Tutorial

Example 3-1:

Three pounds of n-butane are placed in a vessel at 120°F and 60 psia. Calculate the volume of the gas assuming an ideal gas behavior.

Solution:

Step 1: Determine the molecular weight of n-butane from Table 2.1 to give

$$M_a = 58.123$$

Step 2: Solve Equation of state for the volume of gas

$$V = \left(\frac{m}{M}\right)\frac{RT}{p}$$

$$V = \left(\frac{3}{58.123}\right)\frac{(10.73)(120+460)}{60} = 5.35\ \text{ft}^3$$

Example 3-2:

Using the data given in the above example, calculate the density of n-butane.

Solution:

$$\rho_g = \frac{m}{V} = \frac{pM}{RT}$$

$$\rho_g = \frac{(60)(58.123)}{(10.73)(120+460)} = 0.56\ \text{lb/ft}^3$$

Example 3-3:

A gas well is producing gas with a specific gravity of 0.65 at a rate of 1.1 MMscf/day. The average reservoir pressure and temperature are 1,500 psi and 150°F. Calculate:

a. Apparent molecular weight of the gas

b. Gas density at reservoir conditions

c. Flow rate in lb/day

Solution:

a. determine the apparent molecular weight

$$M_a = 28.96\gamma_g$$

$$M_a = (28.96)(0.65) = 18.82$$

b. determine gas density

$$\rho g = \frac{PM}{RT}$$

$$\rho_g = \frac{(1500)(18.82)}{(10.73)(610)} = 4.31\ lb/ft^3$$

c.

Step 1: Because 1 lb-mol of any gas occupies 379.4 scf at standard conditions, then the daily number of moles that the gas well is producing can be calculated from

$$n = \frac{(1.1)(10)^6}{379.4} = 2899\ lb - mol$$

Step 2: Determine the daily mass m of the gas produced

$$m = (n)(M_a)$$

$$m = (2899)(18.82) = 54559\ lb/day$$

Example 3-4:

A gas well is producing a natural gas with the following composition:

Component	y_i
CO_2	0.05
C_1	0.90
C_2	0.03
C_3	0.02

Assuming an ideal gas behavior, calculate:

a. Apparent molecular weight
b. Specific gravity
c. Gas density at 2000 psia and 150°F
d. Specific volume at 2000 psia and 150°F

Solution:

Component	y_i	M_i	$y_i \bullet M_i$
CO_2	0.05	44.01	2.200
C_1	0.90	16.04	14.436
C_2	0.03	30.07	0.902
C_3	0.02	44.11	0.882
			$M_a = 18.42$

a. calculate the apparent molecular weight

$$M_a = \sum_{i=1} y_i M_i$$

$$M_a = 18.42$$

b. Calculate the specific gravity

$$\gamma_g = M_a/28.96 = 18.42/28.96 = 0.636$$

c. Calculate the density

$$\rho_g = \frac{PM_a}{RT} = \frac{(2000)(18.42)}{(10.73)(610)} = 5.628 \text{lb/ft}^3$$

d. Determine the specific volume

$$v = \frac{1}{\rho} = \frac{1}{5.628} = 0.178 \text{ ft}^3/\text{lb}$$

Example 3-5:

A gas reservoir has the following gas composition: the initial reservoir pressure and temperature are 3000 psia and 180°F, respectively.

Component	y_i
CO_2	0.02
N_2	0.01
C_1	0.85
C_2	0.04
C_3	0.03
$i-C_4$	0.03
$n-C_4$	0.02

Calculate the gas compressibility factor under initial reservoir conditions.

Solution:

Component	y_i	T_{ci}, °R	y_iT_{ci}	P_{ci}	$y_i\,p_{ci}$
CO_2	0.02	547.91	10.96	1071	21.42
N_2	0.01	227.49	2.27	493.1	4.93
C_1	0.85	343.33	291.83	666.4	566.44
C_2	0.04	549.92	22.00	706.5	28.26
C_3	0.03	666.06	19.98	616.4	18.48
$i-C_4$	0.03	734.46	22.03	527.9	15.84
$n-C_4$	0.02	765.62	15.31	550.6	11.01
			$T_{pc} = 383.38$		$p_{pc} = 666.38$

Step 1: Determine the pseudo-critical pressure and the pseudo-critical temperature:

$$p_{pc} = \sum_{i=1} y_i p_{ci}$$

$$T_{pc} = \sum_{i=1} y_i T_{ci}$$

Ppc= 666.38 psia

Tpc = 383.38 R

Step 2: Calculate the pseudo-reduced pressure and temperature

$$p_{pr} = \frac{3000}{666.38} = 4.50$$

$$T_{pr} = \frac{640}{383.38} = 1.67$$

Step 3: Determine the z-factor from Figure:

Z = 0.85

Example 3-6:

Using the data in Example 3-5 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.

