Problem 1.

1-(1) $Z_{Ri} = Z_g$ at (p_{Ri}, T_R) : SK Z-factor Chart $Z_g(T_{pr}, p_{pr})$

$T_R = 280\,°F$ (Table 1)

$p_{Ri} = 12\,000$ psia (Table 1)

$T_{pr} = T_R / T_{pc}$, $p_{pr} = p_{Ri} / p_{pc}$

$T_{pc} = \Sigma y_i T_{ci}$ $p_{pc} = \Sigma y_i p_{ci}$: Too time consuming to calc. in exam.

y_i = Initial reservoir gas composition (Table 1 at 1st stage in CVD test)

Use $T_{pc}(\gamma_g)$ & $p_{pc}(\gamma_g)$ correlations (chart or Sutton eqs.)

$\gamma_g = M_g / M_{air}$ $\gamma_g \equiv \left(\frac{\rho_g}{\rho_{air}}\right)_{p_{sc}, T_{sc}}$

$M_g = \Sigma y_i M_i$ M_i from table in App. A : time consuming ~~but~~ doable

$M_g = (y_{C5-} \cancel{M_{C6+}} M_{C5-} + y_{C6+} \cdot M_{C6+}) / \underbrace{(y_{C5-} + y_{C6+})}_{=1}$ | C_{5-} All C_5 and lighter, C_{6+} All C_6 and heavier

$M_g = (0.907)(20.89) + (0.093)(172.5) = 35$

$\gamma_g = 35 / 28.97 = 1.21$

$T_{pc} \cong 480\,°R$ $p_{pc} \cong 630$ psia (read from Chart : Gas Condensate)

(465-485 °R) (595-640 psia) acceptable ranges : Eqs.

$T_{pr} = (280+460)/480 = 740/480 = 1.54$
$p_{pr} = 12000/630 = 19.0$
} Z_g = by extrapolation

$T_{pr} = 1.54$

p_{pr}	Z_g
12	1.27
15	1.48

$\frac{\Delta Z_g}{\Delta p} = 0.07$

$Z_{Ri} = 1.48 + (19-15)(0.07)$

$\boxed{Z_{Ri} = 1.76}$

1-(2) Surface oil $(\bar{o})$ = $C_{6+} = C_6 + C_{7+}$ | Surface Gas $(\bar{g})$ = C_{5-} = $n\text{-}C_5$ $i\text{-}C_5$ $n\text{-}C_4$ .... C_1 CO_2 N_2

$$r_{si} = \frac{n_{\bar{o}} (M/\rho)_{\bar{o}}}{n_{\bar{g}} (RT_{sc}/p_{sc})} \quad ; \quad n_{\bar{o}} = y_{C6+} \quad n_{\bar{g}} = y_{C5-} = 1 - y_{C6+}$$

Field Units : ρ (lb/ft³) , $RT_{sc}/p_{sc} = 379$ scf/lbmole

5.615 ft³/bbl 10^6 scf / MMscf

$M_{C6} = 86$ $M_{7+} = 184$ (Table 1)

$\rho_{C6} = 41.2$ lb/ft³ $\rho_{7+} = 0.816(62.4) = 50.9$

(C_6 : assume $n\text{-}C_6$)

$y_{C6} = 1.09$, $y_{C7+} = 8.21$ } $y_{C6+} = 0.093$ (= 9.30 mol-%)

$$= \frac{y_{6+} (M/\rho)_{6+} \cdot 10^6}{(1-y_{6+})\, 379\, (5.615)}$$

$$= \frac{0.093 (172.5/50.2) \cdot 10^6}{(1-0.093)(379)(5.615)}$$

$\boxed{r_{si} = 165 \text{ STB/MMscf}}$

$M_{6+} = 172.5$

$$\rho_{6+} = \frac{1.09(86) + 8.21(184)}{\frac{1.09(86)}{41.2} + \frac{8.21(184)}{50.9}} = 50.2 \text{ lb/ft}^3$$

Ideal Volume Mixing

1-(3) $B_{gdi} = \frac{p_{sc}}{T_{sc}} \cdot \frac{T_R Z_{Ri}}{p_{Ri}} \cdot \frac{1}{y_{\bar{g}}}$

$= \frac{14.7}{520} \cdot \frac{(280+460)(1.76)}{12\,000} \cdot \frac{1}{0.907}$

$= 0.003383$ ft³/scf

$\boxed{b_{gdi} \equiv \frac{1}{B_{gdi}} = 296 \text{ scf/ft}^3}$

1-(4) $IGIP = HCPV \cdot b_{gdi}$

$= 10^{11} \text{ ft}^3 \cdot 296$

$= 29.6 \cdot 10^{12}$ scf

$\boxed{IGIP \cong 30 \text{ Tcf}}$

1-(5) $IOIP = IGIP \cdot r_{si}$

$= 30 \cdot 10^6 \text{ MMscf} \cdot 165 \frac{\text{STB}}{\text{MMscf}}$

$\boxed{IOIP = 4.95 \cdot 10^9 \text{ STB}}$

1-(6) Value Surface Oil = ~~30·10⁹ Mscf~~ $4.95 \cdot 10^9$ STB × 85 USD/STB = $425 \cdot 10^9$ USD

