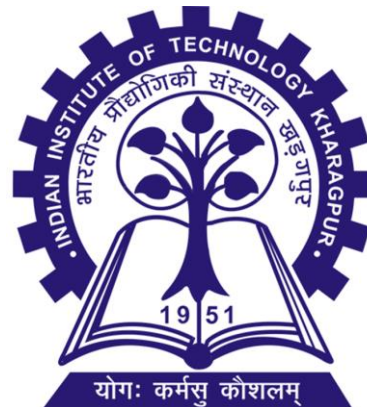


Mass Transfer I (CH21202)

Module IV Distillation



Outline of the Course

➤ Distillation:

- Introduction; Vapour liquid equilibrium, x - y , T - x - y , P - x - y and H - x - y diagrams
- Henry's, Routh's and Dalton's laws
- Ideal and non ideal solutions; Azeotropes, relative volatility, flash vaporization
- Differential distillation, steam distillation, continuous rectification; stage calculation using and McCabe-Thiele methods
- Minimum/maximum reflux ratio, Feed position, Fenske's equation for minimum number of trays
- Azeotropic distillation, extractive distillation

Text Books

1. Mass Transfer Operations- Robert E. Treybal
2. Transport processes and Unit Operations – C. J. Geankoplis
3. Chemical Engineering, Volume 2 – J. M. Coulson, J. F. Richardson, J. R. Backhurst and J. H. Harker
4. Unit Operations of Chemical Engineering – W. L. McCabe, J. C. Smith and P. Harriott
5. Principle of Mass Transfer and Separation Processes – B . K. Dutta

Distillation: Introduction

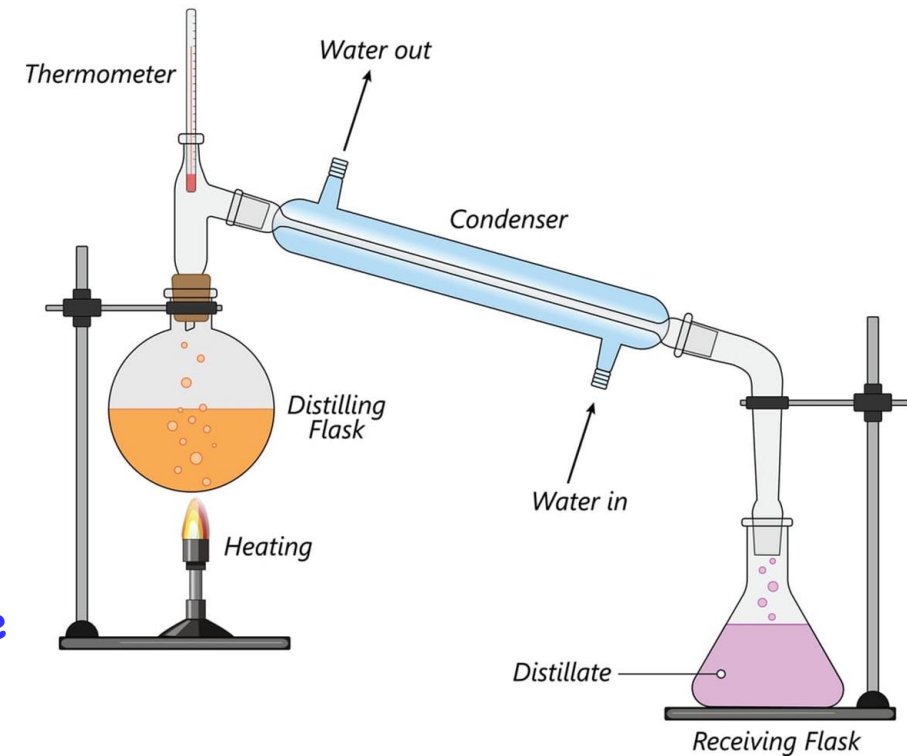
Distillation is the technique of preferential separation of more volatile component(s) from the less volatile once in a feed (liquid mixture) solution by **partial vaporization** of the feed followed by **condensation**.

Difference between Distillation and Evaporation:

- In **evaporation** one or more components should be **non volatile** (ex. Separation of a solution of common salt and water)
- In **distillation** all components are appreciably **volatile**.

Example of Distillation in Process Industries:

- ✓ Separation of aniline and nitrobenzene in the process manufacture of aniline
- ✓ Recovery of ethanol from its solution in water in alcohol industry
- ✓ Increase the benzene purity by removal of trace water
- ✓ Petroleum refinery industry
- ✓ Distillation is called **workhouse of chemical industries**

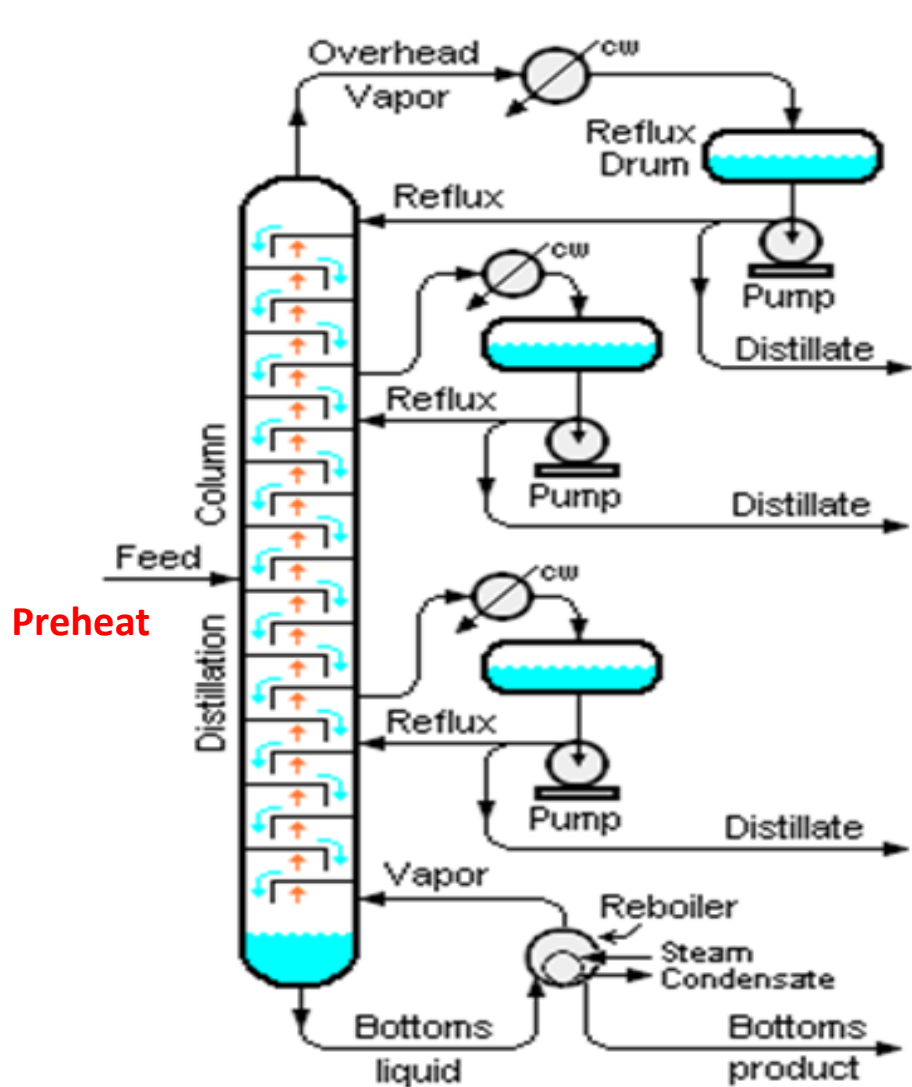


Separation of methanol (64.7°C) and water (100°C)

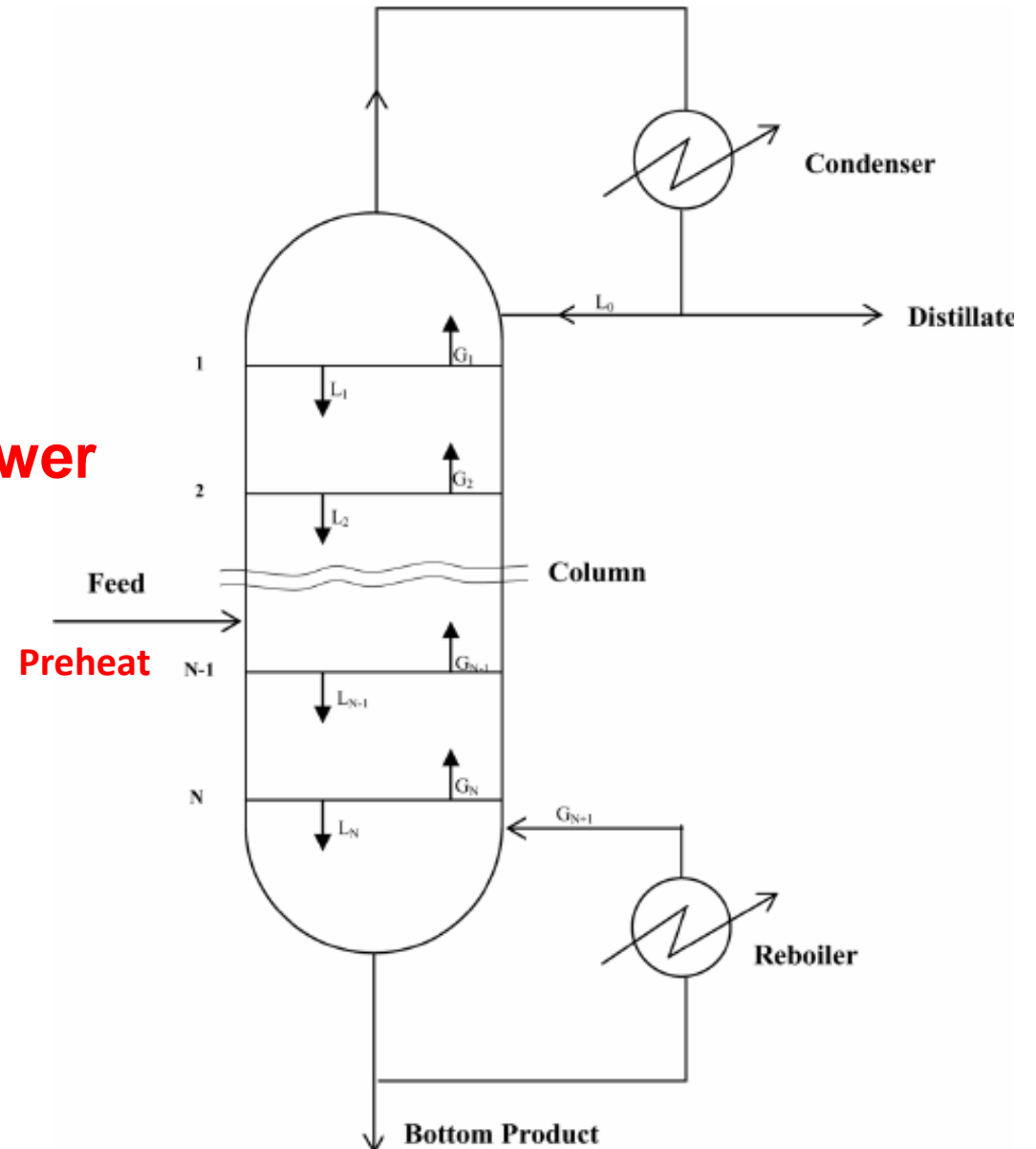
- Light key component (more volatile component) – methanol
- Heavy key component (less volatile component) - water

○ **Direct separation into pure product**

Distillation Column:



Tray Tower



Vapour Liquid Equilibrium (VLE)

- Vapour-liquid equilibria constitute the physical basis of separation of mixture by distillation
- Vapour pressure depends on the temperature and quantity of liquid and vapour

Vapour pressure can be calculated from Clausius-Clapeyron equation or Antoine equation

Clausius-Clapeyron equation:

$$\ln\left(\frac{p^v}{p_1^v}\right) = \frac{\lambda}{R} \left(\frac{1}{T_1} - \frac{1}{T} \right)$$

λ = molar latent heat

p^v, p_1^v = vapour pressure

Antoine equation:

$$\ln p^v = A - \frac{B}{T+C}$$

Parameterisation for T in °C and P in mmHg

	A	B	C	T min. (°C)	T max. (°C)
Water	8.07131	1730.63	233.426	1	100
Water	8.14019	1810.94	244.485	99	374
Ethanol	8.20417	1642.89	230.300	-57	80
Ethanol	7.68117	1332.04	199.200	77	243

T-x-y diagram at Constant Pressure:

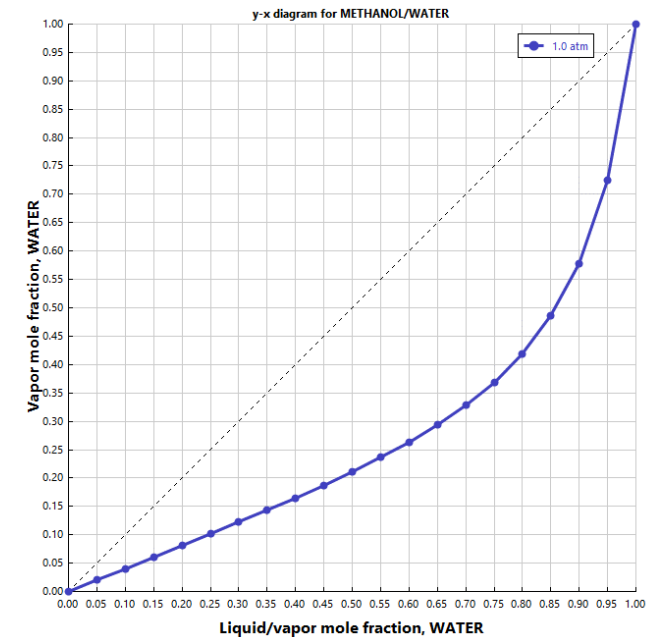
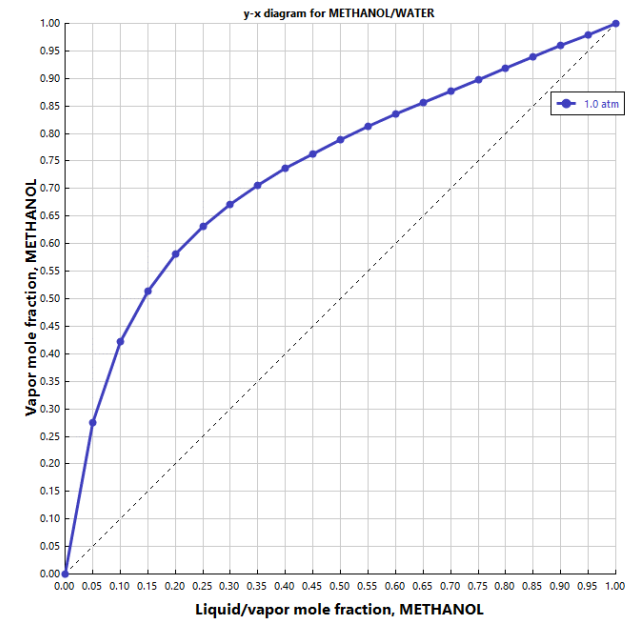
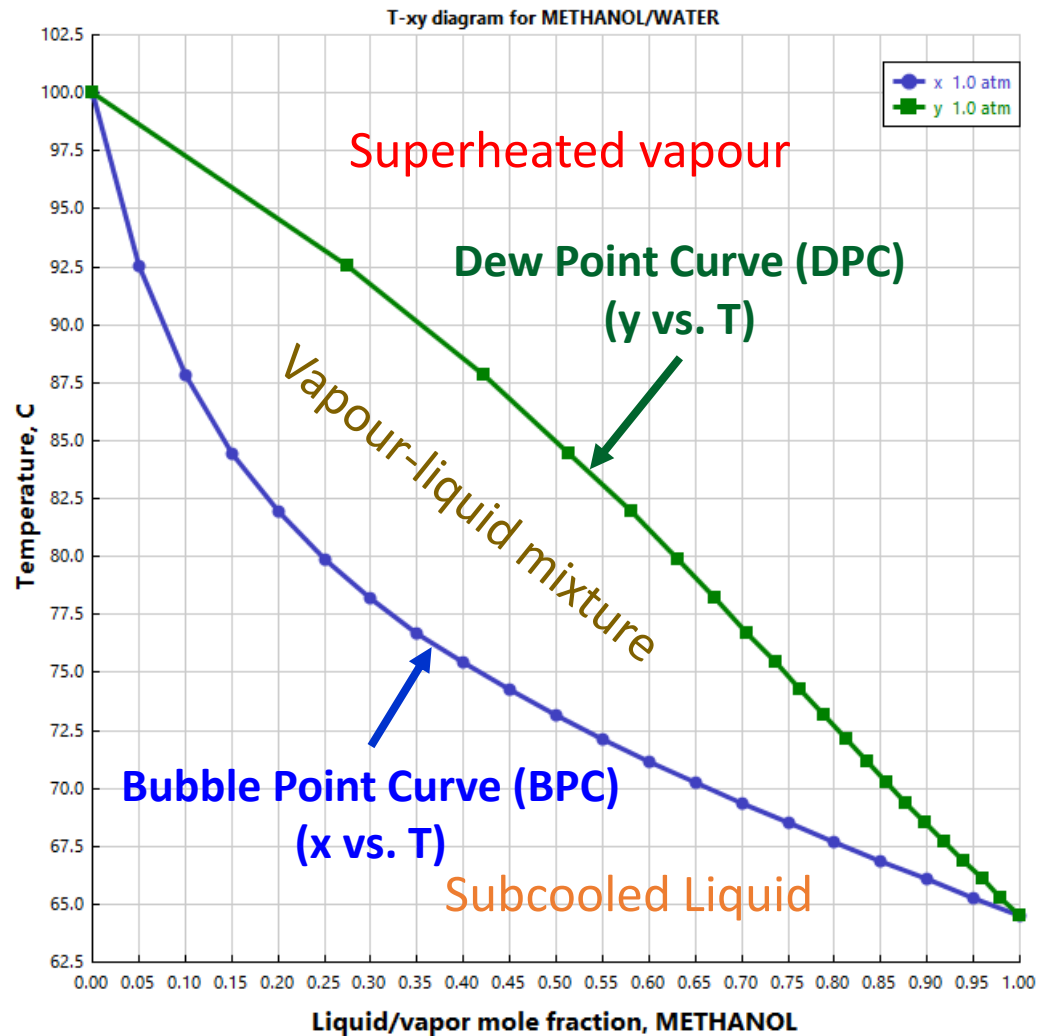
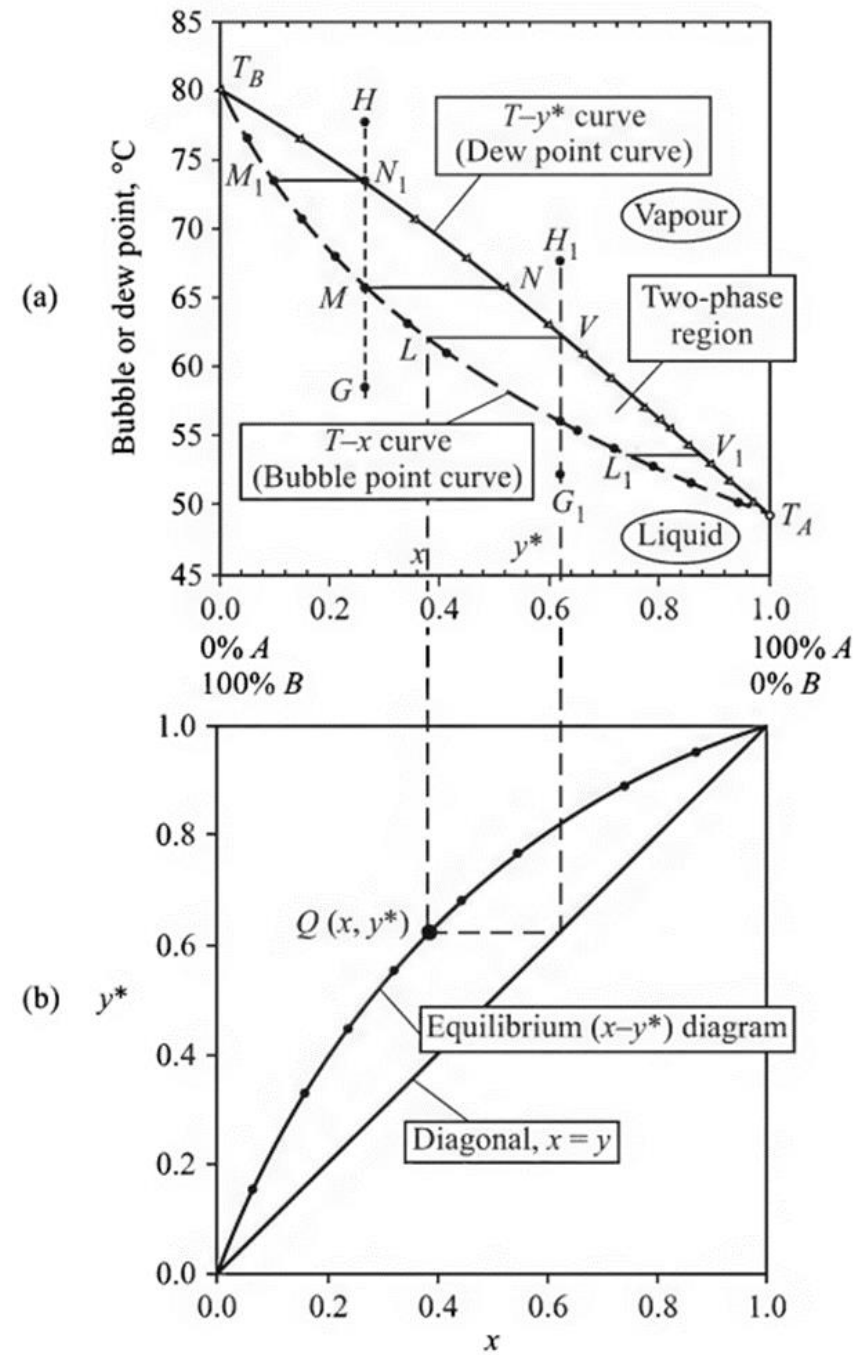


Fig. Constant pressure vapor liquid equilibria

Constant pressure Binary T-x-y and x-y diagram



➤ Vapor-liquid equilibria at increased pressures

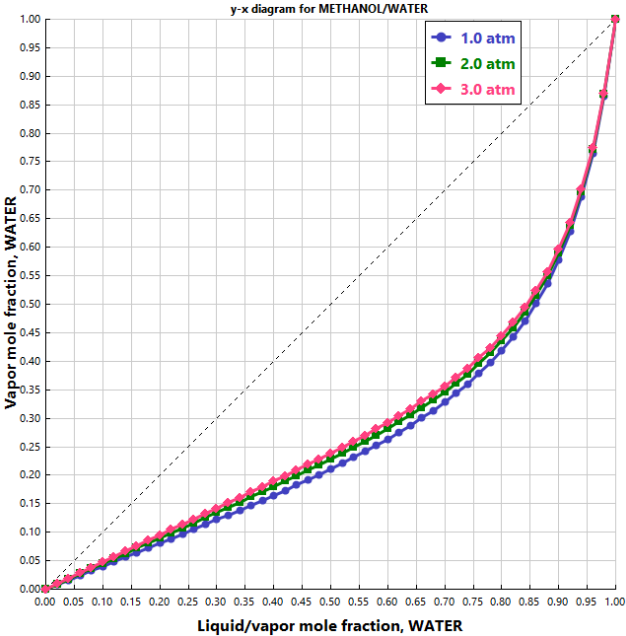
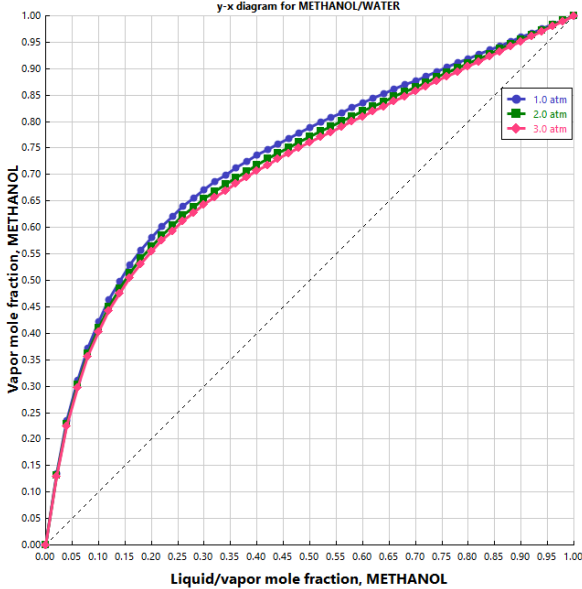
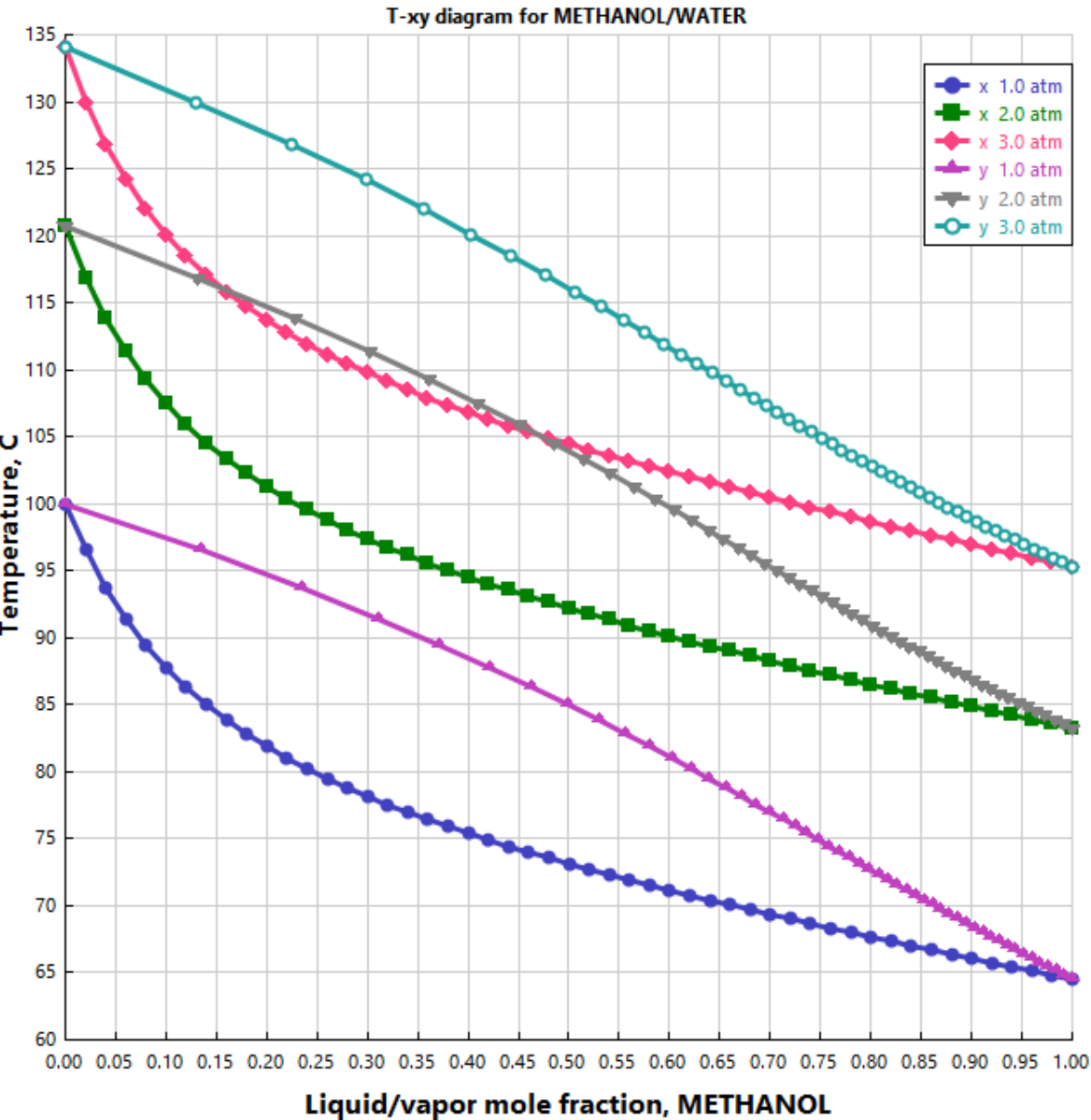


Fig. Vapor liquid equilibria at increased pressures

➤ P-x-y diagram for methanol-water

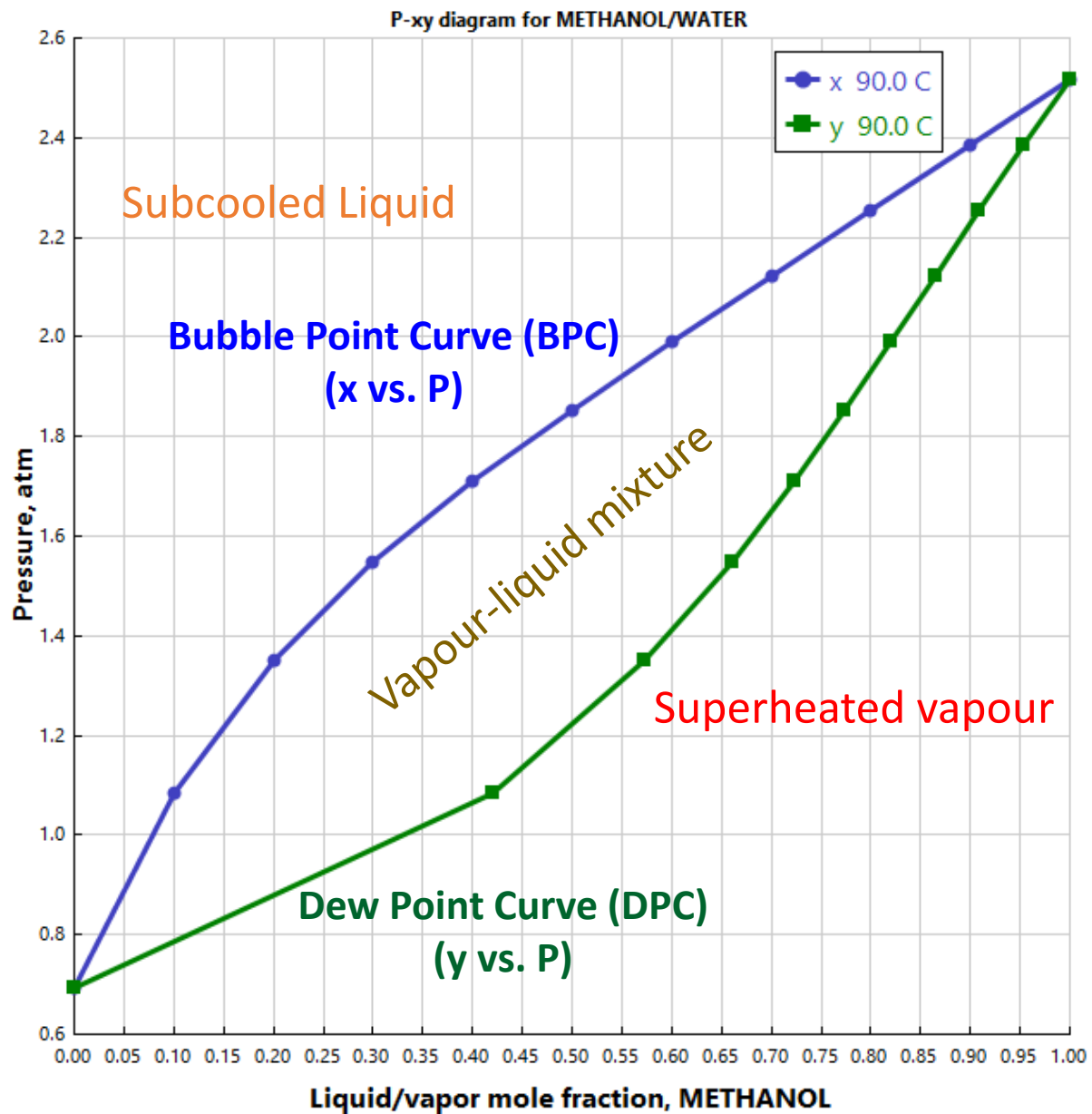
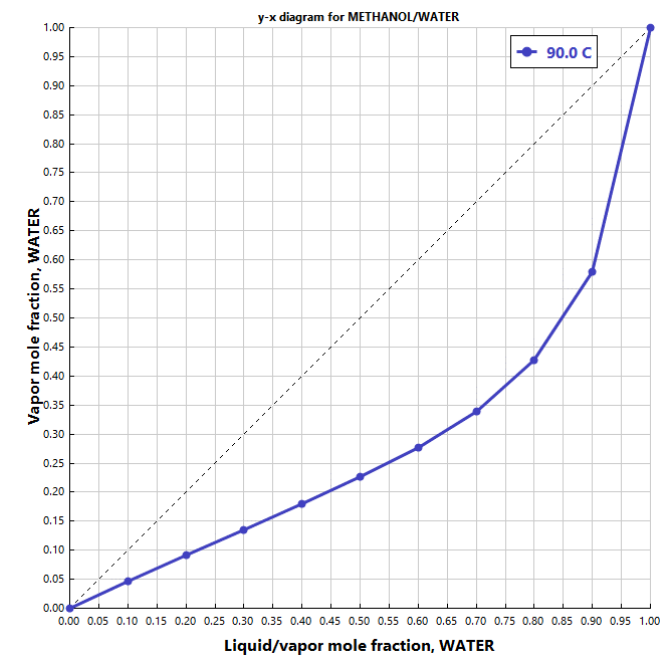
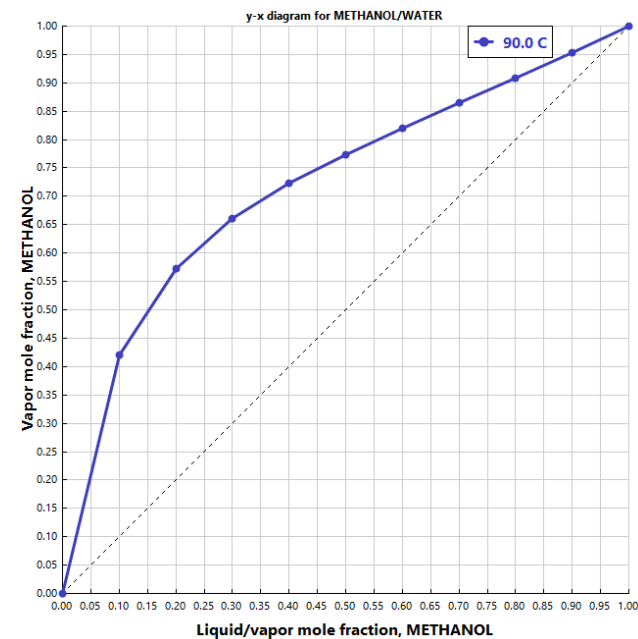


Fig. Constant temperature vapor liquid equilibria



Raoult's Law: (Ideal gas-liquid system)

$$p_A^* = x_A P_A$$

$$y_A = p_A^* / P_t$$

$$P_t = p_A^* + p_B^*$$

P_A = vapour pressure of A at the given temperature

x_A = mole fraction of the solute A in the liquid

p_A^* = equilibrium partial pressure exerted by the solute

y_A = mole fraction of A in vapour phase

P_t = total pressure

Relative volatility (α)

- This is the ratio of the concentration ratio of A and B in one phase to that in the other and is a measure of the separability.

$$\alpha = \frac{\frac{y^*}{(1-y^*)}}{\frac{x}{(1-x)}} = \frac{y^* (1-x)}{x (1-y^*)} \quad (1)$$

$$y^* = \frac{\alpha x}{1 + (\alpha - 1)x}$$

x – mole fraction of the more volatile substance in the liquid

y^* – mole fraction of the more volatile substance in the vapor

- The value of α will ordinarily change as x varies from 0 to 1.
- If $y^* = x$ (except at $x = 0$ or 1), $\alpha=1$ and no separation is possible.
- The larger the value of α above unity, the greater the degree of separability.

