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Research Article

Mathematical formulation of the physical properties of Hydrocarbon Gases and the determination of these parameters in a Gas-Condensate field in Albania

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Abstract

The physic-chemical properties of fluids that saturate a bed have been followed throughout the course of resource exploitation through different analyses. Fluids released from the formation over time of exploitation change due to the change in the phase state of the fluids, their material balance and energy. Determining the type of reservoir fluid and its properties, including physical properties and chemical properties, play a key role in reservoir engineering for many decisions made in the development of an oil and gas field. In this manuscript, the properties of gases are analyzed step by step in both their physical and mathematical contexts, as well as that of gas. In this context, a gas-condensate field located in Albania was taken into consideration, determining its properties through the relevant correlations and the use of different graphs both for the measured value of the initial pressure of the formation and for the different values of the pressure taken into consideration.

Keywords: reservoir, gas, equation, z-factor, composition.

1. Introduction

Based on the phase diagram which makes it possible to describe the liquid for a range of pressures and temperatures, the phase behavior of a reservoir fluid can best be described as P-T or P-V (pressure, temperature, volume) dependent and is different for each fluid in the reservoir (Abdus Satter and Iqbal, 2016). Pressure and temperature do not remain constant but change, in underground oil and gas reservoirs, with the release of fluids to the surface. In the case of gases, this change in pressure and temperature will be accompanied by major changes in their molecular composition (Speight, 2016). Regardless of this, for many purposes and engineering calculations, the behavior of real gases can be approximated to the behavior of ideal gases by using a correction factor called the compressibility factor (Terry, Rogers, 2015).

In the composition of natural gases, we distinguish both hydrocarbon and non-hydrocarbon gases (Ursin, Zolotukhin and Stavanger, 1997). Based on this, natural gases, can be classified into light gases, heavy gases and acid or neutral gases (Zhuang, Liu, 2020). Knowing the physical and chemical properties of gases, which include density, specific volume, isothermal gas compressibility coefficient, gas formation volume factor, gas expansion factor, viscosity, apparent molecular weight, specific gravity, compressibility factor, it can be analyzed that all these properties mentioned above are calculated both in the direct measurements carried out in the laboratory and from the prediction (general mathematical expressions) or the corresponding correlations obtained from the analysis of the various experiments carried out related to real gases (Dake, 1978). Starting from the equation which connects the three variables pressure, volume and temperature, in the case of real gases it can be analyzed that:

$P * V = Z * n * R * T$ (1) (Tarek, Mc Kinney, 2002)

In equation 1 where the gas compressibility factor z is used, we can express it as a ratio of two volumes:

$Z = V\_actual/V\_ideal = V/(((n * R * T)) / P) = (P * V)/(n * R * T)$ (2)

To calculate the gas compressibility factor z, it is necessary to calculate the pseudo-reduced pressure and pseudo-reduced temperature; based on these two variables and using the Standing and Katz chart, it is possible to calculate the gas compressibility factor for different values of the two variables above (Tarek, 2019). Based on this, we write the equations as following:

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

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

Considering the mole fraction of component i in the mixture (γ_i), as well as critical pressure and temperature (P_{ci}, T_{ci}) the relevant expression for pseudo-critical pressure and temperature, is given as following (Terry, Rogers, 2015):

$P_{pc} = \sum_{i=1}(\gamma_i * P_{ci})$ (5)

$T_{pc} = \sum_{i=1}(\gamma_i * T_{ci})$ (6)

On the other hand, when in natural gas we have the presence of non-hydrocarbon components, including H_2S, Co_2 and N_2 often exhibit different compressibility-factors and to distinguish between them, it is possible to correct the pseudocritical properties such as adjusted pseudocritical temperature and adjusted pseudocritical pressure based on two methods (Hamza, Hussein and Mahmoud, 2023). The Wichert-Aziz Correction Method and The Carr-Kobayashi-Burrows Correction Method. In this paper, the Carr Kobayashi-Burrows Correction Method is considered, according to which the equations are given as following (Hamza, Hussein and Mahmoud, 2023):

$T_{pc}^* = T_{pc} - 80 * \gamma_{Co_2} + 130 * \gamma_{H_2S} - 250 * \gamma_{N_2}$ (7)

$P_{pc}^* = P_{pc} + 440 * \gamma_{Co_2} + 600 * \gamma_{H_2S} - 170 * \gamma_{N_2}$ (8)

Another important parameter that must be taken into consideration in the properties of gases is the apparent molecular weight as well as density of gas, which are given as following (Terry, Rogers, 2015):

