CHAPTER 2

2.1 using Equation 2.4: $pV = nRT$

(a) $V = \dfrac{1(10.73)(60+460)}{14.7} = 379.6\ \text{SCF}$

(b) $V = \dfrac{1(10.73)(32+460)}{14.7} = 359.1\ \text{SCF}$

(c) $V = \dfrac{1(10.73)(80+460)}{14.7+10/16} = 378.1\ \text{SCF}$

(d) $V = \dfrac{1(10.73)(60+460)}{15.025} = 371.4\ \text{SCF}$

2.2 (a) number of moles of methane $= 10/16 = .625$ moles

number of moles of ethane $= 20/30 = .667$ moles

total number of moles $= .625 + .667 = 1.292$ moles

(b) from Equation 2.4

$$p = \frac{1.292(10.73)(550)}{500} = 15.25\ \text{psia}$$

(c) molecular wt. of mixture $= \dfrac{\text{wt. of mixture}}{\text{moles of mixture}} = \dfrac{10+20}{1.292} = 23.22$ lb/lb-mole

(d) using Equation 2.6

$$\gamma_g = \frac{23.22}{28.97} = 0.802$$

2.3 using a basis of one mole of gas mixture

Component	Vol. Fraction	Moles	Mol. Wt.	Weight. lb.
Methane	.333	.333	16	5.33
Ethane	.333	.333	30	10.00
Propane	.333	.333	44	14.67
			Total weight	30.00

$$\text{molecular wt.} = 30/1 = 30\ \text{lb/lb-mole} \qquad \gamma_g = \frac{30.00}{28.97} = 1.036$$

2.4 initially the container contains only air but at the end, the container has both air and CO_2

$$\text{moles of air} = \frac{14.7(50)}{10.73(535)} = 0.128 \text{ moles}$$

$$\text{moles of } CO_2 = 10/44 = 0.227 \text{ moles}$$

total moles in the tank at the final state $= 0.128 + 0.227 = 0.355$ moles

using Eq. 2.4: $p = \dfrac{0.355(10.73)(505)}{50} = 38.47$ psia

2.5 cost of acetylene $= \dfrac{\$10.00}{20} = \$0.50$ per lb or $\dfrac{\$10.00}{20/26} = \$13.00$ per lb-mole

$$\text{cost of acetylene per SCF} = \frac{\$10.00}{379.4} = \$0.0264 \text{ per SCF}$$

$$\text{cost of acetylene per MCF} = \$0.0264(1000) = \$26.40 \text{ per MCF}$$

$$\text{amount of acetylene used per day} = \frac{(1+14.7)(200)(520)}{14.7(545)} = 203.8 \text{ SCF/day}$$

$$\text{cost of acetylene per day} = 203.8(\$0.0264) = \$5.38 \text{ per day}$$

2.6 The tank will collapse when the inside pressure reaches the outside pressure minus the pressure that the tank is designed to withstand. This will be used caused by oil being pumped from the tank.

$$\text{collapse pressure} = 29.1 - \frac{0.75(29.9)}{16(14.7)} = 29.005 \text{ inches Hg}$$

the initial volume of the air space, $V_i = \dfrac{3.1416(110^2)}{4}[35 - 25] = 95{,}033$ cu ft

the volume of the air space in the tank at the collapse pressure will be:

$$V_f = \frac{p_i V_i}{p_f} = \frac{29.1(95{,}033)}{29.005} = 95{,}344 \text{ cu ft}$$

the volume of oil removed at the time of collapse will be the difference or 311 cu ft

the pump removes oil at a rate of $20{,}000(5.615)=112{,}300$ cu ft/day

(a) the time of collapse will be $\frac{311}{112{,}300}(24)(60)=3.99$ minutes

(b) total force on roof at time of collapse will be $F=pA$

$$F=(29.1-29.005)\left(\frac{14.7}{29.9}\right)\left[\frac{3.1416(110^2)}{4}\right](144)=63{,}920\ \text{lb}_f$$

(c) The collapse time would have been less.