Problem:

Prepare a the bubble point, dew point and equilibrium curve for an ideal binary mixture of benzene and diethyl ether at 1 atm total pressure.

Component	BP (°C)	A	B	C
Benzene	80	15.9037	2789.01	220.79
Diethyl ether	34.5	16.5414	2847.72	253

Raoult's Law: (Ideal gas-liquid system)

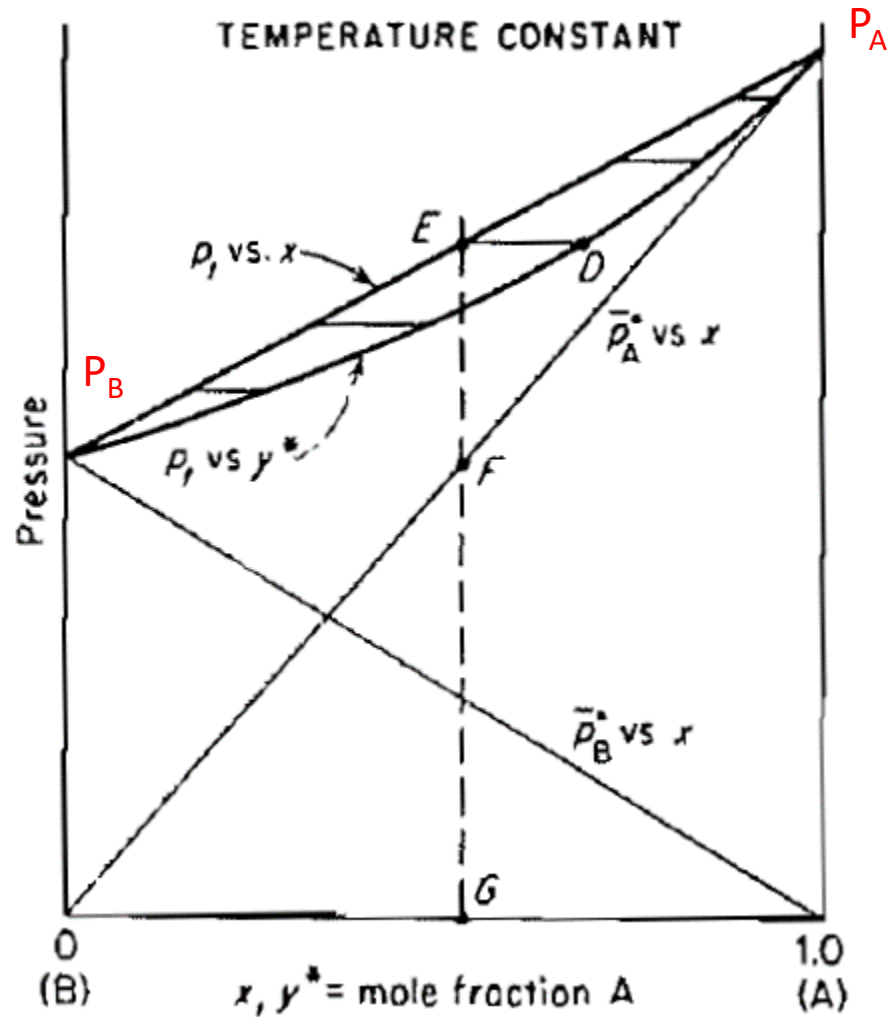


Fig. Ideal solutions

$$y^* = \frac{\text{distance FG}}{\text{distance EG}} = \frac{\bar{P}_A^*}{P_t} = \frac{P_A x}{P_t} \quad (5)$$

$$1 - y^* = \frac{\bar{P}_B^*}{P_t} = \frac{P_B (1 - x)}{P_t} \quad (6)$$

The relative volatility α is, by substitution in equation (1)

$$\alpha = \frac{P_A}{P_B} \quad (7)$$

- When the sum of the separate vapor pressures equals the total pressure, the mixture boils, and the vapor composition is readily computed, assuming the applicability of the simple gas law,

$$P_A + P_B = P_t \quad (8)$$

$$y^* = \frac{P_A}{P_t} \quad (9)$$

$$1 - y^* = \frac{P_B}{P_t} \quad (10)$$

So long as two liquid phases are present, the mixture will boil at the same temperature and produce a vapor of constant composition.

➤ Positive deviations from ideality

- A mixture whose total pressure is greater than that computed for ideality (eq. 4) is said to show positive deviations from Raoult's law.

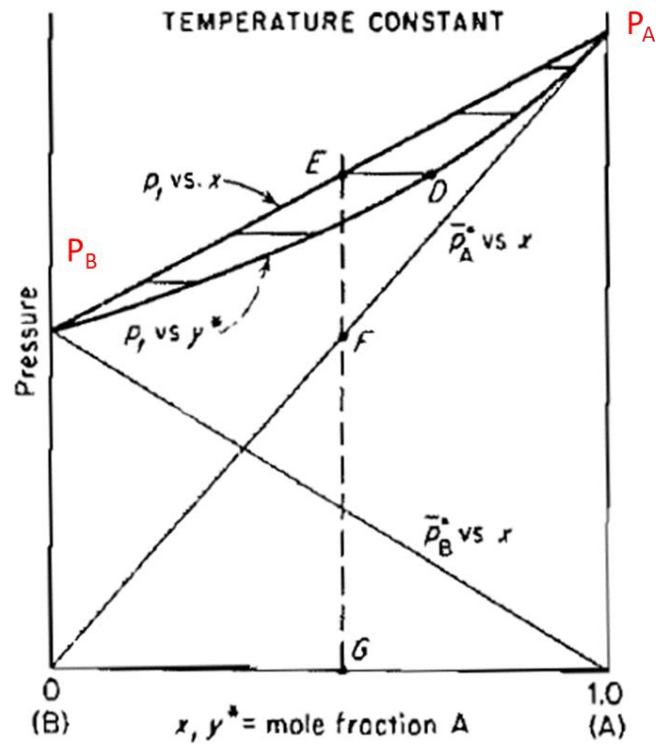
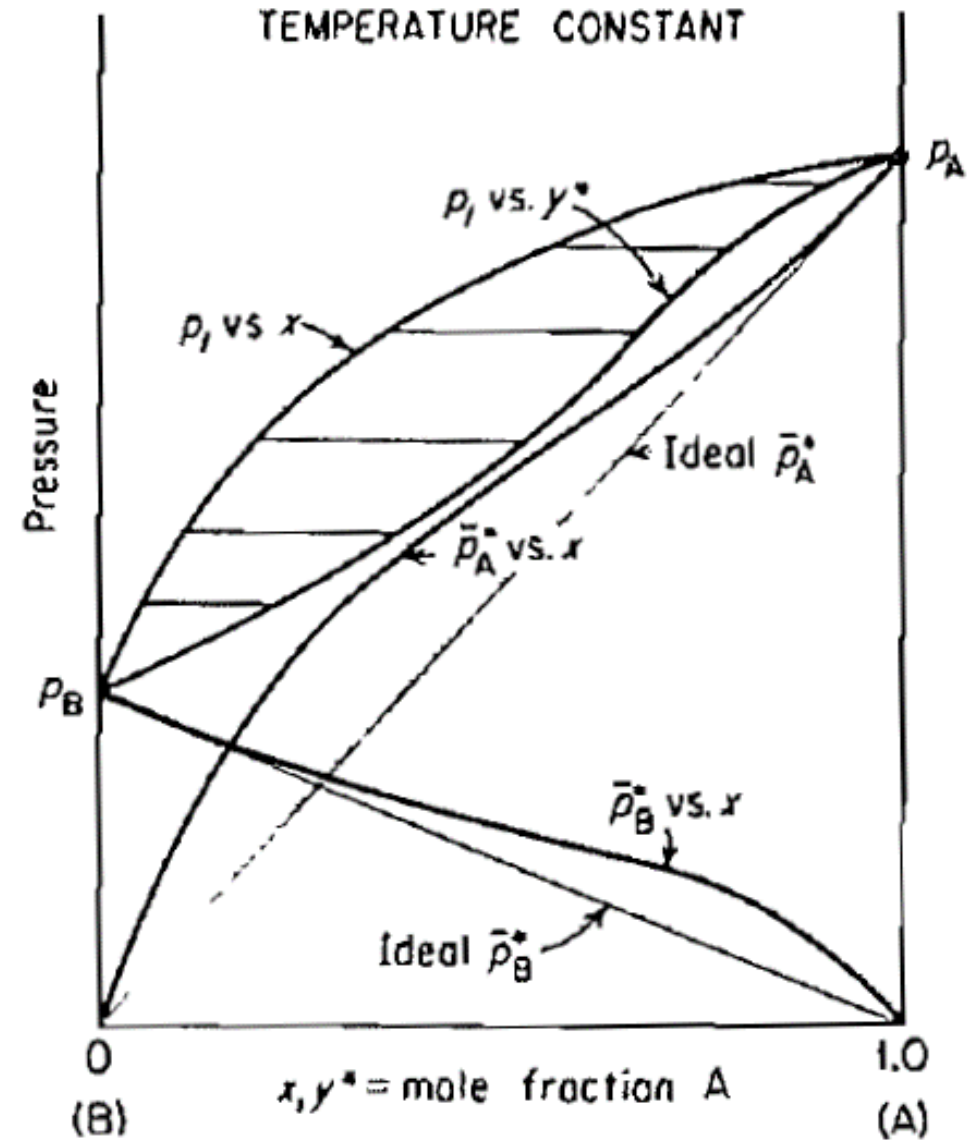
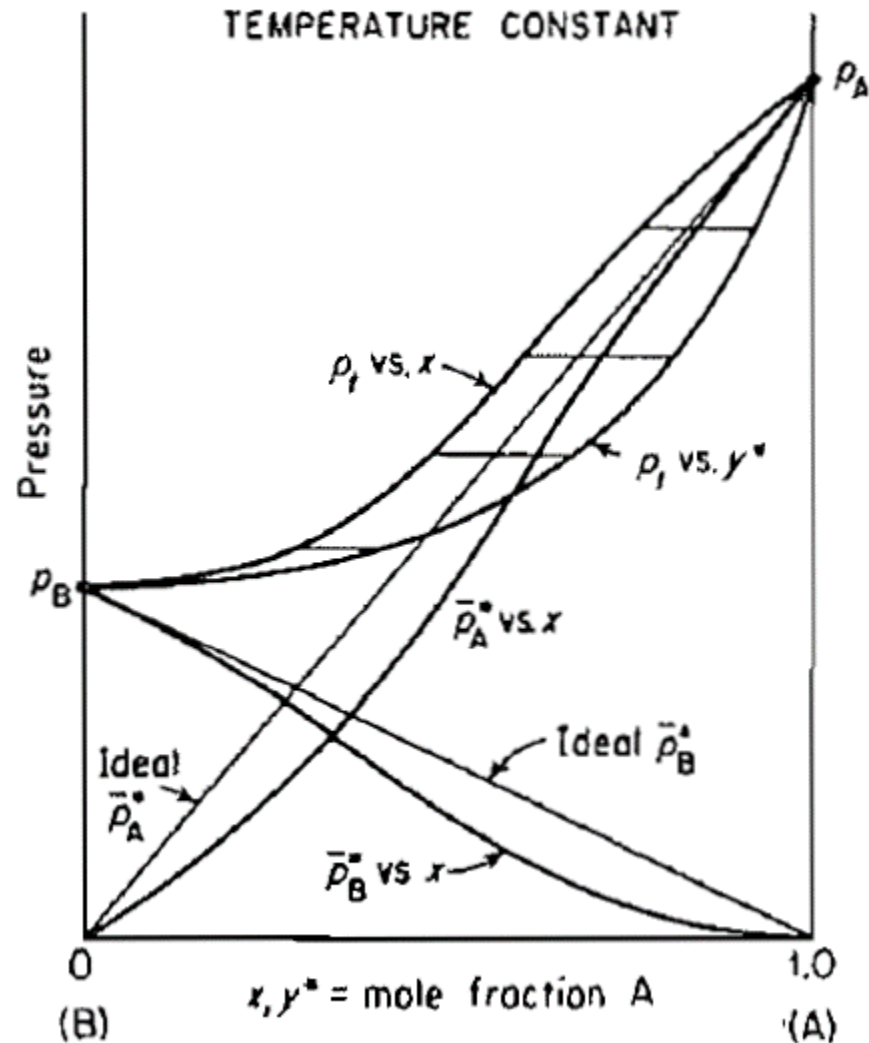


Fig. Ideal solutions

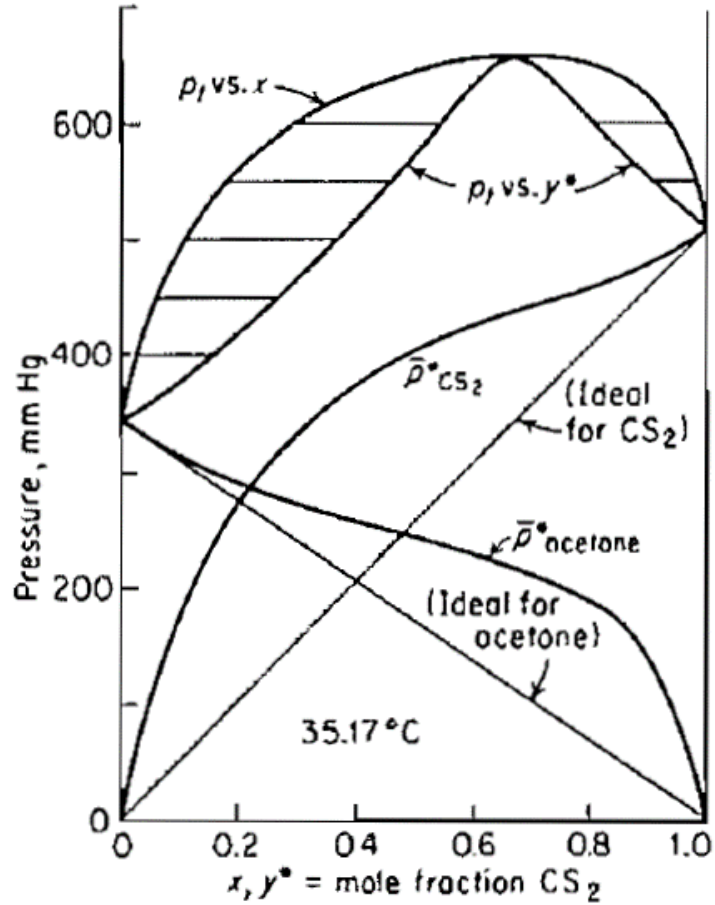


➤ Negative deviations from Ideality

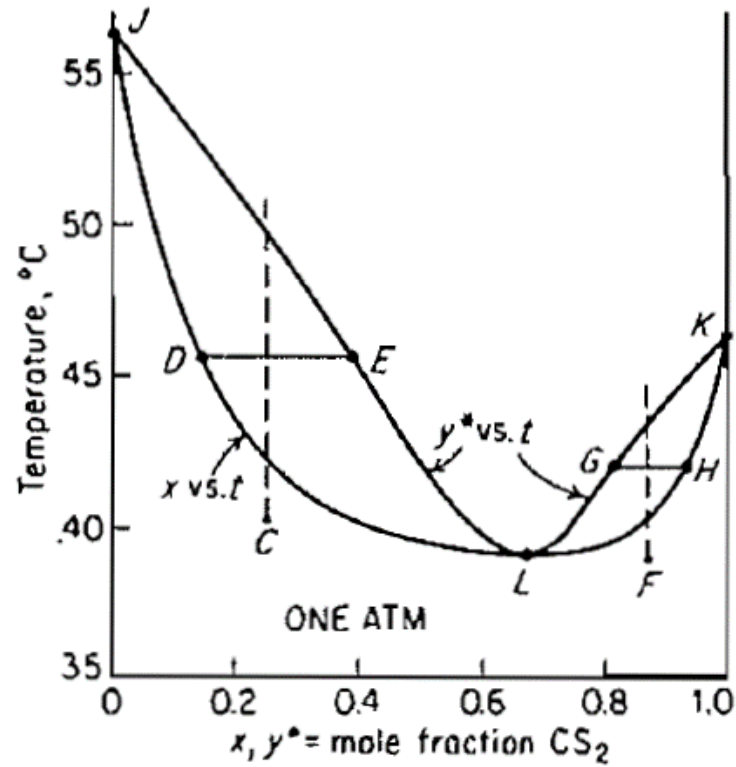
- When the total pressure of a system at equilibrium is less than the ideal value, the system is said to deviate negatively from Raoult's law.



