TPG 4145 - 2006 Exam Solution

Problem 1

a. Z at p_{Ri}, T_R using the SK Chart.

The $p_{pc}, T_{pc} = f(\gamma_{gR})$; $\gamma_{gR} \equiv \frac{\rho_{gsc}}{\rho_{air,sc}} = \frac{M_{gR}}{M_{air}} = \gamma_w$

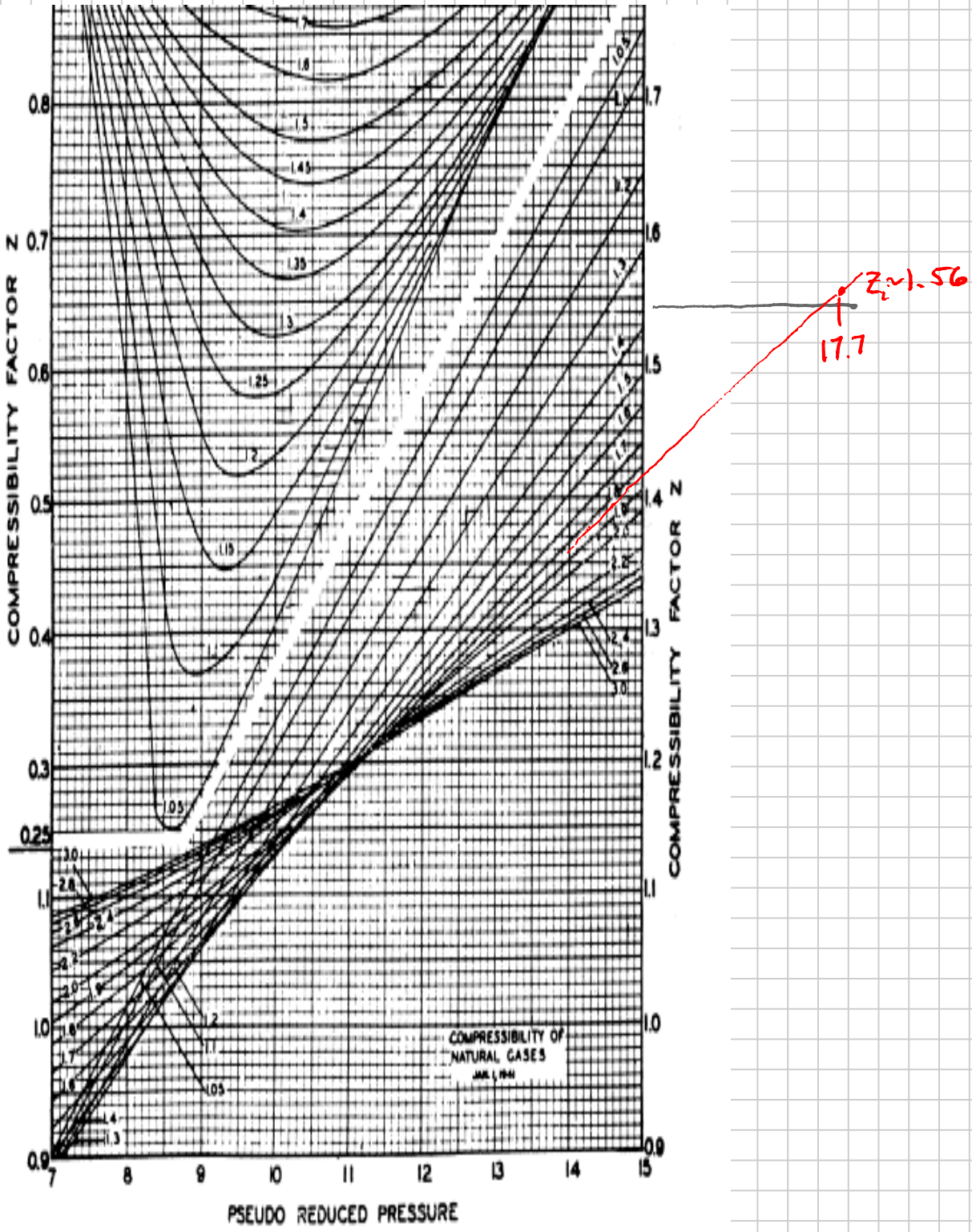
$T_{pc} = 410\,^\circ R = 228\ K$

$p_{pc} = 655\ psia = 45.16\ bara$

$T_{pr} = (150+273)/228 = 1.855$

$p_{pr} = 800/45.16 = 17.71$

} $Z = 1.56$

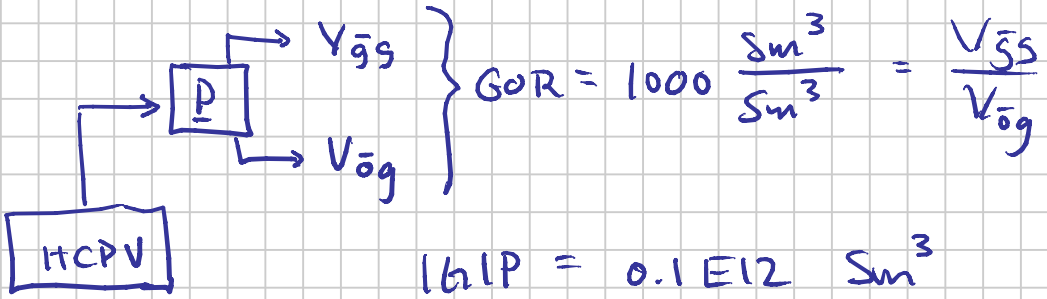


$$B_{gwi} = \left(\frac{P_{sc}}{T_{sc}}\right)\left(\frac{Z_i T_R}{P_i}\right)$$

$$= \left(\frac{1.0135}{15.56+273}\right)\left(\frac{(1.56)(150+273)}{800}\right)$$

$$= \left(\frac{1.0135}{288}\right)\left(\frac{(1.56)(423)}{800}\right)$$

$$= 0.00290 \quad m^3/Sm^3$$



$$GOR = 1000 \frac{Sm^3}{Sm^3} = \frac{V_{\bar{g}s}}{V_{\bar{o}g}}$$

1 bbl = 0.1 E12 Sm^3

$$B_{gd} = \frac{V_{gR}}{V_{\bar{g}g}} = B_{gw} \cdot \underbrace{(1 + C_{og} \cdot r_s)} \qquad (7.12)$$

r_s : STB/scf

$$C_{og} = 133000 \frac{\gamma_{\bar{o}g}}{M_{\bar{o}g}} \qquad (7.13)$$

$$M_{\bar{o}g} = \frac{6084}{\gamma_{API} - 5.9} \qquad (7.14)$$

