Che-313

Mass Transfer Operations – I

Instructor : Dr. D.P. Rao

Project Report

By

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Preface

In this project, we have solved problems based on Phase Equilibria, Single-stage Processes, Multi-Stage Cross Current and Counter Current Processes, for both Type-I and Type-II processes. We have illustrated various methods like Stage to Stage Calculations, Mc-Cabe Thiele diagrams, Ponchon-Savarit Method and Matrix methods, for both design and simulation.

We have programmed MS-Excel sheets for solving most of the problems in a general way. The sheets are user-friendly and any person with a basic knowledge of the subject can use them for solving various types of problems. But few problems which required extrapolation / interpolation from experimental data could not be solved in a general way because of internal constraints imposed by MS-Excel. These problems have been solved using PolyMath Software.

We hope that this small effort in a limited span of time would help in developing a better grasp of this subject.

We are thankful to Dr. D.P. Rao for providing us the opportunity and valuable knowledge of the subject, which is reflected in our effort.

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Question.1

(a) Construct the saturated humidity versus temperature plot for the air-water system over a range from 0°C to 50°C. Also draw parametric lines for 75, 50, 25 percent humidity.

(b) Plot enthalpy of the air – water mixture against temperature on the same plot.

Solution:

Pressure = 1 bar Temperature Range: 273 K to 323 K

Relevant Data for Water:

Antoine's Constants: A = 18.3036 B = 3816.44 C = -46.13

T_c = 647.3 K P_c = 221 atm T_b = 373.2 K

Table 1.1

Molar Specific Heat (C_p) Data

Constants	Water Vapor (1)	Air (2)
A	32.34	31.15
B	1.93 E-03	-1.36 E-02
C	1.06 E-05	2.68 E-05
D	-3.61 E-09	-1.17 E-08

where, $C_p = a + bT + cT^2 + dT^3$

a) Calculation Of Saturated Humidity.

Absolute humidity is defined as the mass of water vapor per unit mass of dry air. At saturation there is an equilibrium between air+water vapor and water.

$$P^s = yP$$

=>

$$y = \frac{P^s}{P}$$

$$y' = \frac{18P^s}{29(P - P^s)} = 0.0058 \qquad \ldots (1)$$

At T = 273 K,

$$P^s = \exp\left(\frac{A - B/(273 + C)}{760}\right) = 0.0036$$

$$y' = \frac{18x0.0058}{29(1 - 0.0058)} = 0.0058$$

Similarly, y' at other T can be calculated and are shown in Table 1.2.

b) Calculation of Enthalpy of mixture of water and air.

We choose T_{ref} = 273 K
Enthalpy of the mixture, $H = yH_1 + (1-y)H_2$ … (2)

$$H_1 = a_1(T - T_{ref}) + \frac{b_1}{2}(T - T_{ref})^2 + \frac{c_1}{3}(T - T_{ref})^3 + \frac{d_1}{4}(T - T_{ref})^4 + H_v \qquad ...(3)$$

where H_v is the enthalpy of vaporization and is calculated using Watsons Correlation:

$$H_v = H_{vnbp}\left[\frac{(1 - T_r)}{(1 - T_{br})}\right]^{0.38}$$

…(4)

and

$$H_2 = a_2(T - T_{ref}) + \frac{b_2}{2}(T - T_{ref})^2 + \frac{c_2}{3}(T - T_{ref})^3 + \frac{d_2}{4}(T - T_{ref})^4 \qquad …(5)$$

At T = 273K,

$$y = \frac{P^s}{P} = \frac{0.0058}{1} = 0.0058$$

$$T_r = \frac{T}{T_c} = \frac{273}{647.3} = 0.4218$$

$$T_{br} = \frac{T_b}{T_c} = \frac{373.2}{647.3} = 0.5765$$

$$H_{vnbp} = 1.093 \text{ x } 8.314 \text{ x } 647.3\left[\frac{0.5765(\ln(221) - 1.013)}{0.93 - 0.5765}\right] = 420.70 \text{ kJ/mol}$$

$$H_v = H_{vnbp}\left[\frac{(1 - 0.4218)}{(1 - 0.5765)}\right]^{0.38} = 473.54 \text{ kJ/mol}$$

$$H_1 = a_1(273 - 273) + \frac{b_1}{2}(273 - 273)^2 + \frac{c_1}{3}(273 - 273)^3 + \frac{d_1}{4}(273 - 273)^4 + 47354$$

$$= 473.54 \text{ kJ/mol}$$

$$H_2 = a_2(273 - 273) + \frac{b_2}{2}(273 - 273)^2 + \frac{c_2}{3}(273 - 273)^3 + \frac{d_2}{4}(273 - 273)^4 = 0$$

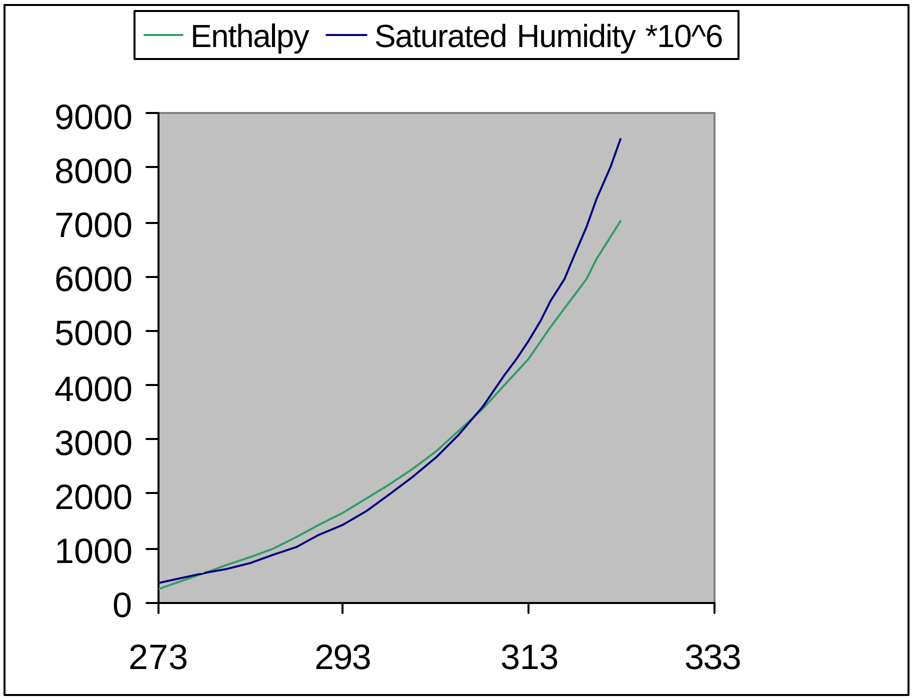
H = 0.0058*47354 + (1-0.0058)*0 = 243.61 J/mol

Similarly, H can be calculated at other T and are shown in Table 1.2

Table 1.2

T (K)	x	H (J/mol)
273	0.0036	243.61
278	0.0052	519.76
283	0.0074	836.41
288	0.0104	1205.79
293	0.0143	1643.03
298	0.0197	2166.59
303	0.0267	2798.79
308	0.0360	3566.37
313	0.0482	4501.05
318	0.0641	5640.16
323	0.0852	7027.27

The plots are shown below:



Question.2 The experimental solubility data of carbon dioxide in Propylene carbonate (ratio of the volume of gas measured at 1 atm, 25 ^{o}C dissolved per unit volume of liquid) at different temperature reported by Mantor et al. [J. Chem. Eng. Data, 27(1982) 243-245] are given below.

T = 26.7 ^{o}C

P(atm)	54.8	54.5	53.5	43.6	31.9	19.4
Solubility	405.9	387.7	376.5	268.5	159.3	85.8

T = 37.8 ^{o}C

P(atm)	59.7	53.9	43.7	33.3	22.8
Solubility	278.8	235.7	171.7	121.3	76.1

T = 71.1 ^{o}C

P(atm)	68.1	60.2	48.8	38.9	29.6
Solubility	153.9	133.6	98.0	77.9	58.4

T = 104.4 ^{o}C

P(atm)	60.9	46.6	21.2
Solubility	82.9	63.2	28.1

Construct the following plots:

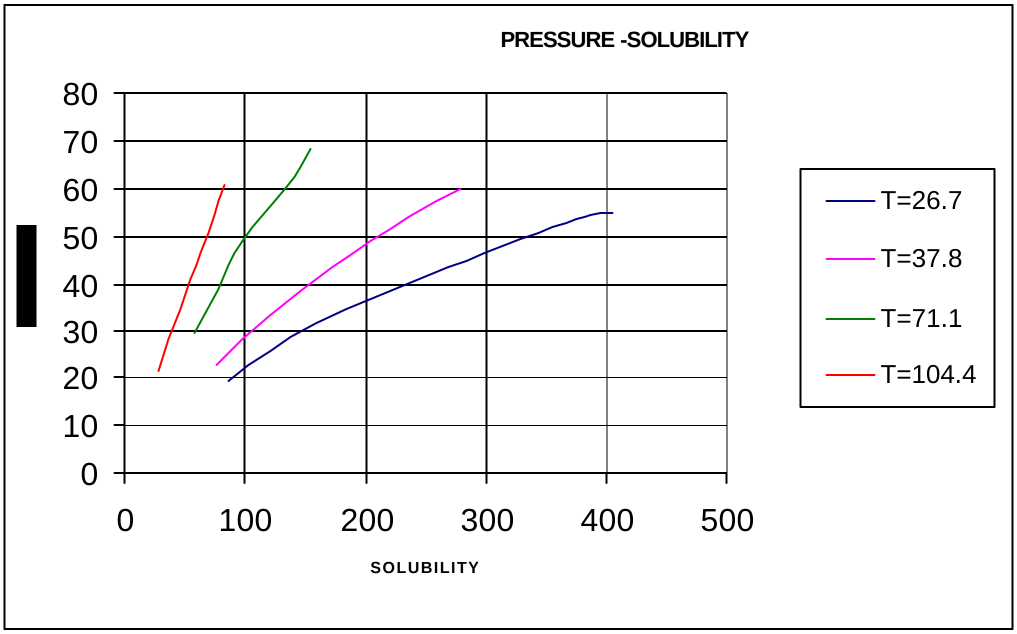
(a) P *vs* x with T *as* parameter
(b) T *vs* x with P as parameter
(c) P *vs* T with x as parameter

Solution:

The given data is :

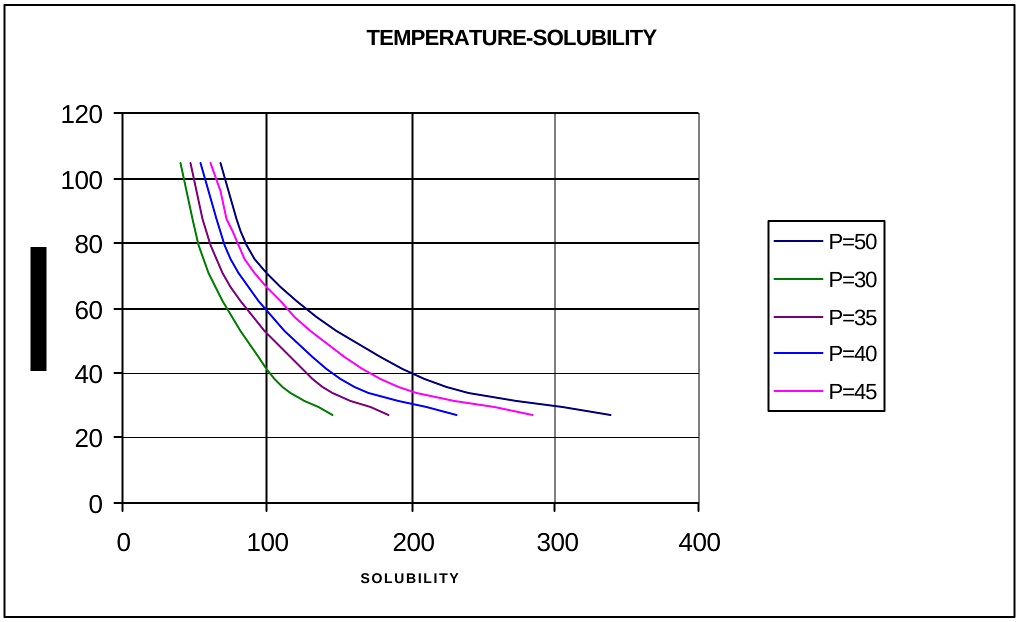
T = 26.7ºC		T = 37.8ºC		T = 71.1ºC		T = 104.4ºC	
P(atm)	S	P(atm)	S	P(atm)	S	P(atm)	S
19.4	85.8	22.8	76.1	29.6	58.4	21.2	28.1
31.9	159.3	33.3	121.3	38.9	77.9	46.6	63.2
43.6	268.5	43.7	171.7	48.8	98	60.9	82.9
53.5	376.5	53.9	235.7	60.2	133.6		
54.5	387.7	59.7	278.8	68.1	153.9		
54.8	405.9						

