TABLE B-6—SEPARATOR GAS AND SEPARATOR OIL COMPOSITIONS FOR WELLSTREAM RECOMBINATION CALCULATION (PROBLEM 4)		
Component i	Gas Mole Fraction y_i	Liquid Volume Fraction x_{Vi}
C_1	0.968	0.020
C_2	0.010	0.006
C_3	0.011	0.011
i-C_4	0.003	0.009
n-C_4	0.003	0.013
i-C_5	0.002	0.016
n-C_5	0.001	0.010
C_6	0.002	0.038
C_{7+}	0.000	0.877

$M_{C_{7+}} = 144$ and $\gamma_{C_{7+}} = 0.775$.

e. $\gamma_{API} = (141.5)/(0.640) - (131.5) = 89.4^\circ API.$

f. Moles of $n_{C_6} = (1000\ m^3)(5.36\ kmol/m^3) = 5360\ kmol.$

g. Volume of $n_{C_5} = (1000\ m^3)(0.15\ m^3/m^3)(6.289\ bbl/m^3) \times (42\ gal/bbl) = 3.962 \times 10^4\ gal.$

h. Mass of $n_{C_4} = (1000\ m^3)(58.39\ kg/m^3)(2.205\ lbm/kg) = 1.2875 \times 10^5\ lbm.$

Problem 4

Problem. During a 24-hour test, a well produced 463 STB oil and 5,783 Mscf of separator gas (these volumes are expressed at 14.4 psia and 60°F). **Table B-6** gives oil and gas compositions. Calculate the well-effluent composition in mole fraction. Use apparent liquid densities for methane and ethane of 0.30 and 0.45 g/cm^3, respectively.

Solution. From Eq. 3.18, the producing gas/oil ratio (GOR) is

$$R_p = q_g/q_o = (5.783 \times 10^6)/(463) = 12,500\ scf/STB,$$

or in terms of the producing oil/gas ratio (OGR) from Eq. 3.19,

$$r_p = 1/R_p = (10^6\ scf/MMscf)/(12,500\ scf/STB) = 80\ STB/MMscf.$$

On a basis of 1 STB, the moles of gas produced is given by solving for n_g from the real gas law [$pV = nZRT$ (Eq. 3.30)], with $Z = 1$,

$$n_g = [(14.4)(12,500)]/[(1.0)(10.73)(60 + 460)] = 32.3\ lbm\ mol.$$

Table B-7 calculates oil molar composition and recombined wellstream composition with 1 STB oil volume as a basis. Ideal solution mixing is assumed for the stock-tank oil. Also, note that the component moles in the stock-tank oil are given by $n_{oi} = 5.6146\ V_i\rho_i/M_i$ (Eq. 3.4).

Problem 5

Problem. A new well was completed with perforations in three separate intervals. Initial pressure at midperforations (4,650 ft subsurface) was 2,000 psig at 150°F. The first 24-hour production test gave the information in **Table B-8.**

On the basis of these data, which of the following do you consider best describes the well effluent.

a. Production of a single phase from a gas-condensate reservoir.
b. Production of separate gas and liquid phases into the well.
c. Production of undersaturated liquid into the well.

Explain the basis for your decision.

Solution. The GOR of 19,000 might be descriptive of a gas-condensate system (Answer a). However, at the reservoir pressure of 2,000 psi and 150°F, it would be unlikely that a 27°API liquid could dissolve in the gas phase. The reservoir gas probably has been or currently is in contact with a reservoir oil. At 2,000 psia, the K values ($K_i = y_i/x_i$) of the heavy components that make up a 27°API crude would be extremely small (mostly $< 10^{-3}$) and the heaviest components would have the lowest K values. Even if the reservoir oil contacting the reservoir gas is very heavy, the resulting amounts of heavy components found in the equilibrium gas would be very small and proportionally more of the lighter fractions would be found in the reservoir gas. The condensate from such an equilibrium gas would tend to have a lower gravity (e.g., $\gamma_{API} > 50$°API).

Answer c is also wrong because it is not possible to dissolve 19,000 scf of gas in 1 STB of such a heavy crude oil.

Consequently, Answer b is the best answer. Both reservoir oil (with a gravity somewhat heavier than 27°API) and reservoir gas (with a much lighter condensate gravity) are both flowing into the well simultaneously. Coning, leakage behind the casing, or multiple completion intervals are three situations that might cause the production characteristics seen in this well.