2.7 (a) basis of 100 lb of mixture

let x = lb of methane

$$\text{moles of mixture} = \text{moles of methane} + \text{moles of ethane} = \frac{\text{weight}}{\text{mol.wt.}} = \frac{100}{.65(28.97)}$$

$$\frac{x}{16}+\frac{100-x}{30}=\frac{100}{.65(28.97)}=5.31$$

$x = 67.8$ lb which suggests that mixture is 67.8% by weight methane

change the basis to one mole of mixture to calculate the mole or volume fraction

let y = methane mole fraction

then, $y(16)+(1-y)(30)=18.83$

$y = 0.798$ which suggests that the mixture is 79.8% by volume methane, recognize that mole fraction = volume fraction for the mixture

(b) The per cent by volume is greater than the per cent by weight for methane because the methane molecule is lighter than the ethane molecule.

2.8 writing a mole balance on the tanks, we get

moles in tank 1 + moles in tank 2 = total moles at the final conditions

$$\frac{p_1V_1}{R'T_1}+\frac{p_2V_2}{R'T_2}=\frac{p_fV_f}{R'T_f}$$

the temperature is constant so the equation becomes $p_1V_1+p_2V_2=p_fV_f$

or $50(50)+25(V_2)=35(50+V_2)$

$V_2=75\text{ cu ft}$

2.9 basis: 1 cu ft

$\frac{p_sV_s}{R'T_s}=\frac{p_cV_c}{R'T_c}$ where the subscripts s and c stand for standard conditions and contact conditions

$$V_s=\frac{p_cV_cT_s}{T_cp_s}=\frac{14.4(1)(520)}{15.025(540)}=0.923\text{ SCF}$$

At the new conditions, the price could be stated in two ways:

1. \$6.00 per 0.923 MCF
2. \$x per MCF

$\frac{6.00}{x}=\frac{0.923}{1}$ or $x=\$6.50$ per MCF

2.10 (a) and (b) the ideal volumes are calculated from the following equation:

$V_i=\frac{p_oV_oT_i}{T_op_i}=\frac{14.7(45{,}000)(620)}{520(p_i)}$ where the subscripts, i and o, refer to ideal and original conditions

the z factors will be calculated from $z=\frac{\text{actual volume}}{\text{ideal volume}}$

