CHE 305 "Separation Processes"

Spring, 2012 - Exam 1

Name: Key CWID: _____

1. A liquid and vapor containing water and ethanol are in equilibrium. The intensive variables that describe this closed system are T, P, x_W, x_E, y_W, and y_E.

a. Define the term "intensive variable."

Property that is not dependent on quantity

b. Use the Gibbs Phase Rule to determine the number of intensive variables that must be specified in order to calculate the remaining intensive variables.

$F = C - P + 2$ $C = 2$ species $P = 2$ phases

$= 2$ can specify only 2 variables (T & P, for example)

c. Write down the independent equations used to determine the remaining intensive variables.

$\sum x_i = 1$ $\sum y_i = 1$

$K_W = y_W / x_W$ $K_E = y_E / x_E$

Note these will not be ideal.

2. A liquid mixture of 60 mol% benzene and 40 mol% toluene is at 1 atm and 88°C.

a. This mixture is heated until the first bubble of vapor is formed. Identify (with an '2a') the initial and final states on the TXY diagram. Write the bubble point temperature here.

89.5 °C

b. The mixture is now heated to 98°C. Identify (with a '2b') the liquid and vapor compositions. Write the concentrations here.

$y_B = 0.72$ $x_B = 0.5$

c. Use the lever rule to find the ratio of vapor to liquid produced.

$V\% = \frac{0.6 - 0.5}{0.72 - 0.5} \approx 45\%$ $\frac{V}{L} = \frac{45}{55} = 0.82$

d. The mixture is now heated until the last drop of liquid is vaporized. Identify (with a '2d') this state on the TXY diagram. Write the dew point temperature here.

96 °C

3. 100 mol/h of a 40 mol% benzene and 60 mol% toluene liquid is fed to a single-stage flash unit operating at 1 atm.

a. 20% of the feed is vaporized. Draw the material balance line on the XY diagram and label it '3a'.

$L/V = 4$ ← slope (w/ − sign)

b. Write the compositions of the vapor and liquid here.

$x_B = 0.36 \quad y_B = 0.575$

c. Confirm that these products satisfy the material balance.

$100 \times 0.4 = 20 \times 0.575 + 80 \times 0.36$

$40 = 40.3$ close (error in reading graph)

d. Use the TXY diagram to find the operating temperature of this flash unit. Label that state '3d'. Write down this temperature here.

~ 96.5 °C

4. 100 mol/h of a liquid mixture with 50 mol% benzene and 50 mol% toluene at a temperature of 90°C is fed to a single-stage flash unit operating at 1 atm (760 mm Hg) and 95.5°C. 50% of the feed is vaporized producing a vapor with 61 mol% benzene and a liquid with 61 mol% toluene.

a. Calculate the K values for benzene and toluene at these conditions.

$P_B^* = 10\text{^}(6.89 - 1204/(220 + 95.5)) = 1185$

$P_T^* = 10\text{^}(6.96 - 1347/(220 + 95.5)) = 490$

$K_B = \frac{1185}{760} = 1.56 \quad K_T = \frac{490}{760} = 0.65$

b. Using the conditions of the feed as a reference state, calculate the enthalpy of the liquid and vapor in kJ/h.