Problem 6

Problem. Table B-9 gives the gas composition of the Sabine field in Texas. This is a typical composition of field gases produced from primary separators. Assuming that this gas is to be compressed and reinjected into a reservoir at 200°F, calculate the compressibility factor, Z; gas formation volume factor (FVF), B_g; and gas density, ρ_g, at 2,000 psig and 160°F. Make the calculations using pseudocritical properties calculated from the gas composition in Table B-9 and from gas gravity.

TABLE B-7—OIL MOLAR COMPOSITION AND RECOMBINED WELLSTREAM COMPOSITION (PROBLEM 4)

Component i	Gas Mole Fraction y_i	Gas Moles $n_{gi} = n_g y_i$ (lbm mol)	Oil Volume V_{oi} (STB)	Liquid Density ρ_i (lbm/ft^3)	Molecular Weight M_i (lbm/lbm mol)	Oil Moles n_{oi} (lbm mol)	Total Moles $n_i = n_{gi} + n_{oi}$ (lbm mol)	Wellstream Mole Fraction z_i
C_1	0.968	31.266	0.020	18.73	16.04	0.131	31.398	0.9123
C_2	0.010	0.323	0.006	28.09	30.07	0.031	0.354	0.0103
C_3	0.011	0.355	0.011	31.66	44.09	0.044	0.400	0.0116
i-C_4	0.003	0.097	0.009	35.01	58.12	0.030	0.127	0.0037
C_4	0.003	0.097	0.013	36.45	58.12	0.046	0.143	0.0041
i-C_5	0.002	0.065	0.016	39.13	72.15	0.049	0.113	0.0033
C_5	0.001	0.032	0.010	39.30	72.15	0.031	0.063	0.0018
C_6	0.002	0.065	0.038	41.19	86.17	0.102	0.167	0.0048
C_{7+}	0.000	0.0000	0.877	48.33	144.00	1.653	1.653	0.0480
Total	1.000		1.000			2.117	34.417	1.0000

Compostions are calculated on the basis of 1 STB oil volume.

TABLE B-8—RESULTS OF FIRST 24-HOUR PRODUCTION TEST (PROBLEM 5)	
Oil produced, STB	65
Stock-tank-oil gravity, °API	27
Gas produced, MMscf	1.23
Gas/oil ratio, scf/bbl separator oil	19,000

Solution. ***Properties From Composition.***

$$M_g = 28.97\gamma_g, \quad \text{(3.28)}$$

$$M = \sum_{i=1}^{N} y_i M_i, \quad \text{(3.50a)}$$

$$T_{pc} = \sum_{i=1}^{N} y_i T_{ci}, \quad \text{(3.50b)}$$

and $p_{pc} = \sum_{i=1}^{N} y_i p_{ci}$. (3.50c)

With the pseudocritical properties in **Table B-10,** these equations give,

$$T_{pc} = 376^\circ\text{R},$$

$$p_{pc} = 667 \text{ psia},$$

$$M_g = 18.83 \quad \text{(Kay's mixing rule)},$$

$$\gamma_g = (18.83)/(28.97) = 0.65 \text{ (air} = 1),$$

$$T_{pr} = T/T_{pc} = (160 + 460)/376 = 1.65,$$

and $p_{pr} = p/p_{pc} = 2{,}015/667 = 3.02$.

Gas Z factor is given by the Hall-Yarborough[1,2] correlation.

$$Z = \alpha p_{pr}/y, \quad \text{(3.42)}$$

where $\alpha = 0.06125t \exp\left[-1.2(1-t)^2\right]$, where $t = 1/T_{pr}$. This gives

$$t = 1/T_{pr} = 1/1.65 = 0.606,$$

$$\alpha = (0.06125)(0.606)\exp\left[(-1.2)(1-0.606)^2\right] = 0.0308,$$

$$y = 0.10996 \; (\mathrm{d}F/\mathrm{d}y = 0.79798),$$

TABLE B-9—GAS COMPOSITION (PROBLEM 6)	
Component	Mole Fraction y_i
C_1	0.875
C_2	0.083
C_3	0.021
i-C_4	0.006
n-C_4	0.008
i-C_5	0.003
n-C_5	0.002
C_6	0.001
C_{7+}	0.001

and $Z = 0.846$.

