Components	y_i	p_{ci} (psi)	T_{ci} (˚R)	Mol.Wt. M_i	$y_i p_{ci}$	$y_i T_{ci}$	$y_i M_i$
CH_4	0.679	673.1	343.0	16.043	469.15	232.90	10.89
C_2H_6	0.116	708.3	549.6	30.070	82.16	63.75	3.49
C_3H_8	0.085	617.4	665.6	44.097	52.50	56.58	3.75
C_4H_{10}	0.015	550.7	765.3	58.123	8.26	11.48	0.87
C_5H_{12}	0.005	489.0	845.6	72.150	2.45	4.23	0.36
C_6H_{14}	0.0004	439.7	914.2	86.177	0.18	0.37	0.034
$C_7H_{16}^{+}$	-	-	-	-	-	-	-
CO_2	0.047	1071.1	547.6	44.010	50.34	25.74	2.09
N_2	0.019	187.5	227.2	**28.013**	3.56	4.32	0.53
H_2S	0.013	493.1	672.4	34.08	6.41	8.74	0.44
$\sum$	1.000				$p_{pc}=$ 675.01	$T_{pc}=$ 408.11	$Mw=$ 22.45
Specific gravity	$SG = Mw/29 = 22.45/29 = 0.77$						
Z factor	0.92						
Corrected Z	0.89						

6.3. Al Hotayba Gas Field

Table 3. Chemical composition and critical properties of Al Hotayba gas field

Components	y_i	p_{ci} (psi)	T_{ci} (˚R)	Mol.Wt. M_i	$y_i p_{ci}$	$y_i T_{ci}$	$y_i M_i$
CH_4	0.785	673.1	343.0	16.043	528.38	269.26	12.59
C_2H_6	0.044	708.3	549.6	30.070	31.16	24.18	1.32
C_3H_8	0.014	617.4	665.6	44.097	8.64	9.32	0.62
C_4H_{10}	0.009	550.7	765.3	58.123	4.96	6.89	0.52
C_5H_{12}	0.005	489.0	845.6	72.150	2.45	4.23	0.36
C_6H_{14}	0.003	439.7	914.2	86.177	1.32	2.74	0.26
$C_7H_{16}^{+}$	0.002	392.8	972.3	100.204	0.79	1.94	0.20
CO_2	0.104	1071.1	547.6	44.010	111.39	56.95	4.57
N_2	0.015	187.5	227.2	**28.013**	2.81	0.34	0.42
H_2S	0.016	493.1	672.4	34.08	7.89	10.76	0.55
$\sum$	1.000				p_{pc}= 699.79	T_{pc}= 386.61	Mw= 21.41
Specific gravity	$SG = Mw/29 = 21.41/29 = 0.74$						
Z factor	0.90						
Corrected Z	0.87						

Figure 3 depicts the variation of pseudocritical properties and molecular weights of natural gases in studied fields. This variance reveal the different concentrations of mixture components.

6.4. Al Braiga Gas Field

Table 4. Chemical composition and critical properties of Al Braiga terminal gas field

Components	y_i	p_{ci} (psi)	T_{ci} (˚R)	Mol.Wt. M_i	$y_i p_{ci}$	$y_i T_{ci}$	$y_i M_i$
CH_4	0.7316	673.1	343.0	16.043	492.44	250.94	11.45
C_2H_6	0.1004	708.3	549.6	30.070	71.11	55.18	3.02
C_3H_8	0.0255	617.4	665.6	44.097	15.74	16.97	1.12
C_4H_{10}	0.1310	550.7	765.3	58.123	72.14	100.25	7.62
C_5H_{12}	0.0161	489.0	845.6	72.150	7.89	13.65	1.16
C_6H_{14}	0.0025	439.7	914.2	86.177	1.10	2.29	0.215
$C_7H_{16}^{+}$	0.0008	392.8	972.3	100.204	0.332	0.78	0.08
CO_2	0.0507	1071.1	547.6	44.010	54.30	27.76	2.23
N_2	0.020	187.5	227.2	**28.013**	3.75	4.54	0.56
H_2S	0.012	493.1	672.4	34.08	5.92	0.069	0.41
$\sum$	1.000				p_{pc} = 724.72	T_{pc}= 472.43	Mw = 27.87
Specific gravity	$SG = Mw/29 = 27.87/29 = 0.96$						
Z factor	0.89						
Corrected Z	0.88						

On the other hand, the specific gravity, Z factor and the corrected values of Z show variation from field to another, this also attributed to the mixture composition of natural gases (Fig. 4).