$M_a = \sum_{i=1} \gamma_i * M_i$ (9)

$P * V = Z * n * R * T \rightarrow P * V = Z * \left(\frac{m}{M_a}\right) * R * T$

$v = \frac{V}{m} \rightarrow v = \frac{Z*R*T}{P*M_a}$

$\rho_g = \frac{1}{v} = \frac{1}{\frac{Z*R*T}{P*M_a}} \rightarrow \rho_g = \frac{P*M_a}{Z*R*T}$ (10)

In relation to the gas compressibility coefficient, which is presented as a change in volume as a result of a change in pressure, we write as follows:

$C_g = -\frac{1}{\mathrm{V}} * \frac{\partial \mathrm{V}}{\partial \mathrm{P}}$

$\mathrm{P} * \mathrm{V} = \mathrm{Z} * \mathrm{n} * \mathrm{R} * \mathrm{T} \Rightarrow \mathrm{V} = \frac{\mathrm{Z} * \mathrm{n} * \mathrm{R} * \mathrm{T}}{\mathrm{P}}$

Differentiating the above equation with respect to pressure at constant temperature gives:

$\frac{\partial \mathrm{V}}{\partial \mathrm{P}} = \frac{\partial}{\partial \mathrm{P}}\left(\frac{\mathrm{Z} * \mathrm{n} * \mathrm{R} * \mathrm{T}}{\mathrm{P}}\right)$

$\frac{\partial \mathrm{V}}{\partial \mathrm{P}} = \mathrm{n} * \mathrm{R} * \mathrm{T} \times \frac{\partial}{\partial \mathrm{P}}\left(\frac{\mathrm{Z}}{\mathrm{P}}\right)$

$\frac{\partial \mathrm{V}}{\partial \mathrm{P}} = \mathrm{n} * \mathrm{R} * \mathrm{T} * \frac{\frac{\partial \mathrm{Z}}{\partial \mathrm{P}} * \mathrm{P} - \frac{\partial \mathrm{P}}{\partial \mathrm{P}} * \mathrm{Z}}{\mathrm{P}^2}$

$\frac{\partial \mathrm{V}}{\partial \mathrm{P}} = \mathrm{n} * \mathrm{R} * \mathrm{T} * \frac{\frac{\partial \mathrm{Z}}{\partial \mathrm{P}} * \mathrm{P} - 1 * \mathrm{Z}}{\mathrm{P}^2}$

$\frac{\partial \mathrm{V}}{\partial \mathrm{P}} = \mathrm{n} * \mathrm{R} * \mathrm{T} * \left[\frac{1}{\mathrm{P}} * \frac{\partial \mathrm{Z}}{\partial \mathrm{P}} - \frac{\mathrm{Z}}{\mathrm{P}^2}\right]$

$\frac{\partial \mathrm{V}}{\partial \mathrm{P}} = \mathrm{n} * \mathrm{R} * \mathrm{T} * \left[\frac{1}{\mathrm{P}} * \frac{\partial \mathrm{Z}}{\partial \mathrm{P}} - \frac{\mathrm{Z}}{\mathrm{P}^2}\right]$

$\mathrm{C_g} = -\frac{\mathrm{P}}{\mathrm{Z} * \mathrm{n} * \mathrm{R} * \mathrm{T}} * \mathrm{n} * \mathrm{R} * \mathrm{T} * \left[\frac{1}{\mathrm{P}} * \frac{\partial \mathrm{Z}}{\partial \mathrm{P}} - \frac{\mathrm{Z}}{\mathrm{P}^2}\right]$

$\mathrm{C_g} = \frac{1}{\mathrm{P}} - \frac{1}{\mathrm{Z}} * \left(\frac{\partial \mathrm{Z}}{\partial \mathrm{P}}\right)$ (11)

For Z=1 and $\left(\partial Z/\partial P\right)_T = 0$, the expression as following is given:

$\mathrm{C_g} = \frac{1}{\mathrm{P}}$ (12)

Also, equation 11 can be expressed in relation to pseudo-reduced pressure and temperature as following (Ahmed, 2019):

$\mathrm{C_g} = \frac{1}{P_{pr} * P_{pc}} - \frac{1}{\mathrm{Z}} * \left[\frac{\partial Z}{\partial (P_{pr} * P_{pc})}\right]_{T_{pr}}$ (13)

$$C_g * P_{pc} = C_{pr} = \frac{1}{P_{pr}} - \frac{1}{Z} * \left[\frac{\partial Z}{\partial (P_{pr})}\right]_{T_{pr}} \quad (14)$$

$$C_g = \frac{C_{pr}}{P_{pc}^*} \quad (15)$$

The gas formation volume factor, which is expressed as the ratio of the gas volume in the conditions of the underground tank to the gas volume in the surface (or standard) conditions, is calculated as following (Hamza, Hussein and Mahmoud, 2023):

$$B_g = 0.02827 * \frac{z*t}{P} \quad (16)$$

All the formulas presented above are used below in the case study take considered for a gas condensate field in Albania, in which all the parameters discussed above, are determined for gas of gas cap.

