Quiz 11
Chemical Engineering Thermodynamics
March 30, 2017

Condensation of a natural gas stream (*Double mixed refrigerant LNG process provides viable alternative for tropical conditions*, Oil & Gas Journal, 100(27) (2002)) results in a liquid stream containing the following compositions. It is desirable to flash the liquid to 5 MPa to produce a liquid and a vapor stream in order to partially separate the components prior to distillation.

	z_i	T_c, °K	P_c, Mpa	ω
METHANE	0.8800	190.6	4.604	0.011
ETHANE	0.0758	305.4	4.88	0.099
PROPANE	0.0442	369.8	4.249	0.152

a) What is the bubble point of this mixture at 5 MPa? (This is the lower limit to the flash tank temperature).
Use solver in excel and the shortcut method. Demonstrate that the method is appropriate after solving. Briefly describe the steps used in solver referencing parameters *(not cells)*.

b) What is the dew point of this mixture at 5 MPa? . (This is the upper limit to the flash tank temperature).
Use solver in excel and the shortcut method. Demonstrate that the method is appropriate after solving Briefly describe the steps used in solver referencing parameters *(not cells)*.

c) If V/F is desired to be 50% what is the flash temperature?
Briefly describe the steps used in solver referencing parameters *(not cells)*. Demonstrate that the method is appropriate after solving.
How does this temperature compare to parts "a" and "b"?

d) If the mixture were flashed at -43°C what fraction would be liquid?
Briefly describe the steps used in solver referencing parameters *(not cells)*. Demonstrate that the method is appropriate after solving.

e) For parts **"c" and "d",** what is the molar ratio of methane in the vapor compared to the liquid phase? (n_{Me}^V/n_{Me}^L)
What is the molar ratio of propane in the liquid compared to the vapor phase? (n_{Prop}^L/n_{Prop}^V)
Comment on the goodness of separation in the flash process for the two cases.

$$\frac{n_i^V}{n_i^L} = \frac{(V/F)y_i}{(L/F)x_i} \qquad \& \qquad \frac{n_i^L}{n_i^V} = \frac{(L/F)x_i}{(V/F)y_i}$$

$$\log_{10} P_r^{sat} = \frac{7}{3}(1+\omega)\left(1-\frac{1}{T_r}\right) \qquad 9.11$$

Shortcut vapor pressure equation. Use care with the shortcut equation below $T_r = 0.5$.

Note: *The shortcut vapor pressure equation must be regarded as an*

approximation for rapid estimates. The approximation is generally good above P = 0.5 bar; the percent error can become significant at lower pressures (and

$$\sum_i \frac{z_i(1-K_i)}{1_i+(V/F)(K_i-1)} = 0$$

$$K_i = \frac{P_i^{sat}}{P} \approx \frac{P_{c,i} 10^{\frac{7}{3}(1+\omega)\left(1-\frac{1}{T_{r,i}}\right)}}{P}$$

Shortcut K-ratio

$$\sum_i x_i = \sum_i (y_i/K_i) = 1$$

$$\sum_i y_i = \sum_i K_i x_i = 1$$

ANSWERS: Quiz 11
Chemical Engineering Thermodynamics
March 30, 2017

a)

	Bubble Point Calculation					
	zi	Tc, °K	Pc, Mpa	w	Tr>0.5	
METHANE	0.88	190.6	4.604	0.011	1.03964573	
ETHANE	0.0758	305.4	4.88	0.099	0.64884243	
PROPANE	0.0442	369.8	4.249	0.152	0.53584769	
n-BUTANE	0	425.2	3.797	0.193	0.46603122	
ISOBUTANE	0	408.1	3.648	0.177	0.48555863	
n-PENTANE	0	469.7	3.369	0.249	0.42187881	
	1	sum xK	1.0000002			
	METHANE	K1	1.13272152			
	ETHANE	K2	0.03995918			
	PROPANE	K3	0.00398994			
	n-BUTANE	nK4	0.00049091			
	ISOBUTANE	iK4	0.00089823			T, °C
	n-PENTANE	nK5	6.8372E-05			
		Temp °K	198.156477	Solve for sum xK = 1 by varying TK		-74.843523
		P Mpa	5	P>0.05MPa		

$$K_i = \frac{P_i^{sat}}{P} \approx \frac{P_{c,i}10^{\frac{7}{3}(1+\omega)\left(1-\frac{1}{T_{r,i}}\right)}}{P}$$

$$\sum_i y_i = \sum_i K_i x_i = 1$$

Solve sum xK to 1 by varying TK. T_{BP} = 198°K (-74.8°C). Tr's >0.5 and Pr> 0.05MPa.

b)

