EXAM IN COURSE
TPG4145 RESERVOIR FLUIDS

Monday December 17, 2007

Time: 0900 – 1300

Permitted aids:
C:
ONLY (1) SPE *Phase Behavior* monograph volume 20 in original book form; handwritten notes written within the original book allowed. (2) Project Solution, up to maximum of six (6) single-sided pages

Problem 1: Calculate all missing numbers in Table 1. Write answers within Table 1.

TABLE 1 – Problems 1&2 – Gas-Oil Reservoir.

Component	Molecular Weight M_i	Liquid Specific Gavity
C1	16.04	
N-C5	72.15	0.6375
N-C10	142.28	0.7329

ρ_{LSC} : $\gamma_S = 0.6375 \cdot 1000 \text{ kg/m}^3 = 637.5 \text{ kg/m}^3$

$$\bar{M}_g = \frac{\sum y_i M_i}{\sum y_i}$$

Two Phases at Temperature = 100 C, Pressure = 100 bar:

↓ K

Molar Amounts: z_i x_i Mole Fractions y_i

Component	Overall	Liquid	Vapor	K-Value
C1	0.5	0.34291	0.94748	2.763
N-C5	0.20000	0.25350	0.04759	0.1877
N-C10	0.3	0.40359	0.00493	0.01222
Sum Mol. Frac	1.0	1.0	1.0	
Moles: gmol	1.0000	0.74018	0.25982	
Mol. Weight: g/gmol	65.137	81.216	19.286	
Z-Factor:		0.4645	0.9261	
Density (g/cc):		0.5638	0.06715	

$$n \cdot z_i = n_v \cdot y_i + (n - n_v) x_i$$

$$F_v \equiv n_v / n$$

$$\Rightarrow z_i = F_v \cdot y_i + (1 - F_v) x_i \quad \leftarrow$$

$n-C_5 : z_i , y_i , x_i$

$\Rightarrow$ Solve for F_V

Because $n = 1$

$$F_V = \frac{z_{C5} - x_{C5}}{y_{C5} - x_{C5}} = 0.25982 = n_V$$

$$F_L = 1 - F_V = 0.74018 = n_L$$

$$K_i = \frac{y_i}{x_i}$$

Ch. 4:

$$\rho = \frac{pM}{RTZ}$$

p [bar]
M [kg/kgmol]
T [K]
ρ [kg/m^3]

$R = 0.08314$
App. A

$T = 100°C + 273$
$= 373$ K

$Z_g = 0.9261$

$\Rightarrow \rho_g = 67.15$ kg/m^3 $= 0.06715$ g/cm^3
g/cc

$Z_o = 0.4645$
$M_o = 81.2$

$\Rightarrow \rho_o = 563.8$ kg/m^3 $= 0.5638$ g/cc

Problem 2: Using results from Problem 1 and Table 2, answer the following:

a. Pressure at 900 m below sea level.
b. Pressure at 1200 m below sea level (WOC).
c. Initial surface gas in Reservoir Gas Zone, IGIP(RG).
d. Initial surface oil ("condensate") in Reservoir Gas Zone, IOIP(RG).
e. Initial surface gas in Reservoir Oil Zone, IGIP(RO).
f. Initial surface oil in Reservoir Oil Zone, IOIP(RO).

Assuming an idealized surface process, where "surface gas" is C1 and "surface oil" is (n-C5 + n-C10), calculate and compare with values in Table 2:

g. Initial solution OGR (r_s) in Reservoir Gas Zone.
h. Initial gas formation volume factor (B_{gd}) in Reservoir Gas Zone.

SG: C_1 — P — SO: C_5 + C_{10}

TABLE 2 – Problems 1&2 – Gas-Oil Reservoir.

Initial Reservoir Pressure (bara) at Gas-Oil Contact	100
Initial Reservoir Temperature (°C)	100
Gas-Oil Contact (m below sea level)	1000
Water-Oil Contact (m below sea level)	1200
Top Gas Reservoir Zone (m below sea level)	900
Bottom Water Zone (m below sea level)	1300
Hydrocarbon Pore Volume, Reservoir Gas (m^3)	1E8
Hydrocarbon Pore Volume, Reservoir Oil (m^3)	1E8
Initial solution OGR (r_s) in Reservoir Gas Zone (Sm^3/Sm^3)	3.6173E-5
Initial solution GOR (R_s) in Reservoir Oil Zone (Sm^3/Sm^3)	94.3
Initial gas formation volume factor (B_{gd}) in Reservoir Gas Zone (m^3/Sm^3)	0.01222
Initial oil formation volume factor (B_o) in Reservoir Oil Zone (m^3/Sm^3)	1.434