Assume : $\gamma_{API} = 60\ ^\circ API$

$$\gamma_{\bar{o}} = \frac{141.5}{131.5+60} = 0.739 \qquad \left(739 \frac{kg}{m^3}\right)$$

$$M_{\bar{o}g} = 112$$

$$C_{og} = 133000\left(\frac{0.739}{112}\right)$$

$$= 877 \quad scf/STB$$

$$= 156 \quad Sm^3/Sm^3$$

$$r_s = \frac{1}{GOR} = \frac{1}{1000\ Sm^3/Sm^3\ (5.615\ scf/STB)}$$

$r_s = 0.000178$ STB/scf $\left[178\ ^{STB}/_{MMscf}\right]$

$\left[1 + (0.000178)(877)\right] = 1.156$

$B_{gd} = B_{gw} \cdot 1.156$

$= (0.00290)(1.156)$

$= 0.00335\ m^3/Sm^3$

$HCPV = IGIP \cdot B_{gd}$

$= 0.1E12\,(0.00335)$

$= 0.000335E12$

$= 0.335\,E9$

$HCPV = 335 \cdot 10^6\ m^3$

(c) At $\begin{cases} P_R = 400 \text{ bara} \\ T_R \\ Z_R \end{cases}$, new $HCPV = HCPV_i - \underbrace{0.2\,HCPV_i}_{We}$

$= 0.8\,HCPV_i$

$\frac{n_R}{n_i} = \frac{\frac{P_R \cdot HCPV}{RT_R Z_R}}{\frac{P_i \cdot HCPV_i}{RT_R Z_i}} = \frac{P_R}{P_i}\left(\frac{0.8\,HCPV_i}{HCPV_i}\right)\left(\frac{Z_i}{Z_R}\right)$

$= \left[\left(\frac{P_R}{Z_R}\right)\Big/\left(\frac{P_i}{Z_i}\right)\right] \cdot 0.8$ ← @400bara