The following plot is generated by plotting Pressure vs Solubility at different temperatures :



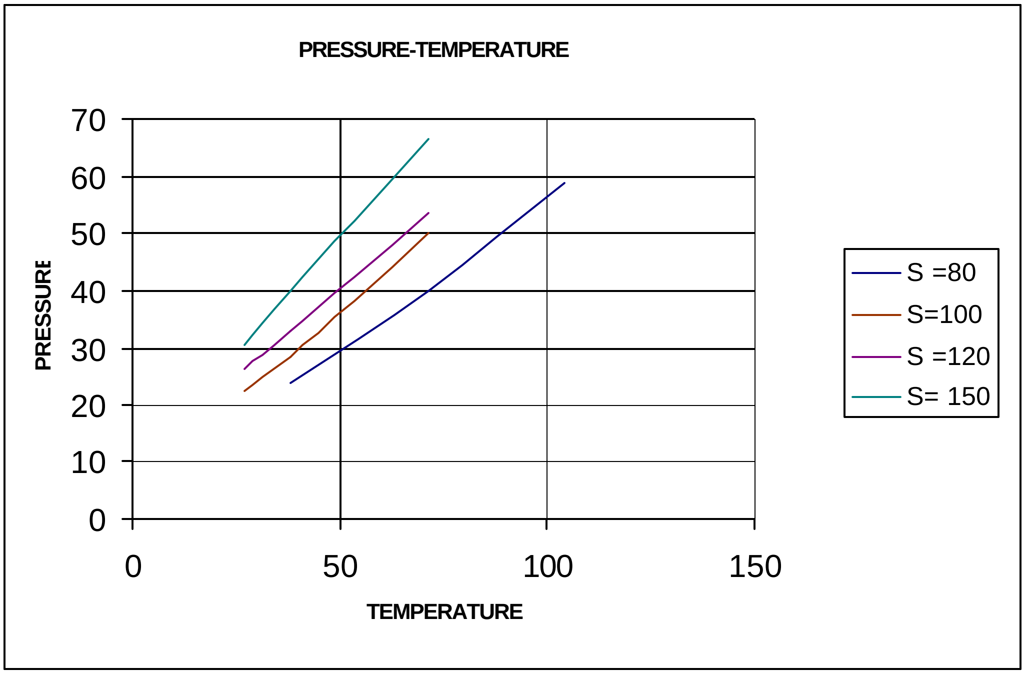
Interpolating the given data for different pressures, we get the following Temperature vs Solubility curves:

P = 50 atm		P = 30 atm		P = 35 atm		P = 40 atm		P = 45 atm	
T(ºC)	S	T(ºC)	S	T(ºC)	S	T(ºC)	S	T(ºC)	S
26.7	339.34	26.7	145.4	26.7	184.34	26.7	230.88	26.7	283.8
37.8	209.68	37.8	105.82	37.8	130.81	37.8	150.9	37.8	179.19
71.1	99.37	71.1	59.22	71.1	69.61	71.1	80.26	71.1	90.88
104.4	67.89	104.4	40.276	104.4	47.19	104.4	54.09	104.4	60.99



Similarly, interpolating the given data for different solubilities, we get the following Pressure vs Temperature curves :

S = 80		S = 100		S = 120		S = 150	
P (atm)	T (ºC)	P (atm)	T (ºC)	P (atm)	T (ºC)	P (atm)	T (ºC)
23.8	37.8	22.46	26.7	26.12	26.7	30.66	26.7
39.89	71.1	28.68	37.8	33.04	37.8	39.88	37.8
58.79	104.4	50.01	71.1	53.63	71.1	66.65	71.1



Question.3 The experimental adsorption isotherms of ethylene on 13X zeolite at different temperature are given below [E. Costa et al., J. Chem. Eng. Data, 36(1991) 218-224]

T = 279 K		T = 293 K		T = 308 K	
P (atm)	N (mole//kg)	P (atm)	N (mole/kg)	P (atm)	N (mole/kg)
0.74	0.845	0.23	0.1583	1.48	0.4599
1.52	1.2606	1.47	0.7082	3.69	0.8261
2.62	1.591	2.24	0.9576	6.56	1.1739
5.37	1.9757	3.33	1.1866	10.88	1.505
11.71	2.2975	6.85	1.6298	18.26	1.8655
20.21	2.4761	9.56	1.8345	31.96	2.2194
32.88	2.6245	13.32	2.0186	50.99	2.3022
53.04	2.6973	20.57	2.2204	71.67	2.4527
		38.26	2.4964		
		62.56	2.6031		
		86.38	2.6415		

where P is in kPa and N in mol of C_2H_4/kg of zeolite.

Construct the following plots:

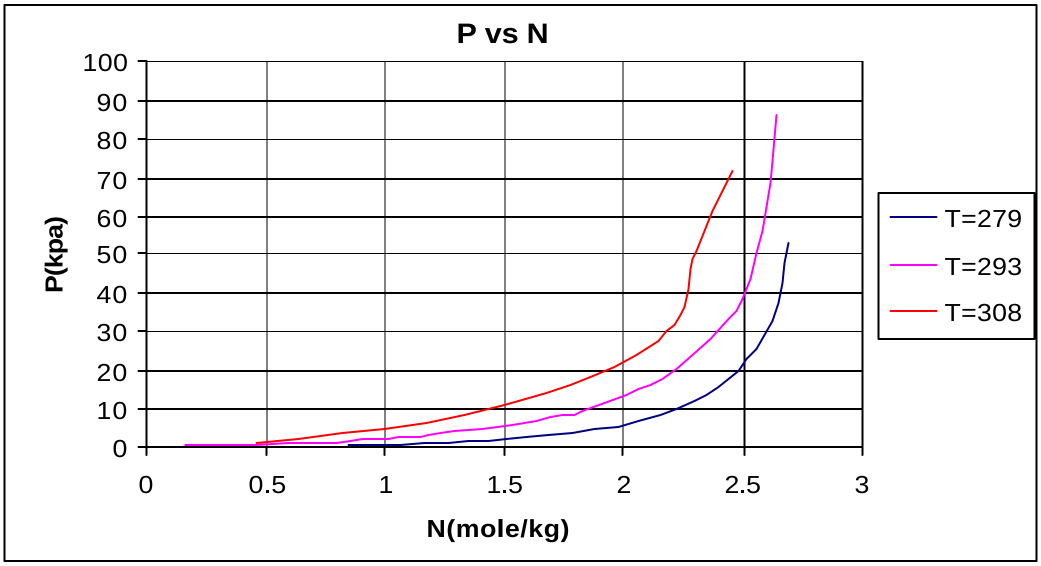
(d) *P vs. x with T as parameter*
(e) *T vs. x* with P as parameter
(f) *P vs. T* with x as parameter

Solution:

The given data is :

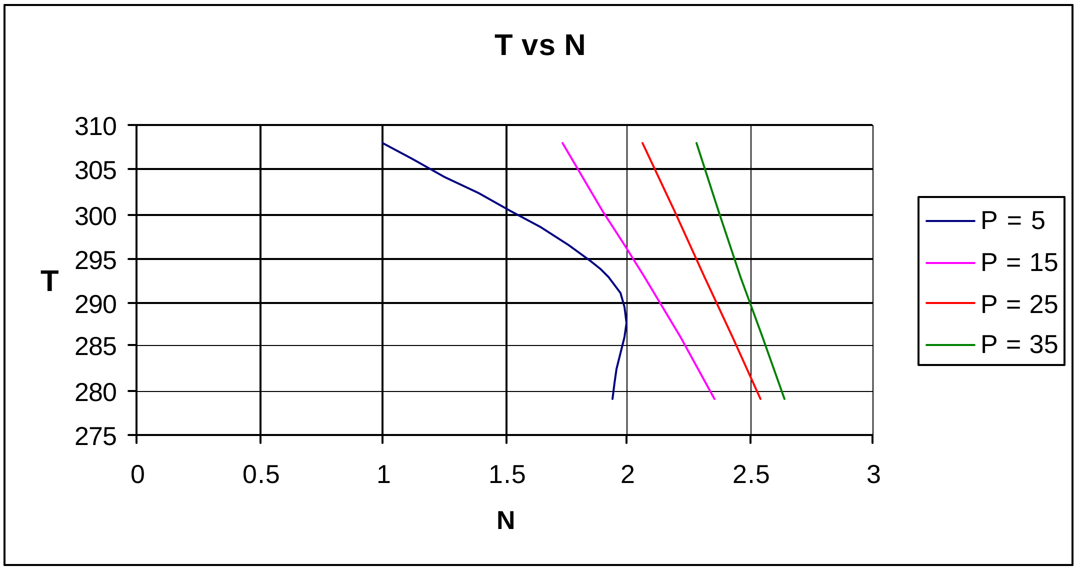
T = 279 K		T = 293 K		T = 308 K	
P (atm)	N (mole//kg)	P (atm)	N (mole/kg)	P (atm)	N (mole/kg)
0.74	0.845	0.23	0.1583	1.48	0.4599
1.52	1.2606	1.47	0.7082	3.69	0.8261
2.62	1.591	2.24	0.9576	6.56	1.1739
5.37	1.9757	3.33	1.1866	10.88	1.505
11.71	2.2975	6.85	1.6298	18.26	1.8655
20.21	2.4761	9.56	1.8345	31.96	2.2194
32.88	2.6245	13.32	2.0186	50.99	2.3022
53.04	2.6973	20.57	2.2204	71.67	2.4527
		38.26	2.4964		
		62.56	2.6031		
		86.38	2.6415		

Plot of Pressure vs Solubilty at different temperatures is shown below :



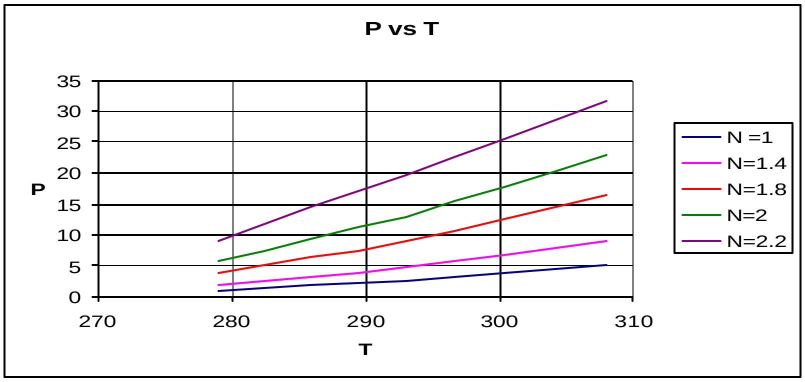
Interpolating the given data for different pressures, we get the following Temperature vs Solubility curves :

P = 5 atm		P = 15 atm		P = 25 atm		P = 35 atm	
T (K)	N	T (K)	N	T (K)	N	T (K)	N
279	1.9413	279	2.3554	279	2.5435	279	2.6411
293	1.9230	293	2.0695	293	2.3154	293	2.4655
308	0.9976	308	1.7316	308	2.0674	308	2.2819



Similarly, interpolating the given data for different solubilities, we get the following Pressure vs Temperature curves :

N =1		N =1.4		N = 1.8		N = 2		N = 2.2	
T (K)	P(atm)	T (K)	P(atm)	T (K)	P(atm)	T (K)	P(atm)	T (K)	P(atm)
279	0.9824	279	1.9076	279	3.7966	279	5.6535	279	9.0145
293	2.4606	293	4.6676	293	8.9963	293	13.0318	293	19.694
308	5.0031	308	8.9828	308	16.4950	308	22.7530	308	31.676



Question.4 A gas stream from a steam reformer is to be scrubbed with propylene carbonate to get synthesis gas to produce ammonia. The scrubbing would be carried out at 30 $^{?}$C and 20 atm. The gas has to be freed most of CO2. The composition of the mixture is: H2 = 60 mol % N2 =20 and CO2 = 20 mol %. Plot the x-y diagram for the system. Density of propylene carbonate is 1.190 g/cm3 at 25 $^{?}$C and 1 atm. Make extrapolations reasonable assumptions if required. The x and y are mole fractions of CO2 in liquid and vapor phases respectively. The Data is given at the end.