Real Process

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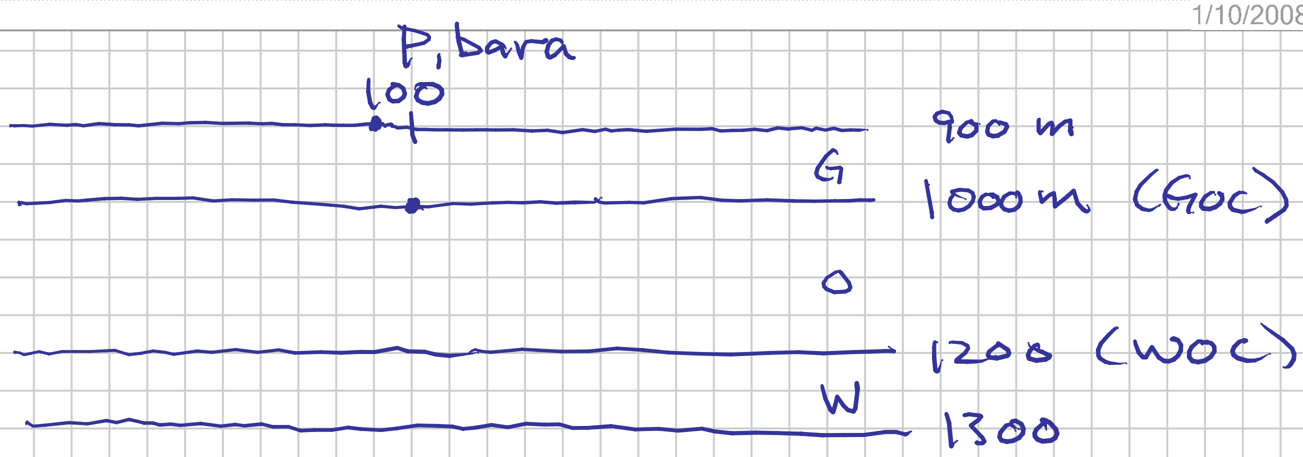

a. Gas Density:

$$P_{900} = P_{1000} - \rho_g \cdot g\,(100)$$

$$= 100 - \underbrace{67\,(9.8)(100)}_{Pa} \cdot \left(10^{-5}\ \frac{bar}{Pa}\right)$$

$$\underline{P_{900m} = 99.34 \text{ bara}}$$

b. Oil Density

$$P_{1200} = P_{1000} + \rho_o\, g\,(200)(10^{-5})$$

$$= 100 + 564\,(9.8)(200)(10^{-5})$$

$$\underline{P_{1200} = 111 \text{ bara}}$$

c. $IGIP\,(RG) = \dfrac{HCPV(RG)}{B_{gdi}} = \dfrac{10^8}{0.01222} = \underline{8.19 \cdot 10^9\ Sm^3}$

d. $IOIP\,(RG) = IGIP\,(RG) \cdot r_{si} = \underline{2.96 \cdot 10^5\ Sm^3}$

e. $IGIP\,(RO) = IOIP\,(RO) \cdot R_{si} = \underline{6.576 \cdot 10^9\ Sm^3}$

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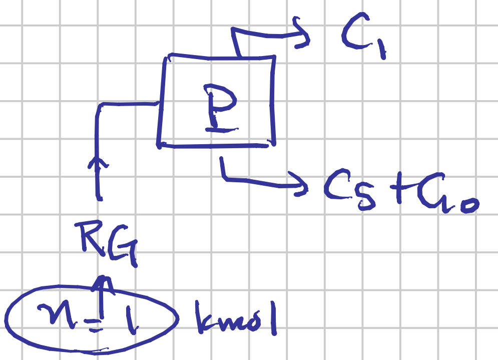
f. $101P(RO) = \dfrac{HCPV(RO)}{B_{oi}} = \underline{6.974 \cdot 10^7 \ Sm^3}$

g.