Gas density is given by

$$\rho_g = pM_g/ZRT, \quad \text{(3.34)}$$

which yields

$$\rho_g = (2{,}015)(18.83)/[(0.846)(10.73)(160 + 460)]$$

$$= 6.74 \text{ lbm/ft}^3.$$

Properties From Specific Gravity Correlations. The Sutton[3] correlations for pseudocritical properties are

$$T_{pc\text{HC}} = 169.2 + 349.5\gamma_{g\text{HC}} - 74.0\gamma_{g\text{HC}}^2 \quad \text{(3.47a)}$$

and $p_{pc\text{HC}} = 756.8 - 131\gamma_{g\text{HC}} - 3.6\gamma_{g\text{HC}}^2$, (3.47b)

which give

$$T_{pc} = 169.2 + 349.5(0.65) - 74.0(0.65)^2 = 365^\circ\text{R},$$

$$p_{pc} = 756.8 - 131.0(0.65) - 3.6(0.65)^2 = 670 \text{ psia},$$

$$T_{pr} = T/T_{pc} = (160 + 460)/365 = 1.70,$$

$$p_{pr} = p/p_{pc} = 2{,}015/670 = 3.01,$$

$$Z = 0.865,$$

and $\rho_g = 6.59 \text{ lbm/ft}^3$.

Problem 7

Problem. Calculate the viscosity of the Sabine field gas of Problem 6 under reservoir conditions of 2,000 psig and 160°F. Use the Lucas[4] and Lohrenz-Bray-Clark[5] viscosity correlations based on gas composition.

TABLE B-10—PSEUDOCRITICAL PROPERTIES (PROBLEM 6)

Component	z_i	M_i	p_{ci} (psia)	T_{ci} °R	z_iM_i	z_ip_{ci} (psia)	z_iT_{ci} °R
C_1	0.8750	16.04	667.8	343.0	14.04	584.3	300.1
C_2	0.0830	30.07	707.8	549.8	2.50	58.7	45.6
C_3	0.0210	44.09	616.3	665.7	0.93	12.9	14.0
i-C_4	0.0060	58.12	529.1	734.7	0.35	3.2	4.4
C_4	0.0080	58.12	550.7	765.3	0.46	4.4	6.1
i-C_5	0.0030	72.15	490.4	828.8	0.22	1.5	2.5
C_5	0.0020	72.15	488.6	845.4	0.14	1.0	1.7
C_6	0.0010	86.17	436.9	913.4	0.09	0.4	0.9
C_{7+}*	0.0010	114.0	360.6	1,023.9	0.11	0.4	1.0
Total	1.0000				18.83	666.8	376.4

*Use properties for n-C_8.

TABLE B-11—LOHRENZ-BRAY-CLARK[5] VISCOSITY CALCULATIONS (PROBLEM 7)

Component	z_i	v_{ci} (ft^3/lbm mol)	Z_{ci}	$z_i v_{ci}$ (ft^3/lbm mol)	$z_i Z_{ci}$
C_1	0.8750	1.590	0.2884	1.391	0.2524
C_2	0.0830	2.370	0.2843	0.197	0.0236
C_3	0.0210	3.250	0.2804	0.068	0.0059
i-C_4	0.0060	4.208	0.2824	0.025	0.0017
C_4	0.0080	4.080	0.2736	0.033	0.0022
i-C_5	0.0030	4.899	0.2701	0.015	0.0008
C_5	0.0020	4.870	0.2623	0.010	0.0005
C_6	0.0010	5.929	0.2643	0.006	0.0003
C_{7+}	0.0010	7.882	0.2587	0.008	0.0003
Total	1.0000			1.752	0.2876