1. Methodology

Regarding the case taken in the study, the initial pressure of the layer was measured which resulted in 375 atm and the temperature which resulted in 40°C. The hydrocarbon gas taken in consideration has the composition as shown below in table 1. Based on table 1 regarding the gas composition, it was continued with the calculations presented in table 2 regarding the pseudocritical pressure and temperature. All the data obtained from the measurements performed and from the calculations made both in table 1 and in table 2 will help us in the continuing with the application of the above formulas for the calculation of the physical parameters of the gas taken into consideration.

In addition to the value of the initial pressure of the layer, we have continued the calculations with several other pressure values different from the initial pressure of the layer and for each value of the pressure we have made the calculation of the corresponding parameters and the graphic presentation in different dependencies with other parameters.

Component	Mole fraction of component i in the mixture γ_i	Critical temperature°R T_{ci}	Critical pressure P_{ci}	Molecular weight of the ith component in the mixture
C_1	0.94	343.04	667.8	16.04
C_2	0.02	549.76	707.8	30.07

C_3	0.005	665.68	616.3	44.11
n-C_4	0.004	765.32	550.7	58.1
n-C_5	0.003	470.4	488.6	72.2
CO_2	0.007	547.6	1071	44.01
H_2S	0.008	672.4	1306	34.08
N_2	0.013	227.3	493	28.016

***Table 1**-Composition of hydrocarbon gas*

Component	Pseudocritical pressure $\gamma_i * P_{ci}$	Pseudocritical temperature $\gamma_i * T_{ci}$
C_1	627.732	322.457
C_2	14.156	10.995
C_3	3.081	3.328
n-C_4	2.202	3.061
n-C_5	1.465	1.411
CO_2	7.497	3.833
H_2S	10.448	5.379
N_2	6.409	2.954
	Σ=672.99 psi	**Σ=353,418 °R**

***Table 2**-Calculation of pseudocritical pressure and temperature*

2. Results and Discussion

Based on the values presented in table 1 and 2 and in the equations above, below is presented the method followed for determining the z-factor in the case of the initial pressure of the layer and then based on this method the values of the z-factor are determined for pressure values different from that of the initial pressure of the layer and their graphic presentation was built.

For P=375 atm T=40°C

Converting the pressure to the psi unit and the temperature to ºR, we get the values:

P_i =375*14.696=5510.99 psi

ºF=1.8 TºC+32=1.8*40+32=104

ºR=ºF+460=104 + 460=564

Secondly, we calculate the pseudo-critical properties by making the Carr-Kobayashi-Burrows corrections:

$T_{pc}^* = T_{pc} - 80 * \gamma_{Co_2} + 130 * \gamma_{H_2S} - 250 * \gamma_{N_2}$

$P_{pc}^* = P_{pc} + 440 * \gamma_{Co_2} + 600 * \gamma_{H_2S} - 170 * \gamma_{N_2}$

T_{pc}^*=353.418 - 80(0.007) +130(0.008)-250(0.013)

T_{pc}^* =350.648

P_{pc}^*= 672.99 + 440(0.007) + 600(0.008) - 170(0.013)

P_{pc}^*=678.66

Thirdly, the pseudo-reduced pressure and temperature are calculated by applying the equations 3 and 4 as following:

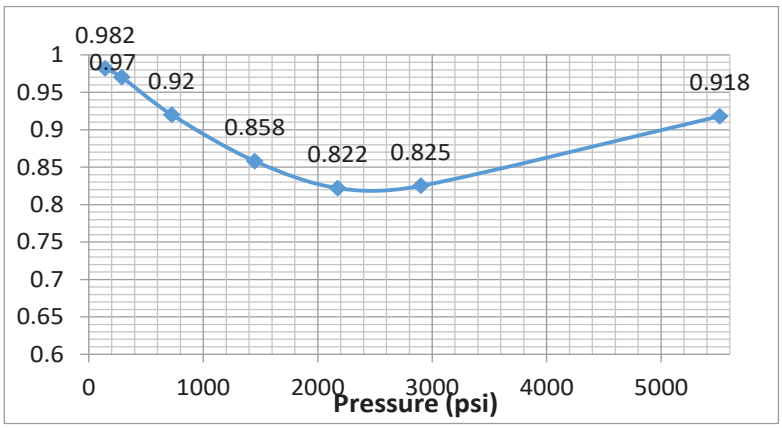

***Figure 1**-Graphical Presentation z=f(p)*

$P_{pr} = \frac{P}{P_{pc}^*} = \frac{5510.99}{678.66} = 8.12$

$T_{pr} = \frac{T}{T_{pc}^*} = \frac{564}{350.648} = 1.608$

The fourth z-factor is calculated from the Standing and Katz chart:

Based on the method and equations used above to determine the z-factor for the initial pressure of the layer, we determine the z-factor for the different pressure values, specifically; 20 Mpa, 15 Mpa,
10 Mpa, 5 Mpa, 2 Mpa and 1 Mpa for the same temperature $T = 40℃$. With the values obtained from the performed calculations, we construct the graph of the z-factor versus pressure.
$20\ Mpa \rightarrow Z = 0.825;\ 15\ Mpa \rightarrow Z = 0.822;\ 10\ Mpa \rightarrow Z = 0.858;\ 5\ Mpa \rightarrow Z = 0.92;$
$2Mpa \rightarrow Z = 0.97;\ 1Mpa \rightarrow Z = 0.982.$
To determine the gas formation volume factor both for the value of the initial pressure of the layer and for the different values of the pressures, we use the equation 16 as following:

For initial pressure:
P= 5510.99 psi T= 564^{0}R z= 0.918
B_g=0.02827 $* \frac{z*T}{p} = 0.02827 * \frac{0.918*564}{5510.99}$ =2.655x10^{-3} ft^3/scft

For $P = 20\ Mpa$
P= 2900.75 psi T= 564^{0}R z= 0.825
B_g=0.02827 $* \frac{z*T}{p} = 0.02827 * \frac{0.825*564}{2900.75}$ =4.534x10^{-3} ft^3/scft

For P = 15 Mpa
P= 2175.57 psi T= 564^{0}R z= 0.822
B_g= 0.02827 $* \frac{z*T}{p} = 0.02827 * \frac{0.822*564}{2175.57}$ =6.02x10^{-3} ft^3/scft

For $P = 10\ Mpa$
P= 1450.38 psi T= 564^{0}R z= 0.858
B_g= 0.02827 $* \frac{z*T}{p} = 0.02827 * \frac{0.858*564}{1450.38}$ =9.432x10^{-3} ft^3/scft

For $P = 5\ Mpa$
P= 725.189 psi T= 564^{0}R z= 0.92
B_g= 0.02827 $* \frac{z*T}{p} = 0.02827 * \frac{0.92*564}{725.189}$ = 20.2x10^{-3} ft^3/scft

For $P = 2\ Mpa$
P= 290.075 psi T= 564^{0}R z= 0.97
B_g= 0.02827 $* \frac{zT}{p} = 0.02827 * \frac{0.97*564}{290.075}$ = 53.31x10^{-3} ft^3/scft

For $P = 1\ Mpa$
P= 145.038 psi T= 564^{0}R z= 0.982
B_g= 0.02827 $* \frac{z*T}{p} = 0.02827 * \frac{0.982*564}{145.038}$ =107.99x10^{-3} ft^3/scft