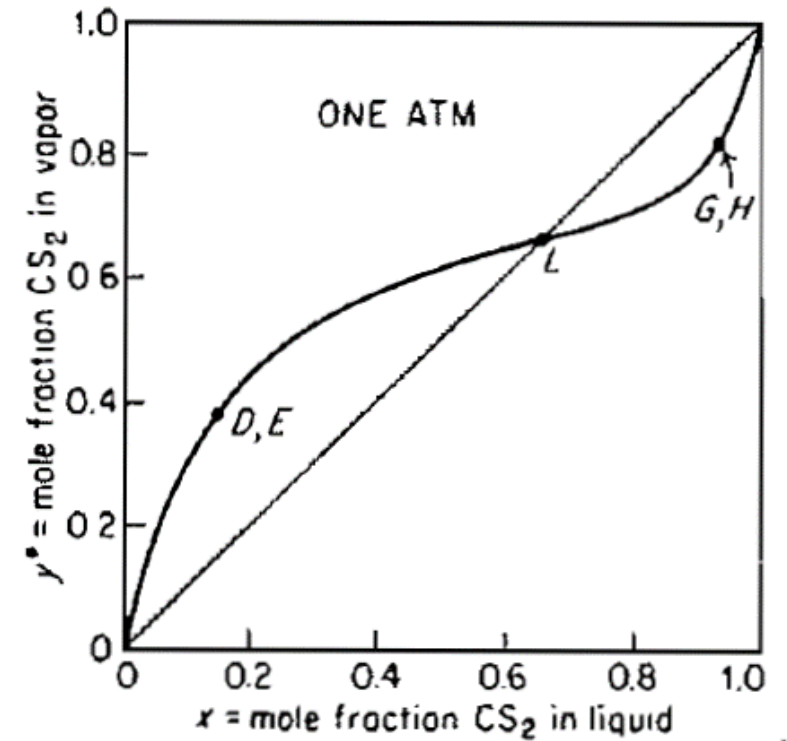
➤ Minimum boiling mixtures - azeotropes



(a)



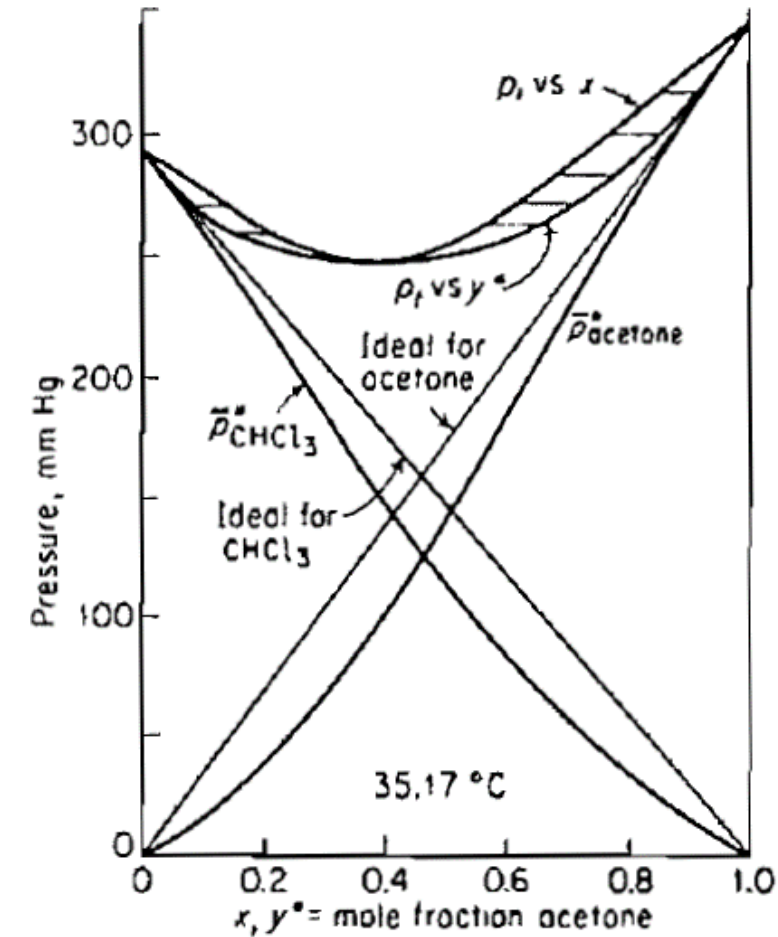
(b)



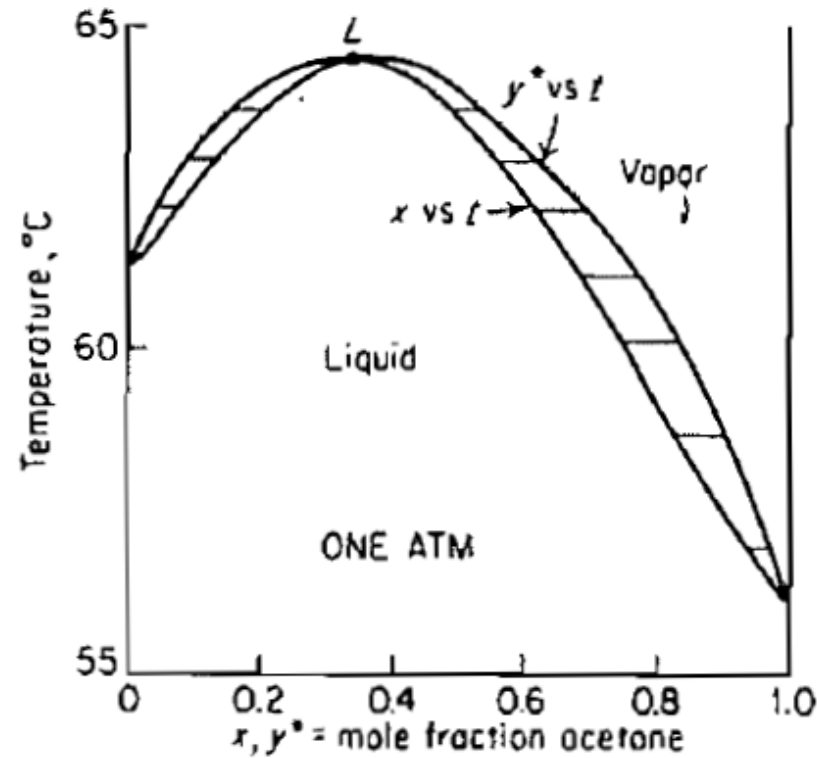
(c)

Fig. Minimum boiling azeotropism in system carbon disulfide - acetone: (a) at constant temperature; (b) and (c) at constant pressure.

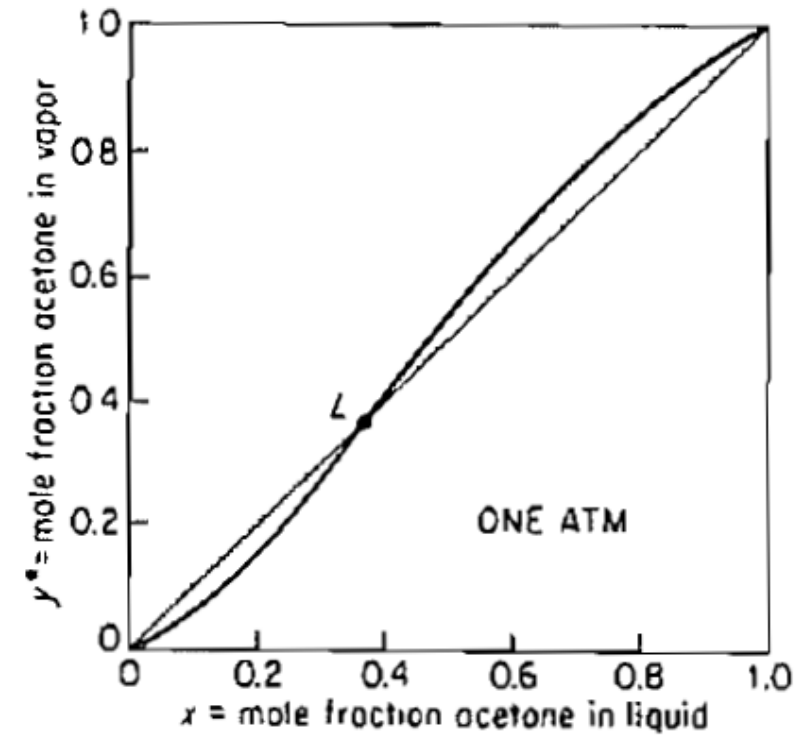
➤ Maximum boiling mixtures -Azeotropes



(a)



(b)



(c)

Fig. Maximum-boiling azeotropism in the system acetone-chloroform: (a) at constant temperature; (b) and (c) at constant pressure.

Enthalpy Concentration Diagram

○ 40 wt% ethanol water mixture at 84 °C

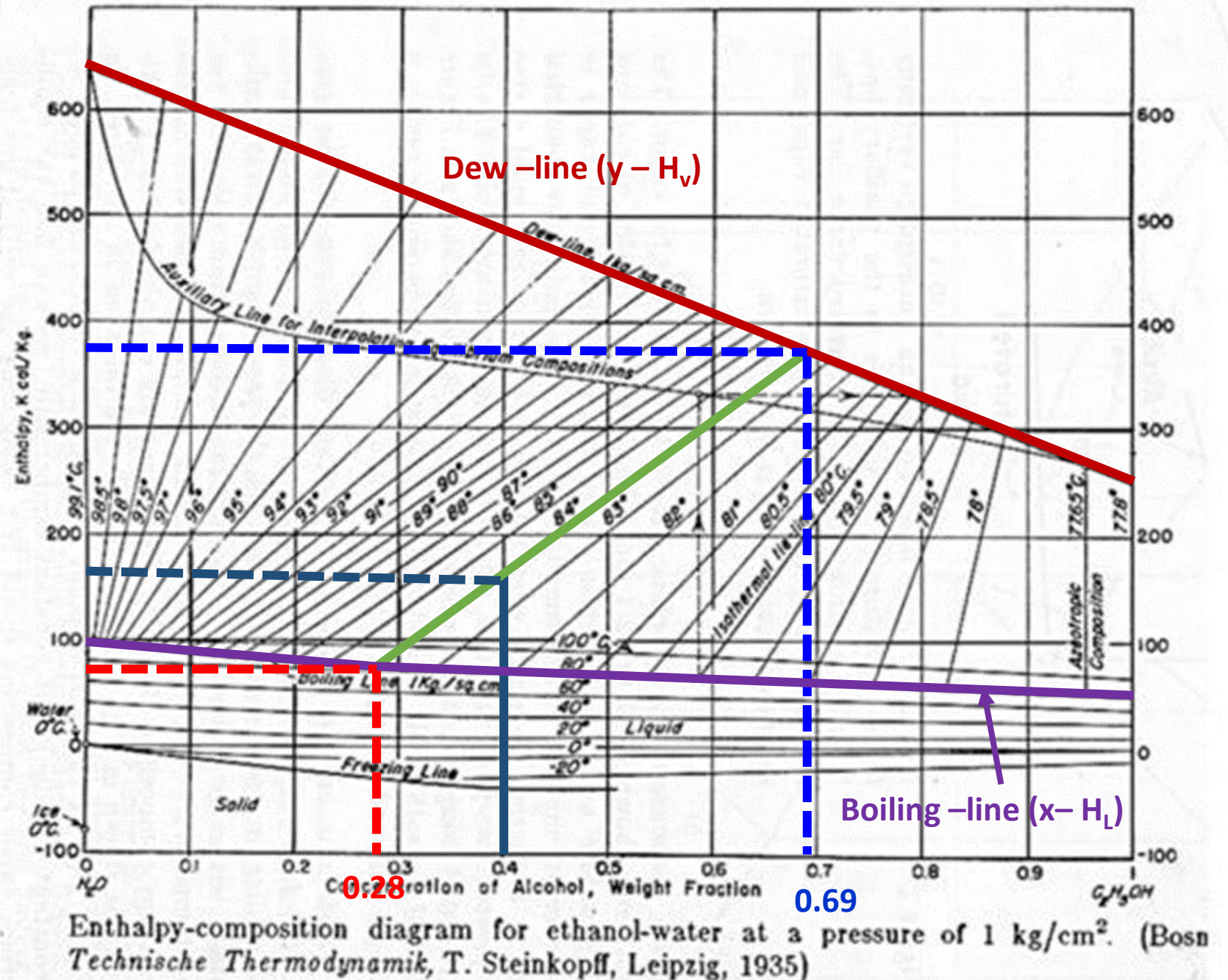
✓ $x_{\text{ethanol}} = 0.28$

✓ $y_{\text{ethanol}} = 0.69$

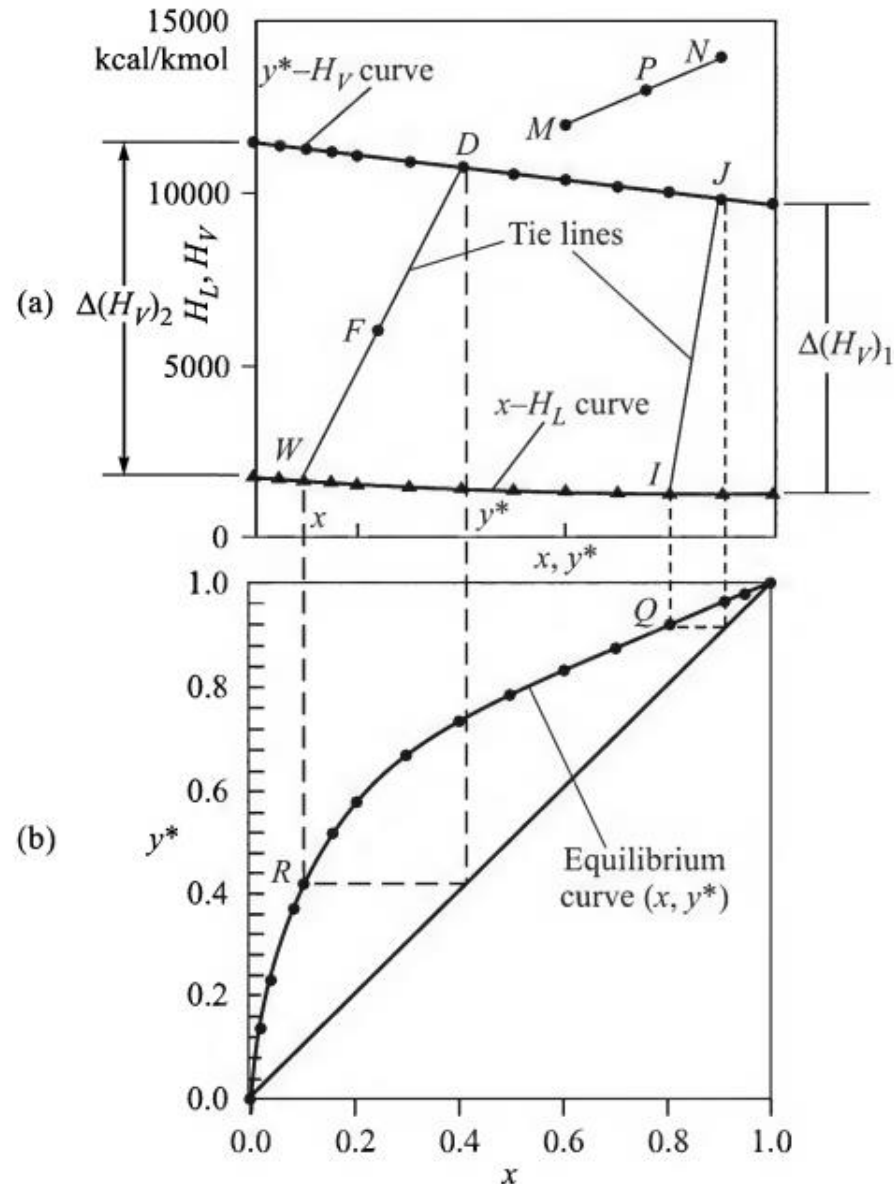
✓ $H_F = 165 \text{ Kcal/kg}$

✓ $H_v = 380 \text{ Kcal/kg}$

✓ $H_L = 70 \text{ Kcal/kg}$



Enthalpy Concentration Diagram to Equilibrium Diagram



Total material balance:

Component A balance:

Enthalpy balance:

$$M + N = P$$

$$Mz_M + Nz_N = Pz_P$$

$$MH_M + NH_N = PH_P$$

$$\frac{M}{N} = \frac{z_N - z_P}{z_P - z_M}$$

$$\frac{M}{N} = \frac{H_N - H_P}{H_P - H_M}$$

$$\frac{H_N - H_P}{z_N - z_P} = \frac{H_P - H_M}{z_P - z_M}$$

Distillation:

- Flash distillation
- Batch distillation
- Steam distillation
- Fractional distillation
- Azeotropic distillation
- Vacuum distillation

Flash Distillation

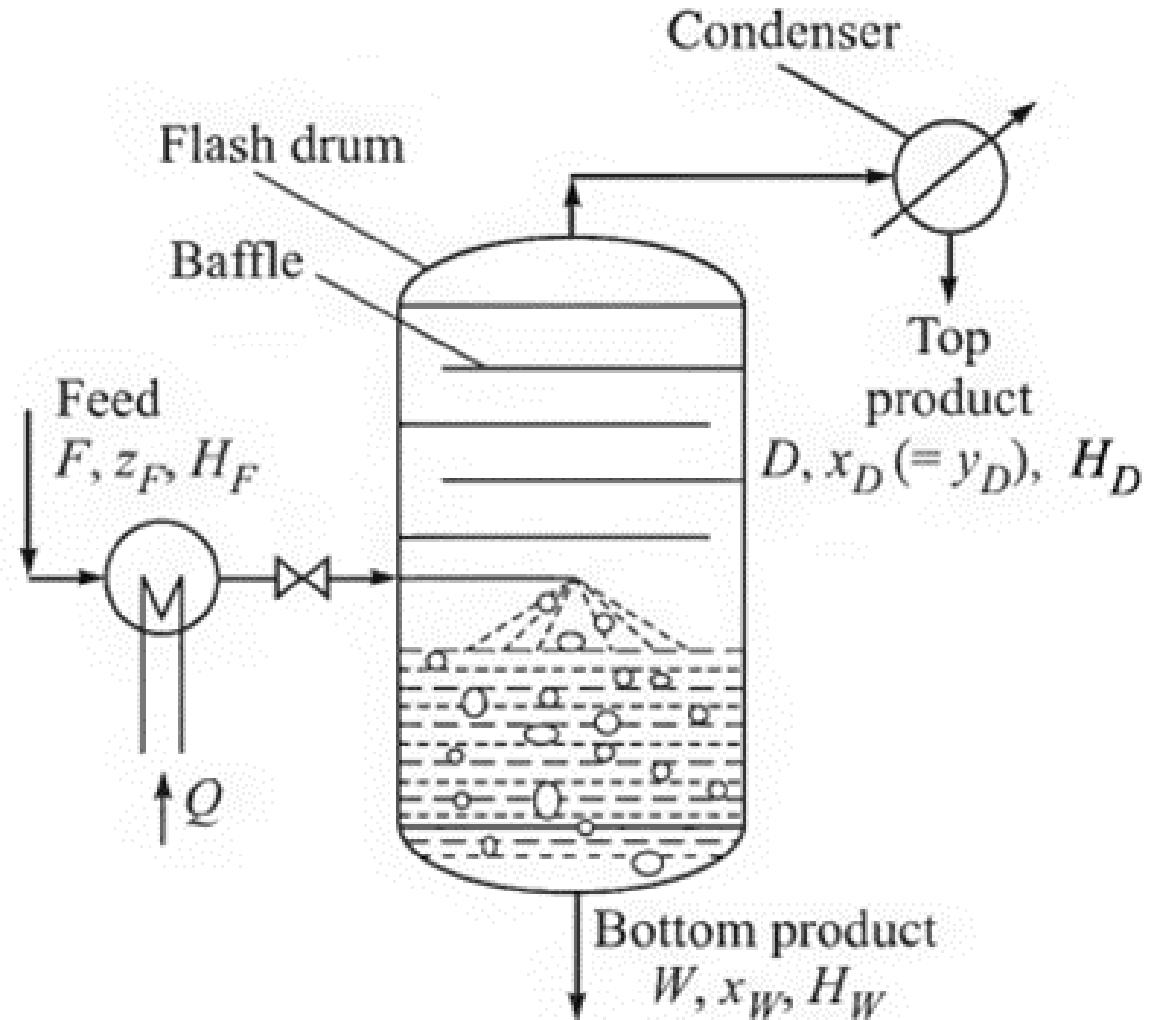
Over all balance: $F = D + W$

Component balance: $Fz_F = Dx_D + Wx_W$

$$(D + W)z_F = Dx_D + Wx_W$$

Enthalpy balance: $FH_F + Q = DH_D + WH_W$

$$-\frac{W}{D} = \frac{x_D - z_F}{x_W - z_F} = \frac{H_D - (H_F + Q/F)}{H_W - (H_F + Q/F)}$$



Problem:

Fifty kmol of 35 mole% aqueous solution of acetone at 25°C is heated and flashed in a drum at 1 atm pressure when 35% of the liquid is vaporized. Using the enthalpy-concentration data, calculate (a) the amounts and the concentrations of the vapour and liquid products, and (b) the heat supplied to the feed.

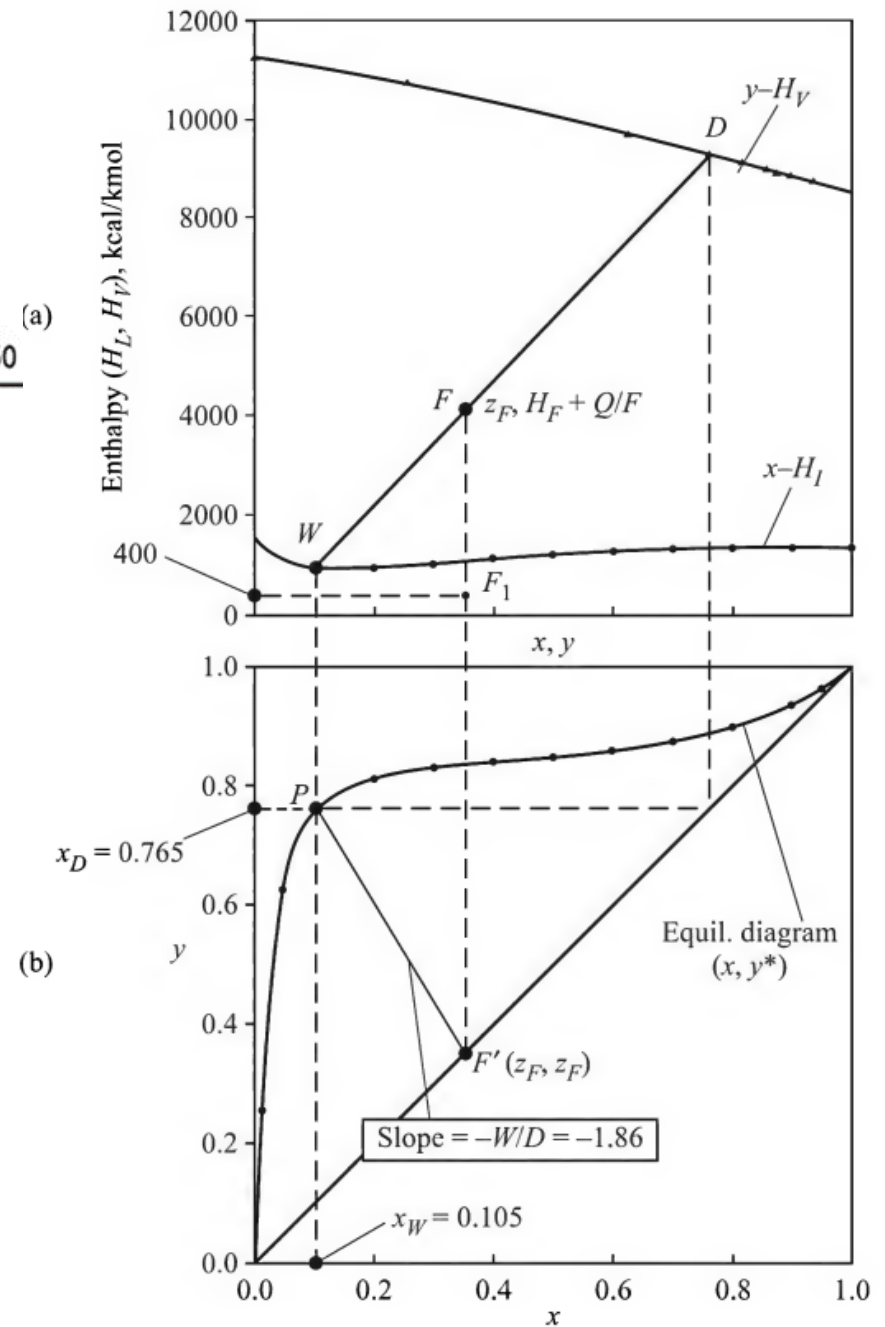
Temperature, θ (°C)	x	y^*	ΔH_s (kcal/kmol)	c_{ps} (kcal/kg·K)
56.5	1.0	1.0	0	0.54
57	0.95	0.963	0	0.56
57.5	0.90	0.935	-10.55	0.56
58.2	0.80	0.898	-23.88	0.61
58.9	0.70	0.874	-41.11	0.66
59.5	0.60	0.859	-60.3	0.70
60	0.50	0.849	-83.56	0.75
60.4	0.40	0.839	-121.5	0.80
61	0.30	0.83	-171.7	0.85
62.2	0.20	0.815	-187.7	0.91
66.6	0.1	0.755	-159.7	0.96
75.7	0.05	0.624	-106.8	0.98
91.7	0.01	0.253	-22.2	1.0
100	0.0	0.0	0	1.0

Solution:

x	1.0	0.90	0.80	0.60	0.20	0.10	0.05	0.01	0.0
y^*	1.0	0.935	0.898	0.859	0.815	0.755	0.625	0.253	0.0
H_L (kcal/kmol)	1300	1297	1294	1248	929	930	1083	1390	1530
H_V (kcal/kmol)	8500	8722	8812	8916	9056	9259	9659	10,754	11,250

$$H_L = c_{ps} M_{av} (T - T_0) + \Delta H_s$$

$$H_V = y_A^* M_A [c_{pA} (T - T_0) + \lambda_A] + (1 - y_A^*) M_B [c_{pB} (T - T_0) + \lambda_B]$$



(a) Enthalpy-concentration, and (b) equilibrium diagram of acetone-water system at 1 atm pressure.

Problem 2:

A liquid mixture containing 50 mol % n-heptane (A) and 50 mol % n-octane (B), at 30 °C, is to be continuously flash-vaporized at 1 std atm pressure to vaporise 60 mol % of the feed. What will be the composition of vapour and liquid if the vaporizer is an ideal one. The vapour pressure of A and B at 30 °C is 780 mmHg and 325 mmHg respectively.

Solution:

Batch Distillation or Differential Distillation

Total material Balance: $-dL = dD$

Component A balance: $-d(Lx) = y^*dD$

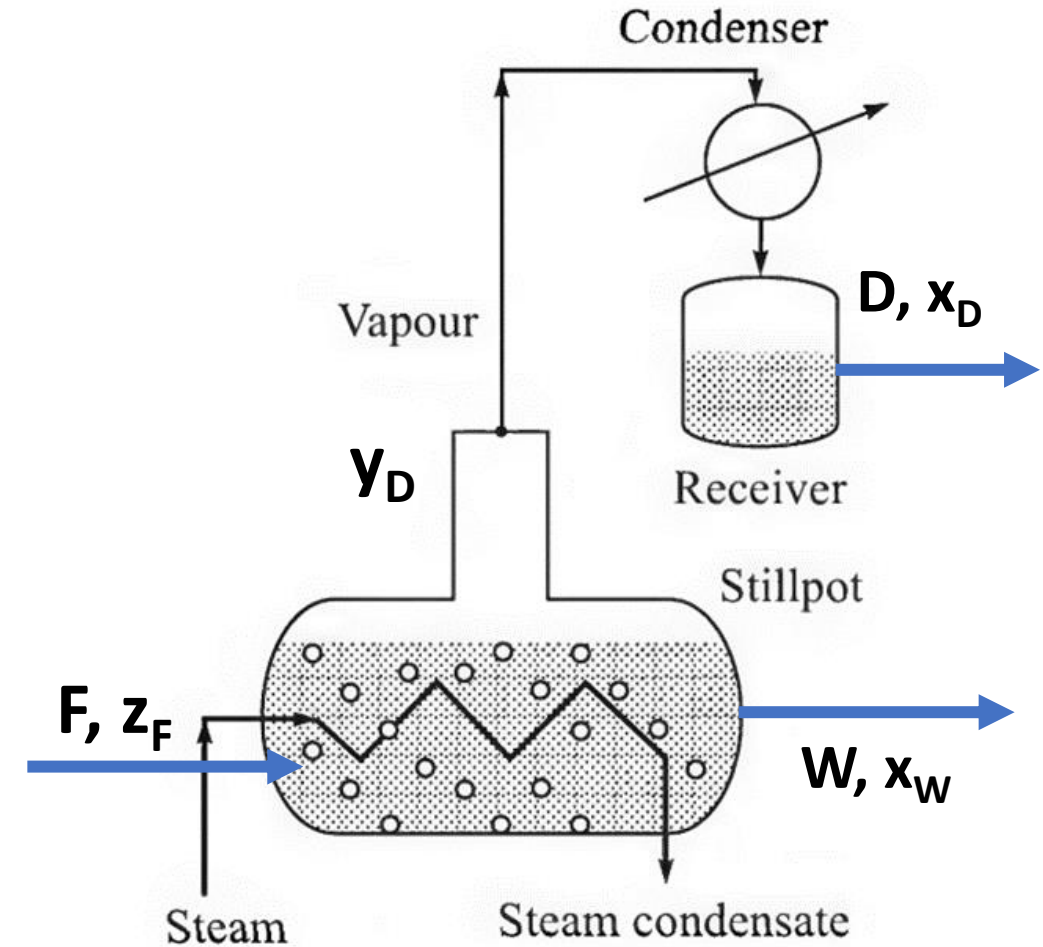
$$-Ldx = y^*dD + xdL = -y^*dL + xdL = -(y^* - x)dL$$

$$\frac{dL}{L} = \frac{dx}{y^* - x}$$

$$\int_W^F \frac{dL}{L} = \int_{x_W}^{x_F} \frac{dx}{y^* - x} \quad (\text{Rayleigh equation})$$

$$\ln \frac{F}{W} = \int_{x_W}^{x_F} \frac{dx}{\frac{\alpha x}{1 + (\alpha - 1)x} - x}$$

$$= \frac{1}{(\alpha - 1)} \ln \frac{x_F(1 - x_W)}{x_W(1 - x_F)} + \ln \frac{1 - x_W}{(1 - x_F)}$$