$n_{\bar{g}} = n_{C_1} = y_{C_1} = 0.94748$ kmol

$\downarrow$

$V_{\bar{g}} = \dfrac{R T_{sc}}{p_{sc}} \cdot n_{\bar{g}}$

23.64

$n_{\bar{o}} = n_{C_5} + n_{C_{10}}$

$= y_{C_5} + y_{C_{10}} = \underline{0.05252 \text{ kmol}}$

$\downarrow$

$V_{\bar{o}} = n_{\bar{o}} \cdot \dfrac{M_{\bar{o}}}{\rho_{\bar{o}}}$

$$M_{\bar{o}} = \frac{y_{C_5} M_{C_5} + y_{C_{10}} M_{C_{10}}}{y_{C_5} + y_{C_{10}}}$$

$= 78.57$ kg/kmol

$$\rho_{\bar{o}} \cong \frac{y_{C_5} M_{C_5} + y_{C_{10}} M_{C_{10}}}{\dfrac{y_{C_5} M_{C_5}}{\rho_{C_5}} + \dfrac{y_{C_{10}} M_{C_{10}}}{\rho_{C_{10}}}} = 652 \text{ kg/m}^3$$

Ideal Volume Mixing

$$r_{si} = \frac{V_{\bar{o}}}{V_{\bar{g}}} = \frac{0.05252\left(\frac{78.57}{652}\right)}{23.64\,(0.94748)}$$

$= 2.83 \cdot 10^{-4} \ Sm^3/Sm^3$

vs

$3.61 \cdot 10^{-4} \ Sm^3/Sm^3$

h) $B_{gd} = \dfrac{p_{sc}}{T_{sc}} \cdot \dfrac{ZT}{p} \cdot \dfrac{1}{y_{\bar{g}}}$

$Z_{\bar{g}} = 0.9261$

$T = 373$ K

$p = 100$ bar

$y_{\bar{g}} = 0.94748$

$\underline{B_{gdi} \cong 0.00991 \ m^3/Sm^3}$

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Problem 3: Based on information in Table 3, calculate the following *at the end of plateau* for two minimum flowing tubing pressures, 100 and 500 psia:

10 yr

a. Minimum number of wells needed to produce *Plateau Field Gas Rate.*
b. Gas recovery factor.
c. Average reservoir pressure.
d. Flowing tubing pressure.

$137 \cdot 10^6$ scf/D

TABLE 3 – Problem 3 – Dry-Gas Reservoir.

Assume Ideal Gas Law and Straight-Line Gas Material Balance ($M=c_w=c_f=0$)

$Z = 1$ → S.L. Gas M.B.

Initial Reservoir Pressure (psia)	1500
Initial Gas in Place (scf)	1E12
Plateau Field Gas Rate (MMscf/D = 10^6 scf/day)	137
Plateau Period (years)	10
Gas Static Column Gravity Term ($p_{reservoir}/p_{surface}$)	1.1
Wellhead Backpressure Deliverability Equation* Constant C	400
Wellhead Backpressure Deliverability Equation* Exponent n	0.8

* $q_g = C(p_c^2 - p_t^2)^n$ with p(psia), q_g(scf/D) | For a single well

$$p_c = \frac{p_R}{1.1} \Rightarrow p_R = 1.1 \cdot p_c$$

$$\frac{p_R}{Z} = \frac{p_i}{Z_i}\left(1 - \frac{G_p}{G}\right) \Longrightarrow p_R = p_i\left(1 - RF_g\right)$$

($\frac{G_p}{G}$ = RF_g)

b.

$$(RF_g)_p = \frac{q_{gF} \cdot t_p}{IGIP} = \frac{137 \cdot 10^6 \cdot 10 \cdot 365}{10^{12}} = 0.5$$

(50%)

Independent of p_{tmin}

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c. $(p_R)_p = 1500(1-0.5)$

$= \underline{750 \text{ psia}}$ Independent of P_{tmin}

d. P_t @ end plateau $= P_{tmin}$

100 psia

500 psia

a. $(N_w)_p = \dfrac{q_{gF}}{(q_{gw})_{P_t = P_{tmin}}}$

@ end plateau

$(P_c)_p$

$$q_{gw} = C \cdot (P_c^2 - P_t^2)^n$$

$P_{tmin} = 100$ psia

$$q_{gw} = 400\left(\left(\frac{750}{1.1}\right)^2 - 100^2\right)^{0.8} = 13.4 \cdot 10^6 \frac{scf}{D}$$

$$\Rightarrow (N_w)_{P_{tmin}=100} = \frac{137 \cdot 10^6}{13.4 \cdot 10^6} = 10.x$$

$\Rightarrow$ <u>11 wells</u>

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$p_{t\,min} = 500$ psia

$(q_w)_p = 7.38 \cdot 10^6$ scf/D

$N_w = 18.x \Rightarrow$ **19 wells**