T = 26.7 C

P (atm)	Solubility
54.8	405.9
54.5	387.6
53.5	376.5
43.6	268.5
31.9	159.3

T= 37.8 C

P (atm)	Solubility
59.7	278.8
53.9	235.7
43.7	171.7
33.3	121.3
22.8	76.1
19.4	85.8

T = 71.1 C

P (atm)	Solubility
68.1	153.9
60.2	133.6
48.8	98
38.8	77.9
29.6	58.4

T =104.4 C

P (atm)	Solubility
60.9	82.9
46.6	63.2
21.2	28.1

Solution:

We assume all the gases and solutions to be ideal.

The scrubbing is being carried out at T = 30 °C and P = 20 atm.
So, we need to extrapolate the solubility data for these values of T and P.
Such extrapolation leads to the following results:

Table 4.1

Solubility At T = 30°C

p (atm)	S
0	0
4	10.14
8	22.94
12	38.03
16	55.29
20	74.69

Now, $$y = \frac{p_s}{P} \qquad \text{... (1)}$$

and Solubility, S = volume of CO_2 per unit volume of propylene carbonate.

$$x' = \frac{102 \text{ x } S}{1.19 \text{x} 22400} \qquad \text{... (2)}$$

$$x = \frac{x'}{1+x'}$$

For p = 4 atm,

$$y = \frac{4}{20}$$

$$x' = \frac{102 \text{ x } 10.14}{1.19 \text{x} 22400} = 0.038$$

$$x' = \frac{0.038}{1+0.038} = 0.037$$

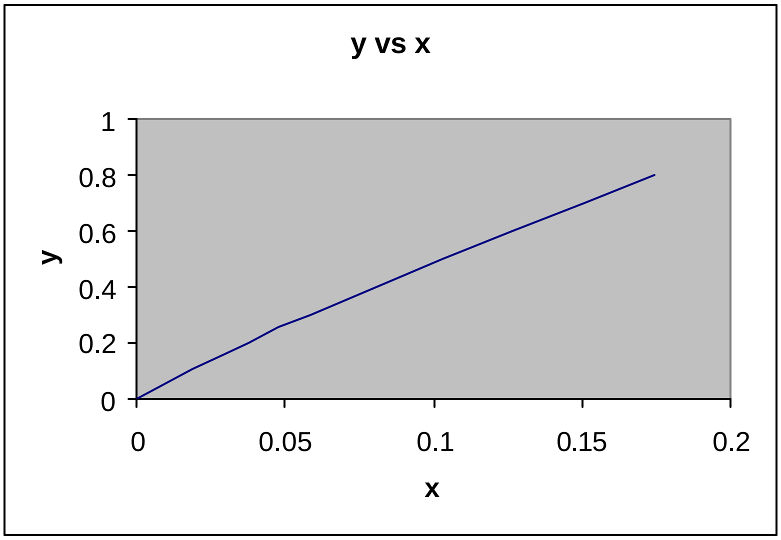
Similarly, other values of y and x can be generated. They are shown in Table 4.2.

Table 4.2

Equilibrium data at T = 30°C

y	x
0	0
0.2	0.037
0.4	0.081
0.6	0.127
0.8	0.175

Using these values, we get the following plot :



Question.5 An air-ethylene mixture containing 50mol % is passed through an adsorber, packed with 13X zeolite, to recover ethylene. The adsorber operates at 293 K. To assess performance of the adsorber we need the x-y data. Construct the x-y plot at P =1 atm and T=293 K. The data is given at the end .

Solution:

We assume all the gases and solutions to be ideal.

The adsorption is being carried out at T = 293 K and P = 100 kPa

Table 5.1
Adsorption data at T = 293 K and P = 100kPa

p (kPa)	N
0.23	0.1582
1.47	0.7082
2.24	0.9576
3.33	1.1866
6.85	1.6298
9.56	1.8345
13.52	2.0186
20.57	2.2204
38.26	2.4964
62.56	2.6031
86.38	2.6415

Now,

$$y = \frac{p_s}{P} \qquad \ldots (1)$$

$$y' = \frac{28\,y}{28\,y + 28.84(1-y)} \qquad \ldots (2)$$

Also, N = moles adsorbed per kg adsorbent.

$$x' = \frac{28N}{28N + 1000} \qquad \ldots (3)$$

At p = 0.23 kPa,

$$y = \frac{0.23}{100} = 0.0023$$

$$y' = \frac{28x0.23}{28x0.23 + 28.84x(1-0.23)} = 0.0022$$

$$x' = \frac{28x0.1582}{28x0.1582 + 1000} = 0.0044$$

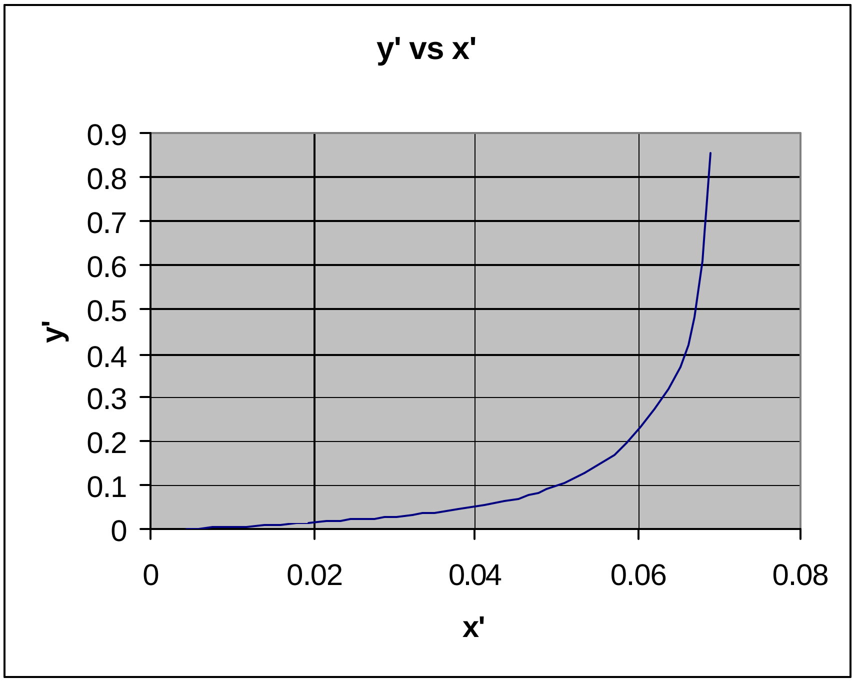
Similarly, other values of y' and x' can be calculated. They are given in Table 5.2.

Table 5.2

Equilibrium data at T = 293 K and P = 100 kPa

y'	x'
0	0
0.0044	0.0022
0.0194	0.0138
0.0261	0.0210
0.0322	0.0313
0.0436	0.0645
0.0489	0.0902
0.0535	0.1278
0.0585	0.1953
0.0653	0.3675
0.0679	0.6103
0.0689	0.8560

The following plot is generated using this data :



Question.6 Design a distillation column requires the vapor-liquid equilibrium of the acetone and water system. The Wilson and Antoine constants for acetone(1) and water(2) are given below.

$\Delta l_{12} = 292.66 \qquad \Delta l_{21} = 1445.26 \text{ cal mol}^{-1}$

$V_1 = 74.05 \qquad V_2 = 18.07 \text{ cm}^3\text{mol}^{-1}$

$$\Lambda ij = \frac{V_j}{V_i}\exp\left(\frac{\Delta l_{ij}}{RT}\right)$$

$$\ln P_1^s = 14.39155 - \frac{2795.817}{t + 230.002}$$

$$\ln P_2^s = 16.26205 - \frac{3799.887}{t + 226.346}$$

where P is in kPa and t in ^{o}C.

(a) Construct T-x-y and x-y diagram at 6 bar assuming the vapor phase obeys ideal gas law and the liquid phase forms ideal solution.

(b) Redo the above but assuming liquid phase to be nonideal solution.

Solution:

P = 6 bar

(a) T-x-y diagram using Wilson's equation.

The Wilson's equation is:

$$?_{12} = (v_2/v_1)\exp(-??_{12}/RT)$$
$$?_{21} = (v_1/v_2)\exp(-??_{21}/RT)$$

$$\ln ?_1 = -\ln(x_1 + ?_{12}x_2) + x_2[?_{12}/(x_1 + ?_{12}x_2) - ?_{21}/(x_2 + ?_{21}x_1)]$$
$$\ln ?_2 = -\ln(x_2 + ?_{21}x_1) + x_1[?_{21}/(x_2 + ?_{21}x_1) – ?_{12}/(x_1 + ?_{12}x_2)]$$

Table 6.1

Antoine's Constants

Constants	Acetone (1)	Water (2)
A	16.6513	18.3036
B	2940.46	3816.44
C	-35.93	-46.13

So, $P^s = \exp(A – B/(T+C)/760$ atm

The equilibrium relation is:

$$y_i = \frac{\gamma_i x_i P_i^s}{P} \qquad \ldots (1)$$

for ideal liquid solution and ideal vapor

$$y_i = \frac{x_i P_i^s}{P}$$

$? y_i = 1$ … (2)

$? x_i = 1$ … (3)

Solving equations (1), (2) and (3) iteratively, we can generate the following table:

Table 6.1

Equilibrium T-x-y data for ideal acetone-water system

T (K)	x	Y
432.47	0.00	0.00
407.82	0.10	0.52
402.34	0.20	0.61
399.76	0.30	0.66
398.05	0.40	0.69
396.62	0.50	0.72
395.45	0.60	0.75
394.40	0.70	0.79
393.59	0.80	0.84
393.15	0.90	0.90
393.38	1.00	1.00

(b) T-x-y diagram for ideal solution.

The equilibrium relation is:

for i = 1 and 2

$$y_i = \frac{\gamma_i x_i P_i^s}{P} \qquad \ldots(4)$$

Clearly, ? $y_i = 1$ … (5)

Also, ? $x_i = 1$ … (6)

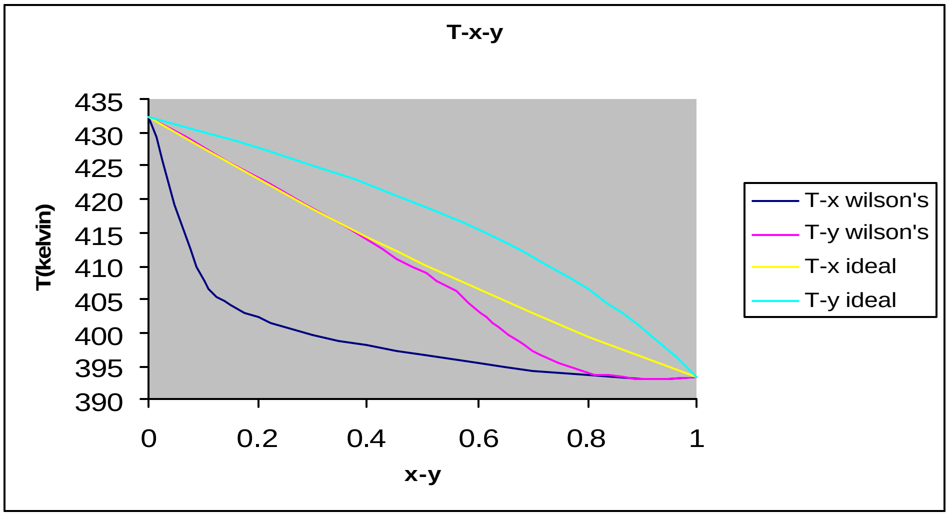
Solving equations (4),(5)and(6) simultaneously, we can generate the following table:

Table 6.2

Equilibrium T-x-y data for non-ideal acetone-water system

T (K)	x	y
432.47	0.00	0.00
427.66	0.10	0.21
423.02	0.20	0.38
418.58	0.30	0.52
414.35	0.40	0.63
410.33	0.50	0.73
406.54	0.60	0.80
402.95	0.70	0.87
399.57	0.80	0.92
396.38	0.90	0.96
393.38	1.00	1.00

The plots corresponding to Tables 6.2 and 6.3 are presented below



Question.7 Sang H. Hua and Ronald P. Danner[J. Chem. Eng. Data, 27(1982) 196-200] has listed the experimental data the adsorption isotherms of iso-butane(1)-ethylene(2) over 13X molecular sieve at 137.8 kPa. The adsorption data

T = 298.15

y_1	.045	.1168	.1515	.2163	.3249	.3485	.531	.7302	.8047	.8745
x_1	.1223	.2085	.3086	.4237	.5161	.5378	.6897	.7274	.766	.8218
Q	2.68	2.63	2.46	2.39	2.30	2.27	2.19	2.14	2.07	2.05

where x and y are the mole fractions of iso-butane in the vapor and solid phase respectively and q is the total mol adsorbed per kg. of adsorbent.