$\hat{H}_B = 0.127(95.5 - 90) + \frac{2.34 \times 10^{-4}}{2}(95.5^2 - 90^2)$

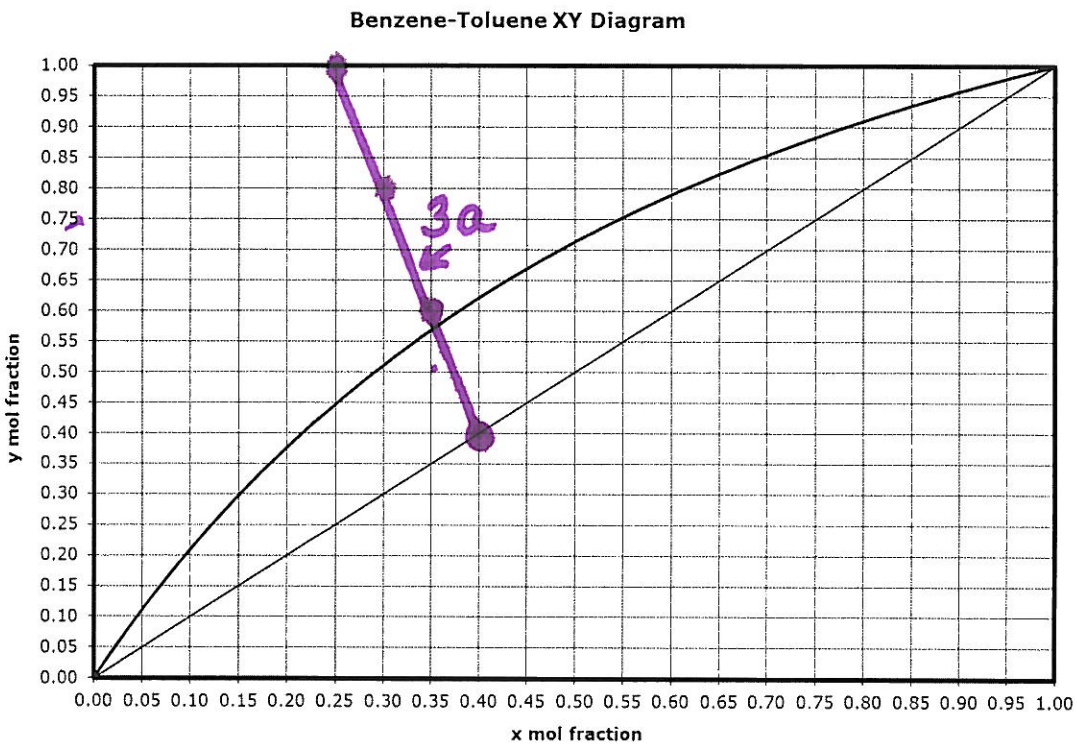
$= 0.82$ kJ/mol

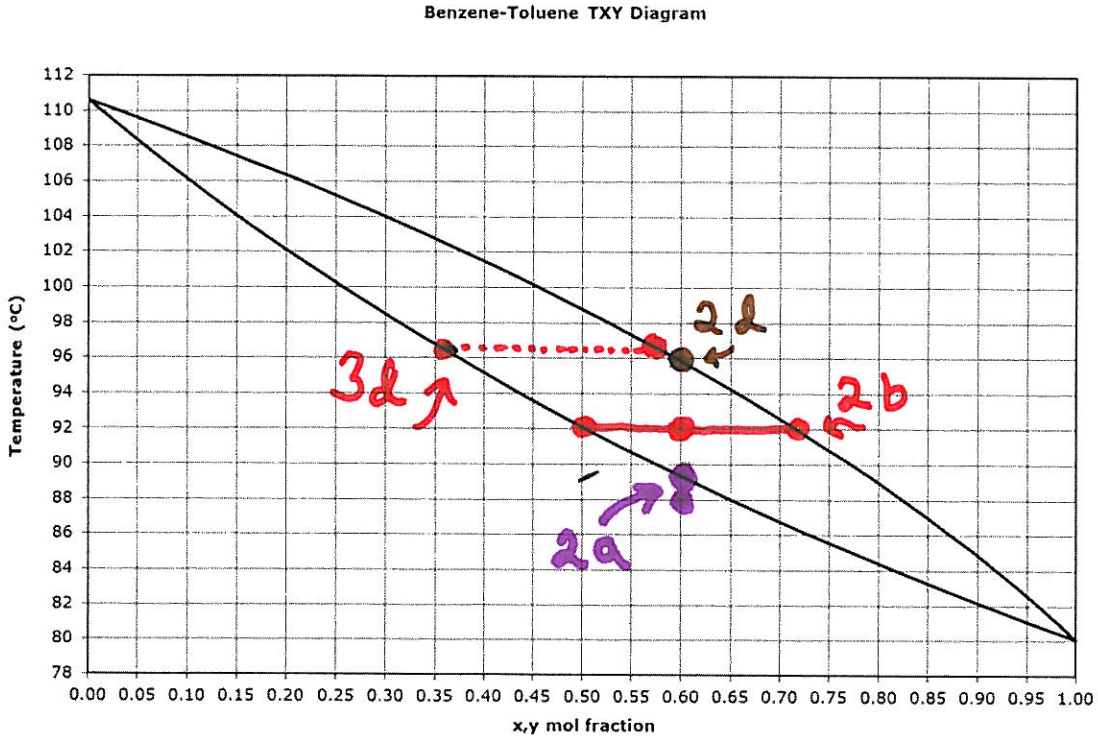
$\hat{H}_T = 0.149(95.5 - 90) + \frac{3.24 \times 10^{-4}}{2}(95.5^2 - 90^2)$

