Excercises in PVT-Analysis

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Problem 1.

The initial pressure of a dry gas reservoir is 3500 psia and the reservoir temperature is 140 ^oF. The composition is given as mole fraction:

Component	y_i
C1	0.8686
C2	0.0609
C3	0.0261
i-C4	0.0048
n-C4	0.0077
i-C5	0.0022
C6	0.0038
C7+	0.0228

Molecular weight and specific density of the C7+ fraction are given as: M_{C7+}=128 and γ_{C7+}=0.8195, respectively.
Calculate B_g at: 3500, 3000, 2000, 1000, and 100 psia.

Problem 2.

The following gas composition is given as mole fraction:

Component	y_i
N_2	0.10
C1	0.70
C2	0.05
C3	0.05
n-C4	0.05
n-C5	0.05

The temperature and pressure are given as: 160 ^oF and 3000 psia, respectively.

Calculate:
a. Z-factor of the gas by using Eilerts method to adjust for N_2.
b. B. Z-factor by using the "corresponding state theorem" directly.

PS!! Use the available information on p. 12.

Problem 3.

A gas with the following composition is sampled at 600 psig and 92 ^{o}F:

Component	y_i (mole %)
N_2	0.26
CO_2	1.92
C1	84.58
C2	8.49
C3	3.06
i-C4	0.36
n-C4	0.77
i-C5	0.16
n-C5	0.19
C6	0.12
C7+	0.09

Molecular weight and specific density of the C7+ fraction are given as: M_{C7+}=103 and γ_{C7+}=0.70.

a. Calculate the molecular weight and specific density of the gas and use these values to determine the pseudocritical pressure and temperature, $_pP_c$ and $_pT_c$, of the gas. Correct the values by using the correction listed in the table below (corrections per mole%):

Compound	$_pP_c$	$_pT_c$
CO_2	+4.4	-0.8
N_2	-1.7	-2.5
H_2S	+6.0	+1.3

b. Calculate pPc and pTc for the C7+ fraction and calculate the pseudocritical values for the gas by using the "corresponding state theorem" directly. Compare the results with with the calculate value in a.
c. Calculate the Z-value and the density (g/cm^3) of the gas at the sampling conditions.
d. Determine the viscosity of the gas at: 3000, 2000, and 1000 psia and 92 ^{o}C.

Problem 4.

The initial reservoir pressure of a dry gas reservoir is 3200 psia. The reservoir temperature is 213 oF and the gas composition is given by:

Component	y_i (molefraction)
CO_2	0.0010
N_2	0.0207
C1	0.8612
C2	0.0591
C3	0.0358
n-C4	0.0172
n-C5	0.0050

The Corresponding State Theorem is applied for the calculations.

a. Calculate the initial gas density in the reservoir
b. Calculate Bg, and determine the initial gas in place (IGIP) for a HCPV=10^9 ft^3.
c. Determine the recovery factor when the reservoir pressure has decreased to 1000 psia.
d. Explain how to estimate IGIP by plotting produced volume, G_p (sc), versus corresponding values of P/Z. Derive the formula.

Problem 5.

The following data are given for a gas condensate field:

- γ_{STO} = 53.3 ^{o}API
- $(GOR)_{sep}$ = 40795 SCF/Sbbl
- $(\gamma_g)_{sep}$ = 0.6174
- $(\gamma_g)_{st}$ = 1.090
- T_{res} = 190 ^{o}F
- P_{res} = 2900 psia
- $(Q_g)_{sep}$ = 3.130x10^6 SCF/D
- $(Q_g)_{st}$ = 0.213x10^6 SCF/D
- Q_{STO} = 76.725 Sbbl/D

Calculate the volume depletion of the reservoir per day (volume reservoir fluid removed from the reservoir per day) by determining the B_o factor using the following methods:

a. The Standing-Katz correlation
    a. γ_{well}/γ_g = f(Sbbl STO, gas gravity)
    b. ${}_pP_c$ and ${}_pT_c$ = f(γ_{well})
b. Standings chart no. 1.
c. Sage and Olds formula.

PS!! The volume depletion of reservoir per day is then: B_o * Q_{STO}

Problem 6.