Solution. ***Lucas Correlation With Composition.***

$$\mu_g/\mu_{gsc} = 1 + \frac{A_1 p_{pr}^{1.3088}}{A_2 p_{pr}^{A_5} + \left(1 + A_3 p_{pr}^{A_4}\right)^{-1}}, \quad \ldots\ldots (3.66a)$$

where $A_1 = \dfrac{(1.245 \times 10^{-3})\exp\left(5.1726 T_{pr}^{-0.3286}\right)}{T_{pr}}$,

$$A_2 = A_1\left(1.6553 T_{pr} - 1.2723\right),$$

$$A_3 = \frac{0.4489\exp\left(3.0578 T_{pr}^{-37.7332}\right)}{T_{pr}},$$

$$A_4 = \frac{1.7368\exp\left(2.2310 T_{pr}^{-7.6351}\right)}{T_{pr}},$$

and $A_5 = 0.9425\exp\left(-0.1853 T_{pr}^{0.4489}\right)$, ... (3.66b)

where $\mu_{gsc}\xi = \left[0.807 T_{pr}^{0.618} - 0.357\exp\left(-0.449 T_{pr}\right) + 0.340\exp\left(-4.058 T_{pr}\right) + 0.018\right]$,

$$\xi = 9,490\left(\frac{T_{pc}}{M^3 p_{pc}^4}\right)^{1/6},$$

and $p_{pc} = RT_{pc}\dfrac{\sum_{i=1}^{N} y_i Z_{ci}}{\sum_{i=1}^{N} y_i v_{ci}}$. .... (3.67)

The Lucas correlation gives

$T_{pc} = 376°\text{R}$,

$Z_{pc} = 0.2876$,

$v_{pc} = 1.752$ ft^3/lbm mol,

$p_{pc} = 663$ psia,

$M = 18.83$ lbm/lbm mol,

$T_{pr} = T/T_{pc} = (160 + 460)/376 = 1.65$,

$p_{pr} = p/p_{pc} = 2,015/663 = 3.04$,

$$\xi = 9,490\left\{(376)/\left[(18.83)^3(663)^4\right]\right\}^{1/6} = 77.3 \text{ cp}^{-1}$$

$$\mu_{gsc}\xi = \left\{0.807(1.65)^{0.618} - 0.357\exp[(-0.449)(1.65)] + 0.340\exp[(-4.058)(1.65)] + 0.018\right\} = 0.948,$$

$\mu_{gsc} = \left(\mu_{gsc}\xi\right)/\xi = 0.948/77.3 = 0.0123$ cp,

$A_1 = 0.0607$,

$A_2 = 0.0886$,

$A_3 = 0.272$,

$A_4 = 1.105$,

$A_5 = 0.7473$,

$\mu_g/\mu_{gsc} = 1.360$,

and $\mu_g = 0.0167$ cp.

Lohrenz-Bray-Clark Correlation. Eqs. 3.133 through 3.135 give the Lohrenz-Bray-Clark correlation.

$$\left[(\mu - \mu^o)\zeta_T + 10^{-4}\right]^{1/4} = 0.10230 + 0.023364\rho_{pr} + 0.058533\rho_{pr}^2 - 0.040758\rho_{pr}^3 + 0.0093324\rho_{pr}^4,$$

where $\zeta_T = 5.35\left(\dfrac{T_{pc}}{M^3 p_{pc}^4}\right)^{1/6}$,

$$\rho_{pr} = \frac{\rho}{\rho_{pc}} = \frac{\rho}{M} v_{pc},$$

and $\mu^o = \dfrac{\sum_{i=1}^{N} z_i \mu_i \sqrt{M_i}}{\sum_{i=1}^{N} z_i \sqrt{M_i}}$. .... (3.133)

$\mu_i \zeta_{Ti} = \left(34 \times 10^{-5}\right) T_{ri}^{0.94}$ .... (3.134a)

for $T_{ri} \leqq 1.5$, and

$\mu_i \zeta_{Ti} = \left(17.78 \times 10^{-5}\right)\left(4.58 T_{ri} - 1.67\right)^{5/8}$ .... (3.134b)

for $T_{ri} > 1.5$, where $\zeta_{Ti} = 5.35\left(T_{ci} M_i^3/p_{ci}^4\right)^{1/6}$.