the B_g for part (b) can be calculated from $B_g=0.02829\frac{zT}{p}$

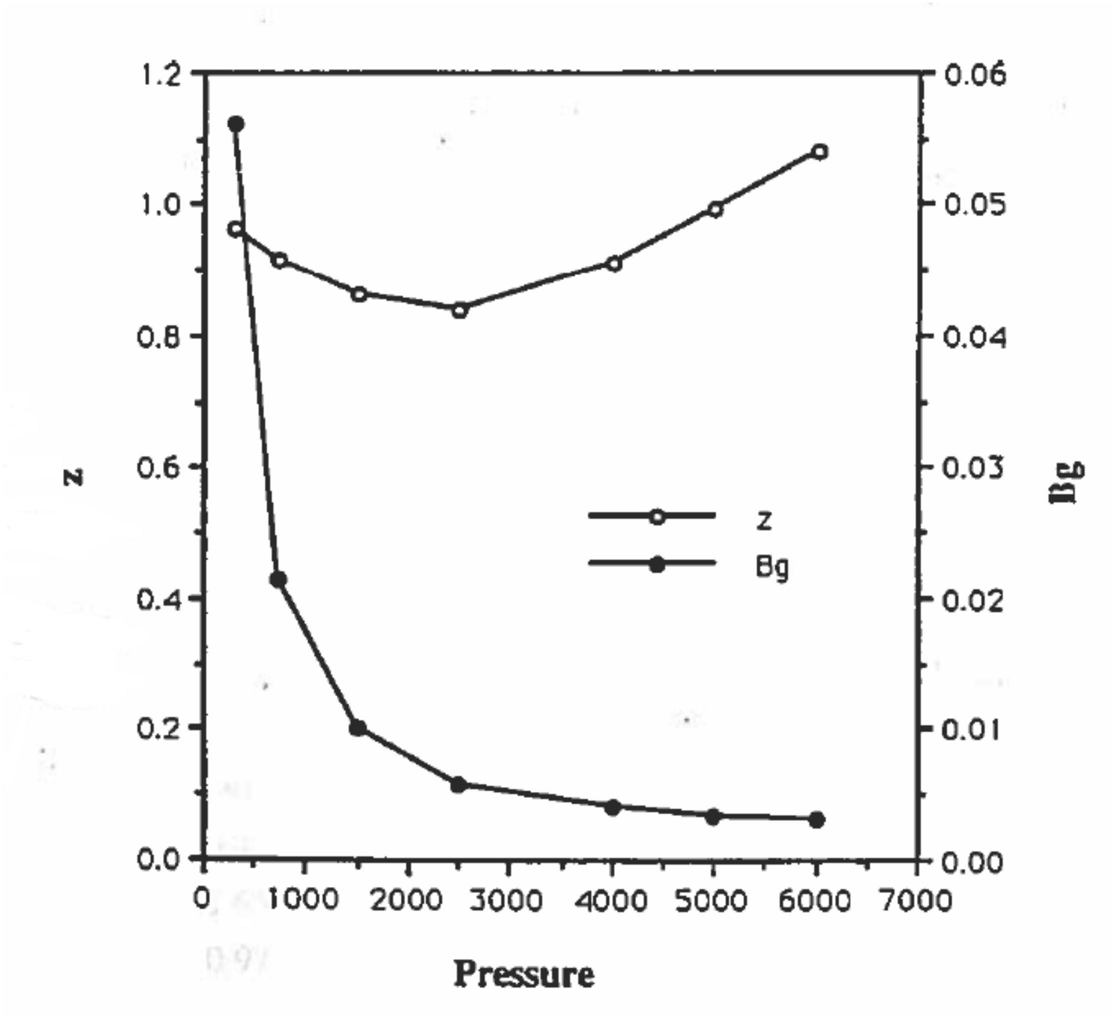
sample calculation, at p = 300 psia, actual volumes = 2529 cc

$$V_i=\frac{14.7(45{,}000)(620)}{520(300)}=2629\text{ cc}\qquad z=\frac{2529}{2629}=0.962$$

$$B_g = 0.02829\frac{(.962)(620)}{300} = 0.05624 \text{ cu ft/SCF}$$

Pressure	actual volume	ideal volume	z	B_g
300	2529	2629	0.962	0.05624
750	964	1052	0.917	0.02144
1500	453	526	0.862	0.01007
2500	265	315	0.840	0.00589
4000	180	197	0.913	0.00400
5000	156.5	158	0.992	0.00348
6000	142.2	131	1.082	0.00316

(c)



