

Natural Gas PVT Analysis

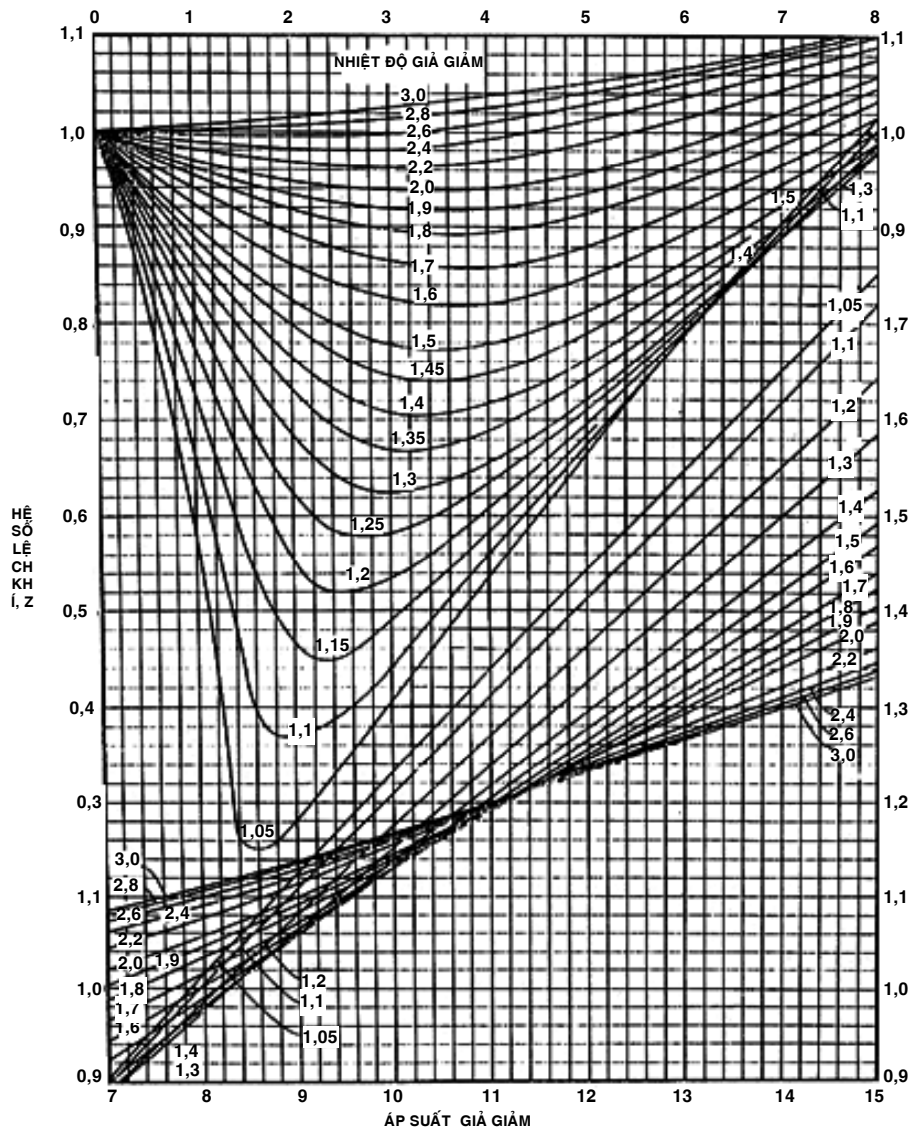
- Behavior of real gas
- Z-factor calculations
- Gas density
- Gas formation volume factor
- Gas viscosity

Real Gas Properties

Equation of State: $pV = nZRT$

Quantity	Description	Unit/Value
p	Pressure	psia
V	Volume	ft³
n	Mole number	lb-moles
Z	Gas compressibility factor	dimensionless
T	Temperature	Rankine
R	Universal Gas constant	10.73 psia.ft³/lb-mole. °R

