Mass Transfer – I (CH21202)

Solutions of Tutorial Sheet No.: MT-I/NCP/2024/3

---

1. A liquid mixture containing 60 mol% n-pentane and 40 mol% n-heptane is vapourized at 1 std atm pressure under differential distillation condition until 40 mol% of the mixture is distilled. What is the average composition of the total vapour distilled and the composition of the liquid left?

If the same amount of vaporization is done in an equilibrium or flash distillation, what will be the composition of the vapour distilled and the composition of the liquid left?

Equilibrium Data:

x	0.0	0.059	0.145	0.254	0.398	0.594	0.867	1.00
y	0.0	0.271	0.521	0.701	0.836	0.925	0.984	1.00

Solution:

Basis: 100 kmoles of mixture

$\therefore F = 100.0,\ D = 40.0,\ W = 60.0;\quad x_F = 0.60$

Now the Rayleigh Equation can be written as:

$$\ln\frac{F}{W} = \int_{x_W}^{x_F} \frac{dx}{y^* - x} \qquad (1)$$

$$or,\ \ln\frac{100}{60} = 0.5108 = \int_{x_W}^{0.6} \frac{dx}{y^* - x} \qquad (2)$$

From the given equilibrium data, the following table was made.

x	0.059	0.145	0.254	0.398	0.594	0.867
$1/(y^* - x)$	4.717	2.66	2.237	2.283	3.021	8.547

These $1/(y^*- x)$ values were plotted against x, and the right hand side of equation (2) was evaluated graphically for different x_W values. It was found that for $x_W = 0.40$, the right hand side became 0.51. Therefore, the composition of the liquid left is 40 mol% n-pentane.

The average composition of the total vapour distilled, $y_{D,avg}$ can be found from the following equation:

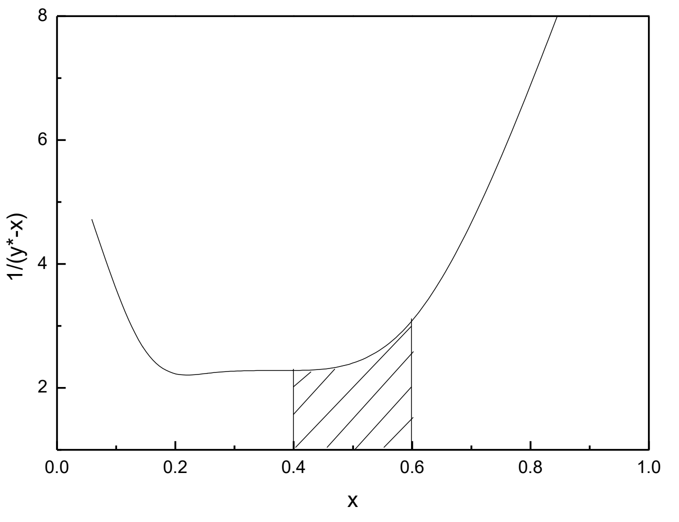
$$F\,x_F = D\,y_{D,avg} + W\,x_W \qquad (3)$$

Putting different values, we get $y_{D,avg} = 0.90$.

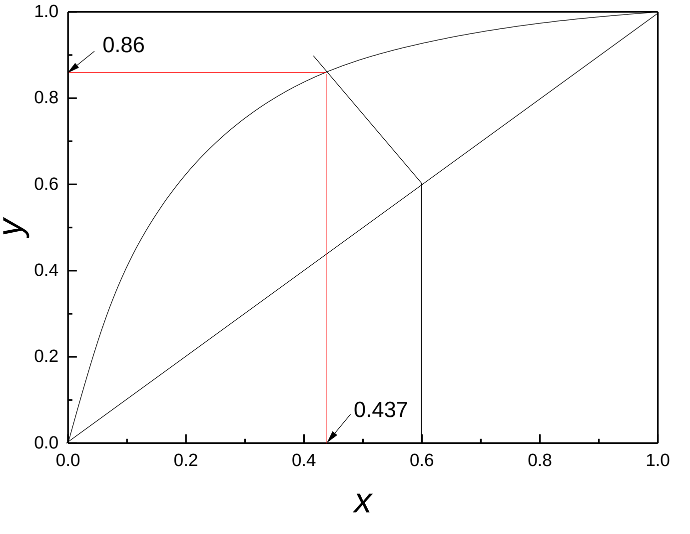
For equilibrium flash vaporization, we have the equation:

$$-\frac{W}{D} = \frac{y_D - Z_F}{x_W - Z_F}\ or, -\frac{60}{40} = -1.5 = \frac{y_D - 0.6}{x_W - 0.6} \qquad (4)$$

A straight line was drawn from x = y = 0.60 on the diagonal having a slope of -1.5. This line cut equilibrium curve at a point whose coordinates gave the values of $y_D = 0.86$ and $x_W = 0.437$.