A reservoir fluid is produced through a 3 step separator system, and the following data are given:

	1. Separator	2. Separator	Stock tank
GOR (SCF/Sbbl)	414	90	25
Gas gravity, γ_g	0.640	0.897	1.54

- γ_{STO} = 27.4 ^{o}API or γ_{STO} = 0.981
- P_{res} = Pb = 3280 psia
- T_{res} = 218 ^{o}F

PS!! Use 1 Sbbl STO as the basis for your calculations.

a. Calculate:
   a. Average specific density of produced gas, $(\gamma_g)_{av}$.
   b. Weight of gas
   c. Weight of STO
   d. Preudo liquid density of dissolved gas at sc.
   e. Pseudo liquid volume of gas at sc.
   f. Pseudo liquidv density of reservoir fluid at sc.
   g. Density of reservoir fluid at reservoir conditions
b. Compare the calculated value by using Standings chart no. 3 directly.

Problem 7.

Separator oil and gas are recombined to give 1 lb-mole reservoir fluid, i. e. $n_g + n_o = 1$. The following data are given:

- $(GOR)_{sep}$ as SCF/sep bbl
- $(\rho_o)_{sep}$ as lb/ft^3
- $(M_o)_{sep}$

Show that :

a. $$(GOR)_{sep} = \frac{379.5 n_g (\rho_o)_{sep} 5.615}{n_o M_o}$$

b. $$n_g = \frac{(M_o)_{sep}(GOR)_{sep}}{(M_o)_{sep}(GOR)_{sep} + 2131(\rho_o)_{sep}}$$

$$n_o = \frac{2131(\rho_o)_{sep}}{(M_o)_{sep}(GOR)_{sep} + 2131(\rho_o)_{sep}}$$

c. Use the formula to chech the composition of the well stream from the listed page of the PVT-report below.

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Well 1

Hydrocarbon Analyses of Separator Products and Calculated Well Stream

Component	Separator Liquid Mol Per Cent	Separator Gas Mol Per Cent	Separator Gas GPM	Well Stream Mol Per Cent
Hydrogen Sulfide				
Carbon Dioxide	0.41	1.92		1.31
Nitrogen	0.04	0.26		0.17
Methane	13.71	84.58		55.74
Ethane	6.43	8.49	2.139	7.65
Propane	6.12	3.06	0.840	4.31
iso-Butane	1.39	0.36	0.117	0.78
n-Butane	4.08	0.77	0.242	2.12
iso-Pentane	1.39	0.16	0.058	0.66
n-Pentane	2.41	0.19	0.069	1.09
Hexanes	5.60	0.12	0.049	2.35
Heptanes plus	58.42	0.09	0.041	23.82
	100.00	100.00	3.555	100.00

Properties of Heptanes plus

	Separator Liquid	Separator Gas	Well Stream
API gravity @ 60° F.	33.6		
Specific gravity @ 60/60° F.	0.8570		0.857
Molecular weight	235	103	235

Calculated separator gas gravity (air = 1.000) = 0.673
Calculated gross heating value for separator gas = 1143 BTU
per cubic foot of dry gas @ 14.696 psia and 60° F.

Primary separator gas collected @ 600 psig and 92 °F.
Primary separator liquid collected @ 600 psig and 92 °F. i.e. 614.7 psia

Primary separator gas/separator liquid ratio 984 SCF/Bbl @ 92° F.

Problem 8.

A separator test of a reservoir fluid is given below.

Calculate:

a. $(GOR)_{total}$ as SCF/Sbbl
b. Average value of specific gravity of produced gas, $(\gamma_g)_{av}$
c. Density of reservoir fluid at P_b by using pseudo liquid density of produced gas.
d. Use Standings chart no. 3 to check $(B_o)_b$
e. Use Standings chart no. 3 to check P_b.