Also, from the results we can conclude that the presence of non hydrocarbon impurities in a gas caused some deviation of compressibility factor. Hence, this gases must be treated before delivered to the consumers.
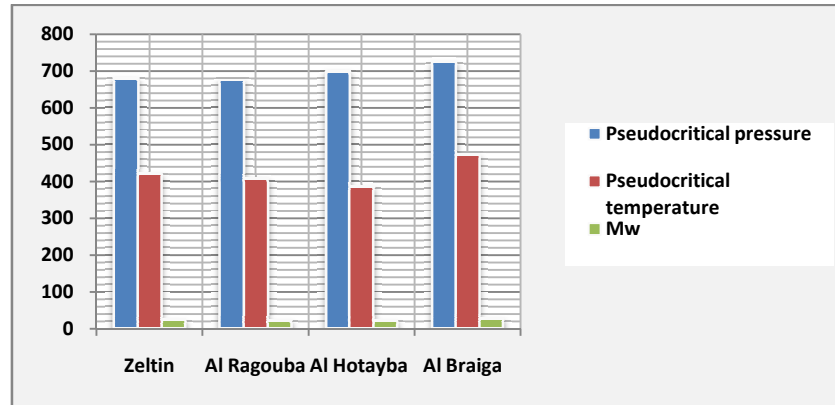
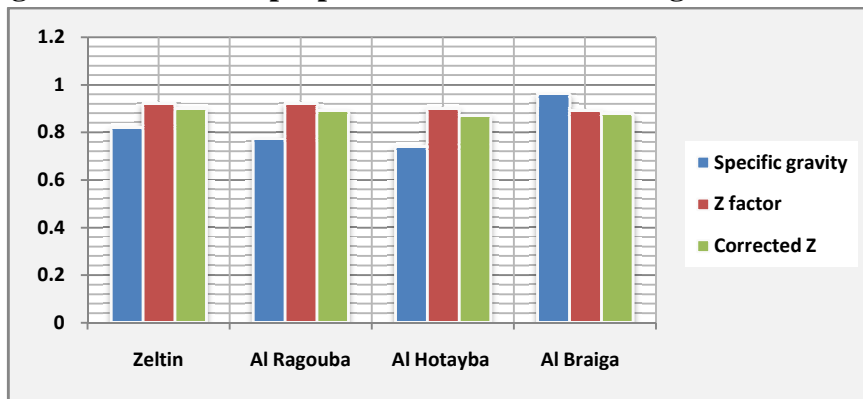**Fig. 3 Pseudocritical properties and molecular weights of natural gases**

Fig. 4 Specific gravity and Z factors of natural gases

7. Conclusion

The presence of non hydrocarbon impurities in a gas must be accounted for when using a gas specific gravity correlation. Errors in Z factors as high as 27 percent occurred when high concentrations of acid gas were ignored.

The pseudocritical properties and molecular weights of natural gases show a variation in studied fields. This variance reveal the different concentrations of mixture components.

The Z factors exhibit a variation from field to another, this also attributed to the mixture composition and the impurities content of natural gases. Consequently, these gases must treated to eliminate from nonhydrocarbons components.

Nomenclature

B_g = gas formation volume factor

MW_g= molecular weight of gas mixture

MW_{air}= molecular weight of air

PVT = pressure-volume-temperature

p = pressure, paia

p_c = critical pressure, psia

p_{pc} = pseudocritical pressure

p_{pr} = pseudoreducedpressure

R = universal gas constant

T = temperature, $°R$

T_c = critical temperature , $°R$

T_{pc} = pseudocritical temperature

T_{pr} = pseudoreduced temperature

y_i = mole fraction of the i-th component

Z =gas compressibility factor

$γ_g$= Specific gravity of gas mixture.

$ε$= Wichert and Aziz pseudocritical temperature adjustment parameter, $°R$

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