$v_{cC_{7+}} = 21.573 + 0.015122 M_{C_{7+}} - 27.656\gamma_{C_{7+}} + 0.070615 M_{C_{7+}}\gamma_{C_{7+}}$. .... (3.135)

On the basis of the data in **Tables B-11 and B-12**, this correlation yields

$T_{pc} = 376°\text{R}$,

$T_{pr} = 1.65$,

$p_{pc} = 663$ psia,

TABLE B-12—LOHRENZ-BRAY-CLARK VISCOSITY[5] CALCULATIONS (PROBLEM 7)

Component	z_i	M_i	p_{ci} (psia)	T_{ci} (°R)	T_{ri}	ξ_i	μ_i (cp)	$z_i\mu_i M_i^{1/2}$	$z_i M_i^{1/2}$
C_1	0.8750	16.04	667.8	343.0	1.81	0.0463	0.0125	0.0438	3.504
C_2	0.0830	30.07	707.8	549.8	1.13	0.0352	0.0108	0.0049	0.455
C_3	0.0210	44.09	616.3	665.7	0.93	0.0329	0.0097	0.0013	0.139
i-C_4	0.0060	58.12	529.1	734.7	0.84	0.0322	0.0090	0.0004	0.046
C_4	0.0080	58.12	550.7	765.3	0.81	0.0316	0.0088	0.0005	0.061
i-C_5	0.0030	72.15	490.4	828.8	0.75	0.0310	0.0083	0.0002	0.025
C_5	0.0020	72.15	488.6	845.4	0.73	0.0312	0.0081	0.0001	0.017
C_6	0.0010	86.17	436.9	913.4	0.68	0.0312	0.0076	0.0001	0.009
C_{7+}	0.0010	114.00	360.6	1,023.9	0.61	0.0314	0.0068	0.0001	0.011
Total	1.0000							0.0516	4.268

TABLE B-13—ANALYSIS OF SOUR CANADIAN GAS (PROBLEM 8)

Component i	Mole Fraction y_i
CO_2	0.0112
H_2S	0.2609
C_1	0.5575
C_2	0.0760
C_3	0.0433
i-C_4	0.0061
n-C_4	0.0137
i-C_5	0.0033
n-C_5	0.0052
C_6	0.0053
C_{7+}	0.0175

$M_{C_{7+}} = 128$ *and* $\gamma_{C_{7+}} = 0.780$.

$p_{pr} = 3.04,$

$M = 18.83,$

$v_{Mpc} = 1.752\ \text{ft}^3/\text{lbm mol},$

$\rho_{pr} = (6.74/18.83)(1.752) = 0.627,$

$$\xi_T = 5.35\left\{(376)/\left[(18.83)^3(663)^4\right]\right\}^{1/6} = 0.0436,$$

$\mu_{gsc} = 0.0516/4.268 = 0.0121$ cp,

and $\mu_g = 0.0121 + \left[(0.131)^4 - 10^{-4}\right]/(0.0436) = 0.0166$ cp.

Problem 8

Problem. Table B-13 gives the analysis of the sour Canadian gas of Problem 2. Use the method developed by Wichert and Aziz[6,7] and calculate adjusted pseudocritical properties for use with the Standing-Katz[8] Z-factor chart. Then, calculate the gas FVF, B_g, at reservoir conditions of 3,050 psig and 236°F. Note that Canadian standard conditions are 14.65 psia and 60°F.

Solution. The Wichert-Aziz pseudocritical correction is given by

$$T_{pc} = T_{pc}^* - \varepsilon, \quad \text{(3.52a)}$$

$$p_{pc} = \frac{p_{pc}^*\left(T_{pc}^* - \varepsilon\right)}{T_{pc}^* + y_{H_2S}\left(1 - y_{H_2S}\right)\varepsilon}, \quad \text{(3.52b)}$$

$$\text{and } \varepsilon = 120\left[\left(y_{CO_2} + y_{H_2S}\right)^{0.9} - \left(y_{CO_2} + y_{H_2S}\right)^{1.6}\right] + 15\left(y_{H_2S}^{0.5} - y_{H_2S}^4\right), \quad \text{(3.52c)}$$

which (with the pseudocritical properties in **Table B-14**) gives

$\varepsilon = 29.8,$

$T_{pc} = 489.6 - 29.8 = 459.8\,^\circ\text{R},$

$$p_{pc} = \frac{(829.5)(489.6 - 29.8)}{(489.6) + (0.2609)(1 - 0.2609)(29.8)} = 770\ \text{psia},$$

