Reservoarfluider og Strømning
Reservoir Fluids and Flow
Course TPG 4145

Homework Problem 3

Handed Out: Feb. 17, 2017
Due Date: March 6, 2017
Hand in on ItsLearning as a single Excel file.
NEW File Naming (thanks!!!): Problem-3- LastName.xls

You can work in groups of max two, meaning that no more than two students will be allowed to turn in what is effectively (exactly) the same solution. If you insist on working with more than one, just make sure that more than one solution is turned in. Ideally (even with two working together) you each should work on your own personal solution, even if you are collaborating with another(s).

Excel etiquette will be factored into pass/fail on this Problem! Not until you hand in a proper Excel solution will you pass. See Fig 3.2 and Table 3.3 for recommended "quality".

The reported molar composition of the sample used in Problem 2 is given in Table 3.1, together with the component properties that can be used in the modified Wilson K-value equation. Fig. 3.1 shows Fig. 2.12 from the Phase Behavior book, also used in Problem 2.

This set of problems will make use of the composition and phase diagram to develop a K-value model for making phase equilibrium calculations at any pressure and temperature (reservoir, tubing, and surface process). The modified Wilson K-value equation will be used, Eqs. 3.159-3.160.

Problem 3.1 – Convergence Pressure Estimation

The convergence pressure is known to vary with overall composition (fixed in this problem) and temperature. One way to determine the convergence pressure in Eq. 3.159 and the empirical constant in Eq. 3.160 is to match the measured saturation pressures and saturation pressure type at a number of temperatures. Table 3.2 gives the reported saturation pressures and types given by Katz, et al.

Assume a value of the empirical constant (exponent) A2=1.6 in Eq. 3.160. This value is outside the recommended value of 0.5 to 0.8, but it is the value required to give a correct critical point of about 170^{o}F.

Determine the temperature dependence of p_K for the saturation conditions given in Table 3.2, specifically for temperatures 102, 145, 181, and 200^{o}F.

Numerical challenge: the search for p_K can be difficult to find automatically using, for example, Solver in Excel. The reason is that $p_K=p_s$ satisfies the saturation pressure condition – a trivial solution where $K_i=1$. This solution is only valid at the true critical point; at temperatures lower and higher, $p_K>p_s$ gives the correct solution for a specified saturation pressure and saturation type (bubblepoint or dewpoint).

There should be a way to find the upper search limit of convergence pressure (p_{Kmax}) for a particular temperature, using the fact that the function being minimized, F_s, (consisting of the sum of incipient mole fractions) has a maximum where $dF_s/dp_K=0$. If you can figure out a way to determine p_{Kmax} automatically (and safely), avoiding the trivial solution should be possible.

The function to be minimized (driven to zero) at the saturation pressure is given by $F_s=(1-f_{gi})f_{bp} + f_{gi}\cdot f_{dp}$, where f_{gi} is the incipient-phase gas mole fraction (BP: $f_{gi}=0$ and DP: $f_{gi}=1$), with $f_{bp}=1-\Sigma y_i=1-\Sigma z_iK_i$ and $f_{dp}=1-\Sigma x_i=1-\Sigma z_i/K_i$. K-value dependence is $K_i(p_K, A_2 \mid T_{ci}, p_{ci}, \omega_i \mid p,T)$, where you will solve for p_K given known values of z_i, T_{ci}, p_{ci}, ω_i, A_2, f_{gi} (BP or DP), and $p=p_s$ at T.

If you don't want to do something sophisticated, just step the value of p_K manually until you find a valid solution, then once close enough, use Solver to converge.

Problem 3.2 – **Plot K-values**
For a reservoir temperature of 200°F, plot K-values versus pressure on a log-log plot with "square grids" (same physical length for each "decade" on x- and y-axes). The pressure should range from 1 to 1000 bara.

For n-C_5, plot the vapor pressure versus temperature using a log scale for pressure and linear scale for 1/T with T in absolute unit K. You should have three points on the curve known from Table 3.1. Read from this figure (or a best-fit equation of the figure) the vapor pressure at the temperature chosen for this problem (T_R*). Does this vapor pressure correspond to the pressure on the K-value plot $K_i(p)$ where $K_i=1$ for C_3 and C_6 components?