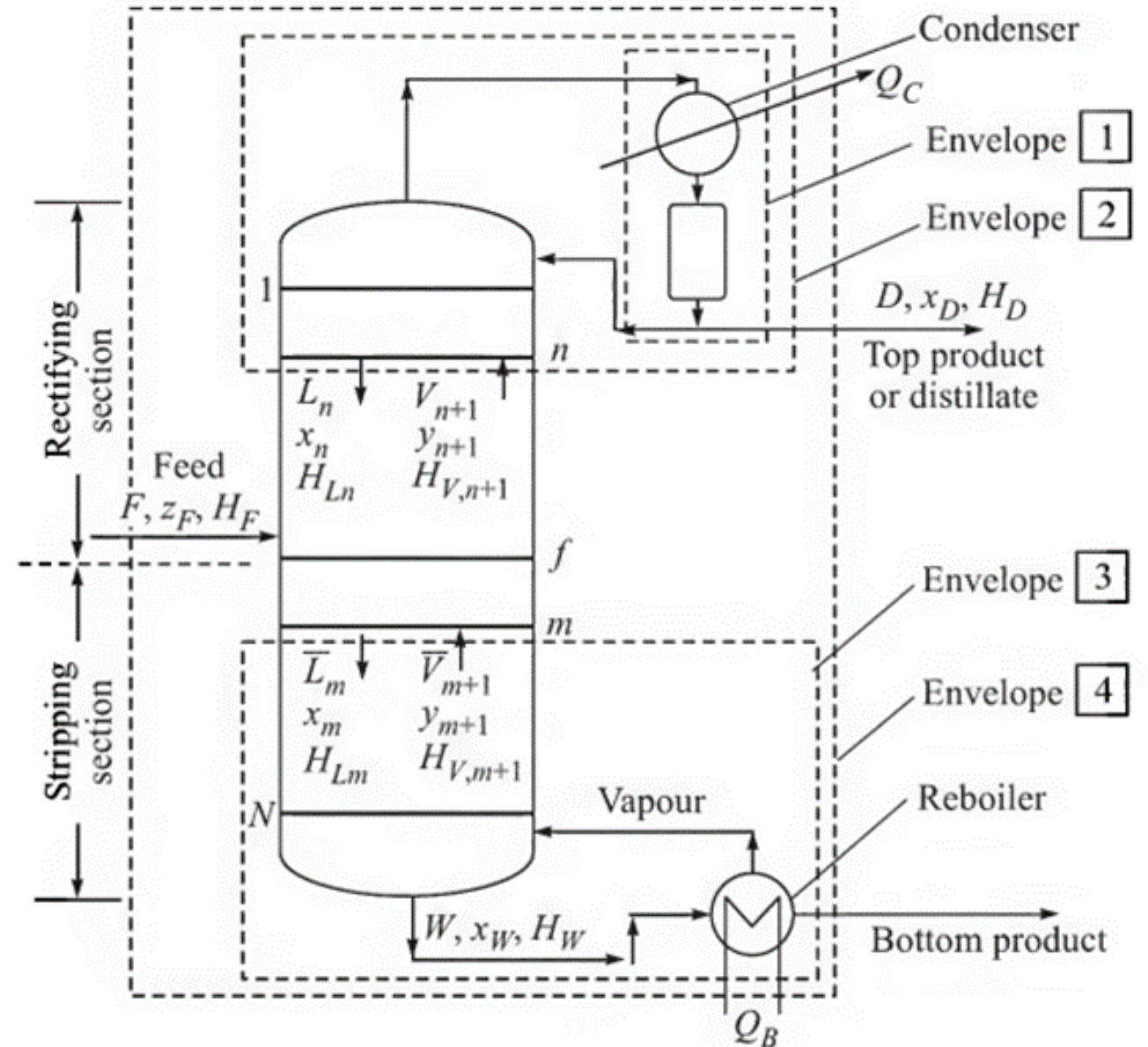
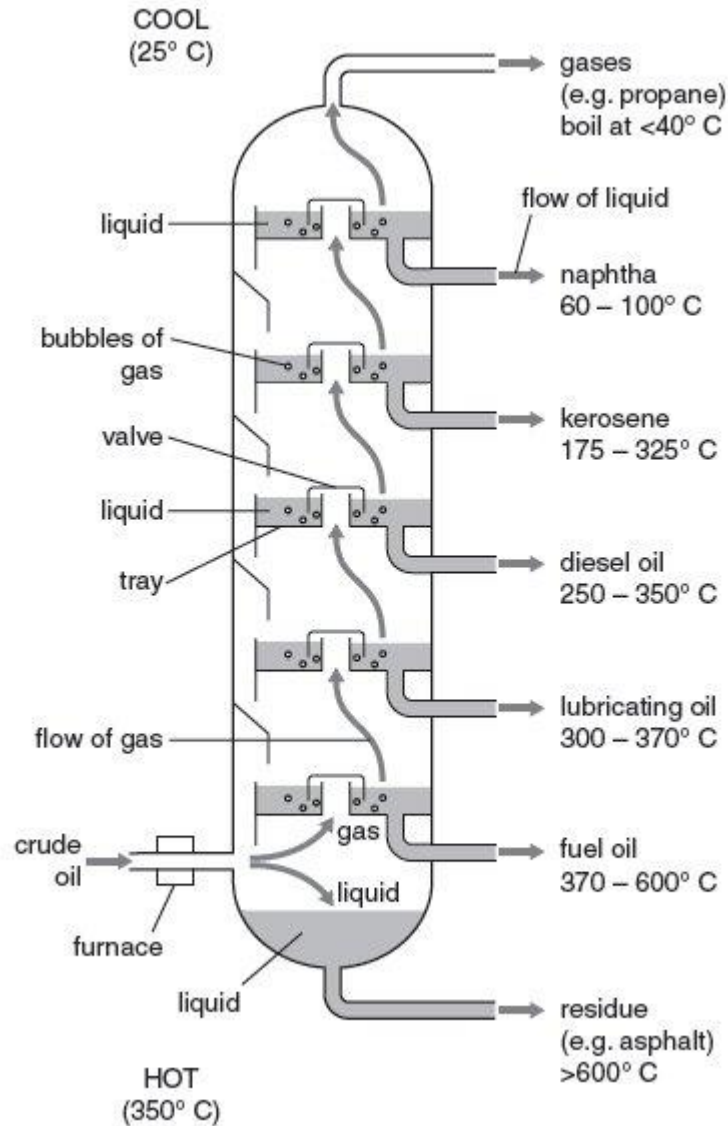
$$\log \frac{Fx_F}{Wx_W} = \alpha \log \frac{F(1-x_W)}{W(1-x_F)}$$

Problem 3:

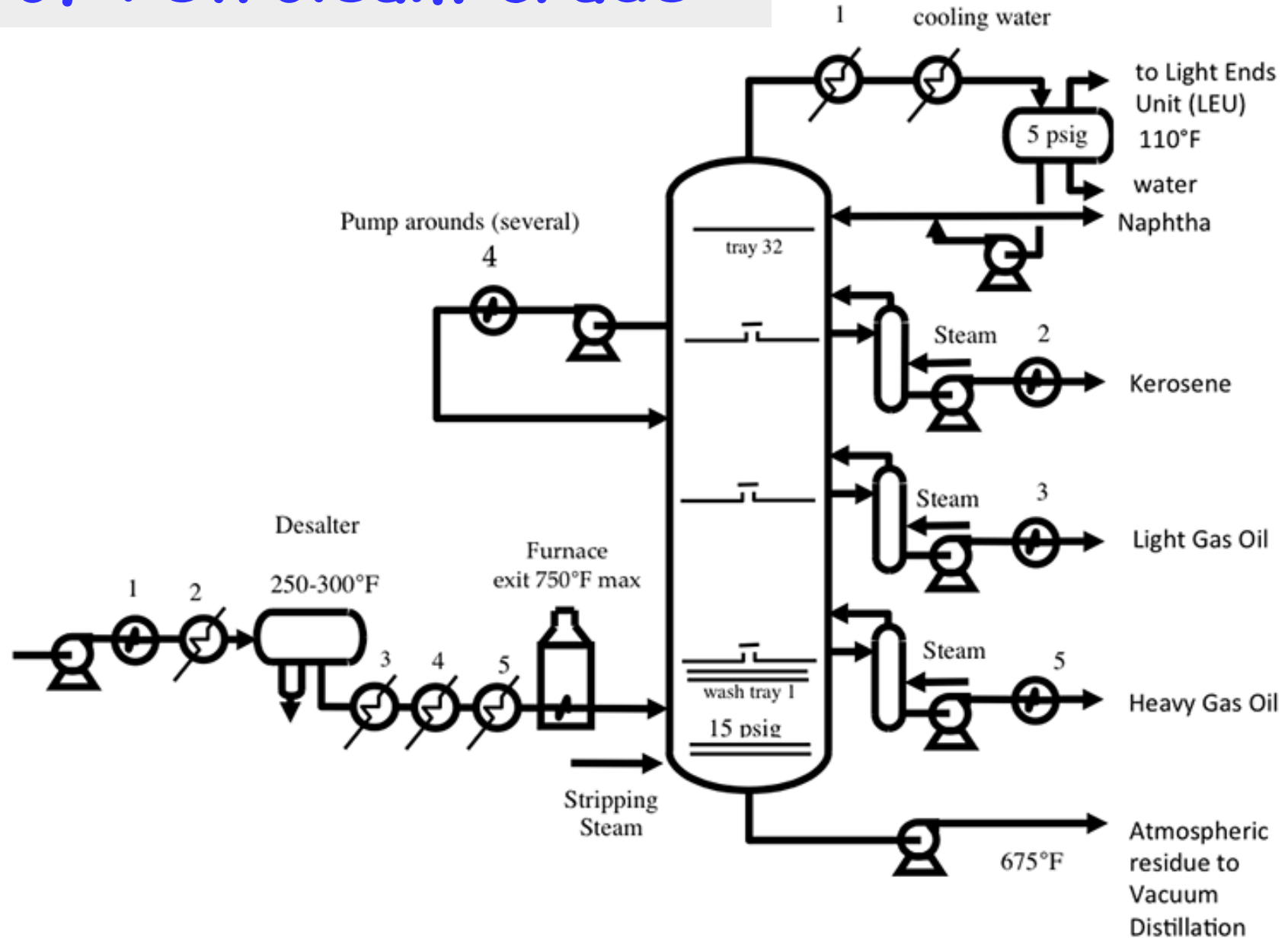
A liquid mixture containing 50 mol % n-heptane (A) and 50 mol % n-octane (B), at 30 °C, is to be subject to differential distillation at 1 std atm pressure to vaporise 60 mol % of the feed. What will be the composition of vapour and liquid if the vaporizer is an ideal one. The vapour pressure of A and B at 30 °C is 780 mmHg and 325 mmHg respectively.

Solution:

Fractional distillation



Distillation of Petroleum crude



Determination of the Number of Trays—the McCabe-Thiele Method

Assumptions:

- the molar rate of overflow of the liquid from one tray to another is constant over any section of the column.

$$L_0 = L_1 = L_2 = \dots = L_n = L$$

$$\text{Similarly, } V_0 = V_1 = V_2 = \dots = V_n = V$$

Rectifying Section/Enriching section:

$$\text{Overall balance: } V = L + D$$

$$\text{Component balance: } V \cdot y_{n+1} = L \cdot x_n + D \cdot x_D$$

$$y_{n+1} = \frac{L}{V} x_n + \frac{D}{V} x_D$$

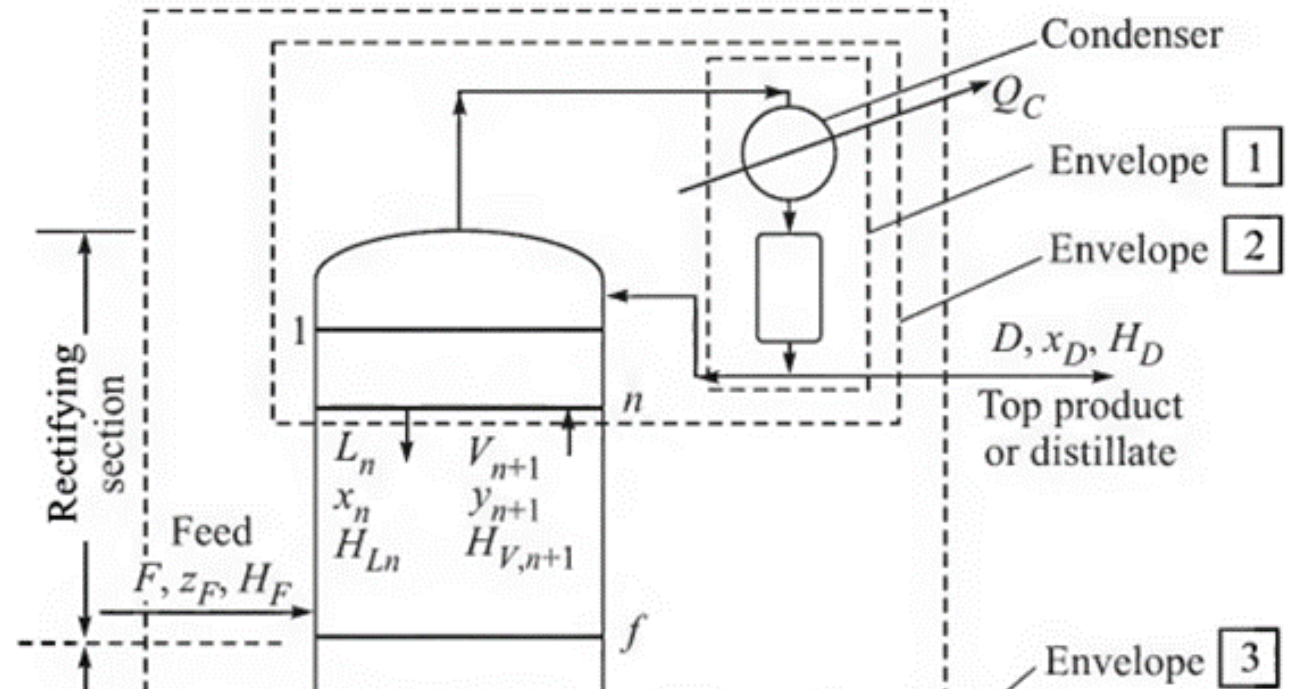
$$y_{n+1} = \frac{L/D}{V/D} x_n + \frac{1}{V/D} x_D$$

$$y_{n+1} = \frac{R}{R+1} x_n + \frac{x_D}{R+1}$$

Slope

Intercept

➤ Equation of operating line of the rectifying section



Reflux Ratio (R):

It is the ratio of the reflux fed back to the top tray and the top product withdrawn is called the reflux ratio (R).

$$R = \frac{L_0}{D} \left(\frac{\text{return}}{\text{withdraw}} \right)$$

Total Reflux: (no withdraw; **D= 0**) then

$$R \rightarrow \infty$$

Minimum Reflux: (no return; **L \rightarrow 0**)

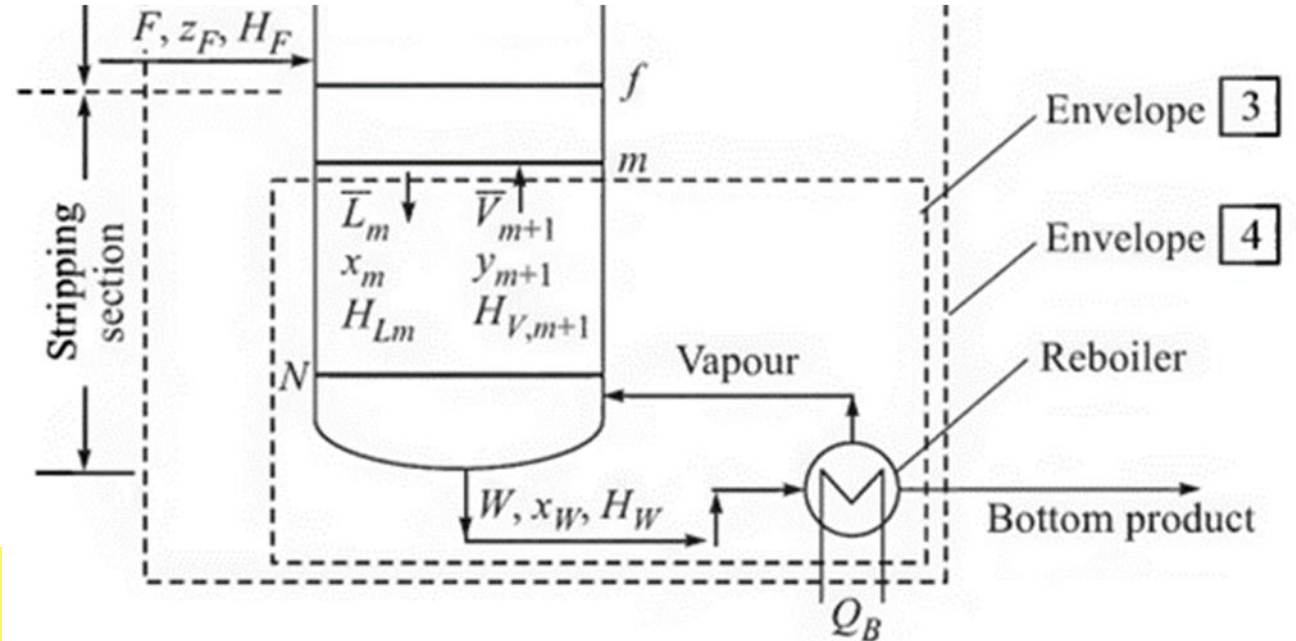
$$R \rightarrow 0$$

$$y_{n+1} = \frac{R}{R+1} x_n + \frac{x_D}{R+1}$$

Stripping Section:

$$\bar{V} = \bar{L} - W$$

➤ Operating line equation


$$R_v = \frac{\bar{V}}{W} = \frac{\text{moles of vapour leaving the reboiler per hour}}{\text{moles of liquid drawn as the bottom product per hour}}$$

Problem:

A mixture of benzene and toluene containing 40 mole% benzene is to be separated continuously in a tray tower at a rate of 200 kmol/h. The top product should have 95 mole% of benzene and the bottom must not contain more than 4 mole% of it. The reflux is a saturated liquid and a reflux ratio of 2.0 is maintained. The feed is a saturated liquid (i.e. it is at its bubble point). Obtain and plot the operating lines for the rectifying and the stripping sections on the x-y plane. What is the boil-up ratio? The vapour-liquid equilibrium data at the operating pressure of 101.3 kPa are given below.

x	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
y	0	0.21	0.38	0.511	0.627	0.719	0.79	0.853	0.91	0.961	1.0

Feed Line:

As the feed enters the column, the liquid and vapour flow rates undergo step changes depending upon the state of the feed (i.e. upon how much liquid and vapour it has). We shall now write the material and energy balance equations over the plate to which the feed is introduced.