2.11 (a) from Eq. 2.9 and 2.10: $p_{pc} = 670$ psia and $T_{pc} = 366$ °R

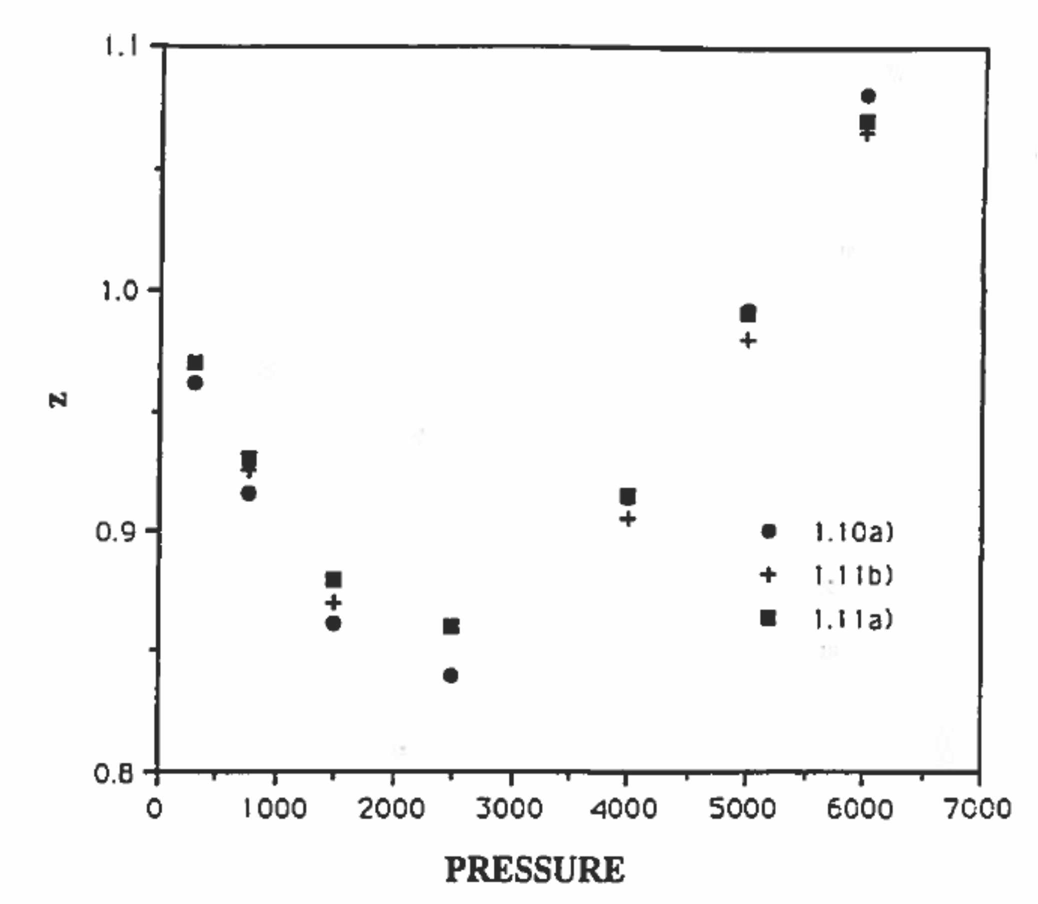
p	p_{pr}	T_{pr}	z (from Figure 2.2)
300	0.45	1.69	0.97
750	1.12	1.69	0.93
1000	1.49	1.69	0.91
1500	2.24	1.69	0.88
2000	2.99	1.69	0.86
2500	3.73	1.69	0.86
3000	4.48	1.69	0.865
4000	5.97	1.69	0.915
5000	7.46	1.69	0.99
6000	8.96	1.69	1.07

(b)

Component	y	M_w	yM_w	p_c	yp_c	T_c	yT_c
Methane	0.875	16.04	14.04	673.1	588.96	343.2	300.30
Ethane	0.083	30.07	2.50	708.3	58.79	549.9	45.64
Propane	0.021	44.09	0.93	617.4	12.97	666.0	13.99
Isobutane	0.006	58.12	0.35	529.1	3.17	734.6	4.41
Butane	0.008	58.12	0.46	550.1	4.40	765.7	6.13
Isopentane	0.003	72.15	0.22	483.5	1.45	829.6	2.49
Pentane	0.002	72.15	0.14	489.8	0.98	846.0	1.69
Hexane	0.001	86.17	0.09	440.1	0.44	914.0	0.91
Heptane	0.001	114.20	0.11	362.2	0.36	1025.0	1.03

$$\gamma_g = \frac{\sum yM_w}{28.97} = \frac{18.84}{28.97} = 0.65 \qquad p_{pc} = \sum yp_c = 671.52 \qquad T_{pc} = \sum yT_c = 376.59$$

p,	300	750	1500	2500	4000	5000	6000
p_{pr},	0.45	1.12	2.23	3.72	5.96	7.45	8.94
T_{pr},	1.65	1.65	1.65	1.65	1.65	1.65	1.65
Z,	0.97	0.925	0.87	0.84	0.905	0.98	1.065



(c) To keep the error less than 2%, the deviation factor would have to be between 1 and 0.98. Reading from the graph, the pressure would have to be less than 180 psia.

(d) A reservoir will contain more SCF of a real gas than of an ideal gas when the deviation factor is less than unity but less than an ideal gas when the deviation factor is greater than unity.