Problem 3.3 – **Flash Calculation**
Create a template Excel sheet that allows one to specify the overall composition z_i, pressure and temperature (p,T) where a two-phase flash calculation will be solved, yielding the phase mole fractions of gas f_g and oil ($1-f_g$), together with gas and oil compositions y_i and x_i. The solution should also be valid if the solution is one-phase, in which case the phase type should be identified by the solution phase mole fractions ($f_g \geq 1$: gas and $f_g \leq 0$: oil).

For each phase, report the molecular weight.

For the gas phase, calculate the heating value in Btu/scf and metric MJ per Sm^3; also, calculate the oil-gas ratio (OGR*) in STB/MMscf and $Sm^3/10^6Sm^3$.

For the oil phase, convert to a gas-oil ratio (GOR*) in Sm^3/Sm^3 and scf/STB.

* For the OGR and GOR calculations, assume surface gas consists of C_{5-} and surface (stock-tank) oil consists of C_{6+}.

If the flash is conducted at standard conditions (14.696 psia and 60°F), calculate the feed mixture GOR in Sm^3/Sm^3 and scf/STB, and the OGR in STB/MMscf and $Sm^3/10^6Sm^3$ – based on calculated phase mole fractions and phase properties, <u>not</u> using the approximation of C_{5-} as surface gas and C_{6+} as surface oil.

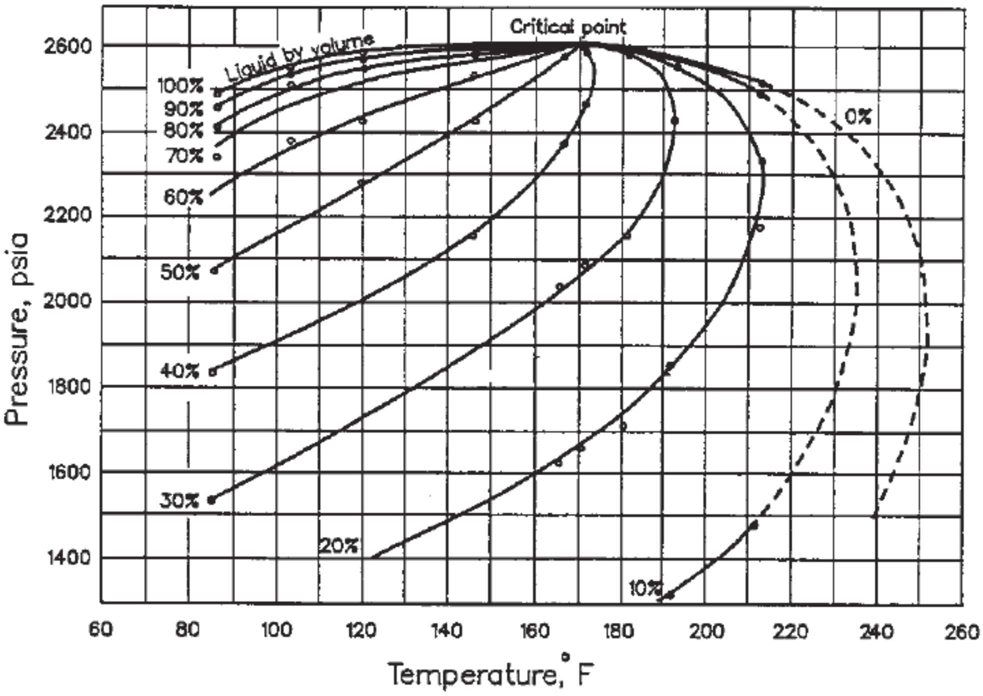


Fig. 3.1 – Sketch of reservoir, originally (above) and after faulting (below).

Fig. 2.12—*p-T* diagram for a gas-condensate system (after Katz *et al.*[5]).