$= 0.98$ kJ/mol

$\hat{H}_L = 0.61 \times 0.98 + 0.39 \times 0.82 = 0.918$ kJ/mol

$H_L = 50 \frac{\text{mol}}{\text{h}} \times 0.918 \frac{\text{kJ}}{\text{mol}} = 46$ kJ/h


Benzene-Toluene XY Diagram
y mol fraction
x mol fraction
3a


Benzene-Toluene TXY Diagram
Temperature (°C)
x,y mol fraction
2d
3d
2b
2a

c. Perform the Rachford-Rice procedure to confirm the above V/L split and temperature (no iteration required this way) to find x_B and y_B.

$$\sum \frac{z_i(1-K_i)}{1+\frac{V}{F}(K_i-1)} = \frac{0.5(1-1.56)}{1+.5(1.56-1)} + \frac{0.5(1-.65)}{1+0.5(.65-1)}$$

$$= -.22 + .21 \checkmark$$

$$x_B = \frac{0.5}{1+0.5(1.56-1)} = 0.39$$

$$y_B = \frac{0.5 \times 1.56}{1+0.5(1.56-1)} = 0.61$$

~~d. Use the overall enthalpy balance to find the heat required for this operation in kJ/h.~~

Antoine Constants

	A	B	C
Benzene	6.89272	1203.531	219.888
Toluene	6.95805	1346.773	219.693

$Log_{10}P^*$ (mm Hg) = A – B/[T(°C)+C]

Enthalpy	a	b	c	d	T_B(°C)
B (L)	1.27E-01	2.34E-04	0	0	
B (V)	7.41E-02	3.30E-04	-2.52E-07	7.76E-11	80.1
T (L)	1.49E-01	3.24E-04	0	0	
T (V)	9.42E-02	3.80E-04	-2.79E-07	8.03E-11	110.62

$C_P = a + bT + cT^2 + dT^3$ (C_P in kJ/mol °C and T in °C)

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a. Define the term "intensive variable."

b. Use the Gibbs Phase Rule to determine the number of intensive variables that must be specified in order to calculate the remaining intensive variables.

c. Write down the independent equations used to determine the remaining intensive variables.

2. A liquid mixture of 40 mol% benzene and 60 mol% toluene is at 1 atm and 88°C.

a. This mixture is heated until the first bubble of vapor is formed. Identify (with an '2a') the initial and final states on the TXY diagram. Write the bubble point temperature here.

95 °C

b. The mixture is now heated to 98°C. Identify (with a '2b') the liquid and vapor compositions. Write the concentrations here.

$x_B \sim 0.32$ $y_B \sim 0.52$

c. Use the lever rule to find the ratio of vapor to liquid produced.

$$V\% = \frac{0.4 - 0.32}{0.52 - 0.32} = 40\% \quad \frac{V}{L} = \frac{40}{60} = 0.67$$

d. The mixture is now heated until the last drop of liquid is vaporized. Identify (with a '2d') this state on the TXY diagram. Write the dew point temperature here.

~101.5 °C

3. 100 mol/h of a 60 mol% benzene and 40 mol% toluene liquid is fed to a single-stage flash unit operating at 1 atm.

a. 20% of the feed is vaporized. Draw the material balance line on the XY diagram and label it '3a'.

$L/V = 4$ ← slope (w/ - sign)

b. Write the compositions of the vapor and liquid here.

$Y_B \sim 0.76 \quad X_B \sim 0.56$

c. Confirm that these products satisfy the material balance.