(a) Plot the data on a triangular diagram and show the tie lines

(b) Construct N-n-X-Y and X-Y diagrams

Solution:

This is a Type II process with the following components:

Inert: Isobutane **Agent**: 13-X molecular sieve **Solute**: Ethylene.

Molecular mass of isobutane and ethylene are 58 g/mol & 28 g/mol, respectively.

So,

$$Y = \frac{58y_1}{58y_1 + 28(1 - y_1)} \quad \text{... (1)}$$

$$X = \frac{58y_1}{58x_1 + 28(1 - x_1)} \quad \text{... (2)}$$

Since there is no zeolite in vapor phase, n = 0 ... (3)

$$N = \frac{1000}{58qy_1 + 28q(1 - y_1)} \quad \text{... (4)}$$

At $y_1 = 0.045$, $x_1 = 0.1223$ & $q = 2.68$,

$$Y = \frac{58x0.045}{58x0.045 + 28(1\text{-}0.045)} = 0.0889$$

$$X = \frac{58x0.1223}{58x0.1223 + 28(1\text{-}0.1223)} = 0.2240$$

n = 0

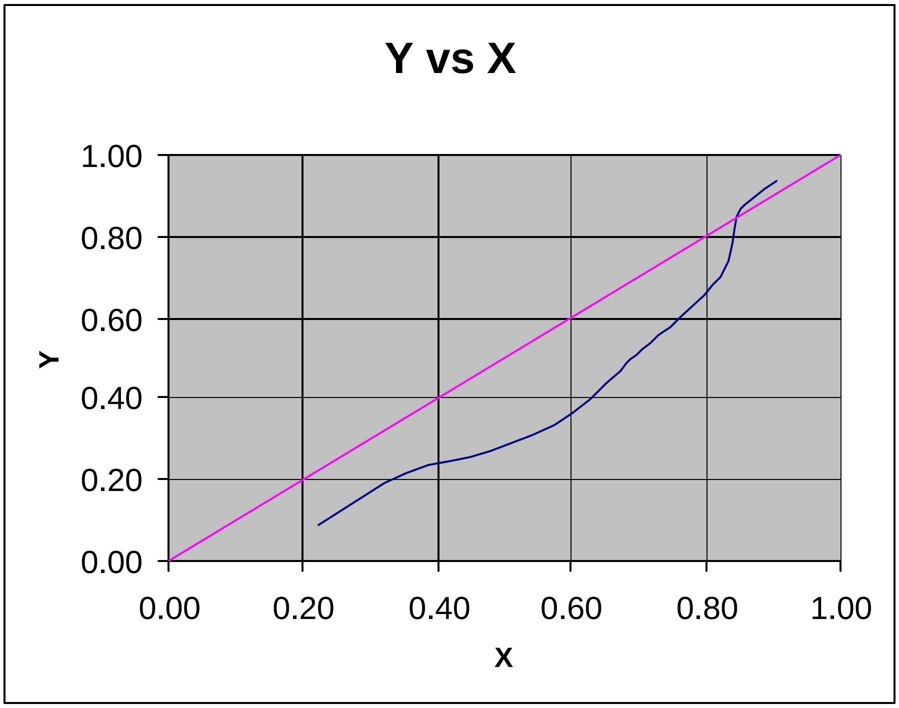
$$N = \frac{1000}{58x2.68x0.045 + 28x2.68x(1\text{-}0.045)} = 12.713$$

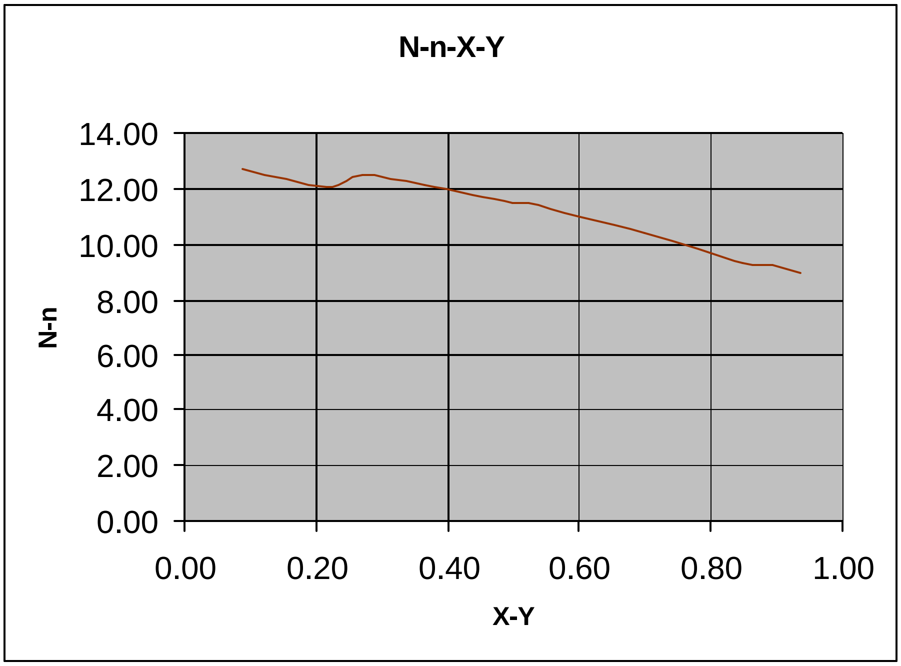
Similarly, other values of Y , X , n & N can be calculated. They are presented in Table 7.1

Table 7.1
N-n-X-Y Data for isobutane-ethylene-zeolite system.

Y	X	n	N
0.0889	0.2240	0	12.7133
0.2150	0.3530	0	12.0692
0.2700	0.4804	0	12.4905
0.3638	0.6036	0	12.1317
0.4992	0.6884	0	11.5183
0.5256	0.7068	0	11.4557
0.7011	0.8216	0	10.3943
0.8486	0.8468	0	9.3634
0.8951	0.8715	0	9.2651
0.9352	0.9052	0	8.9943

This data is plotted to obtain the Y vs X and N-n vs Y-X diagrams:





Question.8 The adsorption isotherm for N2 –O2 mixture on 5A zeolite Molecular Seive can be described by the extended Langmuir .

(a) Construct x-y and n-N-x-y diagrams.
(b) Draw tie lines for x equals to 0.25, 0.5 and 0.75.

$$\frac{N_i}{N_{is}} = \frac{b_i c_i}{1+\sum_i b_i c_i} \qquad b_1 = 4.7, b_2 = 19.7$$

$$N_{1s}(\text{mol/cm}^3) = 5.26x10^{-3}, N_{2s}(\text{mol/cm}^3) = 5.26x10^{-3}$$

Question.8 The adsorption isotherm for N2 –O2 mixture on 5A zeolite Molecular Seive can be described by the extended Langmuir .

(c) Construct x-y and n-N-x-y diagrams.
(d) Draw tie lines for x equals to 0.25, 0.5 and 0.75.

Solution:

The extended Langmuir isotherm equation used is :

$$N_i / N_{is} = b_i c_i / (1 + ? b_i c_i) \qquad \text{... (1)}$$

where N_i is the moles/cm^3 of the adsorbate adsorbed on the surface.

Also,

$$ci = \frac{p_i}{RT} = \frac{x_i P}{RT} \qquad \text{... (2)}$$

Putting equation (2) in (1), we get,

$$N_i = \frac{b_i x_i \frac{PN_{is}}{RT}}{1 + \frac{P}{RT}\sum b_i x_i} \qquad \text{... (3)}$$

We can calculate different values of N_i by setting different values of x(= X).
Using these values of N_i, we can compute Y as follows:

$$Y = \frac{N_1}{N_1 + N_2} \qquad \text{... (4)}$$

As there is no zeolite in vapor phase, n = 0 ... (5)

N can be calculated in mixed units (cm^3/moles) as:

$$N = \frac{1}{N_1 + N_2} \qquad \text{... (6)}$$

At X = 0,

$$c1 = \frac{0x1}{0.0821x298} = 0 \text{ mol/lit.}$$

$$c2 = \frac{1x1}{0.0821x298} = 0.17132 \text{ mol/lit.}$$

$$N_1 = \frac{4.7{*}0{*}0.00526}{1 + 4.7{*}0 + 19.7{*}0.17132)} = 0 \text{ mol/cm}^3$$

$$N_2 = \frac{19.7{*}0.17132{*}0.00526}{1 + 4.7{*}0 + 19.7{*}0.17132} = 0.00235 \text{ mol/cm}^3$$

$$Y = \frac{0}{(0 + 0.00235)} = 0$$

$$n = 0$$

$$N = \frac{1}{0 + 0.00235} = 426.223 \text{ cm}^3\text{/mol}$$

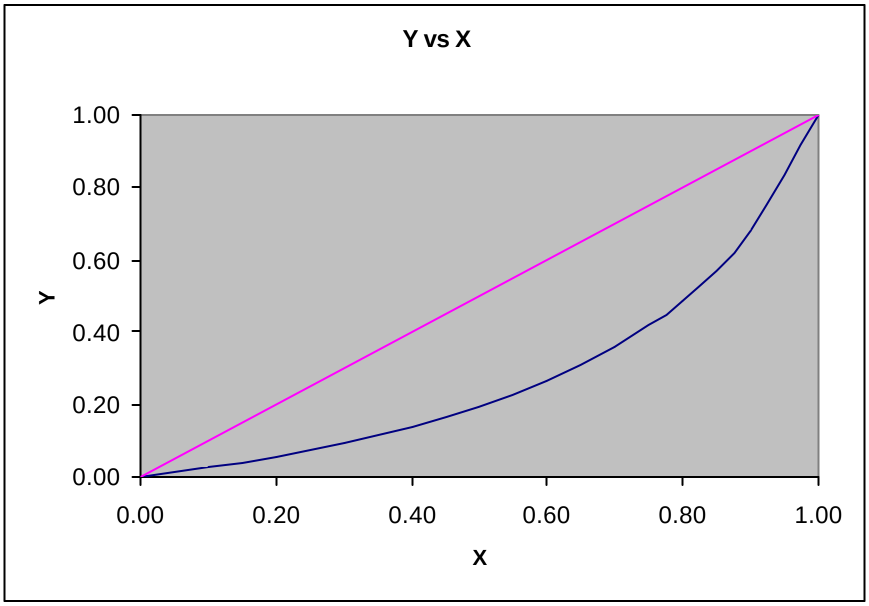
Similarly other values of Y, n & N can be calculated. They are shown in Table 8.1.