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Well 1

SEPARATOR TESTS OF Reservoir Fluid SAMPLE

Separator Pressure PSI Gauge	Separator Temperature °F.	Gas/Oil Ratio (1)	Gas/Oil Ratio (2)	Stock Tank Gravity, °API @ 60° F.	Formation Volume Factor (3)	Separator Volume Factor (4)	Specific Gravity of Flashed Gas
1000 to	150	916	1067			1.165	0.707
250 to	80	115	123			1.064	0.724
0	60	111	111	36.9	1.770	1.000	1.032

Reservoir temp. 274°F

Bubble point pressure : 5185 psia

(1) Gas/Oil Ratio in cubic feet of gas @ 60° F. and 14.7 PSI absolute per barrel of oil @ indicated pressure and temperature.
(2) Gas/Oil Ratio in cubic feet of gas @ 60° F. and 14.7 PSI absolute per barrel of stoc tank oil @ 60° F.
(3) Formation Volume Factor is barrels of saturated oil @ 5170 PSI gauge and 274° F. per barrel of stock tank oil @ 60° F.
(4) Separator Volume Factor is barrels of oil @ indicated pressure and temperature pe; barrel of stock tank oil @ 60° F.

Problem 9.

A muliticomponent system has the following composition:

Component	Mole fraction
C2	0.200
C3	0.400
i-C4	0.100
n-C4	0.300

K_i-values are determined from charts, and the values used are found in the Excel sheet wher the problem is solved.

a. Calculate the composition of vapor and liquid at 80 ^oF and 100 psia. ($0.6<V<0.7$).
b. Determine P_d at 80 $^oF$and the composition of the vapor and liquid ($50<P_d<100$ psia).
c. Determine P_b at 80 ^oF and the composition of vapor and liquid ($100<P_b<200$ psia).

Problem 10.

Gas and oil are sampled from a test separator. The following date are given:

- P_{res} = 4713 psia
- T_{res} = 237 ^oF
- $(P)_{sep}$ = 237 ^oF
- $(T)_{sep}$ = 58 ^oF
- $(GOR)_{sep}$ = 404 SCF/Sbbl
- $(\gamma_g)_{sep}$ = 0.714
- Z_g = 0.952

The samples are submitted to a PVT-lab for analysis.

Lab data for the separator oil:

- Flash to SC:
  - GOR = 201 SCF/Sbbl
  - $(B_o)_{flash}$ = 1.15 sep bbl/Sbbl
  - γ_g = 1.2962
  - $(\rho_o)_{sto}$ = 0.8372

The bubble point of recombined reservoir fluid at T_{res} was determined to be P_b = 2672 psig.

The composition of gas and STO from the flash of separator fluid is given below:

	Olje Mol-%	Gass Mol-%	Sep. væske Mol-%
H_2S Hydrogen Sulfide			
CO_2 Carbon Dioxide	–	2.80	0.79
N_2 Nitrogen	–	0.53	0.15
C_1 Methane	0.00	28.28	7.97
C_2 Ethane	0.05	19.13	5.43
C_3 Propane	0.85	29.70	8.98
iC_4 iso-Butane	0.53	3.14	1.27
nC_4 normal Butane	2.84	9.53	4.72
iC_5 iso-Pentane	1.87	1.93	1.89
nC_5 normal Pentane	3.42	2.52	3.16
C_6 Hexanes	5.96	1.37	4.67
$C_{7}+$ Heptanes-Plus	84.48	1.06	60.97
TOTAL	100.00	100.00	100.00
Molecular Weight	217	37.5	166
Density[1]	0.8372	1.5879	
Gas Gravity (air=1)		1.2962	
$C_{7}+$ Molecular Weight	243	98.3	242
$C_{7}+$ Density	0.8495	0.8517	0.8514

[1] oil (g/cc) gas (g/l)

M_{STO}, ρ_{STO} are determined experimentally. The other values in the table are calculated.

Check the following data:

a. M_{C7+} for the STO
b. Calculate ρ_{C7+} for the STO.
c. Composition of recombined separator fluid
d. Calculate $(\rho_o)_{sep}$ at separator conditions.