$T_{pr} = 696/459.8 = 1.51,$

and $p_{pr} = 3{,}065/770 = 3.98.$

Where the Standing-Katz[8] Z-factor chart is fit by the Hall-Yarborough[1,2] correlation,

$$Z = \alpha p_{pr}/y, \quad \text{(3.42)}$$

where $\alpha = 0.06125t\exp\left[-1.2(1-t)^2\right]$, where $t = 1/T_{pr}$,

$$\text{and } F(y) = 0 = -\alpha p_{pr} + \frac{y + y^2 + y^3 - y^4}{(1-y)^3} - \left(14.76t - 9.76t^2 + 4.58t^3\right)y^2 + \left(90.7t - 242.2t^2 + 42.4t^3\right)y^{2.18+2.82t}, \quad \text{(3.43)}$$

with $t = 1/1.51 = 0.6622,$

$\alpha = 0.06125(0.6622)\exp\left[-1.2(1-0.6622)^2\right] = 0.03537,$

$y = 0.18088,$

and $Z = 0.778,$

and gas FVF given by

$$B_g = \left(\frac{p_{sc}}{T_{sc}}\right)\frac{ZT}{p} \quad \text{(3.38)}$$

yields

$B_g = (14.65/520)\left[(0.778)(696)/(3{,}065)\right] = 0.00498\ \text{ft}^3/\text{scf}.$

TABLE B-14—PSEUDOCRITICAL-PROPERTY CALCULATIONS FOR A SOUR GAS (PROBLEM 8)

	z_i	M_i	p_{ci} (psia)	T_{ci} (°R)	z_iM_i	z_ip_{ci} (psia)	z_iT_{ci} (°R)
CO_2	0.0112	44.01	1,070.6	547.6	0.49	12.0	6.1
H_2S	0.2609	34.08	1,306.0	672.4	8.89	340.7	175.4
C_1	0.5575	16.04	667.8	343.0	8.94	372.3	191.2
C_2	0.0760	30.07	707.8	549.8	2.29	53.8	41.8
C_3	0.0433	44.09	616.3	665.7	1.91	26.7	28.8
i-C_4	0.0061	58.12	529.1	734.7	0.35	3.2	4.5
C_4	0.0137	58.12	550.7	765.3	0.80	7.5	10.5
i-C_5	0.0033	72.15	490.4	828.8	0.24	1.6	2.7
C_5	0.0052	72.15	488.6	845.4	0.38	2.5	4.4
C_6	0.0053	86.17	436.9	913.4	0.46	2.3	4.8
C_{7+}*	0.0175	128.0	386.7	1,099.5	2.24	6.8	19.2
Total	1.0000				26.98	829.5	489.6

*C_{7+} pseudocriticals from Eq. 3.51.

TABLE B-15—SURFACE PRODUCTION DATA (PROBLEM 9)

Reservoir pressure, psia	5,200
Reservoir temperature °F	250
Separator pressure, psia	950
Separator temperature, °F	160
Primary separator gas rate, Mscf/D	4,265
Primary separator gas gravity (air = 1)	0.70
Tank-oil rate, STB/D	370
Tank-oil gravity, °API	45

Problem 9

Problem. Calculate the reservoir voidage, ΔV_R, expressed as cubic feet, resulting from 1 day of production from the gas-condensate reservoir with surface production data given in **Table B-15.**

Solution. On the basis of 1 day of production,

$$\Delta V_R = \Delta V_g = (\Delta V_{\bar{g}}/\Delta t)\Delta t B_{gd} = q_g(1 \text{ day}) B_{gd} = q_g B_{gd}.$$

Surface-gas rate is $q_g = q_o R_p = q_o(R_1 + R_{s+})$, where R_1 is the separator gas/oil ratio (per stock-tank barrel of condensate) and R_{s+} is the solution gas/oil ratio of the separator oil.