2.12 writing a mole balance, initial moles – moles produced = final moles or $n_i - n_p = n_f$

$$n_i = \frac{p_i V_i}{z_i R' T_i} = \frac{2500(0.33)}{0.75(10.73)(590)} = 0.1738 \text{ moles}$$

$$n_p = \frac{43.6 \text{ SCF}}{379.4 \text{ SCF/mole}} = 0.1149 \text{ moles}$$

$$n_f = 0.1738 - 0.1149 = 0.0589 \text{ moles} \qquad z_f = \frac{1000(0.33)}{0.0589(10.73)(590)} = 0.885$$

2.13 $n_i = \frac{p_i V_i}{z_i R' T_i} \qquad n_f = 0.5 n_i = \frac{p_f V_f}{z_f R' T_f}$

assume: $V_f = V_i$ and $T_i = T_f$

$$0.5\frac{p_i V_i}{z_i R' T_i} = \frac{p_f V_f}{z_f R' T_f} \quad \text{or} \quad p_f = z_f\left(0.5\frac{p_i}{z_i}\right)$$

from Eq. 2.9 and 2.10: $p_{pc} = 666$ psia and $T_{pc} = 372°\text{R}$

$T_{ipr} = \frac{620}{372} = 1.68 \qquad p_{ipr} = \frac{6000}{666} = 9.01$ from Figure 2.2: $z_i = 1.09$

$$p_f = z_f\left(0.5\frac{p_i}{z_i}\right) = 0.5\left(\frac{6000}{1.09}\right)z_f = 2752 z_f$$

this becomes a trial and error solution since z_f is a function of p_f

guess a p_f, calculate z_f, and then calculate p_f to see if the assumed p_f is correct

$$p_f = 2400 \text{ psia}$$

$$n_i = \frac{p_i V_i}{z_i R' T_i} = \frac{6000(1\,\text{MM})}{1.09(10.73)(620)} = 0.827 \text{ MM moles}$$

at 500 psia, using Fig. 2.2, $z_{500} = 0.952$

$$n_i = \frac{p_f V_f}{z_f R' T_f} = \frac{500(1\,\text{MM})}{0.952(10.73)(620)} = 0.0789 \text{ MM moles}$$

$$\text{moles produced} = (0.827 - 0.0789)\text{MM} = 0.748 \text{ MM moles}$$

$(0.748 \text{ MM moles})(379.4 \text{ SCF/mole}) = 283.8 \text{ MM SCF}$ of gas produced

2.14

p	z	dz/dp (slope)	c_g
1000	0.86	-0.001	2200 (10^6)
2200		0	455 (10^6)
4000	0.89	0.000085	154 (10^6)

2.15 from Eq. 2.9 and 2.10: $p_{pc} = 664$ psia and $T_{pc} = 389°R$

$$p_{pr} = \frac{5000}{664} = 7.53 \qquad T_{pr} = \frac{663}{389} = 1.70$$

from Figure 2.5: $c_r T_{pr} = 0.3$

$$c_r = \frac{0.3}{1.74} = 0.17 \text{ therefore } c_g = \frac{c_r}{p_{pc}} = \frac{0.17}{665} = 260\left(10^{-6}\right)\text{psi}^{-1}$$

2.16 $$c_r = \frac{1}{p_{pr}} - \frac{1}{z}\left(\frac{dz}{dp_{pr}}\right) = \frac{1}{4.0} - \frac{1}{0.653}\left(\frac{0.705 - 0.608}{5.0 - 3.0}\right) = 0.176$$