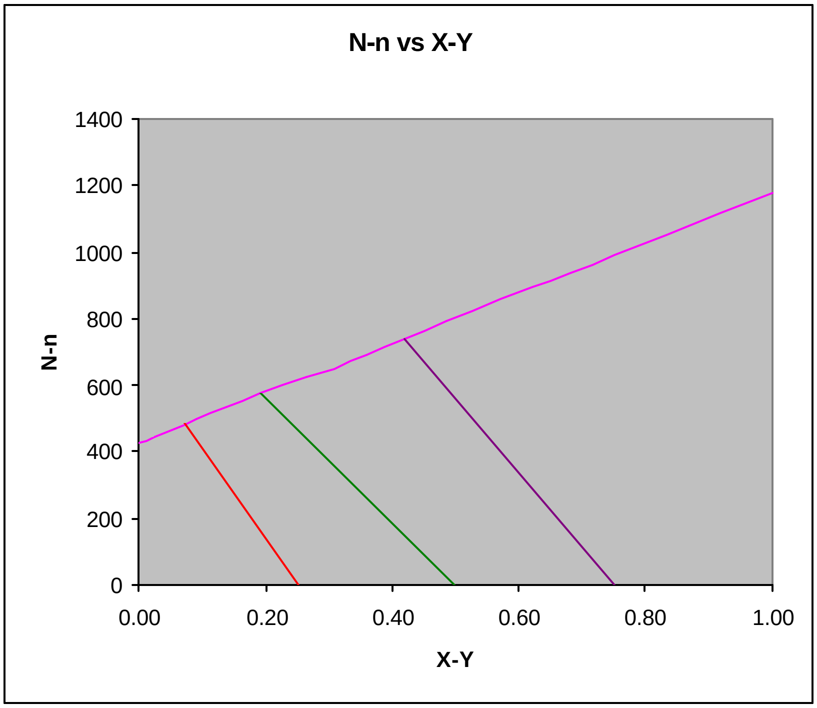
Table 8.1

N-n-X-Y Data for N_2-O_2 adsorption on 5A Zeolite

X	Y	n	N
0	0	0	426.220
0.1	0.026	0	445.680
0.2	0.056	0	468.635
0.3	0.093	0	496.120
0.4	0.137	0	529.624
0.5	0.193	0	571.368
0.6	0.264	0	624.814
0.7	0.358	0	695.689
0.8	0.488	0	794.178
0.9	0.682	0	940.323
1	1	0	1179.751

Using this data, we can generate the following plots:





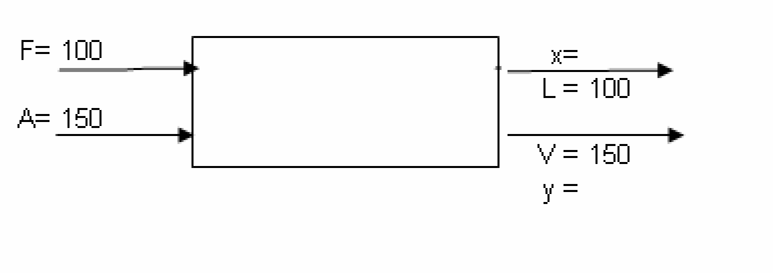
Question.9 Component B of a binary mixture of A and B is extracted using solvent C in a single mixer-setter unit. The feed rate to the unit is 100 kg/h and its mass fraction of B is 0.2. Pure Solvent is fed to the unit at a rate of 150 kg/h. Assuming the solutions are dilute:

(a) Find the exit stream compositions.
(b) Find the maximum possible mass fraction of B in the solvent stream.

(c) Find the solvent rate if the desired G is fractional recovery in the extract phase is 0.5.

The equilibrium relation is $y = 2x$.

Solution:



(i) This is a Type II problem with the following components:

Inert (I): A Solute (S): B Agent (A): C

(I + S) flow rate, F = 100 kg/h ...(1)

A flow rate, A = 150 kg/h ...(2)

Solute Balance: $x_F F = xL + yV$ ...(3)

Equilibrium Relation: $y = 2x$ ...(4)

Consider solution to be dilute, so L = F and V = A.

Solving above equations simultaneously, we get:

$x = 0.05$ and $y = 0.1$

(ii) Maximum B is recovered when V = 0.

Setting V = 0 in equation (3), we get $x = x_F = 0.2$.

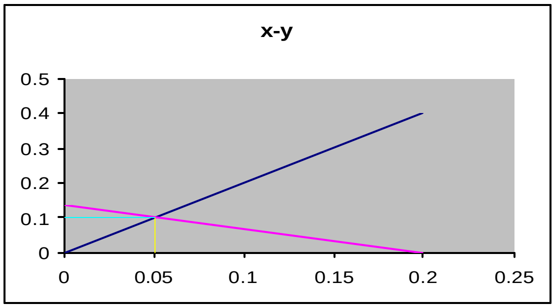
So, $y_{max} = 0.4$.

(iii) $f_R = 0.5$ $\Rightarrow 1- (xL/x_F F) = 0.5$ $\Rightarrow x = 0.5*0.2 = 0.1$

So, $y = 2*0.1 = 0.2$

Putting these values of x and y in equation (3), we get:

A = 100 kg/h

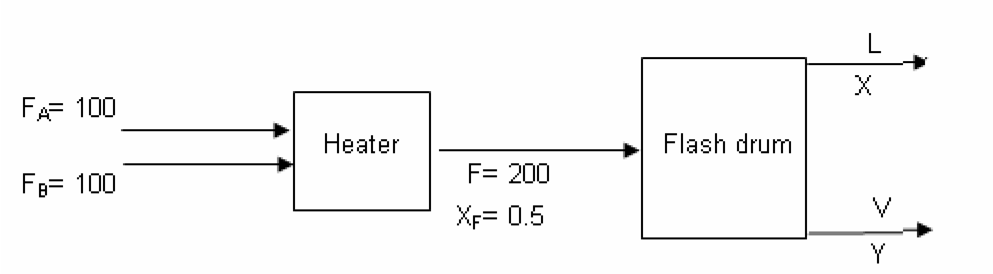


Question.10 An equimolar binary mixture of A and B is passed through a heater and the resulting vapor-liquid mixture is separated in a flash drum. The vapor and liquid flow rates from the flash drum are equal. The relative volitality is2.25.
Determine the mole fraction of A in the vapor and liquid phases:

(a) using graphical method.
(b) Analytical method.

Redo this problem using enthalpy concentration diagram.

Solution:.



(i) Graphical Solution:

$$a_{AB} = 2.25$$

$$\alpha = \frac{y(1-x)}{x(1-y)} = 2.25$$

$$y = 2.25x/(1+1.25x) \qquad \text{... (1)}$$

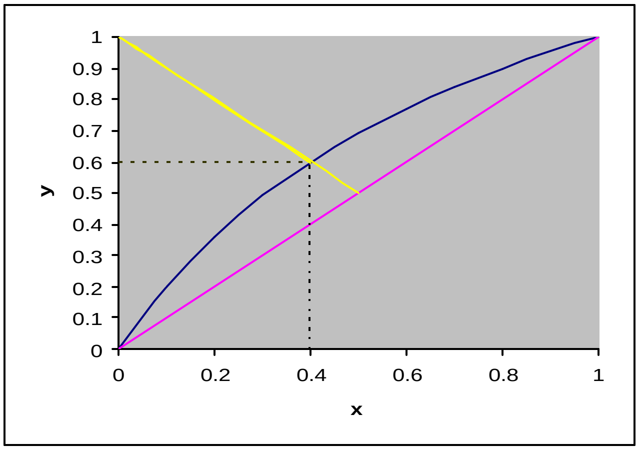
Also, x_F = 0.5 and (L/V) = 1.

Equation (1) gives the equilibrium curve.
The operating line is:

$$y = -\frac{L}{V}(x - x_F) + x_F \qquad \text{... (2)}$$

It is a straight line passing through x_F = 0.5 and slope –L/V = -1.
Equations (1) and (2) are plotted in the figure below, the intersection point is:

$$x = 0.4 \text{ and } y = 0.6$$



b) Analytical Solution

Equilibrium Relation: $$y = \frac{2.25x}{1+\_1.25x} \qquad \text{... (3)}$$

Operating Line: $y = -(x-0.5) + 0.5$ ... (4)

Solving equations (3) & (4) simultaneously, we get:

$x = 0.4$ and $y = 0.6$

Using enthalpy concentration diagram:

We have,

Enthalpy of liquid A at boiling point, $h_A = 100$ J/mol
Enthalpy of liquid B at boiling point, $h_B = 150$ J/mol

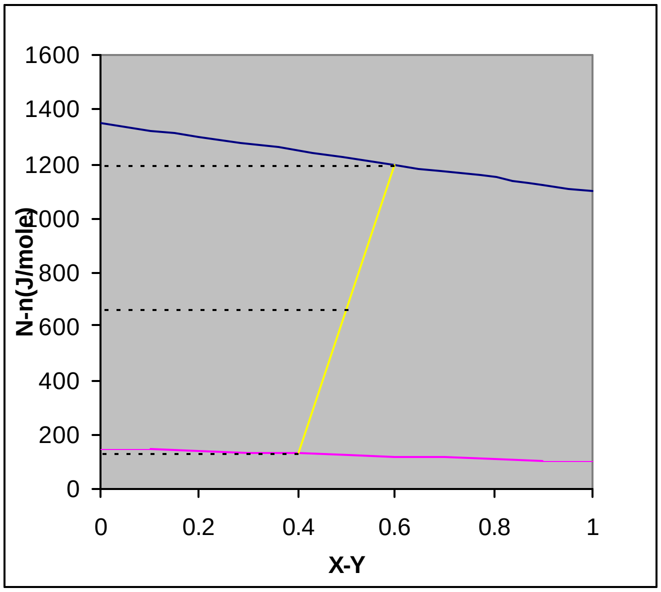
Enthalpy of vaporization of A, $?H_{vA} = 1000$ J/mol
Enthalpy of vaporization of B, $?H_{vB} = 1200$ J/mol

So,

$n = xh_A + (1-x)h_B$ ... (5)
$N = y(h_A + ?H_{vA}) + (1-y)(h_B + ?H_{vB})$ ... (6)

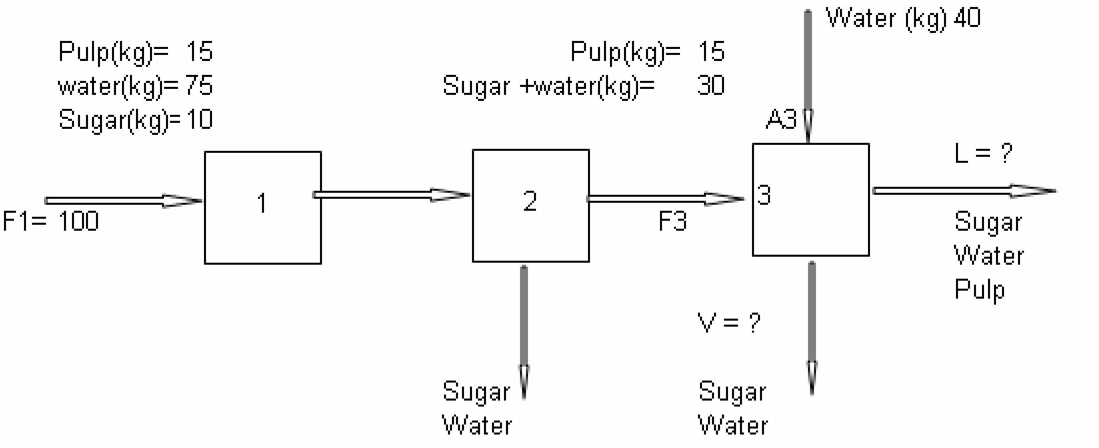
Using equations (5) & (6), we plot the Enthalpy-Concentration diagram. Next, the tie line passing through $x_F = 0.5$ is plotted by trial and error. The plot yields $x = 0.4$ and $y = 0.6$.

Also, heat duty of the heater = 535 J/mol



Question.11 The sugarcane used for producing sugar contains 75 mass% water, 10 mass% sugar and 15 mass% fiber. To extract juice from cane, it is crushed in crushers consisting of three sets of rollers. Even after passing through the first two rollers, the pulp retained 0.3 kg/kg of cane fed to the crushers. To extract sugar further, water is sprinkled uniformly over the pulp at a rate of 0.4 kg water/kg cane and sent to third set of rollers. The pulp retains 0.3 kg of dilute juice/kg of cane after passing through the third set of roller.
How much sugar is extracted in the third stage.