Estimating the additional gas from the separator oil (Eqs. 3.61 through 3.63),

$$R_{s+} = A_1 \gamma_{gs1} \quad \text{(3.61a)}$$

$$\text{and } A_1 = \left[\left(\frac{p_{sp1}}{18.2} + 1.4\right)10^{\left(0.0125\gamma_{\text{API}} - 0..00091 T_{sp1}\right)}\right]^{1.205}; \quad \text{(3.61b)}$$

$$\gamma_{gs1} = A_2 + A_3 R_{s+}, \quad \text{(3.62)}$$

where $A_2 = 0.25 + 0.2\gamma_{\text{API}}$ and $A_3 = -(3.57 \times 10^{-6})\gamma_{\text{API}}$;

$$\text{and } R_{s+} = \frac{A_1 A_2}{(1 - A_1 A_3)} \quad \text{(3.63)}$$

$$\text{gives } A_1 = \left[\left(\frac{950}{18.2} + 1.4\right)10^{(0.0125)(45) - (0.00091)(160)}\right]^{1.205} = 385,$$

$$A_2 = 0.25 + 0.02(45) = 1.15,$$

$$A_3 = -3.57 \times 10^{-6}(45) = -1.607 \times 10^{-4},$$

$$R_{s+} = \frac{(385)(1.15)}{1 - (385)(-1.607 \times 10^{-4})} = 417 \text{ scf/STB},$$

and $\gamma_{gs1} = 1.15 - 1.607 \times 10^{-4}(417) = 1.08$ (air = 1).

The total GOR's and OGR's are given by

$$R_1 = (4.265 \times 10^6)/(370) = 11,527 \text{ scf/STB},$$

$$R_p = 11,527 + 417 = 11,944 \text{ scf/STB},$$

and $r_p = 1/R_p = 8.37 \times 10^{-5}$ STB/scf $= 83.7$ STB/MMscf.

Total gas specific gravity is given by

$$\bar{\gamma}_g = \frac{\gamma_{g1} R_{s1} + \gamma_{gs1} R_{s+}}{R_{s1} + R_{s+}}, \quad \text{(3.64)}$$

which yields

$$\bar{\gamma}_g = [11,527(0.70) + 417(1.08)]/(11,527 + 417)$$

$$= 0.713 \text{ (air = 1)}.$$

The condensate stock-tank-oil molecular weight is estimated from the Cragoe[9] correlation (Eq. 3.59),

$$M_o = \frac{6,084}{\gamma_{\text{API}} - 5.9}, \quad \text{(3.59)}$$

resulting in

$$M_o = 6,084/(45 - 5.9) = 156,$$

which gives the wellstream specific gravity from Eq. 3.55.

$$\gamma_w = \frac{\bar{\gamma}_g + 4,580\, r_p \gamma_o}{1 + 133,000\, r_p (\gamma/M)_o}. \quad \text{(3.55)}$$

This yields

$$\gamma_w = \frac{0.713 + (4,580)(83.7 \times 10^{-6})(0.8017)}{1 + (133,000)(83.7 \times 10^{-6})(0.8017/156)}$$

$$= 0.963 \text{ (air = 1)}.$$

The Sutton[3] pseudocritical correlations

$$T_{pcHC} = 169.2 + 349.5\gamma_{gHC} - 74.0\gamma_{gHC}^2 \quad \text{(3.47a)}$$

$$\text{and } p_{pcHC} = 756.8 - 131\gamma_{gHC} - 3.6\gamma_{gHC}^2 \quad \text{(3.47b)}$$

give $T_{pc} = 437^\circ R$ and $p_{pc} = 627$ psia, and reduced properties are

$$T_{pr} = T/T_{pc} = 710/437 = 1.625$$

and $p_{pr} = p/p_{pc} = 5,200/627 = 8.293$.

The gas volumetric properties are given by Eqs. 3.42 and 3.43,

$$Z = \alpha p_{pr}/y, \quad \text{(3.42)}$$

where $\alpha = 0.06125t\,\exp\left[-(1.21 - t)^2\right]$, where $t = 1/T_{pr}$,

$$\text{and } F(y) = 0 = -\alpha p_{pr} + \frac{y + y^2 + y^3 - y^4}{(1 - y)^3}$$
$$- \left(14.76t - 9.76t^2 + 4.58t^3\right)y^2$$
$$+ \left(90.7t - 242.2t^2 + 42.4t^3\right)y^{2.18 + 2.82t}, \quad \text{(3.43)}$$

giving $Z = 1.024$. With Eq. 7.12,

$$B_{gd} = \left(\frac{p_{sc}}{T_{sc}}\right)\frac{ZT}{p}\left(1 + C_{\bar{o}g} r_s\right) \quad \text{(7.12)}$$

and $C_{\bar{o}g}$ given by

$$C_{\bar{o}g} = 133,000\left(\frac{\gamma_{\bar{o}g}}{M_{\bar{o}g}}\right) \quad \text{(7.13)}$$
$$= 133,000(0.8017/156)$$
$$= 683 \text{ scf/STB}.$$