$100 \times 0.6 = 20 \times .76 + 80 \times .56$

$60 = 60$ ✓

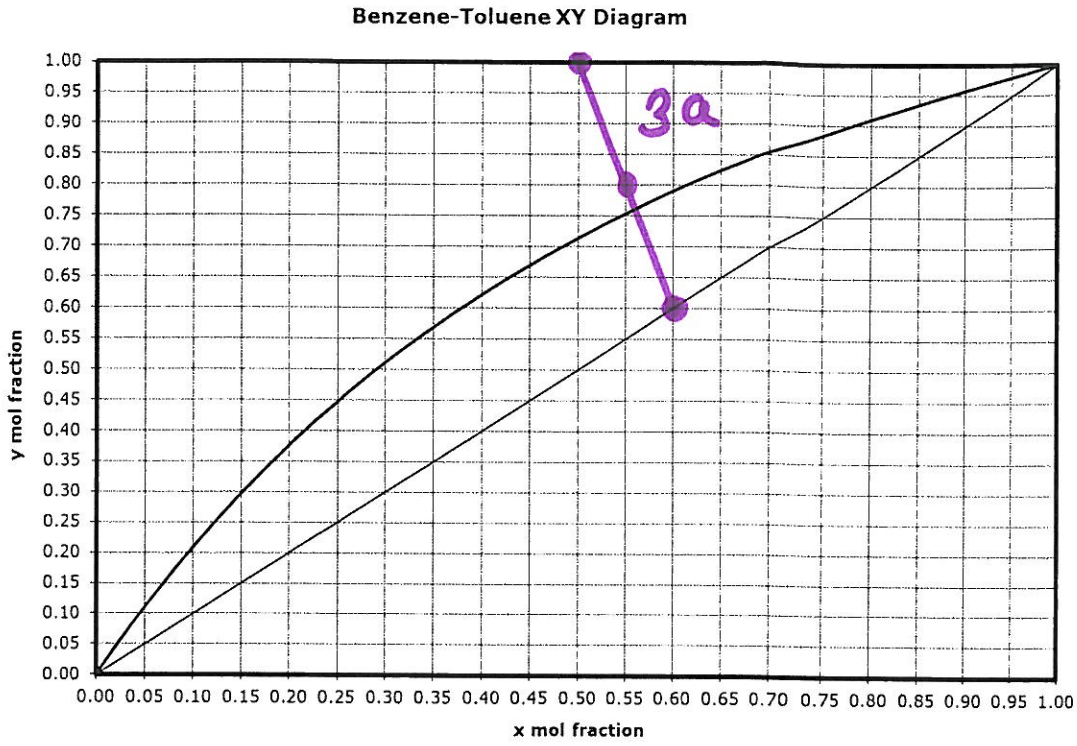
d. Use the TXY diagram to find the operating temperature of this flash unit. Label that state '3d'. Write down this temperature here.