Value Surface Gas = $30 \cdot 10^9$ Mscf × 4 USD/Mscf = $120 \cdot 10^9$ USD

% Value from Surface Oil = $\frac{425}{425+120} = \boxed{78\%}$

1-(7) $\frac{p_R}{Z_R} = \frac{p_{Ri}}{Z_{Ri}}\left(1 - \frac{G_p}{G}\right)$ $\quad p_R = p_d = 6765$ psia (Table 1)

$Z_R @ p_d = 1.238$ (Table 1)

$\frac{G_p}{G} = 1 - \frac{p_R/Z_R}{p_{Ri}/Z_{Ri}}$

$= 1 - \frac{(6765/1.238)}{(12000/1.76)} = 0.198$ (~20%)

$N_p = \int q_o\, dt = \int q_g r_p\, dt$ | when $p_R \geq p_d$, $r_p = r_{si}$

$G_p = \int q_g\, dt$

$N_p = \int q_g r_{si}\, dt = r_{si} \cdot \int q_g\, dt = r_{si} \cdot G_p$

$N = r_{si} \cdot G$

$\frac{N_p}{N} = \frac{r_{si} G_p}{r_{si} G} = \frac{G_p}{G}$ when $p_R \geq p_d$

$\boxed{\frac{G_p}{G} = \frac{N_p}{N} = 20\% \ @ \ p_R = p_d}$

1-(8) $$\frac{P_R}{Z_R}\left[1 - c_e(P_{Ri} - P_R)\right] = \frac{P_{Ri}}{Z_{Ri}}\left(1 - \frac{G_p}{G}\right)$$

$$c_e = \frac{c_f + c_w S_{wi} + M(c_f + c_w)}{1 - S_{wi}}$$

$$= \frac{6.5 + 3.5(0.35) + 3.3(6.5 + 3.5)}{1 - 0.35} \cdot 10^{-6}$$

$$c_e = 62.6 \cdot 10^{-6}\ psi^{-1}$$

$$\frac{G_p}{G} = 1 - \frac{(P_R/Z_R)}{(P_{Ri}/Z_{Ri})}\left[1 - c_e(P_{Ri} - P_R)\right]$$

$$= 1 - 0.8\left[1 - 62.6 \cdot 10^{-6}(12000 - 6765)\right]$$

$$\boxed{G_p/G = 0.462 = 46.2\,\% = N_p/N}$$

Again $\left(\frac{G_p}{G} = \frac{N_p}{N}\right)_{P_R \geq P_d}$

(9) The heaviest component(s) C_{7+} have the biggest impact on dewpoint calculation, through the term ~~[illegible]~~ $y_{7+}/K_{7+} = x_{7+}$. The incipient oil main component is C_{7+} and x_{7+} is therefore important.

$$\boxed{K_{7+}}$$

Problem 2

2-(1) Text somewhat unclear:

(a) p_{wf} @ $q_g = 52\,500$ Mscf/D <u>during</u> test

$$Bq_g^2 + Aq_g = (p_R^2 - p_{wf}^2)$$; p^2 ok because $p_R \lessapprox 2500$ psia

Test values given in problem: [

$A = 1$ psi²/(Mscf/D)

$B = 27 \cdot 10^{-6}$ psi²/(Mscf/D)²

$p_{Ri} = 1370$ psia

solve for p_{wf}:

$$p_{wf}^2 = p_{R_i}^2 - Bq_g^2 - Aq_g$$

$$= (1370)^2 - (27 \cdot 10^{-6})(52500)^2 - (1)(52500)$$

$$p_{wf} = [1876900 - 126918]^{1/2}$$

$$\boxed{p_{wf} = 1323 \text{ psia}}$$

(b) p_{wf} @ $q_g = 52\,500$ Mscf/D for the "development" well (pss) with $s = 0$ and $d_t = 6.5''$ I.D.

$$A_{pss} = \underset{1}{A_{test}} \cdot \left[\underbrace{\ln(r_e/r_w) - 3/4}_{10} + \underbrace{s_{development}}_{0}\right] / \left[\underbrace{p_D(t_{test})}_{7.5} + \underbrace{s_{test}}_{+22}\right]$$

$$A_{pss} = A_{development} = 0.339$$

B (reservoir) same for test & development $= 27 \cdot 10^{-6}$

$$p_{wf} = \left[1370^2 - (27 \cdot 10^{-6})(52\,500)^2 - (0.339)(52\,500)\right]^{1/2}$$

$$\boxed{p_{wf} = 1336 \text{ psia}}$$

2-(2) Tubing rate equation:

$$q_g = C_t (p_w^2 - p_t^2)^{0.5}$$

or

$$\frac{1}{C_t^2} q_g^2 = p_w^2 - p_t^2$$

$$B_t q_g^2 = p_w^2 - p_t^2 \quad ; \quad B_t = \frac{1}{C_t^2}$$

During Test, from part (1)(a), $p_{wf} = 1323$ psia @ $q_g = 52500$ Mscf/D

$$p_w = p_{wf} / e^{s/2} = 1323/1.08 = 1225 \text{ psia}$$

Test: $$B_{t4} = \frac{p_w^2 - p_t^2}{q_g^2} = \frac{1225^2 - 744^2}{(52500)^2}$$; $p_t = 744$ psia given