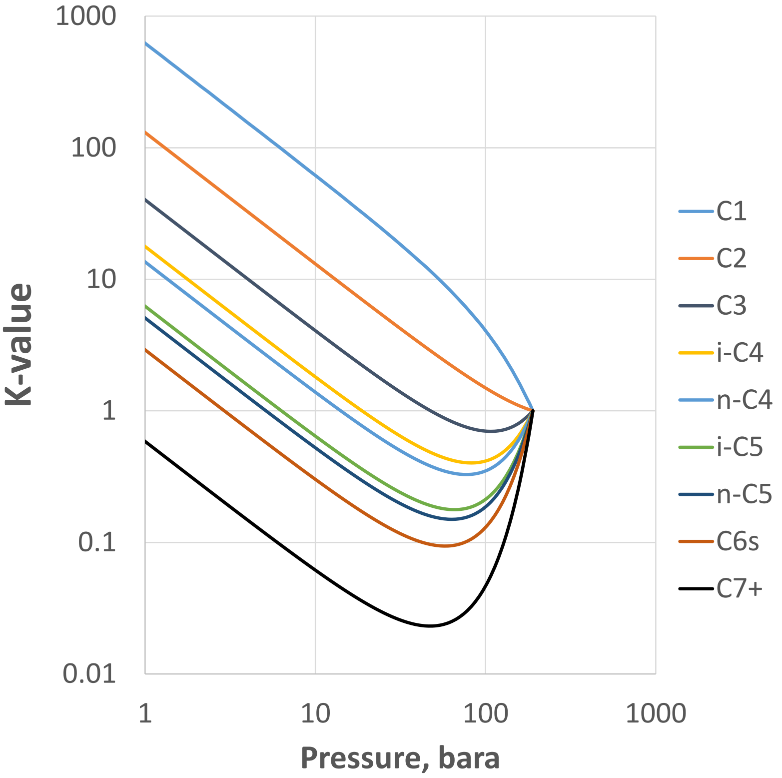


Fig. 3.2 – Recommended solution “style” for Problem 3.2.

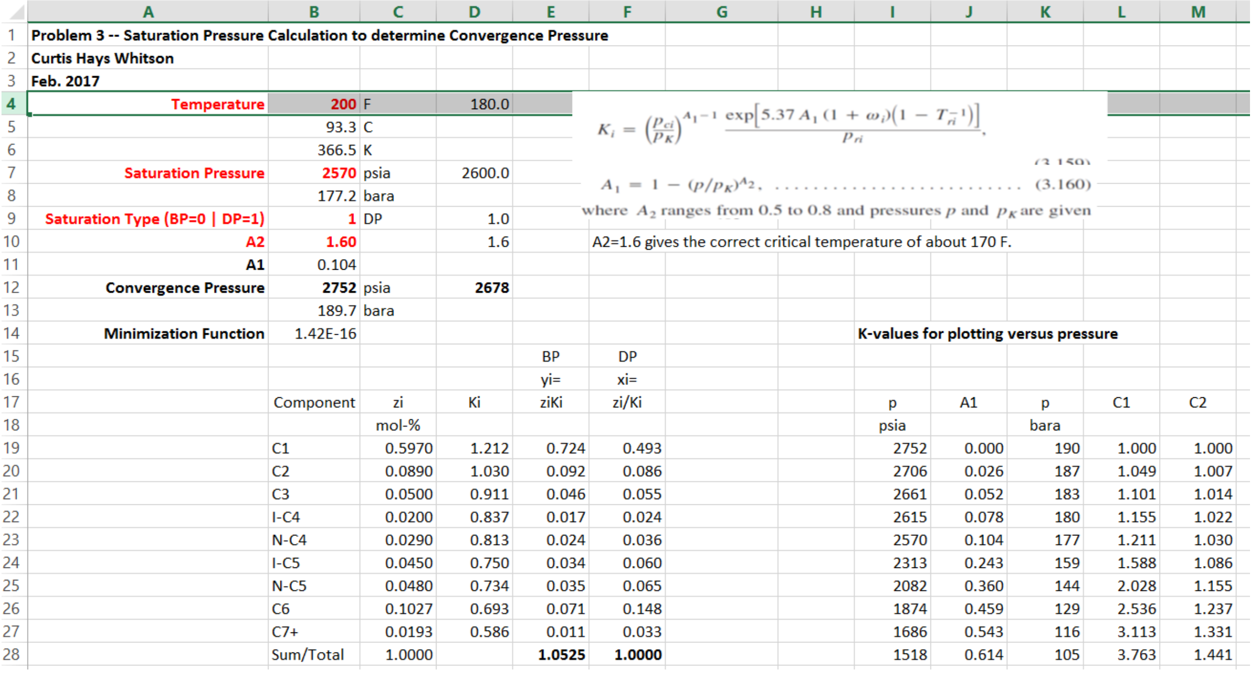
Table 3.1 – Component amounts and properties.