Lab data for the separator gas are given below:

		Mass-%	Mol-%	Liquid Yield ($L/1000\ Sm^3$)	Liquid Yield (gal/Mscf)
H_2S	Hydrogen Sulfide ..	7.03	3.30		
CO_2	Carbon Dioxide	2.31	1.70		
N_2	Nitrogen	61.67	79.37		
C_1	Methane	13.19	9.06	322.0	2.41
C_2	Ethane	9.93	4.65	171.0	1.28
C_3	Propane	1.18	0.42	18.3	0.14
iC_4	iso-Butane	2.84	1.01	42.5	0.32
nC_4	normal Butane	0.52	0.15	7.4	0.06
iC_5	iso-Pentane	0.63	0.18	8.6	0.07
nC_5	normal Pentane	0.37	0.09	4.8	0.04
C_6 –	Hexanes	0.33	0.16	3.8	0.03
C_7+	Heptanes-Plus				
	TOTAL	100.00	100.00	578.4	4.35

GAS PROPERTIES

Average Molecular Weight .... :	20.6			
Average Gas Gravity .... :	0.7130	(air=1)		
Heptanes-Plus Molecular Weight .... :	98.7			
Density at Standard Conditions .... :	0.8734	g/Liter		
Density at Separator Conditions .... :		g/Liter		
Calculated Critical Pressure .... :	46.65	bar	676.9	psia
Calculated Critical Temperature .... :	-56.0	°C	390.9	°R
Compressibility Factor at Separator Conditions . :	0.9420			
Ideal Gas Heating Value .... :	42.81	MJ/m^3	1149	BTU/cuft

The following data are to be checked:

e. $_pP_c$ and $_pT_c$ for the gas (the values for n-C7 are to be used for C7+)
f. Z_g at separator conditions.
g. Liquid yield for C2 and C3 as Gal/1000 SCF or $L/1000\ Sm^3$.
h. Correct the $(GOR)_{rig}$.

Recombination of separator gas and oil to give the reservoir fluid is shown below.

		Recombined Separator Liquid		Separator Gas		Recombined Reservoir Fluid
		Mass-%	Mol-%	Mass-%	Mol-%	Mol-%
H_2S	Hydrogen Sulfide					
CO_2	Carbon Dioxide	0.21	0.79	7.03	3.30	1.86
N_2	Nitrogen	0.03	0.15	2.31	1.70	0.81
C_1	Methane	0.77	7.97	61.67	79.37	38.43
C_2	Ethane	0.98	5.43	13.19	9.06	6.98
C_3	Propane	2.39	8.98	9.93	4.65	7.13
iC_4	iso-Butane	0.45	1.27	1.18	0.42	0.91
nC_4	normal Butane	1.65	4.72	2.84	1.01	3.14
iC_5	iso-Pentane	0.82	1.89	0.52	0.15	1.15
nC_5	normal Pentane	1.37	3.16	0.63	0.18	1.89
C_6	Hexanes	2.37	4.67	0.37	0.09	2.72
C_7+	Heptanes-Plus	88.96	60.97	0.33	0.16	34.99
	TOTAL	100.00	100.00	100.00	100.00	100.00
Molecular Weight		166		20.6		104
Gas Gravity (air=1)				0.7130		
C_7+ Molecular Weight		242.8		98.7		242.7
C_7+ Density		0.8514				0.8514

i. Separator gas and oil are physically recombined at reservoir conditions. The total volume of fluid in the PVT cell should be 200 cm^3. What is the volume of separator gas and oil that should be loaded to the cell?
j. Check the composition of recombined reservoir fluid.
k. Check P_b by using Standings chart no. 2.
l. Determine $(B_o)_b$ by using Standings chart no. 3.

Important formula/correlations in PVT-Analysis.

Temperature:

$^oK = 273.15 + {}^oC$
$^oF = 1.8 \times {}^oC + 32$
$^oR = {}^oF + 459.69$

Pressure:

1atm = 1013.250 mBar = 1.013250 bar = 101.3250 kPa = 0.1013250
1MPa = 10 bar
psia = 14.69595 + psig
1 atm = 760.002 mmHg at 0 ^oC

Density:

1 g/cm^3 = 62.43 lb/ft^3 = 350.54 lb/bbl
1 lb/ft^3 = 16.0185 kg/m^3
$\rho_w = 0.999015$ g/cm^3 (60 ^oF, 1 atm)
$\rho_w = 0.9991$ g/cm^3 (15 ^oC, 1 atm)