Solution:

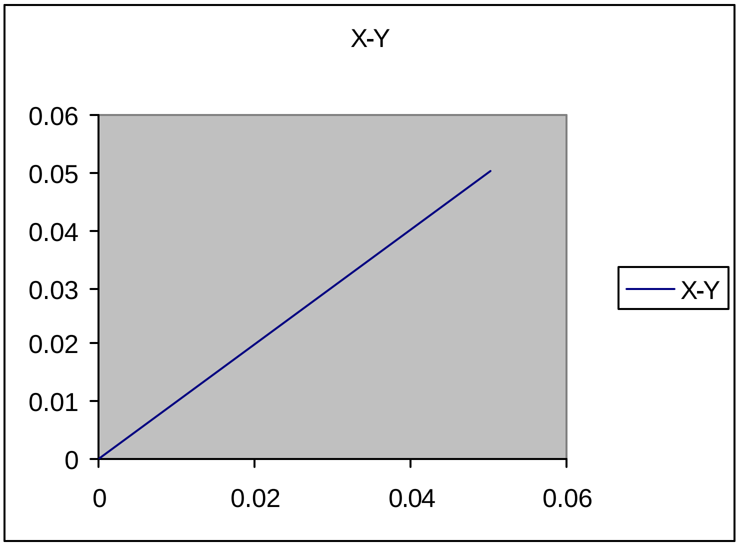


Feed to the1st crusher, $F_1 = 100$ kg/h

Mass fraction of pulp in the feed = 0.15
Mass fraction of water in the feed = 0.75
Pulp retained after passing through two rollers = 0.3 (kg per kg F_1)
Water sprinkled in the 3rd crusher = 0.4 (kg per kg F_1)
Fraction of juice retained after passing through 3rd crusher = 0.3 (kg per kg F_1)
Mass fraction of sugar on pulp free basis = 0.117647059
(This will remain same in feed for third crusher)

Applying mass balance on third crusher

$F_3 + A_3 = L + V$ …(1)
L and V are on pulp free basis
Since we are treating it as a type I process
V = 40 kg/h
L = 30 kg/h
Now applying mass balance on solute
$X_{F3}*F_3 = L*X + V*Y$ …(2)
Equilibrium relation is $Y = X$ …(3)
Solving equation …(1) and …(2) either graphically or Analytically We get
X = 0.0504 and Y = 0.0504



Question.12 Like CNG and other gases viz. hydrogen and nitrogen, acetylene cannot be compressed, charged and distributed at high pressure gas cylinders since it has a tendency to detonate. Therefore it is distributed, for metal processing in cylinders as dissolved gas in acetone. The acetone is held in highly porous matrix of asbestos placed in the cylinder.

The cylinder has a volume of 40l. The matrix holds 11.5 kg acetone. The cylinder is charged at 20 bar. It is returned for refilling when pressure drops to 2 bar, Assume the cylinder is filled and used at 25’ C.
The solubility data are given below:

Pressure (bar):	0.0	10	15	20
Solubility (mol of acetylene/kg acetone):	0.0	10	16.5	23

(a) Determine the amount of gas available for use in one refilling.
(b) Determine the loss of acetone on use for one refilling.
(c) The amount of gas filled in the cylinder.

Solution:

We assume all the gases and solutions to be ideal.

Therefore the equilibrium relation is :

$$y*P = x*Ps \qquad \ldots(1)$$

The saturation pressure at T = 25 C

$$Ps = 0.1651 \text{ bar}$$

Firstly, consider the situation at P_1 = 20 bar.

Solubility at this Pressure = 22.4 mol of acetylene/kg acetone.

Therefore, $x_1 = 0.5650$

Using (1), we get $y_1 = 0.00466$

Also, total number of moles in vapour phase = $\frac{P_1 V}{RT} = 32.6987$
Number of moles of ethylene = $y_1*P_1 = 0.09331$
Number of moles of acetone = $(1-y_1)*P_1 = 19.9066$

Moles of acetone in liquid phase = 178.3691
Therefore, number of moles of acetylene in liquid phase = 231.737

So, total moles of ethylene = 231.8305

Now, consider the situation at P_2 = 2 bar

Solubility at this pressure = 1.7771

Therefore, $x_2 = 0.0934$

Again, using (1) we get $y_2 =$ 0.0077

Total number of moles in vapour phase = $\frac{P_2 V}{RT}$ = 3.26987

Number of moles of ethylene = $y_2 * P_2$ = 0.0154
Number of moles of acetone = $(1-y_2)*P_2$ = 1.9845

Moles of acetone escaped = $V\frac{P_1 y_1 - P_2 y_2}{RT}$ = 1.5179

Therefore, moles of acetone in liquid phase = 13.7388
Therefore , number of moles of acetylene in liquid phase =1.4161

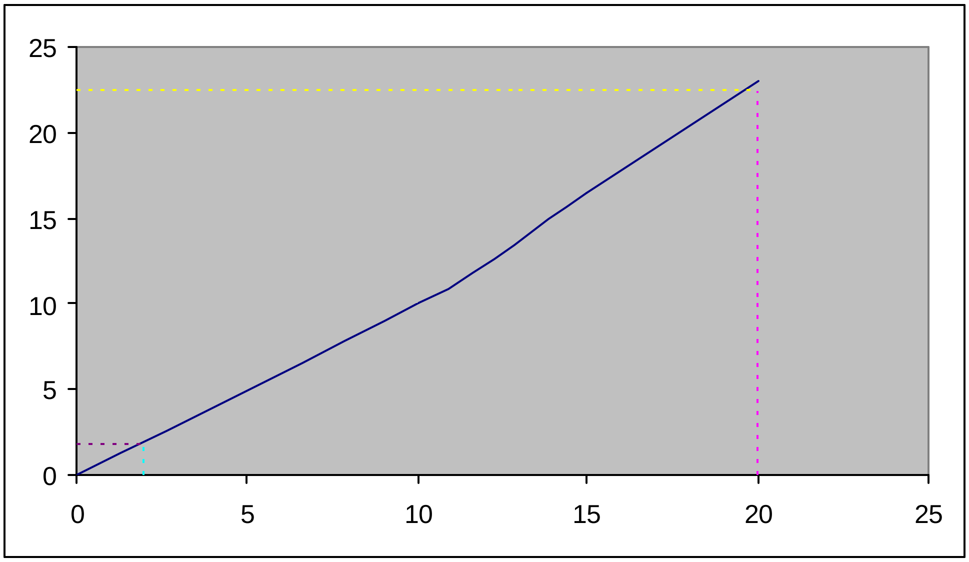
So, total moles of ethylene = 1.4315

Hence,

(a) Amount of gas available for use in one filling = 230.399 moles

(b) Acetone lost in every filling = 1.5179 moles

(C) Amount of gas initially filled = 231.830 moles



Question.13 A gas mixture 20 mol % CO2, 60 mol% hydrogen and 20 mol% nitrogen is to be scrubbed with 30% MEA aqueous solution in a single absorber operating at 1 atm. and 250 C. The gas leaving the absorber is to contain 10% CO2. The entering solution is free from CO2. Nitrogen and hydrogen are not soluble in the solution. Assume the water vapor be neglected.
The equilibrium partial pressure of CO2 over aqueous solutions of mono-ethanolamine (30%) at 25oC are:

Partial pressure 0f CO2, mm Hg.	5.6	12.8	29.0	56.0	98.7	155	232
Mol CO2/ mol solution	0.058	0.060	0.062	0.064	0.066	0.068	0.070

Determine the amount of amount solution required.

Solution:

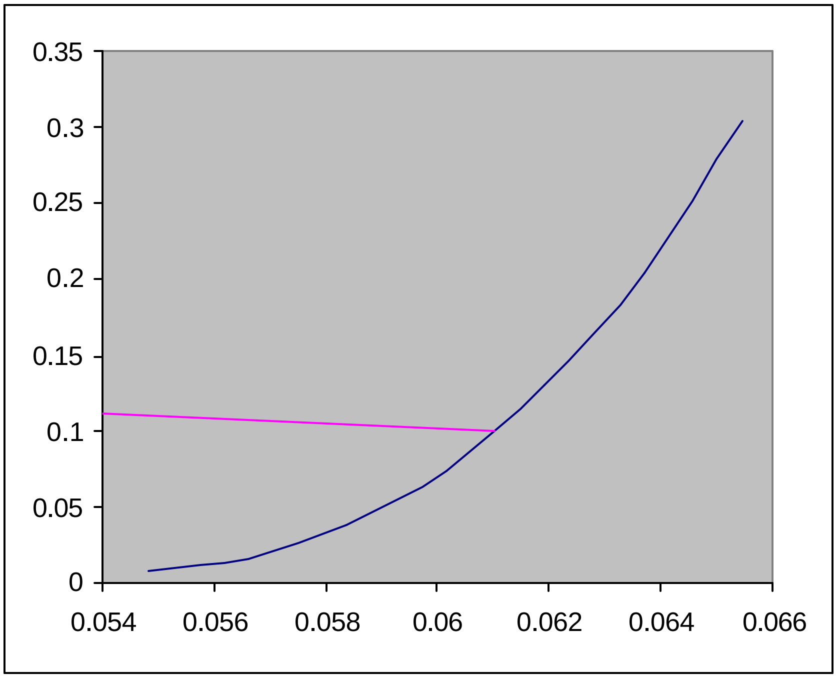
Basis : 100 mol/hr of feed.

Firstly, we need to calculate the y and x values corresponding to the given data.

y	x
0.0073	0.0548
0.0168	0.0566
0.0381	0.0583
0.0736	0.0601
0.1298	0.0619
0.2039	0.0636
0.3051	0.0654

The operating line must pass through (0,xi) and (x_F,y_F).
Here, xi = 0.2, x_F = 0.1 and y_F = 0.061.

The y vs x curve along with the operating line is shown below :



Slope of the operating line = $\frac{0.2-0.1}{.061} = 1.639$

Therefore, $-\frac{L}{V}$ = -1.639

Here L = 100 mol/hr
So, V = 61 mol/hr
So, required agent flow rate = 61 mol/hr.

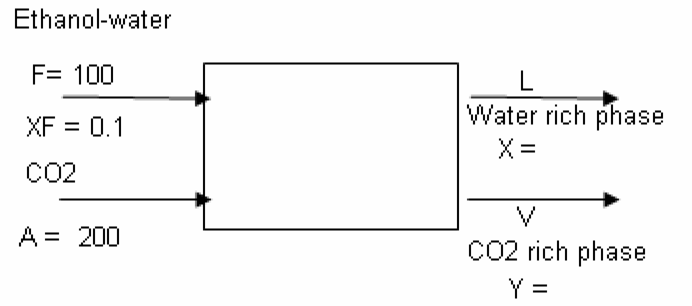
Question.14 One of the ways of fractionating the ethanol-water mixture to get nearly pure ethanol(to overcome the obstacle of azeotrope formation) is by super-critical extraction with CO2. A 100 kg of the ethanol - water mixture of 0.1 mass fraction is bought in contact with 200 kg of CO2 at 298 kelvin and 100 atm .The mass fraction of ethanol in the CO2 -rich phase(y) and water - rich phase (x) at equilibrium is given by the relation y= kx , k = 0.09.

a) find the amount of ethanol that can be extracted .

b)Consider the complete recovery of both ethanol and water by reducing the pressure of CO2 rich phase ,
determine the mass fraction of ethanol -water mixture.

The experimental measurement indicate the water content in the CO2 rich phase is 0.1 mass %.

Solution:



In this system,
Ethanol is solute , Water is Inert , CO2 is agent.