Calculating Z using Standing-Katz Chart



Step 1: Calculate pseudo-critical pressure and temperature (Sutton)

$$p_{pc} = 7568 - 131.0\gamma_g - 3.6\gamma_g^2$$

$$T_{pc} = 169.2 - 349.5\gamma_g - 74.0\gamma_g^2$$

Step 2: Calculate pseudo-reduced pressure and temperature:

$$p_{pr} = \frac{p}{p_{pc}}; T_{pr} = \frac{T}{T_{pc}}$$

Step 3: Use Standing-Katz chart to determine Z

Wichert-Aziz Correction Method

Corrected pseudo-critical temperature:

$$\bar{T}_{pc} = T_{pc} - \varepsilon, \text{ } ^\circ\text{R}$$

Corrected pseudo-critical pressure:

$$\bar{p}_{pc} = \frac{p_{pc} T_{pc}}{T_{pc} + B(1 - B)\varepsilon}, \text{ psia}$$

Pseudo-critical temperature adjustment factor

$$\varepsilon = 120 \left(A^{0.9} - A^{1.6} \right) + 15 \left(B^{0.5} - B^{4.0} \right),$$

Exercise

Given the following real gas composition,

Component	Mole fraction
C1	0.63
C2	0.02
CO2	0.1
H2S	0.2

Determine the density of the gas mixture at 1,000 psia and 110 °F using Wichert-Aziz correction method.

Sutton Correction Method

Step1: Calculate the parameters J and K:

$$J = \frac{1}{3} \left[\sum_i y_i \left(\frac{T_c}{p_c} \right)_i \right] + \frac{2}{3} \left[\sum_i y_i \left(\frac{T_c}{p_c} \right)_i^{0.5} \right]^2, \text{ } ^\circ \text{R/psia}$$

$$K = \sum_i y_i \left(\frac{T_c}{p_c} \right)_i^{0.5}, \text{ } ^\circ \text{R/psia}^{0.5}$$

Step 2: Calculate the adjustment parameters:

$$F_J = \frac{1}{3} \left[y \left(\frac{T_c}{p_c} \right) \right]_{C_{7+}} + \frac{2}{3} \left[y \left(\frac{T_c}{p_c} \right)^{0.5} \right]_{C_{7+}}^2$$

$$\varepsilon_J = 0.6081 F_J + 1.1325 F_J^2 - 14.004 F_J y_{C_{7+}} + 64.434 F_J y_{C_{7+}}^2$$

$$\varepsilon_K = \left(\frac{T_c}{p_c} \right)_{C_{7+}} \left[0.3129 y_{C_{7+}} - 4.8156 y_{C_{7+}}^2 + 27.3751 y_{C_{7+}}^3 \right]$$

Sutton Correction Method (cont.)

Step 3: Adjust the parameters J and K

$$\bar{J} = J - \varepsilon_J$$

$$\bar{K} = K - \varepsilon_K$$

Step 4: Calculate the adjusted pseudo-critical terms

$$T_{pc} = \frac{\bar{K}^2}{\bar{J}}$$

$$p_{pc} = \frac{T_{pc}}{\bar{J}}$$

Exercise

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Dranchuk and Abou-Kassem Correlation

$$Z = 1 + \left[A_1 + \frac{A_2}{T_{pr}} + \frac{A_3}{T_{pr}^3} + \frac{A_4}{T_{pr}^4} + \frac{A_5}{T_{pr}^5} \right] \rho_r + \left[A_6 + \frac{A_7}{T_{pr}} + \frac{A_8}{T_{pr}^2} \right] \rho_r^2 - A_9 \left(\frac{A_7}{T_{pr}} + \frac{A_8}{T_{pr}^2} \right) \rho_r^5 + A_{10} (1 + A_{11} \rho_r^2) \frac{\rho_r^2}{T_{pr}^2} \exp(-A_{11} \rho_r^2)$$

$$\rho_r = \frac{0.27 p_{pr}}{Z T_{pr}}$$

$$A_1 = 0.3265 ; A_2 = -1.0700 ; A_3 = -0.5339$$

$$A_4 = 0.01569 ; A_5 = -0.05165 ; A_6 = 0.5475$$

$$A_7 = -0.7361 ; A_8 = 0.1844 ; A_9 = 0.1056$$

$$A_{10} = 0.6134 ; A_{11} = 0.7210$$

Exercise 2: PVT Analysis

Using the data in the table below and assuming real gas behavior, calculate the density of the gas phase under initial reservoir conditions. Compare the results with that of ideal gas behavior.