from Fig. 2.4: $c_r T_{pr} = 0.21 \qquad c_r = \dfrac{0.21}{1.3} = 0.16$

2.17 from Figure 2.6: $\mu_1 = 0.01185$ cp

adding corrections for N_2, CO_2, H_2S

$$\mu_1 = 0.01185 + 0.0002 + 0.00025 + 0.0002 = 0.0125 \text{ cp}$$

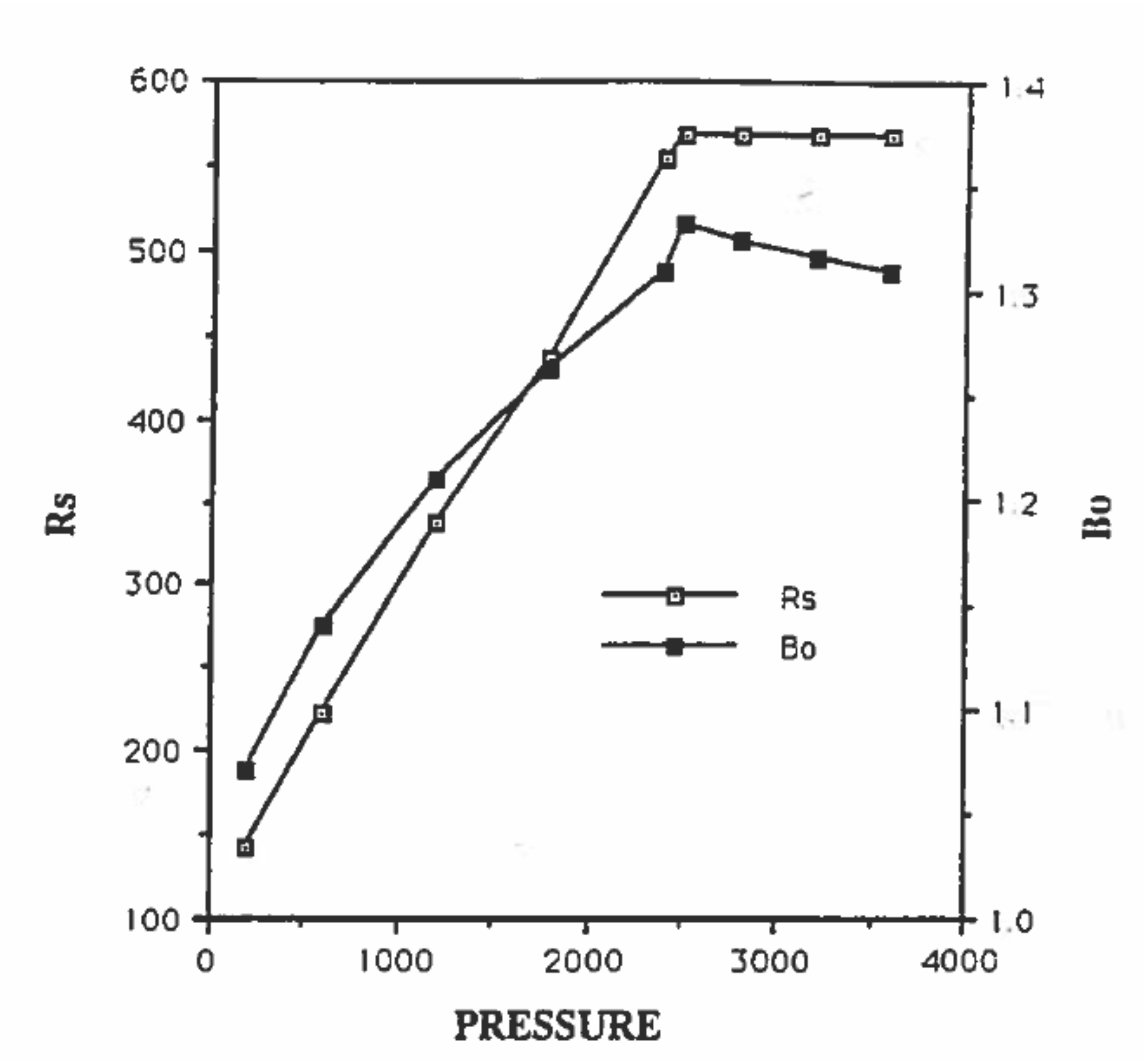
from Eq. 2.9 and 2.10: $T_{pc} = 455\ °R$ and $p_{pc} = 656$ psia

$$p_{pr} = \frac{7000}{656} = 10.61 \qquad T_{pr} = \frac{680}{455} = 1.50$$

from Figure 2.7 $\mu/\mu_1 = 3.2 \qquad \mu = 3.2(0.0125) = 0.040$ cp

2.18 (a) composition of oil and gas, pressure, and temperature

(b)



(c) The oil is undersaturated originally. The horizontal portion of the curve indicates that there is no more free gas present (above 2500 psia) to go into solution. Therefore, above 2500 psia, the oil is undersaturated.