8
6
4
2
1/(y*-x)
0.0
0.2
0.4
0.6
0.8
1.0
x



1.0
0.8
0.6
0.4
0.2
0.0
y
0.86
0.437
0.0
0.2
0.4
0.6
0.8
1.0
x

2. A liquid mixture containing 40 mol% n-heptane (A), 60 mol% n-octane (B), at 30^oC, is to be continuously flash vaporized at 1 std atm pressure to vaporize 50 mol % of the feed. What will be the composition of the vapour and liquid?

If the same liquid mixture is subjected to differential distillation at atmospheric pressure with 50 mol% of the liquid distilled, what will be the composition of the composited distillate and the residue?

Temperature-Vapour pressure Data:

Temp.(^oC)	98.4	105	110	115	120	125.6
P_A(mm Hg)	760	940	1050	1200	1350	1540
P_B(mm Hg)	333	417	484	561	650	760

Solution:

The equilibrium data were converted as follows:

$$\alpha = P_A / P_B \quad x_A = \frac{P_t - P_B}{P_A - P_B} = \frac{760 - 417}{940 - 417} = 0.655 \qquad y_A = \frac{x_A\, P_A}{P_t} = 0.655 \text{ x } 940/760 = 0.810$$

Temp.(^oC)	98.4	105	110	115	120	125.6
P_A(mm Hg)	760	940	1050	1200	1350	1540
P_B(mm Hg)	333	417	484	561	650	760
α	2.28	2.25	2.17	2.14	2.04	2.03
x	1.0	0.655	0.487	0.312	0.157	0.0
y	1.0	0.810	0.674	0.492	0.279	0.0

Basis: F = 100 mol Feed, x_F = 0.40, D = 50 mol, W = 50 mol, $-W/D$ = -50/50 = -1.0.

The equilibrium data were plotted. The point representing the feed composition is located on the diagonal line at P and the operating line was drawn with a slope –1.0 to intersect the equilibrium curve at T, where y^*_D = 0.48 mole fraction n-heptane and x_w = 0.31 mole fraction n-heptane.

For differential distillation with constant relative volatility:

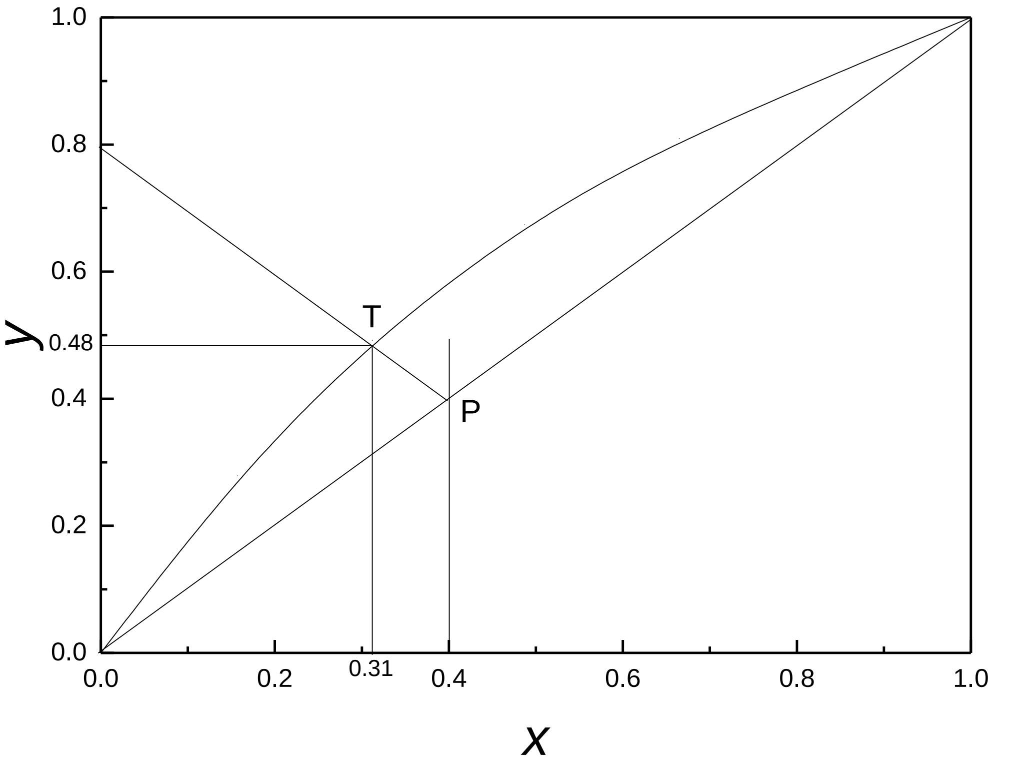
$$\ln \frac{Fx_F}{Wx_W} = \alpha_{av} \ln \frac{F(1-x_F)}{W(1-x_W)}$$

or, $$\ln \frac{0.8}{x_W} = 2.16 \ln \frac{1.2}{(1-x_W)}$$

By trial and error, the value of x_W was determined to be 0.272.