$n_p = n_i - n_R$

Wet Gas RF

$\left(\frac{n_p}{n_i}\right) = 1 - \frac{n_R}{n_i}$

$RF_w = RF_g = RF_o$

$P_R \geq P_{di}$

$RF_g = RF_o = RF_w$

$Z\left(T_{pr} = 1.855,\ P_{pr} = \frac{400}{45.16} = 8.86\right)$

$Z_R = 1.07$

$$RF_g = RF_o = RF_w = 1 - 0.8 \frac{(P_R/Z_R)}{(P_i/Z_i)}$$

$$= 1 - 0.8 \frac{(400/1.07)}{(600/1.56)}$$

$$= 0.417 = \underline{41.7\ \%} \qquad (c)\ \xi(d)$$

(2)

a. $\dot{m}_g = q_g\,[Sm^3/d] \cdot \rho_{gsc}$ ↙

$\dot{m}_o = q_o\,[sep.\,m^3/d] \cdot \rho_{osp}$ ↙

$$\rho_{gsc} = \frac{P_{sc} \cdot M_g}{R\,T_{sc}} = \frac{(1.0135)(20.41)}{(0.083143)(288.7)} = \underline{0.862\ \frac{kg}{m^3}}$$

$$= (\rho_{air,sc})\,\gamma_g$$

$$M_g = \sum y_i M_i$$

	Separator Gas mol-%	M
N_2	1.28	28
CO_2	1.60	44
C_1	83.07	16
C_2	7.27	30
C_3	3.18	44
iC_4	0.84	58
nC_4	1.18	58
iC_5	0.41	72
nC_5	0.45	72
C_6	0.48	86
C_{7+}	0.24	115
M_{7+}	115	
y_{7+}	0.72	

$$\dot{m}_g = \left(0.2 \cdot 10^6\ \frac{Sm^3}{d}\right)\left(0.862\ \frac{kg}{Sm^3}\right)$$

$$= 0.172 \cdot 10^6\ kg/d$$

$$= \underline{172\,000\ kg/d}$$

$$\dot{m}_o = \left(1000\ \frac{m^3}{d}\right)\left(730\ \frac{kg}{m^3}\right)$$

$$= \underline{730\,000\ kg/d}$$

$$\frac{\sum y_i M_i}{\sum y_i} \frac{= 2041}{100} \Rightarrow \bar{M}_g = 20.41$$

$$\dot{n}_g = \dot{m}_g / M_g \quad ; \quad M_g = 20.41$$

$$\dot{n}_o = \dot{m}_g / M_o \quad ; \quad M_o = 102$$

(b) $\dot{n}_g = (172\,000)/(20.41) = 8427$ kmol/d

$\dot{n}_o = (730\,000)/(102) = 7157$ kmol/d

(c) mol-% C in the wellstream?

$$z_{C_1} = \frac{\dot{n}_g \cdot y_{C_1} + \dot{n}_o x_{C_1}}{\dot{n}_g + \dot{n}_o}$$

$$= \frac{(8427)(83.07) + (7157)(20.52)}{8427 + 7157} = \frac{700\,000 + 146860}{15584}$$

$$z_{C_1} = 54.31 \text{ mol-\% } C_1$$

(d) $K_{C_1} = \frac{y_{C_1}}{x_{C_1}} = \frac{83.07}{20.52} = 4.05$

$K_{C_3} = \frac{y_{C_3}}{x_{C_3}} = \frac{3.18}{6.95} = 0.46$

$K_{C_{7+}} = \frac{y_{C_{7+}}}{x_{C_{7+}}} = \frac{0.24}{33.12} = 0.0072$

(e) est $K_{C_{7+}}$ at 1 atm, Tsp using log-log K-P slope = -1

$$K_i = \frac{P_{vi}}{P}$$

$$0.0072 = \frac{P_{vi}}{60}$$

$$\Rightarrow P_{vC_{7+}} = (0.0072)(60) = 0.432 \text{ bara}$$

$$K_{C_{7+}}^{1\text{ atm}} \simeq \frac{0.432 \text{ bara}}{1 \text{ bara}} = 0.432 \checkmark$$

3.

a. $P_{wf} = 138 \text{ bara} \times 14.5 \frac{\text{psia}}{\text{bara}} = 2000 \text{ psia}$

$B_o = 1.2797 \text{ RB/STB} = 1.2797 \text{ m}^3/\text{Sm}^3$

$R_s = 359 \text{ scf/STB} \frac{\text{bbl}}{5.615 \text{ scf}} = 64 \text{ Sm}^3/\text{Sm}^3$