(d) The reservoir had no original gas cap since the oil was undersaturated.

(e) solubility $= \dfrac{567-143}{2500-200} = 0.184\ \mathrm{SCF/STB/psi}$

(f) project R_{so} curve from 2500 psia to 3600 psia by extending the straight line

$$R_{so} = 769 \text{ SCF/STB}$$

Since there are 1000 SCF of gas for every STB and only 769 are required for saturation, the reservoir oil would be saturated. There would also be a gas cap.

2.19 (a) see plot in last problem

(b) There is no more gas to go into solution to increase the volume as the pressure is increased, therefore the volume is reduced with increased pressure. The break in the curve occurs when the last gas goes into solution.

(c) Since there is no additional gas to go into solution to increase the volume as the pressure is increased, the increased pressure reduces the volume instead of increasing the volume as it does below the saturation pressure. The negative slope (above saturation pressure) is smaller than the positive slope (below saturation pressure) because the liquid is only slightly compressible.

(d) initial STB in place, $N = \dfrac{\text{reservoir bbl in place}}{B_{oi}} = \dfrac{250\left(10^6\right)}{1.310} = 190.8\left(10^6\right)\text{STB}$

(e) initial volume of dissolved gas $= NR_{soi} = 190.8\left(10^6\right)567 = 108.2\left(10^9\right)\text{SCF}$

(f) $B_o = \dfrac{V_t}{V_o} = 1 + \beta\left(T - 60\right) = 1 + 0.0006\left(160 - 60\right) = 1.06 \text{ bbl/STB}$

2.20 $Y_g = 0.00091\left(165\right) - 0.0125\left(30\right) = -0.225$

$$R_{so} = 0.80\left[\frac{2500}{18\left(10\right)^{-0.225}}\right]^{1.204} = 567 \text{ SCF/STB}$$

$$\gamma_o = \frac{141.5}{131.5 + 30} = 0.876$$

$$F = 567\left(\frac{.8}{.876}\right)^{.5} + 1.25\left(165\right) = 748$$

$$B_o = .972 + 0.000147\left(748^{1.175}\right) = 1.322 \text{ bbl/STB}$$

2.21 amount of gas in solution $= 0.25(85)(500) = 10{,}625$ SCF

free gas above liquid $= 20{,}000 - 10{,}625 = 9375$ SCF

volume occupied by undissolved gas $= \dfrac{znR'T}{p} = \dfrac{0.90\left(\dfrac{9375}{379.4}\right)(10.73)(580)}{500} = 277$ cu ft

volume of oil and solution gas $= 1000 - 277 = 723$ cu ft or 128.8 bbl

$$B_o = \frac{128.8}{85} = 1.515 \text{ bbl/STB}$$

2.22 $\dfrac{B_o}{B_{ob}} = e^{c_o(p_b - p)} = e^{20\left(10^{-6}\right)(3200-4400)} = 0.976$

2.23 (a) from Eq. 2.36: $\log\left[\log\left(\mu_{od}+1\right)\right] = 1.8653 - .025086(35) - .5644\log(130)$

$$\mu_{od} = 3.2 \text{ cp}$$

from Eq. 2.37: $\mu_o = A\mu_{od}{}^{B}$

$A = 10.715(750+100)^{-.515} = .332 \qquad B = 5.44(750+150)^{-.338} = .546$

$\mu_o = .332(3.2)^{.546} = 0.63$ cp

(b) $\mu_{ob} = 0.63$ cp

from Eq. 2.38

$\mu_o = \mu_{ob} + 1.3449(10^{-3})(p - p_b)10^{A}$

$A = -1.0146 + 1.3322[\log(\mu_{ob})] - .4876[\log(\mu_{ob})]^2 - 1.15036[\log(\mu_{ob})]^3$