Component	z mol-%	M	Tc K	Pc bar	ω	Tb C	ϒ water=1
C1	0.5970	16.04	190.6	46.0	0.011	-161	
C2	0.0890	30.07	305.3	48.7	0.099	-88.3	
C3	0.0500	44.10	369.8	42.5	0.152	-41.9	
I-C4	0.0200	58.12	407.9	36.4	0.186	-11.4	
N-C4	0.0290	58.12	425.1	38.0	0.200	-0.295	
I-C5	0.0450	72.15	460.4	33.8	0.229	28.2	
N-C5	0.0480	72.15	469.7	33.7	0.252	36.3	
C6	0.1027	80.7	495.0	31.8	0.271	56.4	0.660
C7+	0.0193	107.4	560.9	26.9	0.344	113	0.715
Sum/Total	1.0000						
C6+ (gasoline)							0.670
						(Reported as 80)	
						API	79.7

Table 3.2 – Saturation Pressures versus Temperature.

	Plot	
Temp	Psat	Sat Type
oF	psia	BP | DP
85	2498	BP
102	**2565**	**BP**
119	2590	BP
145	**2600**	**BP**
151	2600	BP
166	2600	BP
169	2600	CP
171	2600	DP
181	**2600**	**DP**
192	2590	DP
200	**2570**	**DP**
212	2530	DP

TABLE 3.3 – RECOMMENDED SOLUTION "STYLE" FOR PROBLEM 3.1.



	A	B	C	D	E	F	G	H	I	J	K	L	M
1	**Problem 3 -- Saturation Pressure Calculation to determine Convergence Pressure**												
2	**Curtis Hays Whitson**												
3	**Feb. 2017**												
4	**Temperature**	**200**	F	180.0									
5		93.3	C										
6		366.5	K										
7	**Saturation Pressure**	**2570**	psia	2600.0									
8		177.2	bara										
9	**Saturation Type (BP=0 | DP=1)**	**1**	DP	1.0									
10	**A2**	**1.60**		1.6		A2=1.6 gives the correct critical temperature of about 170 F.							
11	**A1**	0.104											
12	**Convergence Pressure**	**2752**	psia	**2678**									
13		189.7	bara										
14	**Minimization Function**	1.42E-16							**K-values for plotting versus pressure**				
15					BP	DP							
16					yi=	xi=							
17		Component	zi	Ki	ziKi	zi/Ki			p	A1	p	C1	C2
18			mol-%						psia		bara		
19		C1	0.5970	1.212	0.724	0.493			2752	0.000	190	1.000	1.000
20		C2	0.0890	1.030	0.092	0.086			2706	0.026	187	1.049	1.007
21		C3	0.0500	0.911	0.046	0.055			2661	0.052	183	1.101	1.014
22		I-C4	0.0200	0.837	0.017	0.024			2615	0.078	180	1.155	1.022
23		N-C4	0.0290	0.813	0.024	0.036			2570	0.104	177	1.211	1.030
24		I-C5	0.0450	0.750	0.034	0.060			2313	0.243	159	1.588	1.086
25		N-C5	0.0480	0.734	0.035	0.065			2082	0.360	144	2.028	1.155
26		C6	0.1027	0.693	0.071	0.148			1874	0.459	129	2.536	1.237
27		C7+	0.0193	0.586	0.011	0.033			1686	0.543	116	3.113	1.331
28		Sum/Total	1.0000		**1.0525**	**1.0000**			1518	0.614	105	3.763	1.441

$$K_i = \left(\frac{p_{ci}}{p_K}\right)^{A_1-1} \frac{\exp\left[5.37\,A_1\,(1+\omega_i)\left(1-T_{ri}^{-1}\right)\right]}{p_{ri}}, \qquad (3.159)$$

$$A_1 = 1 - (p/p_K)^{A_2}, \ \ldots\ldots\ldots\ldots \qquad (3.160)$$

where A_2 ranges from 0.5 to 0.8 and pressures p and p_K are given