$$F + L + \bar{V} = \bar{L} + V$$

$$FH_F + LH_{L,f-1} + \bar{V}H_{V,f+1} = \bar{L}H_{L,f} + VH_{V,f}$$

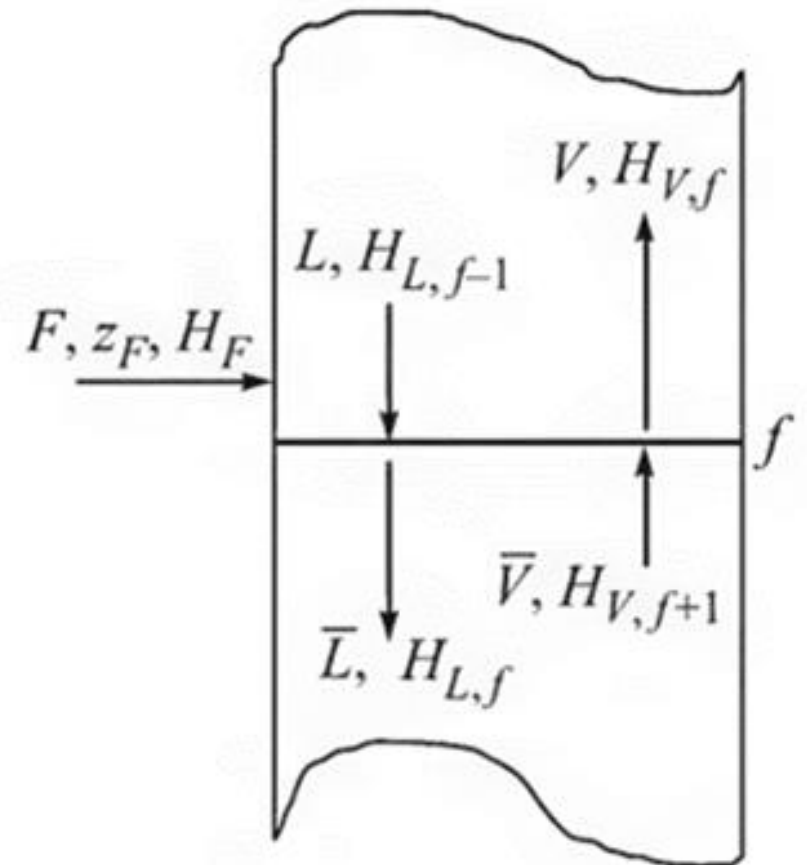
$$H_{L,f-1} \approx H_{L,f} \approx H_L, \quad H_{V,f+1} \approx H_{V,f} \approx H_V$$

$$FH_F + LH_L + \bar{V}H_V = \bar{L}H_L + VH_V$$

$$(\bar{L} - L)H_L = (\bar{V} - V)H_V + FH_F = (\bar{L} - L)H_V + (H_F - H_V)F$$

$$(\bar{L} - L)(H_L - H_V) = (H_F - H_V)F$$

$$\frac{\bar{L} - L}{F} = \frac{H_F - H_V}{H_L - H_V} = \frac{H_V - H_F}{H_V - H_L} = q$$



Feed Line:

$\bar{L} - L$ = increase in the liquid flow rate across the feed tray as a result of introduction of the feed = rate of input of liquid with the feed. So q is the fraction of liquid in the feed

$$q = \frac{\text{heat required to convert 1 mole feed to saturated vapour}}{\text{molar heat of vaporization of the saturated liquid}}$$

1. feed is a liquid at its bubble point (saturated liquid): $q = 1$;
 2. if it is a vapour at dew point (saturated vapour), $q = 0$.
 3. feed is a two-phase mixture of liquid and vapour, q represents the fraction of liquid in it.
- ❖ So $(1 - q)$ gives a measure of the 'quality' of the feed.

Feed Line:

$$Vy = Lx + Dx_D \text{(Rectifying section)}$$

$$\bar{V}y = \bar{L}x - Wx_D \text{(stripping section)}$$

$$(V - \bar{V})y = (L - \bar{L})x + (Dx_D + Wx_w) = (L - \bar{L})x + Fx_F$$

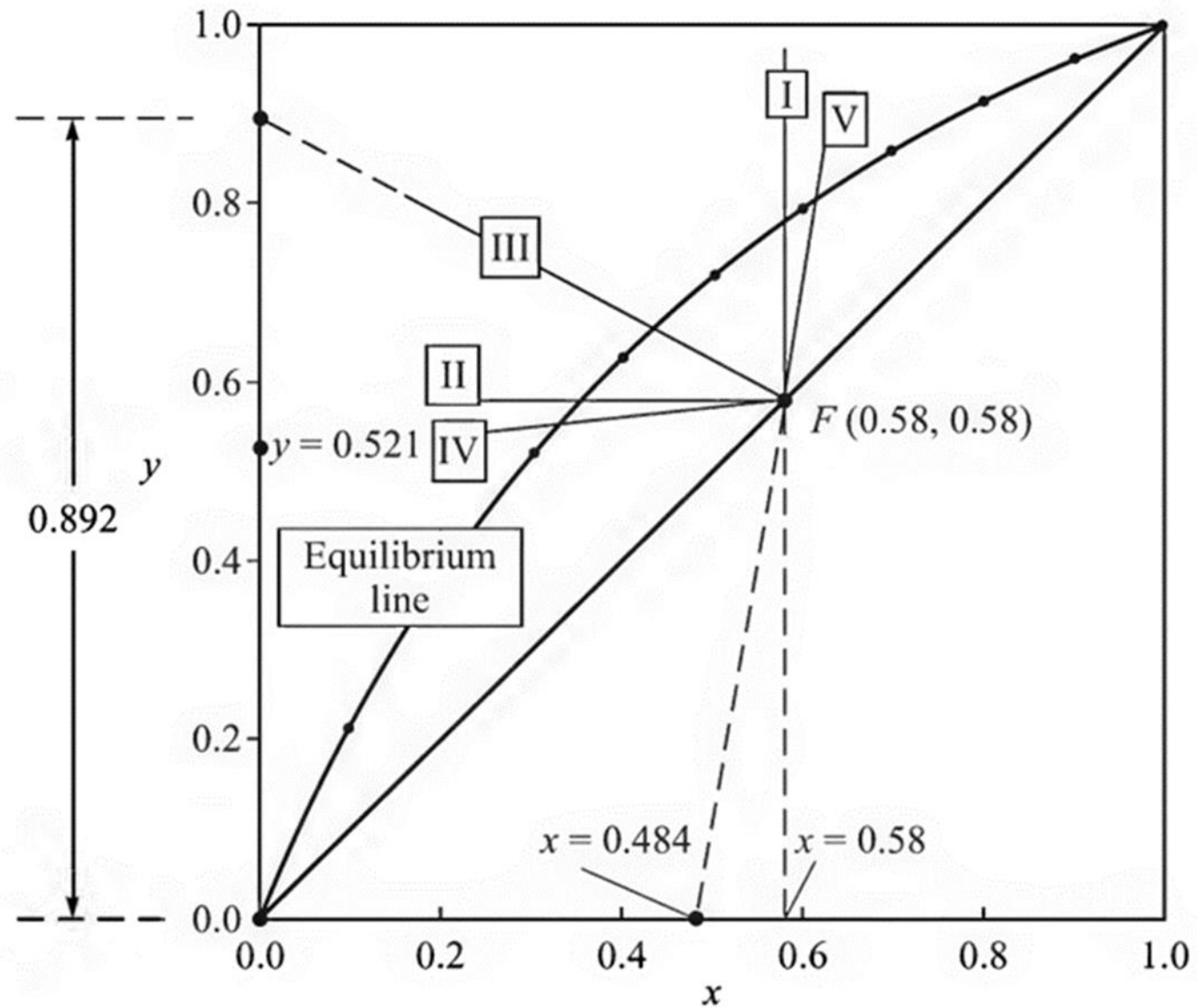
$$\frac{\bar{V} - V}{F} + 1 = \frac{\bar{L} - L}{F} = q$$

$$-(q - 1)y = -qx + x_F$$

$$y = \frac{q}{q-1}x - \frac{x_F}{Q-1}$$

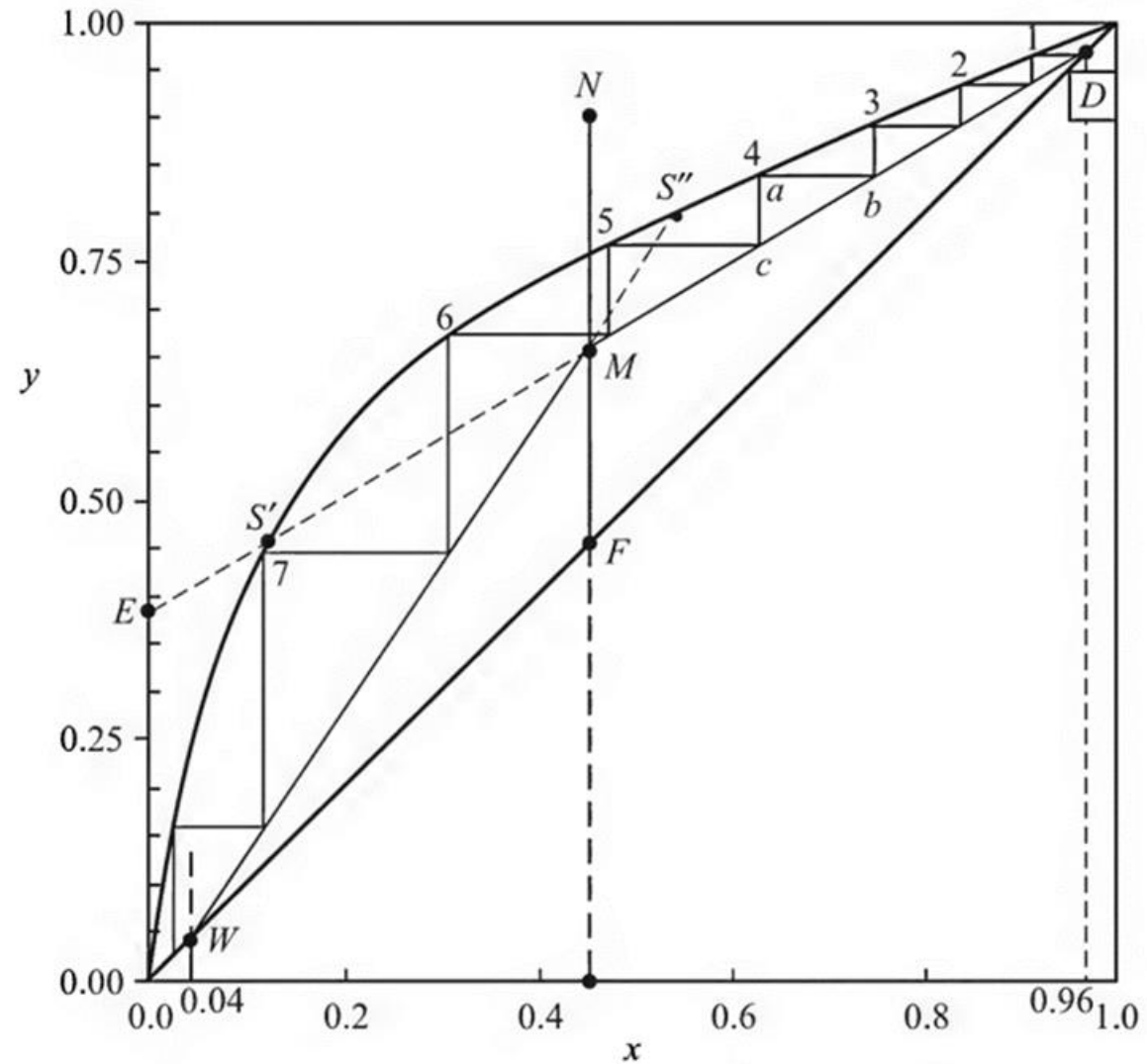
- feed is a saturated liquid, $q = 1$; and the slope of the feed line is infinite. So the feed line is a vertical line through (z_F, z_F) .
- feed is a saturated vapour, $q = 0$; and the slope of the feed line is zero. So the feed line is a horizontal line through (z_F, z_F) .
- feed is a mixture of liquid and vapour or a superheated vapour or a subcooled liquid, the slope of the feed line can be calculated from the enthalpy data

Feed Line:



Feed lines for different conditions of the feed: (I) saturated liquid, (II) saturated vapour, (III) two-phase mixture, (IV) superheated vapour, and (V) subcooled liquid.

Graphical Representation of McCabe –Thiele Method: Number of ideal tray calculation

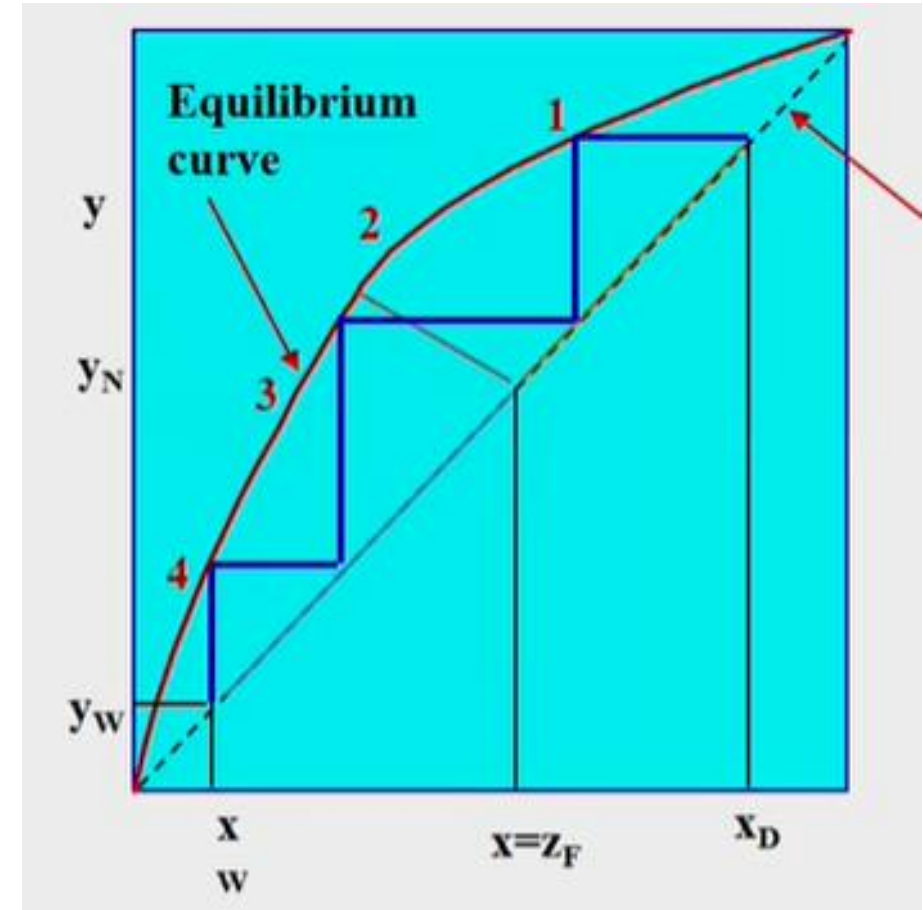


McCabe–Thiele construction for the number of ideal trays.

Minimum Number of trays

Total Reflux

- Reflux ratio becomes
$$R = L_o/D = L_o/0 = \text{infinity}$$
- No product is drawn from the reboiler either
- All the liquid following to the reboiler is vaporized and feed back to the column
- So in a column operating at total reflux under steady state conditions, there should not be flow of feed into it.
- Recycling all exiting vapour as reflux and all exiting liquid as boil up. **Operating line has slope of one.**
- No product is produced: feed must then go to zero.