So with $r_s = 1/R_p$,

$$B_{gd} = \left[(14.7/520)(1.024)(160 + 460)/(5,200)\right]$$
$$\times \left[1 + (683/11,944)\right]$$
$$= 0.00395 \text{ ft}^3/\text{scf}.$$

The initial daily reservoir voidage is then

$$\Delta V_g = (\Delta V_{\bar{g}}/\Delta t)(\Delta t)(B_g)$$
$$= (370)(11,944)(0.00395) = 17,470 \text{ ft}^3 = 3,110 \text{ bbl}.$$

Problem 10

Problem. Table B-16 shows the composition of a reservoir oil in the Kabob field, Canada. Bubblepoint pressure is 3,100 psia at 236°F reservoir temperature. Calculate the density in lbm/ft^3 of the reservoir oil at bubblepoint conditions using ideal-solution principles according to the Standing-Katz[8] method.

Solution. Following the calculation procedure outlined in Chap .3, pseudoliquid density, ρ_{po}, is calculated explicitly with Eqs. 3.94 through 3.97. From **Table B-17** and Eqs. 3.93 and 3.94, volumes and masses needed for the calculations are

$$V_{C_{3+}} = 1.385 \text{ ft}^3,$$
$$m_{C_2} = 3.40 \text{ lbm},$$

and $m_{C_{2+}} = 69.97$ lbm.

Recalling Eq. 3.95,

$$\rho_{C_{2+}} = \frac{-b + \sqrt{b^2 - 4ac}}{2a}, \quad \text{(3.95)}$$

where $a = 0.3167V_{C_{3+}}$, $b = m_{C_2} - 0.3167m_{C_{2+}} + 15.3V_{C_{3+}}$, and $c = -15.3m_{C_{2+}}$, we calculate

$$a = 0.3167(1.385) = 0.439;$$
$$b = 3.40 - 0.3167(69.97) + 15.3(1.385) = 2.43;$$
$$c = -15.3(69.97) = -1,071;$$

$$\text{and } \rho_{C_{2+}} = \frac{-(2.43) + \sqrt{(2.43)^2 - 4(0.439)(-1,071)}}{2(0.439)}$$
$$= 46.70 \text{ lbm/ft}^3,$$

the pseudoliquid density of the C_{2+} mixture at standard conditions. From Eq. 3.96,

$$V_{C_{2+}} = V_{C_{3+}} + \frac{m_{C_2}}{\rho_{C_2}}$$
$$= V_{C_{3+}} + \frac{m_{C_2}}{15.3 + 0.3167\rho_{C_{2+}}}, \quad \text{(3.96)}$$

TABLE B-16—OIL COMPOSITION (PROBLEM 10)

Component	Mole Fraction
CO_2	0.0111
C_1	0.3950
C_2	0.0969
C_3	0.784
i-C_4	0.0159
n-C_4	0.0372
i-C_5	0.0123
n-C_5	0.0211
C_6	0.0295
C_{7+}	0.3026

$M_{C_{7+}} = 182$ and $\gamma_{C_{7+}} = 0.8275$.

TABLE B-17—STANDING-KATZ[8] DENSITY CALCULATION (PROBLEM 10)

Component	z_i	M_i	ρ_i (lbm/ft^3)	$m_i = z_i M_i$ (lbm)	$V_i = m_i/\rho_i$ (ft^3)
C_1	0.3950	16.04		6.34	
C_2	0.0969	30.07		2.91	
CO_2	0.0111	44.01		0.49	
C_3	0.0784	44.09	31.66	3.46	0.109
i-C_4	0.0159	58.12	35.01	0.92	0.026
C_4	0.0372	58.12	36.45	2.16	0.059
i-C_5	0.0123	72.15	39.13	0.89	0.023
C_5	0.0211	72.15	39.30	1.52	0.039
C_6	0.0295	86.17	41.19	2.54	0.062
C_{7+}	0.3026	182.00	51.61	55.07	1.067
Total	1.0000			76.31	

Note: CO_2 is treated as C_2.