A= -1.293

$\mu_o = 0.73$ cp

(c) $\mu_{od} = 3.2$ cp

$$A = 10.715(300+100)^{-.515} = 0.490 \quad B = 5.44(300+150)^{-.338} = 0.690$$

$$\mu_o = 0.49(3.2)^{0.69} = 1.09 \text{ cp}$$

2.24 at 2000 psia:

$$R_{so} = \frac{44{,}500}{500}(5.615) = 500 \text{ SCF/STB}$$

$$B_o = \frac{650}{500} = 1.300 \text{ bbl/STB}$$

$$B_t = 1.300 \text{ bbl/STB}$$

at 1500 psia:

$$R_{so} = 500 \text{ SCF/STB}$$

$$B_o = \frac{669}{500} = 1.338 \text{ bbl/STB}$$

$$B_t = 1.338 \text{ bbl/STB}$$

at 1000 psia:

$$R_{so} = \left[\frac{44{,}500 - \left(\frac{150(1000)}{0.02829(.91)(655)}\right)}{500}\right](5.615) = 400 \text{ SCF/STB}$$

$$B_o = \frac{650}{500} = 1.300 \text{ bbl/STB}$$

$$B_t = \frac{650+150}{500} = 1.600 \text{ bbl/STB}$$

at 500 psia:

$$R_{so} = \left[\frac{44{,}500 - \left(\frac{700(500)}{0.02829(.95)(655)}\right)}{500}\right](5.615) = 276 \text{ SCF/STB}$$

$$B_o = \frac{615}{500} = 1.23 \text{ bbl/STB}$$

$$B_t = \frac{650+700}{500} = 2.63 \text{ bbl/STB}$$

2.25 (a) from Eq. 2.42

$$c_w = \frac{1}{7.033(4000)+541.5(20)-537(150)+403{,}300} = 2.76\left(10^{-6}\right)\text{psi}^{-1}$$

(b) from Eq. 2.39:

$$\begin{aligned}
\Delta V_{wt} &= -1.0001\left(10^{-2}\right)+1.3339\left(10^{-4}\right)(150)+5.50654\left(10^{-7}\right)150^2 = 0.02240\\
\Delta V_{wp} &= -1.95301\left(10^{-9}\right)(4000)150-1.72834\left(10^{-13}\right)\left(4000^2\right)150\\
&\quad -3.58922\left(10^{-7}\right)4000-2.25341\left(10^{-10}\right)4000^2 = -0.006628\\
B_w &= (1+0.0224)(1-0.006628) = 1.016 \text{ bbl/STB}
\end{aligned}$$

2.26 (a) from Eq. 2.44: with $S = 0$

$$\mu_w = AT^B = 109.574(70)^{-1.12166} = 0.93 \text{ cp}$$

(b) $\mu_w = 109.574(200)^{-1.12166} = 0.29 \text{ cp}$

2.27 (a) from Eq. 2.39:

$$\begin{aligned}
\Delta V_{wt} &= -1.0001\left(10^{-2}\right)+1.33391\left(10^{-4}\right)(180)+5.50654\left(10^{-7}\right)180^2 = 0.03185\\
\Delta V_{wp} &= -1.95301\left(10^{-9}\right)(p)180-1.72834\left(10^{-13}\right)\left(p^2\right)180-3.58922\left(10^{-7}\right)p-2.25341\left(10^{-10}\right)p^2
\end{aligned}$$

at $p = 6000$ psia $\quad \Delta v_{wp} = -0.01350$

at $p = 1000$ psia $\quad \Delta V_{wp} = -0.000967$

$$\begin{aligned}
B_{w6000} &= (1+0.03185)(1-0.01350) = 1.0179 \text{ bbl/STB}\\
B_{w1000} &= (1+0.03185)(1-0.000967) = 1.0309 \text{ bbl/STB}
\end{aligned}$$

$$\text{volume change} = \frac{500}{1.0179} - \frac{500}{1.0309} = 6.2 \text{ cc}$$

(b) salinity has been found to have an insignificant effect on B_w, therefore the answer for part (b) is the same as that for part (a)