Specific density:

For liquids: Determined relative to water at sc.
For gases: Determined relative to air at sc.

$$\gamma_o = \frac{\rho_o}{\rho_w} = \frac{141.5}{131.5 + {}^oAPI}$$

$$^oAPI = \frac{141.5}{\gamma_o} - 131.5$$

Cragoe`s formula (empirical formula giving molecular weight of hydrocarbons):

$$M_o = \frac{6084}{^oAPI - 5.9}$$

$$\gamma_g = \frac{M_g}{M_{air}} = \frac{M_g}{28.96}$$

Volume:

1 bbl = 5.615 ft^3 = 0.15898 m^3
1 ft^3 = 0.0283 m^3
1 US Gallon = 3.785 litre
1 Imp. Gallon = 4.546 litre
Molar volume of gas at standard conditions:
V_m = 379.51 SCF/lb mole (60 ^oF and 14.69595 psia)
V_m = 23644.7 cm^3/g mole = 23.6447 m^3/kg mole (15 ^oC and 101.3250 kPa)

Air:

$Z_{air} = 0.9959$ (60 ^oF, 14.69595 psia)
$M_{air} = 28.96$

Gas constant:

R = 10.732 (psia, ft^3, ^oR, lb mole)
R = 0.082054 (atm, litre, ^oK, g mole)
R = 8.3145 (kPa, m^3, ^oK, kg mole)

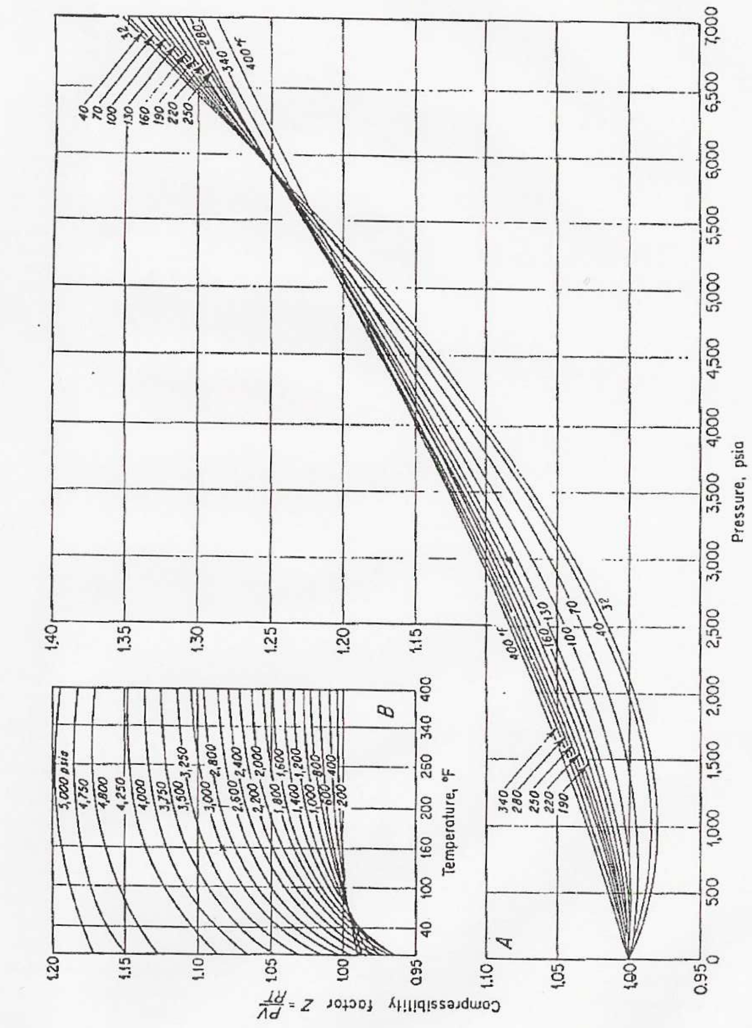

Fig. 4-31. Compressibility factors Z for nitrogen. (*From Eilerts et al.*[32])