Component	Mole Percent	Molecular Weight	Critical Press. (psia)	Critical Temp. (R)
	(1)	(2)	(3)	(4)
C1	0.85	16.043	666.4	343.00
C2	0.04	30.070	706.5	549.59
C3	0.03	44.097	616.0	665.73
iC4	0.03	58.123	527.9	734.13
nC4	0.02	58.123	550.6	765.29
iC5	0.00	72.150	490.4	828.77
nC5	0.00	72.150	488.6	845.47
C6	0.00	86.177	436.9	913.27
C7	0.00	100.204	396.8	972.37
C8	0.00	114.231	360.7	1023.89
C9	0.00	128.258	331.8	1070.35
C10	0.00	142.285	305.2	1111.67
H2S	0.00	34.080	1300.0	672.12
CO2	0.02	44.010	1071.0	547.58
N2	0.01	28.013	493.1	227.16
He	0.00	4.003	33.0	9.36
Air	0.00	28.960	546.9	238.36
O2	0.00	31.999	731.4	278.24

Density of Nature Gases

$$c_g = \frac{pM}{ZRT}$$

Iso-thermal gas compressibility

$$c_g = \frac{1}{p} - \frac{1}{Z} \left(\frac{\partial Z}{\partial p} \right)_T$$

$$c_r = c_g p_{pc} = \frac{1}{p_{pr}} - \frac{1}{Z} \left(\frac{\partial Z}{\partial p_{pr}} \right)_{T_{pr}}$$

$$\left(\frac{\partial Z}{\partial p_{pr}} \right)_{T_{pr}} = \frac{0.27}{Z T_{pr}} \left(\frac{(\partial Z / \partial \rho)_{T_{pr}}}{1 + \frac{\rho_r}{Z} (\partial Z / \partial \rho)_{T_{pr}}} \right)_{T_{pr}}$$

$$c_r = \frac{1}{p_{pr}} - \frac{0.27}{Z^2 T_{pr}} \left(\frac{(\partial Z / \partial \rho)_{T_{pr}}}{1 + \frac{\rho_r}{Z} (\partial Z / \partial \rho)_{T_{pr}}} \right)_{T_{pr}}$$

Iso-thermal gas compressibility

$$c_g = -\frac{1}{V} \left(\frac{\partial V}{\partial p} \right)_T ; V = \frac{nZRT}{p}$$

$$\left(\frac{\partial V}{\partial p} \right)_T = nRT \left[\frac{1}{p} \left(\frac{\partial Z}{\partial p} \right) - \frac{Z}{p^2} \right]$$

$$c_g = \frac{1}{p} - \frac{1}{Z} \left(\frac{\partial Z}{\partial p} \right)_T$$

Iso-thermal gas compressibility

$$c_r = \frac{1}{p_{pr}} - \frac{0.27}{Z^2 T_{pr}} \left(\frac{\frac{\partial Z}{\partial \rho}}{1 + \frac{\rho_r}{Z} \frac{\partial Z}{\partial \rho}} \right)_{T_{pr}}$$

$$\left(\frac{\partial Z}{\partial \rho} \right)_{T_{pr}} = \left(A_1 + \frac{A_2}{T_{pr}} + \frac{A_3}{T_{pr}^3} + \frac{A_4}{T_{pr}^4} + \frac{A_5}{T_{pr}^5} \right) + 2 \left(A_1 + \frac{A_2}{T_{pr}} + \frac{A_3}{T_{pr}^3} \right) \rho_r$$

$$- 5 A_9 \left(\frac{A_7}{T_{pr}} + \frac{A_8}{T_{pr}^2} \right) \rho_r^4 + \frac{2 A_{10}}{T_{pr}^3} \rho_r \text{EXP} \left(- A_{11} \rho_r^2 \right)$$

$$c_g = \frac{c_r}{p_{pc}}$$

Exercise

Given the following real gas composition,

Component	Mole fraction
C1	0.75
C2	0.07
C3	0.05
n-C4	0.04
n-C5	0.04
C6	0.03
C7	0.02

Calculate the isothermal gas compressibility at 1000 psia and 100 °F.