$$\boxed{B_{t4} = 3.44 \cdot 10^{-4} \quad psi^2/(Mscf/D)^2}$$

2-(3) From Fetkovich paper,

$$C_{t\,new} = C_{t\,old} \left(\frac{d_{t\,new}}{d_{t\,old}}\right)^{2.612}$$

; Using 2.6 instead of 2.612 is OK

$$B_{t\,new} = \frac{1}{C_{t\,new}^2} \Rightarrow$$

$$B_{t\,old} = \frac{1}{C_{t\,old}^2}$$

$$\frac{B_{t\,new}}{B_{t\,old}} = \frac{B_{t6.5}}{B_{t4}} = \frac{C_{t\,old}^2}{C_{t\,new}^2} = \left[\left(\frac{d_{t\,old}}{d_{t\,new}}\right)^{2.612}\right]^2$$

$$\boxed{B_{t6.5} = B_{t4} \left[\left(\frac{d_4}{d_{6.5}}\right)^{2.612}\right]^2}$$

$$= 3.44 \cdot 10^{-4} \left[\left(\frac{4}{6.5}\right)^{2.612}\right]^2$$

$$= 2.72 \cdot 10^{-5}$$

$$\boxed{B_{t6.5} = 27.2 \cdot 10^{-6} \quad psi^2/(Mscf/D)^2}$$

Note:
$B_{t6.5} \sim B$ reservoir non-Darcy effect

2-(4) Convert reservoir A_{pss} and B to surface pressures, then add tubing B_t to reservoir B to get total 'wellhead' B_{wh}.

Reservoir $$\frac{B q_g^2}{(e^{s/2})^2} + \frac{A q_g}{(e^{s/2})^2} = \frac{p_R^2 - p_{wf}^2}{(e^{s/2})^2}$$

$$B' q_g^2 + A' q_g = \underbrace{\left(\frac{p_R}{e^{s/2}}\right)^2} - \underbrace{\left(\frac{p_{wf}}{e^{s/2}}\right)^2}$$

$$B' q_g^2 + A' q_g = p_c^2 - p_w^2 .$$

$$A' = A/(e^{s/2})^2 = 0.339/(1.08)^2 = 0.291$$
$$B' = B/(e^{s/2})^2 = 27\cdot10^{-6}/(1.08)^2 = 23.1\cdot10^{-6}$$

$$\boxed{A_{wh} = A' = 0.291 \quad psi^2/(Mscf/D)}$$

$$B_{wh} = B' + B_{t65} = 23.1\cdot10^{-6} + 27.2\cdot10^{-6}$$

$$\boxed{B_{wh} = 50.3\cdot10^{-6} \quad psi^2/(Mscf/D)^2}$$

$$\boxed{B_{wh} q_g^2 + A_{wh} q_g = (p_c^2 - p_t^2)}$$

2-(5) Abandonment (end of life) rate $q_g = 10\,000$ Mscf/D at $p_t = 10$ psia. Solve for p_c

$$p_c^2 = p_t^2 + B_{wh} q_g^2 + A_{wh} q_g$$

$$p_c = \left[(10)^2 + (50.3\cdot10^{-6})(10\,000)^2 + (0.291)(10\,000)\right]^{1/2}$$

$$p_c = 89.7 \sim 90 \text{ psia}$$

$$p_R = p_c \cdot e^{s/2} = (89.7)(1.08) = 97 \text{ psia}$$

$$\boxed{(p_R)_{Abandonment} \sim 97 \text{ psia}}$$

2-(5) Cont'd

Use basic gas material balance

$$\frac{P_R}{Z_R} = \frac{P_{Ri}}{Z_{Ri}} \cdot \left(1 - \frac{G_p}{G}\right)$$

Approximate gas recovery factor G_p/G assuming $Z_R = Z_R \sim 1$

$$RF_g = \frac{G_p}{G} \sim 1 - \frac{P_R}{P_{Ri}} = 1 - \frac{97}{1370}$$

$$\boxed{RF_g \sim 93\%}$$ Approximate RF requested

Calculating Z_{Ri} from $\gamma_g = 0.7$ to estimate T_{pc} & P_{pc}, reservoir temperature is not given in exam and it is unrealistic to ask you to remember the value from Fetkovich paper (120°F).

$T_{pc} = 390°R$ $\quad P_{pc} = 670$ psia (Fig. 3.7)

$$\left.\begin{array}{l} T_{pr} = (120+460)/390 = 1.49 \\ P_{pr_i} = 1370/670 = 2 \end{array}\right\} Z_{Ri} = 0.82 \; ; \; Z_R$$

$P_{pr} = 97/670 = 0.15 \qquad (Z_R)_{97\,psia} \cong 1$

$$RF_g = 1 - \frac{(97/1)}{(1370/0.82)}$$

$$\boxed{RF_g = 94\%}$$