Table 4-7. Additive Volume Correction Factors for Gases Containing Nitrogen

Properties of mixture containing 7.907 mole % (11.350 mass %) added nitrogen

Additive volume correction factors C at indicated temperature, °F

Pressure, psia	70	100	130	160	190	220	250	280
5,000	1.0010	1.0046	1.0049	1.0038	1.0034	1.0037	1.0044	1.0034
4,750	1.0011	1.0047	1.0054	1.0048	1.0048	1.0046	1.0044	1.0035
4,500	1.0010	1.0055	1.0059	1.0050	1.0053	1.0053	1.0049	1.0038
4,250	1.0014	1.0053	1.0061	1.0056	1.0059	1.0053	1.0052	1.0040
4,000	1.0016	1.0063	1.0068	1.0060	1.0062	1.0053	1.0054	1.0043
3,750	1.0032	1.0073	1.0076	1.0066	1.0065	1.0057	1.0058	1.0047
3,500	1.0056	1.0083	1.0083	1.0078	1.0070	1.0059	1.0055	1.0049
3,250	1.0073	1.0101	1.0094	1.0083	1.0070	1.0057	1.0054	1.0048
3,000	1.0093	1.0109	1.0101	1.0085	1.0074	1.0061	1.0051	1.0050
2,800	1.0115	1.0118	1.0110	1.0086	1.0073	1.0064	1.0054	1.0050
2,600	1.0124	1.0122	1.0108	1.0086	1.0076	1.0065	1.0055	1.0054
2,400	1.0143	1.0124	1.0103	1.0086	1.0080	1.0066	1.0055	1.0056
2,200	1.0165	1.0131	1.0087	1.0086	1.0081	1.0066	1.0055	1.0055
2,000	1.0162	1.0128	1.0101	1.0085	1.0081	1.0068	1.0052	1.0055
1,800	1.0168	1.0135	1.0093	1.0079	1.0073	1.0064	1.0049	1.0050
1,600	1.0150	1.0108	1.0079	1.0069	1.0062	1.0053	1.0040	1.0038
1,400	1.0116	1.0096	1.0064	1.0056	1.0047	1.0038	1.0027	1.0019
14.4	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

Properties of mixture containing 18.280 mole % (25.013 mass %) added nitrogen

Additive volume correction factors C at indicated temperature, °F

Pressure, psia	70	100	130	160	190	220	250	280
5,000	1.0035	1.0079	1.0088	1.0086	1.0089	1.0093	1.0092	1.0071
4,750	1.0048	1.0079	1.0101	1.0095	1.0096	1.0098	1.0095	1.0071
4,500	1.0055	1.0090	1.0107	1.0104	1.0104	1.0106	1.0103	1.0075
4,250	1.0065	1.0106	1.0116	1.0115	1.0111	1.0111	1.0107	1.0079
4,000	1.0076	1.0120	1.0134	1.0127	1.0122	1.0116	1.0112	1.0088
3,750	1.0103	1.0137	1.0149	1.0135	1.0132	1.0121	1.0115	1.0092
3,500	1.0136	1.0158	1.0161	1.0146	1.0139	1.0123	1.0113	1.0096
3,250	1.0173	1.0182	1.0176	1.0159	1.0142	1.0125	1.0113	1.0094
3,000	1.0201	1.0204	1.0190	1.0163	1.0146	1.0129	1.0113	1.0096
2,800	1.0236	1.0222	1.0201	1.0166	1.0147	1.0134	1.0114	1.0092
2,600	1.0264	1.0233	1.0199	1.0173	1.0152	1.0131	1.0111	1.0092
2,400	1.0288	1.0240	1.0199	1.0175	1.0153	1.0125	1.0107	1.0093
2,200	1.0314	1.0248	1.0202	1.0170	1.0147	1.0117	1.0102	1.0090
2,000	1.0319	1.0250	1.0195	1.0160	1.0140	1.0115	1.0098	1.0087
1,800	1.0322	1.0239	1.0177	1.0147	1.0132	1.0108	1.0091	1.0079
1,600	1.0284	1.0199	1.0157	1.0134	1.0117	1.0092	1.0076	
1,400	1.0235	1.0172	1.0134	1.0109	1.0094			
14.4	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000