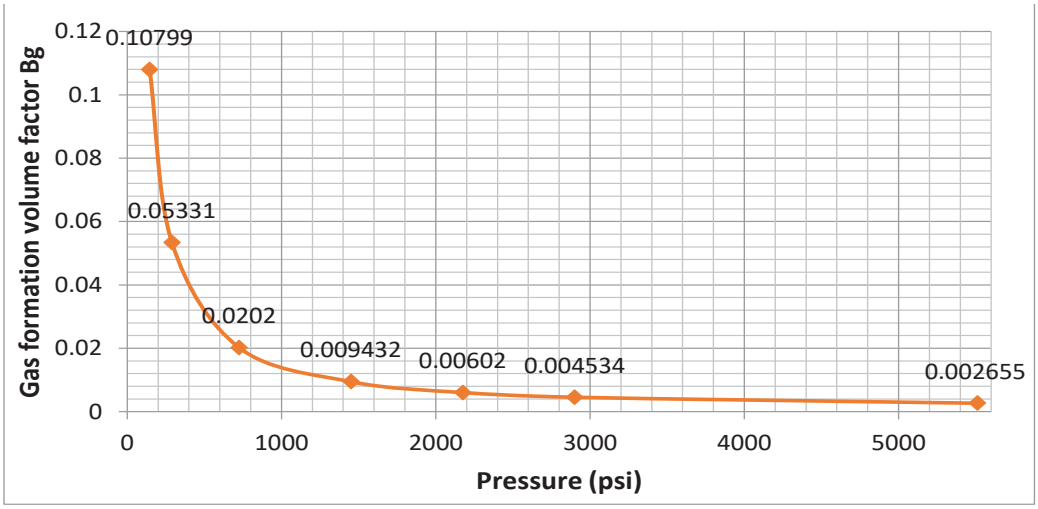

***Figure 2**-Graphical Presentation $B_g = f(p)$*

Another parameter that will be determined is the gas density and gas compressibility coefficient, which are calculated as following:

$$M_a = \sum_{i=1} \gamma_i * M_i \rightarrow M_a = 17.291$$

P=5510.99psi and T=564°R

$$T_{pc}^{*} = 350.648 \rightarrow T_{pr} = 1.608$$

$$P_{pc}^{*} = 678.66 \rightarrow P_{pr} = 8.12$$

$$Z = 0.918$$

$$\rho_g = \frac{P*M_a}{Z*R*T}$$

$$\rho_g = \frac{5510.99*17.29}{0.918*10.73*564} = \text{lb/ft}^3$$

$$\Delta z = z_2 - z_1 = 0.93 - 0.86 = 0.07$$

$$\Delta P_r = P_{r_2} - P_{r_1} = 7.9 - 8.9 = -1$$

$$\left[\frac{\partial Z}{\partial (P_{pr})}\right]_{T_{pr}} = -0.07$$

$$C_{pr} = \frac{1}{P_{pr} * P_{pc}} - \frac{1}{Z} * \left[\frac{\partial Z}{\partial (P_{pr} * P_{pc})}\right]_{T_{pr}}$$

$$C_{pr} = \frac{1}{P_{pr}} - \frac{1}{Z} * \left[\frac{\partial Z}{\partial (P_{pr})}\right]_{T_{pr}}$$

$$C_{pr} = \frac{1}{8.12} - \frac{1}{0.918} * [-0.07] = 0.1993$$

$$C_g = \frac{C_{pr}}{P_{pc}^{*}}$$

C_g=0.1993/678.66=2.936*10^(-4) psi^(-1)
The pseudo-critical properties presented above, which are expressed through the parameters P_pc and T_pc, do not in themselves represent critical properties of the gas mixture, but are parameters that make possible the correlative relationship which, together with the graphs taken into consideration, reach the accuracy of designated for determining the respective properties of hydrocarbon gases. From the formulas and calculations performed, it can be judged on the dependence of the parameters defined above on temperature and pressure (Zhuang, Liu, 2020). As the pressure increases, the gas density and, compressibility factor increases, but the average free path of molecules decreases, while the speed remains unchanged. Another important parameter that must be taken into consideration is the viscosity of gases (Whiston, 2016). As the temperature increases, the viscosity of the gas decreases therefore, at high pressures, the viscosity of gases changes as a function of temperature so as viscosity of liquids (Ahmed, 2019). Gases with higher molecular weight usually have higher viscosity. While in relation to the increase in pressure, the density of the gas increases, but the average free path of molecules decreases, while the speed remains unchanged (Ahmed, 2019). So as the pressure increases, the dynamic viscosity of the gas remains practically unchanged.

Conclusion

In this paper, the properties of hydrocarbon gases have been treated both in a physical and mathematical context step by step. After performing various measurements in the gas-condensate field in relation to the initial pressure of the layer and the average temperature of the reservoir, the composition of the gas sample from gas cap taken into consideration was analyzed. Analyzing all the parameters calculated above in relation to the sample taken in the study, we can say that the phase behavior of the gas is connected and directly influenced by the change in pressure and temperature. The dimensionless pseudocritical parameters used in connection with pressure and temperature, as well as the graphs that express the dependence between them, help in the correlation and accuracy determined in the calculations performed.

Nomenclature

M_a-apparent molecular weight of gas
ϱ_g-gas density
M_i-molecular weight of the ith component in the mixture
C_g-isothermal gas compressibility
T_{pc}^*-the adjusted pseudo-critical temperature
P_{pc}^*-the adjusted pseudo-critical pressure
B_g-gas formation volume factor
P_{pr}-pseudo-reduced pressure
T_{pr}-pseudo-reduced temperature
C_{pr}-isothermal pseudo-reduced compressibility

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