$V.Y + L.X = F.X_F$ (solute balance) ...(1)
$L + V = F + A$ (Overall balance) ...(2)
$Y = K.X$ (Equilibrium relation) …(3)
$F.(1-X_F) = L.(1-X)$ (inert balance) ...(4)
$K = 0.09$
$F = 100$
$A = 200$
$X_F = 0.1$
Solving the above set of equation we get
$X = 0.085$
$Y = 7.72E-03$
$L = 98.44$ Kg
$V = 201.55$ Kg

$$\text{Percentage of Ethanol Extracted} = \frac{V.Y}{F.X_F} * 100 = 15.55\%$$

b)
When % of water in the CO2 rich phase is 0.1 (mass %) then,

$V.Y + L.X = F.X_F$ (solute balance) ...(5)
$L + V = F + A$ (Overall balance) ...(6)
$Y = K.X$ (Equilibrium relation) ...(7)
$F.(1-X_F) = L.(1-X) + V.(w_p/100)$ (inert balance) ...(8)
$K = 0.09$
$F = 100$
$A = 200$
$w_p = 0.1$ (wp is percentage of water)
Solving the above set of equation we get
$X = 0.0916$
$Y = 8.24E-03$

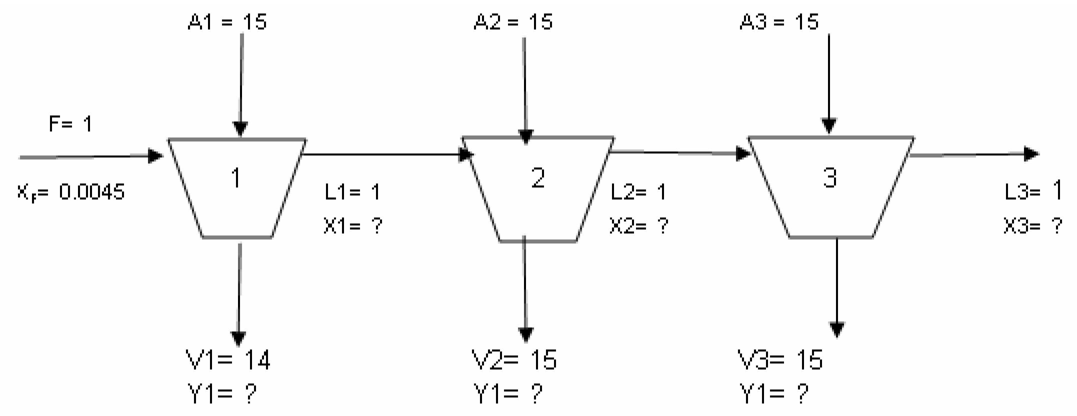
L= 98.85 Kg
V= 201.15 Kg
Mass -fraction of Ethanol -Water mixture is 0.0916.

Question.15 A house-wife found that the clothes she washed are giving off detergent smell on drying (bone-dry). Her Chemical-Engineer-son/daughter was curious to find out how much of detergent is with the clothes. On weighing, the clothes were found to be 5 kg (bone-dry). He/she rinsed them in 45 l of fresh water. On chemical analysis, it was found that the detergent fraction in the water, after the rinse, was 0.0001.

(a) Find out the amount of detergent that was there with the cloths initially.

(b) The clothes were rinsed thrice, each time with 15 l of fresh water and squeezed, after each rinse. The clothes retained 1 kg of 'water' after squeezing. Find the amount of detergent left with the clothes at the end.

Solution:



Weight of cloth(bone dry) = 5 kg
Water used for rinsing= 45 litre
Detergent fraction in the water after the rinse = 0.0001
b)
amount of water used in each wash = 15 litre
amount of water retained by clothes after squeezing = 1 kg

Solution
a)
Amount of detergent that was there in the cloth initially = 0.0045 kg

b)

As this is a type 1 process equilibrium relation is y = x

applying solute balance at each stage

Stage-1
$F=1$
$L_1=F$
$V_1=A_1 - F = 14$
$X_F=0.0045$

$FX_F = L_1.X_1 + V_1.Y_1$ (solute balance) ...(1)
$X_1= \quad Y_1$ (Equilibrium Relation) ...(2)

Solving the above two equation we get
$X_1= 0.0003$
$Y_1= 0.0003$

Stage-2
$L_1=1$
$L_2=L_1$
$V_2=15$
$L_1X_1 = L_2.X_2 + V_2.Y_2$ (solute balance) ...(3)
$X_2=Y_2$ (Equilibrium Relation) ...(4)

Solving the above two equation we get
$X_2=1.875 \text{ x } 10^{-5}$
$Y_2=1.875 \text{ x } 10^{-5}$

Stage-3
$L_2= 1$
$L_3= L2$
$V_3= 15$
$L_2.X_2 = L_3.X_3 + V_3.Y_3$ (solute balance) …(5)
$X_3 = Y_3$ (Equilibrium Relation) …(6)

Solving the above two equation we get
$X_3 = 1.17 \text{ x } 10^{-6}$
$Y_3 = 1.17 \text{ x } 10^{-6}$

Amount of detergent left in the cloth at the end $=7.19 \text{ x } 10^{-6}$ kg

Question.16 A mixture of A and B is fed to a countercurrent cascade at a rate of 100 kmol/h. The mole fraction of A in the feed is 0.01. Pure agent, C immiscible with B is used to separate A from B. The equilibrium relation is $y = 2.0\,x$.

If it is desired to recover 90% of solute determine the minimum agent rate. The agent rate of 1.2 A_{min}. Assume dilute solutions are valid. Determine the number of stages using :

i. The stage to stage calculations.
ii. The McCabe-Thiele method.
iii. By the matrix method

Solution:

Flow rate of A and B =100g
Mole fraction of A in feed =0.01
equilibrium relation (y=kx) k =2
Fractional recovery = 0.9
Flow rate of Agent C = 1.2 A_{smin}
Mole fraction of A in Agent Feed = 0

a)Stage to stage calculation

Assuming dilute solution

$F=L_1=L_2 \ldots.=L_j$ …(1)

$V_1=V_2=\ldots=Vj$ …(2)

$F=100 \quad x_F=0.01$

$$f_R = 1 - \frac{L.xN}{F.xF} = 0.9 \qquad \ldots(3)$$

$x_N = 0.001$

Minimum Agent Flow rate Required $A_{smin} = \dfrac{F.(xF - xN)}{(kxF - xN)}$ …(4)

A_{smin} =45g
Agent feed rate =1.2 times A_{smin}
A_s = 54g

Stage 1

$F.x_F = L_N.x_N + V_1.y_1$ (overall solute balance) …(5)

$y_1 = 1.67 \times 10^{-2}$

$x_1 = 8.3 \times 10^{-3}$

Stage2

$F.x_F + V_2.y_2 = L_1x_1 + V_1.y_1$ (solute balance) …(6)

$y_1 = k.x_1$ (equilibrium relation) …(7)

$y_2 = 1.36 \times 10^{-2}$

$x_2 = 6.79 \times 10^{-3}$

Stage3

$L_1.x_1 + V_3.y_3 = L_2x_2 + V_2y_2$ …(8)

$y_2 = k.x_2$ …(9)

$y_3 = 1.07 \times 10^{-2}$

$x_3 = 5.36 \times 10^{-3}$

Stage4

$L_2.x_2 + V_4.y_4 = L_3x_3 + V_3y_3$ …(10)

$y_3 = k.x_3$ …(11)

$y_4 = 8.08 \times 10^{-3}$

$x_4 = 4.04 \times 10^{-3}$

Stage5

$L_3.x_3 + V_5.y_5 = L_4x_4 + V_4y_4$ …(12)

$y_4 = k.x_4$ …(13)

$y_5 = 5.63 \times 10^{-3}$

$x_5 = 2.81 \times 10^{-3}$

Stage6

$L_4.x_4 + V_6.y_6 = L_5x_5 + V_5y_5$ …(15)

$y_5 = k.x_5$ …(16)

$y_6 = 3.36 \times 10^{-3}$

$x_6 = 1.68 \times 10^{-3}$

Stage7

$L_5.x_5 + V_7.y_7 = L_6x_6 + V_6y_6$ …(17)

$y_6 = k.x_6$ …(18)

$y_7 = 1.26 \times 10^{-3}$

$x_7 = 6.29 \times 10^{-4}$

Since x_7 is less than x_N so no of stages = 6.64

Solution by Matrix Method:

$p_1 = -0.519$ $q_1 = 0.519$

$p_2 = -0.692$ $q_2 = 0.332$

$p_3 = -0.778$ $q_3 = 0.239$

$p_4 = -0.829$ $q_4 = 0.184$

$p_5 = -0.863$ $q_5 = 0.147$

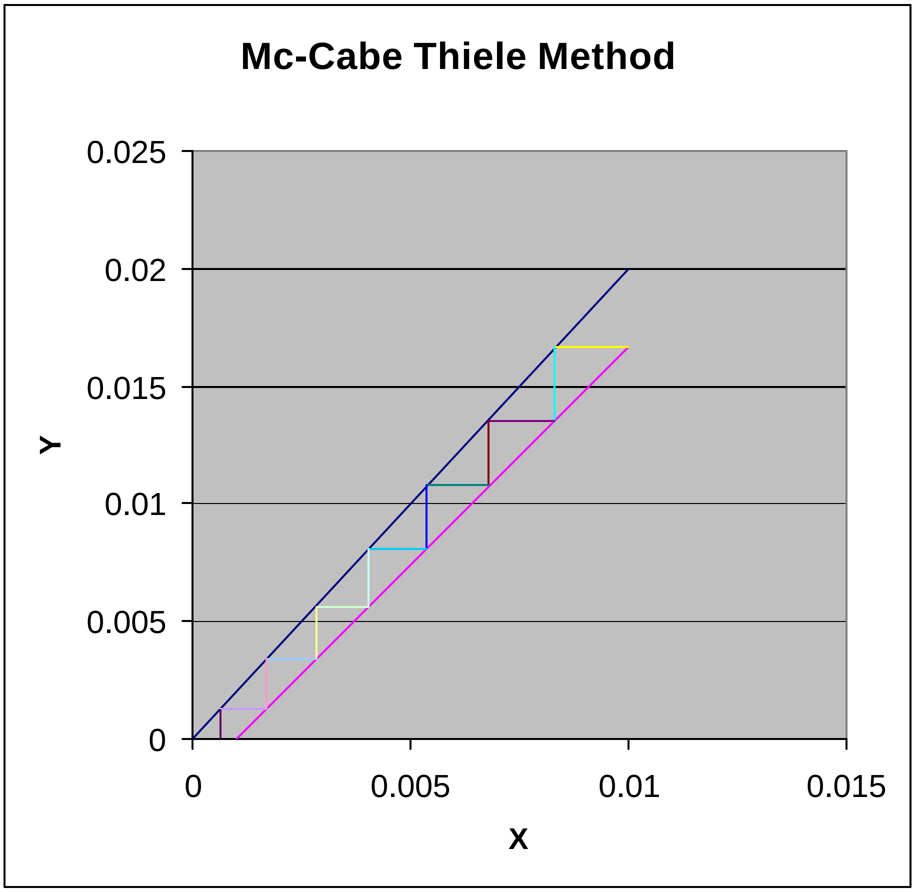
$p_6 = -0.887$ $q_6 = 0.121$

$p_7 = -0.906$ $q_7 = 0.101$

$v_N = 0.108$

Since $q_7 < 0.108$, therefore number of stages = 6.64

c)Solution by mc-cabe thiele diagram



Number of stages = 6.64

Question.17 Component B is extracted from a liquid mixture of A and B using solvent C, which is immiscible with A, in a countercurrent staged extractor. The mass of solute in the feed is 0.05. The flow rate of feed is 1000kg/h. The solvent flow rate is 1500 kg/h and it contains 0.005 of solute. It is desired to extract 90 of solute entering the extractor. The equilibrium relation is y=1.5 x. Find the number equilibrium stages required.