Gas Formation Volume Factor

Gas Expansion Factor

$$B_g = \frac{V_{p,T}}{V_{sc}}$$

$$B_g = 0.02827 \frac{ZT}{p}, \text{ft}^3/\text{scf}$$

$$B_g = 0.005035 \frac{ZT}{p}, \text{bbl}/\text{scf}$$

$$E_g = \frac{1}{B_g}$$

$$E_g = 35.37 \frac{p}{ZT}, \text{scf}/\text{ft}^3$$

$$E_g = 198.6 \frac{p}{ZT}, \text{scf}/\text{bbl}$$

Gas Viscosity Calculations – Carr-Kobayashi-Burrows Method

Step 1: Calculate the pseudo-critical pressure, pseudo-critical temperature, and apparent molecular weight

Step 2: Obtain the viscosity of the natural gas at 1 atmosphere and the temperature of interest from Carr's atmospheric gas viscosity correlation

Step 3: Correct the viscosity using the inserts of Carr's atmospheric gas viscosity correlation

Gas Viscosity Calculations – Carr-Kobayashi-Burrows Method (contd.)

Step 4: Calculate the pseudo-reduced pressure temperature, and apparent molecular weight.

Step 5: From the pseudo-reduced pressure and temperature obtain the viscosity ratio using Carr's viscosity ratio correlation

Step 6: Obtain the gas viscosity at the pressure and temperature of interest by multiplying the viscosity at 1 atmosphere and system temperature

Gas Viscosity Calculations – Standing Method

$$B_g = \frac{V_{p,T}}{V_{sc}}$$

$$B_g = 0.02827 \frac{ZT}{p}, \text{ ft}^3/\text{scf}$$

$$\mu_1 = (\mu_1)_{uncorrected} + (\Delta\mu)_{N_2} + (\Delta\mu)_{CO_2} + (\Delta\mu)_{H_2S}$$

$$(\mu_1)_{uncorrected} = \left(1.709 \cdot 10^{-5} - 2.062 \cdot 10^{-6} \gamma_g \right) (T - 460) \\ + 8.188 \cdot 10^{-3} - 6.15 \cdot 10^{-3} \log(\gamma_g)$$

$$(\Delta\mu)_{N_2} = y_{N_2} \left[8.48 \cdot 10^{-3} \log(\gamma_g) + 9.59 \cdot 10^{-3} \right]$$

$$(\Delta\mu)_{CO_2} = y_{CO_2} \left[9.08 \cdot 10^{-3} \log(\gamma_g) + 6.24 \cdot 10^{-3} \right]$$

$$(\Delta\mu)_{H_2S} = y_{H_2S} \left[8.49 \cdot 10^{-3} \log(\gamma_g) + 3.73 \cdot 10^{-3} \right]$$

Gas Viscosity Calculations – Standing Method

$$\ln \left[T_{pr} \left(\frac{\mu_g}{\mu_1} \right) \right] = a_0 + a_1 p_{pr} + a_2 p_{pr}^2 + a_3 p_{pr}^3 + T_{pr} (a_4 + a_5 p_{pr} + a_6 p_{pr}^2 + a_7 p_{pr}^3) \\ + T_{pr}^2 (a_8 + a_9 p_{pr} + a_{10} p_{pr}^2 + a_{11} p_{pr}^3) + T_{pr}^3 (a_{12} + a_{13} p_{pr} + a_{14} p_{pr}^2 + a_{15} p_{pr}^3)$$

$$\begin{aligned} a_0 &= -2.4621182 \quad , & a_8 &= -7.93385684 \quad .10^{-1}, \\ a_1 &= 2.97054714 \quad , & a_9 &= 1.39643306 \quad , \\ a_2 &= -2.86264054 \quad .10^{-1}, & a_{10} &= -1.49144925 \quad .10^{-1}, \\ a_3 &= 8.05420522 \quad .10^{-3}, & a_{11} &= 4.41015512 \quad .10^{-3}, \\ a_4 &= 2.80860949 \quad , & a_{12} &= 8.39387118 \quad .10^{-2}, \\ a_5 &= -3.49803305 \quad , & a_{13} &= -1.86408848 \quad .10^{-1}, \\ a_6 &= 3.60373020 \quad .10^{-1}, & a_{14} &= 2.03367881 \quad .10^{-2}, \\ a_7 &= -1.044324 \quad , & a_{15} &= -6.09579263 \quad .10^{-4} \end{aligned}$$

Exercise

Given the following real gas composition,

Component	Mole fraction
CO ₂	0.06
N ₂	0.03
C ₁	0.75
C ₂	0.07
C ₃	0.04
n-C ₄	0.03
n-C ₄	0.02

Calculate the gas density, isothermal gas compressibility, and gas viscosity at 2500 psia and 175 °F.