Solution:

Component	y_i	M_i	$y_i \bullet M_i$	T_{ci}, ° R	$y_i T_{ci}$	p_{ci}	$y_i p_{ci}$
CO_2	0.02	44.01	0.88	547.91	10.96	1071	21.42
N_2	0.01	28.01	0.28	227.49	2.27	493.1	4.93
C_1	0.85	16.04	13.63	343.33	291.83	666.4	566.44
C_2	0.04	30.1	1.20	549.92	22.00	706.5	28.26
C_3	0.03	44.1	1.32	666.06	19.98	616.40	18.48
i - C_4	0.03	58.1	1.74	734.46	22.03	527.9	15.84
n -C_4	0.02	58.1	1.16	765.62	15.31	550.6	11.01
			M_a = 20.23		T_{pc} = 383.38		P_{pc}= 666.38

Step 1: Calculate the apparent molecular weight

Ma=20.23

Step 2: Determine the pseudo-critical pressure

Ppc = 666.18

Step 3: Calculate the pseudo-critical temperature

Tpc = 383:38

Step 4: Calculate the pseudo-reduced pressure and temperature

$$p_{pr} = \frac{3000}{666.38} = 4.50$$

$$T_{pr} = \frac{640}{383.38} = 1.67$$

Step 5: Determine the z-factor from Figure

Z = 0.85

Step 6: Calculate the density of the gas assuming a real gas behavior:

$$\rho g = \frac{PM}{ZRT}$$

$$\rho_g = \frac{(3000)(20.23)}{(0.85)(10.73)(640)} = 10.4\ \text{lb/ft}^3$$

Step 7: Calculate the density of the gas assuming an ideal gas behavior

$$\rho g = \frac{PM}{RT}$$

$$\rho_g = \frac{(3000)(20.23)}{(10.73)(640)} = 8.84\ \text{lb/ft}^3$$

The results of the above example show that the ideal gas equation estimated the gas density with an absolute error of 15% when compared with the density value as predicted with the real gas equation.

Example 3-7:

Rework Example 3-5 by calculating the pseudo-critical properties from Equations 3-16 and 3-17.

Solution:

Step 1: Calculate the specific gravity of the gas:

$$\gamma_g = \frac{M_a}{28.96} = \frac{20.23}{28.96} = 0.699$$

Step 2: Solve for the pseudo-critical properties by applying Equations 3-16 and 3-17:

$$T_{pc} = 168 + 325(0.699) - 12.5(0.699)^2 = 389.1\ ^\circ R$$

$$p_{pc} = 677 + 15(0.699) - 37.5(0.699)^2 = 669.2\ \text{psia}$$

Step 3: Calculate Ppr and Tpr.

$$p_{pr} = \frac{3000}{669.2} = 4.48$$

$$T_{pr} = \frac{640}{389.1} = 1.64$$

Step 4: Determine the gas compressibility factor from Figure:

Z = 0.845

Example 3-8:

A gas well is producing at a rate of 15,000 ft3/day from a gas reservoir at an average pressure of 2,000 psia and a temperature of 120°F. The specific gravity is 0.72. Calculate the gas flow rate in scf/day.

Solution:

Step 1: Calculate the pseudo-critical properties from equations 3-16 and 3-17.

Tpc = 395.5 R

Ppc = 668.4 psia

Step 2: Calculate the Ppr and Tpr:

$$p_{pr} = \frac{2000}{668.4} = 2.29$$

$$T_{pr} = \frac{600}{395.5} = 1.52$$

Step 3: Determine the z-factor from Figure:

Z = 0.78

Step 4: Calculate the gas expansion factor

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

$$E_g = 35.37 \frac{2000}{(0.78)(600)} = 151.15 \text{ scf/ft}^3$$

Step 5: Calculate the gas flow rate in scf/day by multiplying the gas flow rate (in ft3/day) by the gas expansion factor Eg as expressed in scf/ft3: Gas flow rate = (151.15) (15,000) = 2.267 MMscf/day

Example 3-9:

Using the data given in Example 3-8, calculate the viscosity of the gas.

Solution:

Step 1: Calculate the apparent molecular weight of the gas:

$$M_a = \gamma_g * 28.96$$

$$M_a = 0.72 * 28.96 = 20.85$$

Step 2: Determine the viscosity of the gas at 1 atm and 140°F from Figure 3-3

$$\mu 1 = 0.0113$$

Step 3: Calculate Ppr and Tpr:

$$Ppr = 2.99$$

$$Tpr = 1.52$$

Step 4: Determine the viscosity rates from Figure 3-4

$$\frac{\mu g}{\mu 1} = 1.5$$

Step 5: Solve for the viscosity of the natural gas:

$$\mu g = \frac{\mu g}{\mu 1} * \mu 1 = 1.5 * 0.0113 = 0.01695 \text{ cp}$$