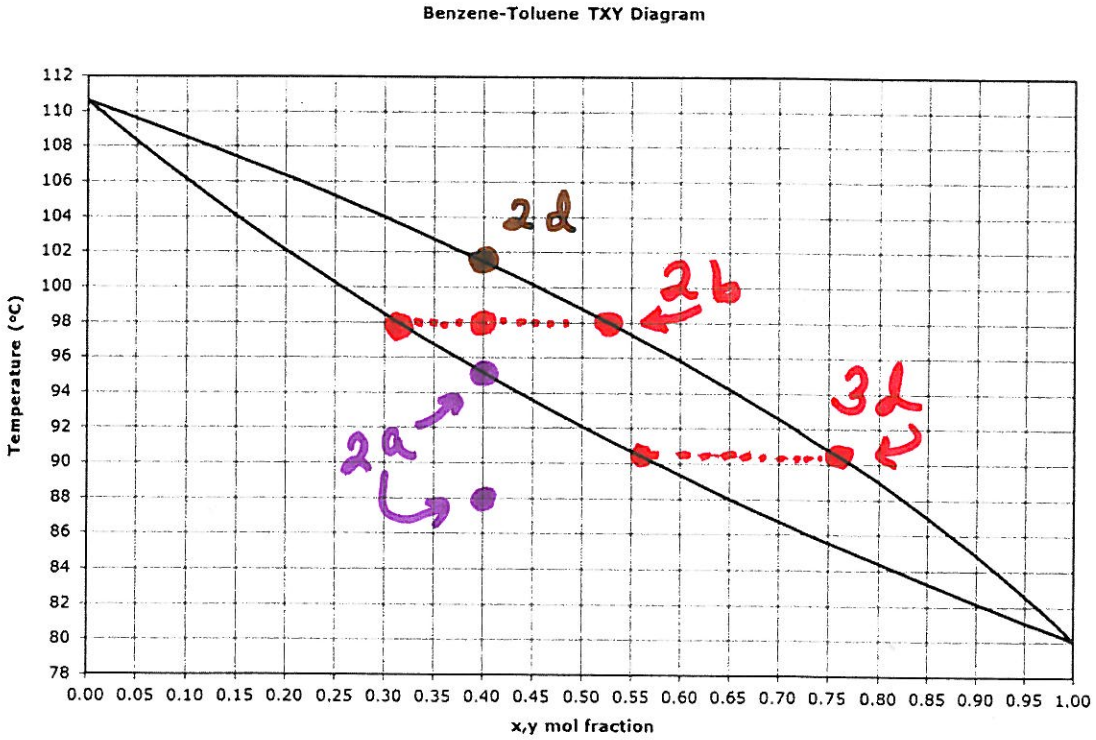
$\sim 90.5\,^{\circ}C$

4. 100 mol/h of a liquid mixture with 50 mol% benzene and 50 mol% toluene at a temperature of 90°C is fed to a single-stage flash unit operating at 1 atm (760 mm Hg) and 95.5°C. 50% of the feed is vaporized producing a vapor with 61 mol% benzene and a liquid with 61 mol% toluene.

a. Calculate the K values for benzene and toluene at these conditions.

b. Using the conditions of the feed as a reference state, calculate the enthalpy of the liquid and vapor in kJ/h.


Benzene-Toluene XY Diagram
y mol fraction
x mol fraction
3a
1.00
0.95
0.90
0.85
0.80
0.75
0.70
0.65
0.60
0.55
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
0.00 0.05 0.10 0.15 0.20 0.25 0.30 0.35 0.40 0.45 0.50 0.55 0.60 0.65 0.70 0.75 0.80 0.85 0.90 0.95 1.00


Benzene-Toluene TXY Diagram
Temperature (°C)
x,y mol fraction
2d
2b
3d
2a
112
110
108
106
104
102
100
98
96
94
92
90
88
86
84
82
80
78
0.00 0.05 0.10 0.15 0.20 0.25 0.30 0.35 0.40 0.45 0.50 0.55 0.60 0.65 0.70 0.75 0.80 0.85 0.90 0.95 1.00

3. 100 mol/h of a 60 mol% benzene and 40 mol% toluene liquid is fed to a single-stage flash unit operating at 1 atm.

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4. 100 mol/h of a liquid mixture with 50 mol% benzene and 50 mol% toluene at a temperature of 90°C is fed to a single-stage flash unit operating at 1 atm (760 mm Hg) and 95.5°C. 50% of the feed is vaporized producing a vapor with 61 mol% benzene and a liquid with 61 mol% toluene.

a. Calculate the K values for benzene and toluene at these conditions.

Alternative to Antoine's Eq

$K_B = \frac{y_B}{x_B} = \frac{.61}{.39} = 1.56$

$K_T = \frac{y_T}{x_T} = \frac{.39}{.61} = 0.64$

b. Using the conditions of the feed as a reference state, calculate the enthalpy of the liquid and vapor in kJ/h.

Alternate (approximate)

$C_{pB} = 0.127 + 2.34\times10^{-4}\times90 = 0.148 \frac{kJ}{mol\cdot°C}$

$C_{pT} = 0.149 + 3.24\times10^{-4}\times90 = 0.178$ "

$\hat{H}_B = 0.148(5.5) = 0.81$ kJ/mol

$\hat{H}_T = 0.178(5.5) = 0.98$ "

$H_L = 50\frac{mol}{h}(0.61\times0.98 + 0.39\times0.81)\frac{kJ}{mol}$

$= 46$ kJ/h