Average composition of the composited distillate,

$$y_{D,av} = (F\,x_F - W\,x_W) / D = (100 \text{ x } 0.4 - 50 \text{ x } 0.272) / 50$$
$$= 0.528.$$


1.0
0.8
0.6
0.48
0.4
0.2
0.0
y
T
P
0.0
0.2
0.31
0.4
0.6
0.8
1.0
x

3. A liquid mixture containing 50 mol% ethanol (*A*), 50 mol% n-propanol (*B*) is subjected to differential distillation at atmospheric pressure with 50 mol% of the liquid distilled. What will be the compositions of the composited distillate and the residue? Given the vapour pressures of A and B at 80^{o}C as 787 mm Hg and 364 mm Hg, respectively.

Solution:

Basis: F = 100 mol Feed, x_F = 0.50, D = 50 mol, W = 50 mol,

Relative volatility at 80^{o}C = 787/364 = 2.16

It is assumed that the relative volatility is constant in the temperature range of operation.

For differential distillation with constant relative volatility:

$$\ln \frac{Fx_F}{Wx_W} = \alpha \ln \frac{F(1-x_F)}{W(1-x_W)}$$

or, $$\ln \frac{1.0}{x_W} = 2.16 \ln \frac{1.0}{(1-x_W)}$$

By trial and error, the value of x_W was determined to be 0.37.

Average composition of the composited distillate,

$y_{D,av}$ = (F x_F – W x_W) / D = (100 x 0.5 – 50 x 0.37) / 50
= 0.63.

4. 100 moles of acetonitrile-nitromethane mixture is differentially distilled in a batch still at a pressure of 75 kPa. The feed contains 60 mole% acetonitrile. Distillation is continued till the liquid left behind in the still contains 30 mole% acetonitrile. The vapour-liquid equilibria for the system at this pressure are correlated as follows:

$y^* = 1.12\,x + 0.15$ for $0.2 \le x \le 0.4$ and

$y^* = 0.76\,x + 0.25$ for $0.4 \le x \le 0.7$,

where x and y^* refer to the mole fractions of acetonitrile in the liquid and equilibrium vapour, respectively. Find the average composition of the distillate collected.

Solution:

Differential distillation obeys Rayleigh equation:

$$\ln\frac{F}{W} = \int_{x_W}^{x_F} \frac{dx}{y^* - x}$$

Where, F = moles of feed = 100 moles, W = moles of residue,

x_F = mole fraction of more volatile component in the feed = 0.6

x_W = mole fraction of more volatile component in the residue = 0.3

For the present case,

$$\ln\frac{100}{W} = \int_{0.3}^{0.6} \frac{dx}{y^* - x} = \int_{0.3}^{0.4} \frac{dx}{(1.12\,x + 0.15) - x} + \int_{0.4}^{0.6} \frac{dx}{(0.76\,x + 0.25) - x}$$

$$\text{Or, } \ln\frac{100}{W} = \frac{1}{0.12}\ln\frac{(0.12)(0.4)+0.15}{(0.12)(0.3)+0.15} - \frac{1}{0.24}\ln\frac{(0.24)(0.6)-0.25}{(0.24)(0.4)-0.25}$$

$$= 2.077$$

Therefore, W = 12.53 moles and $D = F - W$ = 100 – 12.53 = 87.47 moles

The average distillate composition, $y_{D,avg}$ can be found from the following equation:

$$F\,x_F = D\,y_{D,avg} + W\,x_W$$

Putting different values, we get $y_{D,avg} = 0.643$.

5. An ideal solution containing 10% methanol (A), 80% ethanol (B) and 10% n-propanol (C) is flash vaporized at 80°C and 1 atm pressure. Compute the amount of liquid and vapour products and their composition. Given the vapour pressures of A, B and C at 80°C as 1302 mm Hg, 787 mm Hg and 364 mm Hg, respectively.

Solution:

Basis: 100 moles of feed
For flash vaporization of multi-component system,

$$y_{i,D} = \frac{(1+W/D)\,Z_{i,F}}{1+(W/D\;m_i)}$$

Substance	Vap. Pressure (mm Hg)	m	z_F	1st trial (W/D) = 0.5	2nd trial (W/D) = 0.667	Liq. Product Composition
A	1302	1.7131	0.10	$y_{AD} = 0.1161$	$y_{A,D} = 0.1193$	$x_{A,W} = 0.0701$
B	787	1.0355	0.80	$y_{B,D} = 0.8092$	$y_{B,D} = 0.8111$	$x_{B,W} = 0.7833$
C	364	0.4789	0.10	$y_{C,D} = 0.0734$	$y_{C,D} = 0.0696$	$x_{C,W} = 0.1456$
			Total =	0.9987	1.0	1.0

Therefore, W/D = 0.667. Again, F = D + W. Hence, D = 60 moles and W = 40 moles.

Therefore, 60% will be the vapour products and 40% liquid products with the composition given in the last two columns.