$\mu_o = 0.49 \text{ cp}$

$r_s = 16.58 \cdot 10^{-6} \text{ STB/scf} = 16.58 \text{ STB/MMscf} \times \frac{5.615 \text{ scf}}{\text{STB}}$

$= 9.31 \cdot 10^{-5} \text{ Sm}^3/\text{Sm}^3$

$B_{gd} = 0.00173 \frac{\text{RB}}{\text{scf}} \times 5.615 \frac{\text{ft}^3}{\text{RB}} = 0.0097 \text{ m}^3/\text{Sm}^3$ (*)

$\mu_g = 0.0168 \text{ cp}$

b. $q_o = q_{oo} + q_{og}$

$q_g = q_{go} + q_{gg}$

$r_s = \frac{q_{og}}{q_{gg}} \qquad R_s = \frac{q_{go}}{q_{oo}}$

$q_o = q_{oo} + r_s q_{gg}$

$q_g = q_{oo} R_s + q_{gg}$

$q_{gg} = q_g - q_{oo} R_s$

$q_o = q_{oo} + r_s (q_g - q_{oo} R_s)$

$= q_{oo} + r_s q_g - q_{oo} \cdot r_s R_s$

$q_o - r_s q_g = q_{oo} (1 - r_s R_s)$

$q_o - r_s (q_o \cdot R_p) = q_{oo} (1 - r_s R_s)$

$$q_{oo} = q_o \underbrace{\frac{(1 - r_s R_p)}{(1 - r_s R_s)}}_{\text{fraction of total } q_o \text{ from RO}}$$

$$= 1000 \cdot \frac{(1 - (9.31 \cdot 10^{-5})(1000))}{(1 - (9.31 \cdot 10^{-5})(64))}$$

$$= 1000 \cdot \frac{0.9069}{0.994}$$

$$\underline{q_{oo} = 912 \text{ Sm}^3/\text{d}}$$

So from RO

$$q_g = q_{gg} + q_{oo} R_s$$

$$q_{go} = q_{oo} R_s = (912)(64)$$

$$\underline{q_{go} = 58368 \text{ Sm}^3/\text{d}}$$

$$(1000)(1000) = q_{gs} + (912)(64)$$

$$\underline{q_{gg} = 941632 \text{ Sm}^3/\text{d}}$$

SG from RG

$$q_{og} = q_{gg} \cdot r_s$$

$$= (941632)(9.31 \cdot 10^{-5})$$

$$\underline{q_{og} = 88 \text{ Sm}^3/\text{d}}$$

c. $q_{gR} = q_{gg} \cdot B_{gd} = (941632)(0.0097) = \underline{9147 \text{ m}^3/\text{d}}$

$q_{oR} = q_{oo} \cdot B_o = (912)(1.2797) = \underline{1167 \text{ m}^3/\text{d}}$

d. $\left(\frac{K_{rg}}{K_{ro}}\right) = \left(\frac{q_{gR}}{q_{oR}}\right)\left(\frac{\mu_g}{\mu_o}\right) = \left(\frac{9147}{1167}\right)\left(\frac{0.0168}{0.49}\right) = \underline{\underline{0.27}}$

4. RG: if $\frac{1}{GOR} < r_s$ @ $P_{Ri} = 4000$ psia ✗ No

RO if $GOR < R_s$ at $P_{Ri} = 4000$ psia ✗ No

$$GOR = \frac{237 \cdot 10^9}{126 \cdot 10^6} = 1881 \frac{scf}{STB} \Rightarrow \frac{1}{GOR} = 5.3 \cdot 10^{-4} \frac{STB}{scf}$$

$$r_s = 33.76 \cdot 10^{-6} \text{ STB/scf}$$

$$R_s = 823 \text{ scf/STB}$$

(a) $\Rightarrow$ RG + RO ✓

b. $HCPV = HCPV_{RG} + HCPV_{RO}$

✓ $IOIP = IOIP_{RG} + IOIP_{RO}$

$$= HCPV_{RG}\underbrace{\left(\frac{1}{B_{gd}} \cdot r_{si}\right)}_{a} + HCPV_{RO}\underbrace{\left(\frac{1}{B_{oi}}\right)}_{b} \quad (1)$$