	Dew Point Calculation						
	zi	Tc, °K	Pc, Mpa	w	xi	Tr>0.5	
METHANE	0.88	190.6	4.604	0.011	0.20793399	1.39042126	
ETHANE	0.0758	305.4	4.88	0.099	0.19098528	0.86776127	
PROPANE	0.0442	369.8	4.249	0.152	0.60107848	0.71664222	
n-BUTANE	0	425.2	3.797	0.193	0	0.62326974	
ISOBUTANE	0	408.1	3.648	0.177	0	0.64938567	
n-PENTANE	0	469.7	3.369	0.249	0	0.56422034	
	1	sum y/K	0.99999774				
	METHANE	K1	4.23211235				
	ETHANE	K2	0.39688923				
	PROPANE	K3	0.07353449				
	n-BUTANE	nK4	0.01577271				
	ISOBUTANE	iK4	0.02400451				T, °C
	n-PENTANE	nK5	0.00378116				
		Temp °K	265.014292	Solve for sum y/K = 1 by varying TK			-7.9857081
		P Mpa	5	P>0.05MPa			

$$K_i = \frac{P_i^{sat}}{P} \approx \frac{P_{c,i}10^{\frac{7}{3}(1+\omega)\left(1-\frac{1}{T_{r,i}}\right)}}{P}$$

Shortcut *K*-ratio

$$\sum_i x_i = \sum_i (y_i/K_i) = 1$$

Solve sum y/K to 1 by varying TK. T_{DP} = 265°K (-7.99°C). Tr's >0.5 and Pr> 0.05MPa.

c)

		Flash Given T and P					
	zi	Tc, °K	Pc, Mpa	w	xi	yi	Tr>0.5
METHANE	0.88	190.6	4.604	0.011	0.7677278	0.9922722	1.0665802
ETHANE	0.0758	305.4	4.88	0.099	0.144342	0.007258	0.6656522
PROPANE	0.0442	369.8	4.249	0.152	0.0879303	0.0004697	0.5497301
n-BUTANE	0	425.2	3.797	0.193	0	0	0.4781049
ISOBUTANE	0	408.1	3.648	0.177	0	0	0.4981382
n-PENTANE	0	469.7	3.369	0.249	0	0	0.4328086
	1	sum D	3.442E-07		1.0000002	0.9999998	
	METHANE	K1	1.2924792				
	ETHANE	K2	0.050283				
	PROPANE	K3	0.0053413				
	n-BUTANE	nK4	0.0006948				
	ISOBUTANE	iK4	0.001248				T, °C
	n-PENTANE	nK5	0.0001022				
		Temp °K	203.29019				-69.70981
		P Mpa	5	P>0.05MPa			
		V/F	0.5	Solve for sum D = 0 by varying TK			
		L/F	0.5				

$$K_i = \frac{P_i^{sat}}{P} \approx \frac{P_{c,i} 10^{\frac{7}{3}(1+\omega)\left(1-\frac{1}{T_{r,i}}\right)}}{P} \quad \text{Shortcut } K\text{-ratio}$$

	niV/niL	niL/niV
METHANE	1.2924792	0.7737068
ETHANE	0.050283	19.887437
PROPANE	0.0053413	187.2214

$$\sum_i \frac{z_i(1-K_i)}{1_i + (V/F)(K_i - 1)} = 0$$

Solve SumD = 0 by varying TK. T50% = 203°K (-69.7°C). This is between the BP and DP limits for the flash tank. Tr's >0.5 and Pr> 0.05MPa.

d)

		Flash Given T and P					
	zi	Tc, °K	Pc, Mpa	w	xi	yi	Tr>0.5
METHANE	0.88	190.6	4.604	0.011	0.40785	0.9522977	1.2067156
ETHANE	0.0758	305.4	4.88	0.099	0.2973157	0.0418805	0.7531107
PROPANE	0.0442	369.8	4.249	0.152	0.2948341	0.0058218	0.6219578
n-BUTANE	0	425.2	3.797	0.193	0	0	0.5409219
ISOBUTANE	0	408.1	3.648	0.177	0	0	0.5635874
n-PENTANE	0	469.7	3.369	0.249	0	0	0.4896743
	1	sum D	-1.59E-07		0.9999999	1	
	METHANE	K1	2.3349214				
	ETHANE	K2	0.1408622				
	PROPANE	K3	0.019746				
	n-BUTANE	nK4	0.003296				
	ISOBUTANE	iK4	0.0054509				T, °C
	n-PENTANE	nK5	0.0006184				
		Temp °K	230				-43
		P Mpa	5	P>0.05MPa			
		V/F	0.8672092	Solve for sum D = 0 by varying V/F			
		L/F	0.1327908				

$$K_i = \frac{P_i^{sat}}{P} \approx \frac{P_{c,i} 10^{\frac{7}{3}(1+\omega)\left(1-\frac{1}{T_{r,i}}\right)}}{P} \quad \text{Shortcut } K\text{-ratio}$$

	niV/niL	niL/niV
METHANE	15.248531	0.0655801
ETHANE	0.9199203	1.0870507
PROPANE	0.1289543	7.7546831

$$\sum_i \frac{z_i(1-K_i)}{1_i + (V/F)(K_i - 1)} = 0$$

L/F = 0.133. Solve for sumD = 0 by varying V/F. Tr's >0.5 and Pr> 0.05MPa.

e) The ratios are given in the excel sheet in the bottom right for parts "c" and "d" For the first case there is good separation of propane to the liquid phase, 187 times the vapor phase. For the second case there is good separation of methane to the vapor phase, 15 times the liquid composition.