Solution:

Flow rate of A and B =1000 g

Mole fraction of A in feed = 0.05
equilibrium relation (y=kx) k =1.5
Fractional recovery = 0.9
Flow rate of Agent C = 1500
Mole fraction of A in Agent Feed = 0.005
a)
Stage to stage calculation

Assuming dilute solution

$F=L_1=L_2\ldots.=L_j$ …(1)

$V_1=V_2=\ldots=V_j$ …(2)

$F=1000,\ x_F = 0.05$

$$f_E = 1 - \frac{L.x_N}{F.x_F} = 0.9$$ …(3)

$x_N = 0.005$

Stage 1

$F.x_F = L_N.x_N + V_1.y_1$ (overall solute balance) …(1)

$y_1 =$ 0.08
$x_1 =$ 0.17

Stage2

$F.x_F + V_2.y_2 = L_1x_1 + V_1y_1$ …(7)

$y_1 = k.x_1$ …(8)

$y_2 =$ 0.0100
$x_2 =$ 0.0067

Stage3

$L_1.x_1 + V_3.y_3= L_2x_2 + V_2y_2$ …(9)

$y_2 = k.x_2$ …(10)

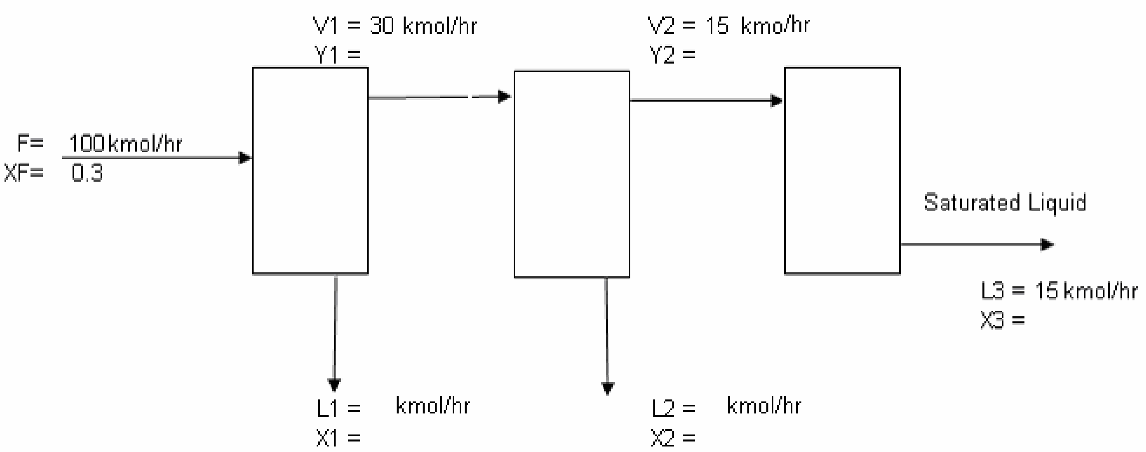
$y_3 =$ 0.0011
$x_3 =$ 0.0007

Since x_3 is less than x_N so no of stages = 2.281

Question.18 A saturated binary liquid mixture of A and B is partially vaporized and subjected to flash distillation. The mole fraction of A in feed 0.3. The feed rate is 100kmol/h. The vapor from the flash drum is drawn at a rate of 30kmol/h. This vapor is subjected to flash condensation. The liquid drawn from the second flash drum is 15 kmol/h. The vapor from the second drum is condensed as drawn as saturated liquid. Find the compositions the streams leaving the two drums. Find the heat duties of the three heat exchangers.

The molar latent heat of vaporization and of A and B are 20MJ/kmol and 40MJ/kmol respectively. You may neglect that the sensible heat of liquid mixture in comparison to the latent heats. The relative volatility α_{AB} =3.0.

Solution:



Stage to Stage Calculation

$F = 100$
$V_1 = 30$
$X_F = 0.3$

$F=V_1 + L_1$	(mass balance)	...(1)
$F.X_F = V_1.Y_1 + L_1.X_1$	(component balance)	...(2)

a_{AB} = 3

$$\alpha = \frac{Y_1(1\text{-}X_1)}{X_1(1\text{-}Y_1)} = 3$$

(Equilibrium balance) ...(3)

Solving the above equations we get
L_1 =70 kmol/hr
X_1 =0.227
Y_1 =0.469

V_2=15
$V_1 = L_2 + V_2$ ...(4)
$V_1.Y_1 = L_2.X_2 + V_2.Y_2$ ...(5)
a_{AB} = 3

$$\alpha = \frac{Y_2(1\text{-}X_2)}{X_2(1\text{-}Y_2)} = 3$$ ...(6)

Solving the above equations we get

L_2 =15
X_2 =0.3356
Y_2 =0.6025

$V_2 = L_3$
$X_3 = Y_2$
L_3 =15
X_3 =0.602

h_A = 0
H_A= 20 MJ/kmol
h_B = 0
H_B = 40 MJ/kmol

n= h =$X.h_A + (1-X).h_B$ ...(7)
N= H =$Y.H_A + (1-Y).H_B$ ...(8)

$Q_1 = V_1.Y_1.H_A + V_1.(1-Y_1).H_B$ ...(9)
$Q_2 = V_2.Y_2.H_A + V_2.(1-Y_2).H_B - Q_1$ ...(10)
$Q_3 = - (V_2.Y_2.H_A + V_2.(1-Y_2).H_B)$ ...(11)

Solving ….(9),…(10),….(11) we get

Q1 =918.535 MJ/kmol
Q2 =-499.294 MJ/kmol
Q3 =-419.240 MJ/kmol

Answer

X1 =	0.227	Y1 =	0.469
X2 =	0.335	Y2 =	0.602
X3 =	0.602		
Q1 =	918.535 MJ/kmol		
Q2 =	-499.294 MJ/kmol		
Q3 =	-419.240 MJ/kmol		

Question.19 Ethanol is to be extracted continuously from the ethanol-water mixture using CO_2 at 100 atm and 25°C. The feed contains 0.08 mass fraction of ethanol and 90% of ethanol in the feed has to be extracted.
Determine:

(i) the minimum CO_2 rate required for the specified separation.
(ii) the number of stages required if the supercritical fluid rate is 1.5 times the minimum. You may assume CO_2 and H_2O are immiscible. The distribution coefficient of ethanol on mass fraction basis is 0.09. The extraction will be carried out at isothermal conditions.

Solution:

Flow rate of Ethanol and water =100 g
Mole fraction of A in feed =0.08
Distribution coefficient , k = 0.09
Fractional recovery = 0.9
Flow rate of Agent CO2 =1.5Asmin
Mole fraction of Ethanol in Agent Feed =0.0025

a)

Stage to stage calculation

Assuming dilute solution
$F=L_1=L_2\ldots.=L_j$ …(1)
$V_1=V_2=\ldots=V_j$ …(2)

$F=100$, $x_F=0.08$

$$f_R = 1 - \frac{L.x_N}{F.x_F} = 0.9 \qquad \ldots(3)$$

$x_N = 0.008$

Minimum Agent Flow rate Required, $A_{smin} = F.(x_F - x_N)/(kx_F - x_N)$ …(4)
$A_{smin} = 1000$ g
Agent feed rate =1.5 times A_{smin}
$A_s = 1500$ g

Stage 1
$F.x_F = L_N.x_N + V_1.y_1$ (overall solute balance) …(5)
$y_1 = 0.0048$
$x_1 = 0.0533$

Stage2
$F.x_F + V_2.y_2 = L_1 x_1 + V_1 y_1$ …(6)
$y_1 = k.x_1$ …(7)

$y_2 = 0.0030$
x2 = 0.0335

Stage3
$L_1.x_1 + V_3.y_3 = L_2 x_2 + V_2 y_2$ …(9)
$y_2 = k.x_2$ …(10)
$y_3 = 0.0017$
$x_3 = 0.0189$

Stage4
$L_2.x_2 + V_4.y_4 = L_3.x_3 + V_3.y_3$ …(11)
$y_3 = k.x_3$ …(12)
$y_4 = 0.00072$
$x_4 = 0.00879$

Stage5
$L_3.x_3 + V_5.y_5 = L_4 x_4 + V_4 y_4$ …(13)
$y_4 = k.x_4$ …(14)
$y_5 = 7.32 \times 10^{-4}$
$x_5 = 8.13E \times 10^{-5}$

Since x_5 is less than x_N so no of stages = 4.014

Question.20 A mixture of water-acetic acid is being fractionated in a tray column at 1 atm. The feed is saturated liquid. Its flow rate is 100 kmol/h and mole fraction is 0.5. The distillate mole fraction is 0.84 and its rate is 50 kmol/h. The column is equipped with a total condenser and partial reboiler. The reflux ratio is 2. Using the Ponchon-Savarit method find the number of stages required.

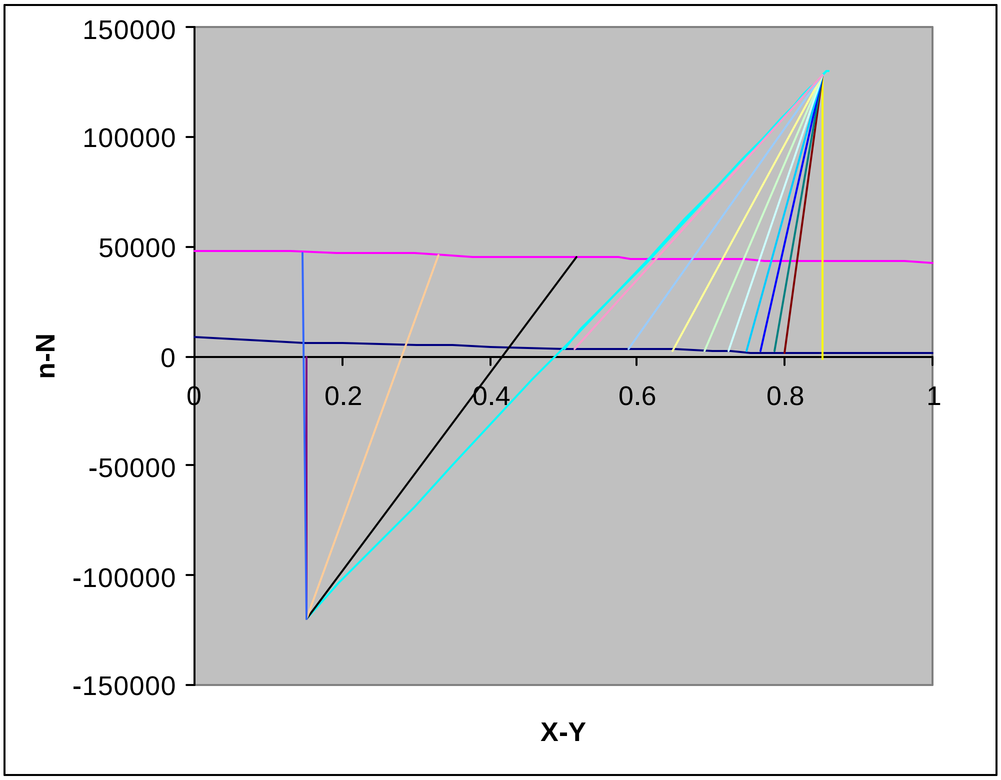
Solution:

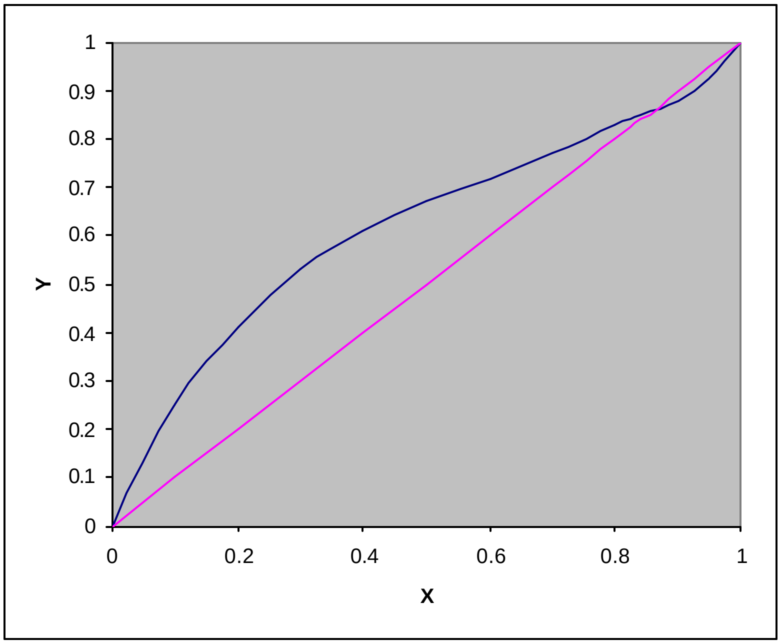
The following data is generated for various stages

T	x	y	H(J/mol)	H(J/mol)
391.10	0.00	0.00	48481.57	8581.314
385.00	0.10	0.25	46943.08	7126.716
380.70	0.20	0.41	46009.51	6009.617
377.60	0.30	0.53	45357.90	5108.874
375.40	0.40	0.61	44935.43	4361.253
373.80	0.50	0.67	44631.42	3712.832
372.70	0.60	0.72	44395.49	3140.867
372.02	0.70	0.77	44183.03	2627.590
371.70	0.80	0.83	43952.68	2159.398
371.68	0.84	0.85	43879.81	1985.282
371.80	0.90	0.88	43776.48	1735.958
372.21	0.95	0.93	43629.53	1548.250
373.20	1.00	1.00	43391.53	1431.401

Using this data the Ponchon-Savarit method can be applied as shown below:

Number of stages = 11.


150000
100000
50000
0
-50000
-100000
-150000
n-N
0
0.2
0.4
0.6
0.8
1
X-Y


1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Y
0
0.2
0.4
0.6
0.8
1
X