✓ $IGIP = IGIP_{RG} + IGIP_{RO}$

$$= HCPV_{RG}\underbrace{\left(\frac{1}{B_{gd}}\right)}_{c} + HCPV_{RO}\underbrace{\left(\frac{1}{B_{oi}} \cdot R_{si}\right)}_{d} \quad (2)$$

$$IOIP = HCPV_{RG} \cdot a + HCPV_{RO} \cdot b$$

$$IGIP = HCPV_{RG} \cdot c + HCPV_{RO} \cdot d$$

$$HCPV_{RO} = (IOIP - HCPV_{RG} \cdot a)/b$$

$$IGIP = HCPV_{RG} \cdot c + \frac{d}{b}(IOIP - HCPV_{RG} \cdot a)$$

$$IGIP = HCPV_{RG}\left(c - \frac{d}{b}a\right) + \frac{d}{b} \cdot IOIP$$

$$HCPV_{RG} = \frac{16\overline{IP} - \left(\frac{d}{b}\right)10\overline{IP}}{\left(c - \frac{d}{b}a\right)} \quad [scf] \quad [ft^3] \quad [scf/ft^3]$$

$$HCPV_{RO} = \frac{1}{b}\left(10\overline{IP} - HCPV_{RG}\cdot a\right) \quad \left[\frac{RB}{STB}\right] \quad [STB] \quad [STB] \quad [RB]$$

$$\frac{d}{b} = 823$$

$$\left(c - \frac{d}{b}a\right) = 188$$

$$HCPV_{RG} = \frac{(237\cdot 10^9) - (823)(126\cdot 10^6)}{188} = 7.09\cdot 10^8 \text{ ft}^3$$

$$\Rightarrow HCPV_{RO} = (1.496)\left(126\cdot 10^6 - 7.09\cdot 10^8 (0.00653)\right) = 1.816\cdot 10^8 \text{ RB}$$

$$a = \frac{r_{si}}{B_{gdi}} = 33.76\cdot 10^{-6}/0.00517 = 0.00653 \text{ STB/ft}^3$$

$$b = \frac{1}{B_{oi}} = 1/1.496 = 0.668 \text{ STB/RB}$$

$$c = \frac{1}{B_{gdi}} = 1/0.00517 = 193 \text{ scf/ft}^3$$

$$d = R_{si}/B_{oi} = 823/1.496 = 550 \text{ scf/RB}$$

$B_{gdi} = 0.00092 \frac{RB}{scf} = 0.00517 \text{ ft}^3/\text{scf}$ (*)

$B_{oi} = 1.496 \text{ RB/STB}$

(b)

$$HCPV = HCPV_{RG} + HCPV_{RO}$$

$$= 7.09\cdot 10^8 \text{ ft}^3 \left[\frac{RB}{5615 \text{ ft}^3}\right] + 1.816\cdot 10^8 \text{ RB} \quad [RB]$$

$$HCPV = 3.08\cdot 10^8 \text{ RB}$$

(c)

$$10IP = HCPV_{RG}\cdot a + HCPV_{RO}\cdot b$$

$$10IP = HCPV_{RG}\cdot c + HCPV_{RO}\cdot d$$

$$a = \frac{r_{si}}{B_{gdi}} = 33.76\cdot 10^{-6}/0.00517 = 0.00653 \text{ STB/ft}^3$$

$$b = \frac{1}{B_{oi}} = 1/1.496 = 0.668 \text{ STB/RB}$$

$$c = \frac{1}{B_{gdi}} = 1/0.00517 = 193 \text{ scf/ft}^3$$

$$d = R_{si}/B_{oi} = 823/1.496 = 550 \text{ scf/RB}$$

$$10IP_{RG} = (0.00653)(7.09\cdot 10^8) = 4.63\cdot 10^6 \text{ STB}$$

$$OIP_{RO} = (0.668)(1.816 \cdot 10^8) = 1.213 \cdot 10^8 \text{ STB}$$

$$IGIP_{RG} = (193)(7.09 \cdot 10^8) = 1.37 \cdot 10^{11} \text{ scf}$$

$$IGIP_{RO} = (550)(1.816 \cdot 10^8) = 9.99 \cdot 10^{10} \text{ scf}$$

$OIP = 1.255 \cdot 10^8$ STB vs $1.26 \cdot 10^8$ STB ✓

$IGIP = 2.369 \cdot 10^{11}$ scf vs $2.37 \cdot 10^{11}$ scf ✓