Fenske's Equation (Minimum number of trays by Analytical Method)

$$\frac{y_W}{1-y_W} = \alpha_W \frac{x_W}{1-x_W}$$

The vapour leaving the reboiler and entering the lowest tray (tray number N_m in this case) has a mole fraction y_w of the component A. The liquid leaving this tray has a composition x_{Nm} . So the point (x_{Nm}, y_w) lies on the operating line. Because the operating line coincides with the diagonal at total reflux, $x_{Nm} = y_w$

$$\frac{x_{Nm}}{1-x_{Nm}} = \alpha_W \frac{x_W}{1-x_W}$$

Now for N_m trays

$$\frac{y_{Nm}}{1-y_{Nm}} = \alpha_{Nm} \frac{x_{Nm}}{1-x_{Nm}} = \alpha_{Nm} \alpha_W \frac{x_W}{1-x_W}$$

Similarly, for $(N_m - 1)$ trays

$$\frac{y_{(Nm-1)}}{1-y_{(Nm-1)}} = \alpha_{(Nm-1)} \frac{x_{(Nm-1)}}{1-x_{(Nm-1)}} = \alpha_{(Nm-1)} \alpha_{Nm} \alpha_W \frac{x_W}{1-x_W}$$

[Note that the point $(x_{(Nm-1)}, y_{Nm})$ lies on the operating line which coincides with the diagonal; therefore, $x_{Nm-1} = y_{Nm}$]

Continuing the procedure up to the top tray (where $y_1 = x_D$)

$$\frac{x_D}{1-x_D} = \frac{y_1}{1-y_1} = \alpha_1 \alpha_2 \dots \alpha_{Nm} \alpha_W \frac{x_W}{1-x_W}$$

$$\frac{x_D}{1-x_D} = \frac{y_1}{1-y_1} = (\alpha_{av})^{N_m + 1} \cdot \frac{x_W}{1-x_W}$$

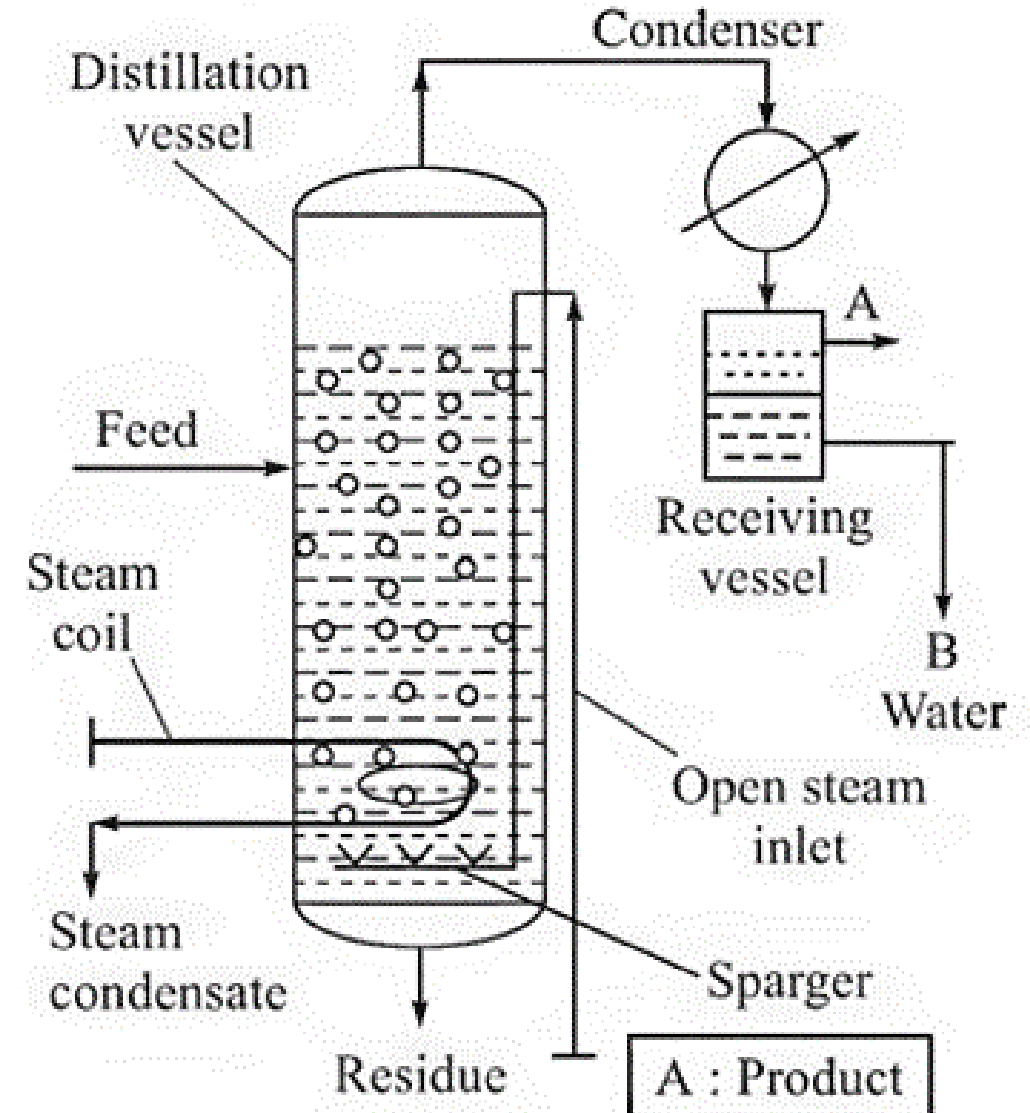
$$N_m + 1 = \frac{\log \frac{x_D(1-x_W)}{x_W(1-x_D)}}{\log \alpha_{av}}$$

Fenske's Equation

Steam Distillation:

❖ Component are not miscible to each other

- Separation of a high boiling material from a solution.
Examples: decolourization/ deodorization of vegetable oils, recovery and purification of essential oils
- Separation and purification of hazardous and inflammable substances like turpentine
- Separation of a thermally unstable substance from a mixture
- Separation of volatile impurities from waste water.
Examples: removal of ammonia, volatile organic compounds (VOCs) like halogenated hydrocarbons from waste water



Steam Distillation:

Case 1: The substance A is **immiscible** with water. The feed contains A and traces of nonvolatile impurities.

$$P_{\text{t}} = P_A + P_B$$

Here partial pressure of a substance is same as vapour pressure

❖ If m_A moles of substance volatilized out by putting in m_B moles of steam and if the system is operated at equilibrium then

$$\frac{m_A}{m_B} = \frac{P_A}{P_B} = \frac{P_A}{1 - P_A}$$

$$m_A = m_B \frac{P_A}{1 - P_A}$$

❖ if the system does not operate at equilibrium, the partial pressure of A will be less than its vapour pressure. To take into account such a deviation, we define a factor called **vaporizing efficiency E** of the product such that the partial pressure of A in the steam phase is $p_A = EP_A$

$$m_A = m_B \frac{EP_A}{1 - EP_A}$$

$$E \sim 0.6 - 0.9$$

Steam Distillation:

Case 2: The feed is a mixture of A and C; C is an essentially non-volatile substance. A and C form an ideal solution and are immiscible with water

If the moles of A in the still at any time t is m_A , its mole fraction in C is

$$x_A = \frac{m_A}{m_A + m_C}$$

Partial pressure of A in the vapour: $p_A = E x_A P_A$

Moles of A per mole of steam:

$$\frac{p_A}{P_B} = \frac{E x_A P_A}{P_t - E x_A P_A}$$

If \dot{m}_B^* is the rate of supply of steam, the rate of volatilization of A; then

$$\frac{dm_A}{dt} = \dot{m}_B^* \frac{p_A}{P_B} = \dot{m}_B^* \frac{E x_A P_A}{P_t - E x_A P_A}$$

Integrating from $t = 0, m_A = m_{Ai}$; to $t = t, m_A = m_{Af}$

$$- \int_{m_{Ai}}^{m_{Af}} \left[P \left(1 + \frac{m_C}{m_A} \right) - E P_A^v \right] dm_A = E \dot{m}_B P_A^v \int_{t=0}^t dt$$

$$\left(\frac{P}{E P_A^v} - 1 \right) (m_{Ai} - m_{Af}) + \frac{P m_C}{E P_A^v} \ln \frac{m_{Ai}}{m_{Af}} = \dot{m}_B t = \text{total steam required}$$

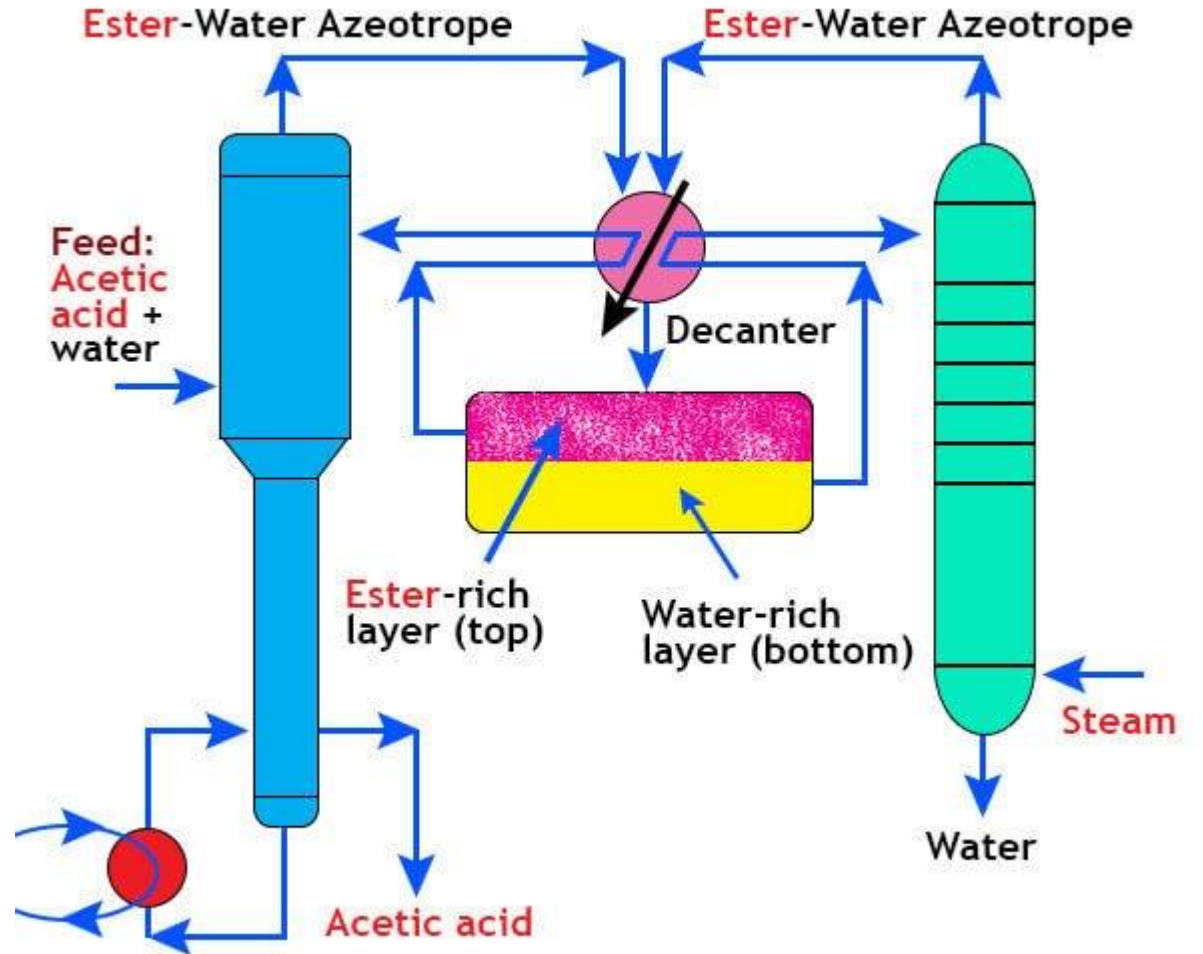
Problem: Geraniol ($C_{10}H_{18}O$) is an essential oil of commercial value. It is conventionally purified by steam distillation. A pilot scale unit is charged with 0.5 kg of crude geraniol containing a small amount of non-volatile impurities. Live saturated steam at 105°C is passed through the still at a rate of 20 kg/h. Calculate the distillation time assuming that geraniol is immiscible with water. Neglect condensation of steam. The vaporization efficiency is 0.8. Vapour pressure of water at 105°C is 1.211 bar and that of geraniol(A) is given by

$$\ln P_A = 21.1 - 7217/T; \quad P_A \text{ is in mmHg and } T \text{ in K}$$

Azeotropic Distillation

Component	Boiling Point (°C)
Water (A)	100.0
Acetic Acid (B)	118.1
N-butyl acetate (E)	125.0
Min. Azeotrope (A-E)	90.2

Component	Boiling Point (°C)
Ethanol (A)	78.3
Water (B)	100.0
Original azeotrope (A-B) (89.4%, 10.6%)	78.2
Benzene (E)	80.2
Min. Azeotrope (A-B-E) (22.8%, 23.3%, 53.9%)	64.86

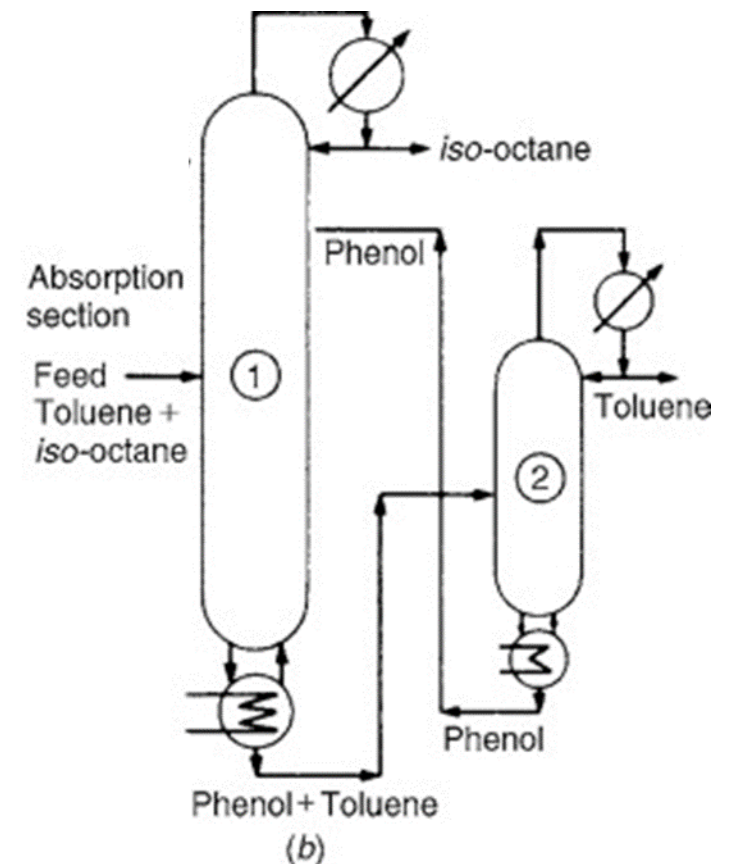


Extractive Distillation:

Extractive distillation is an effective separation technique for azeotrope mixtures or close boiling point mixture.

- A polar solvent, entrainer or separating agent with high boiling point is added to interact with the components in the azeotropic or close-boiling mixtures.
- Solvent will not form azeotropes with the other components in the mixture

Component	Boiling Point (°C)
toluene (A)	110.8
Iso-octane (B)	99.3
Phenol (E)	181.4



Extractive Distillation:

■ Butadiene separation from C₄-stream of naphtha cracker

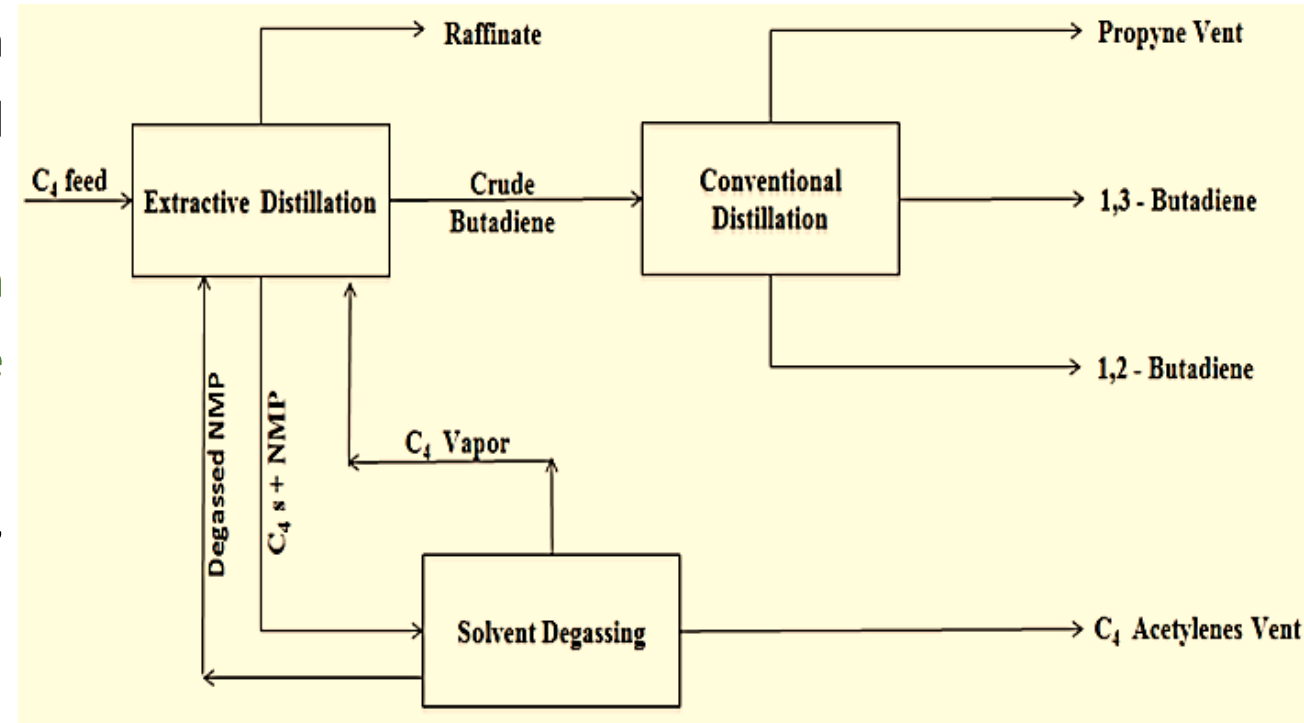
- ❑ **Butadiene** is a byproduct of the steam cracking process used to produce ethylene and other alkenes.
- ❑ **Aliphatic hydrocarbons** mixed with steam at high temperatures (900 °C), produce a complex mixture of unsaturated hydrocarbons, including butadiene.
- ❑ Heavier feeds favor the formation of heavier olefins, **butadiene**, and aromatic hydrocarbons

Feed (C₄):

- Butanes, butene, **butadiene (40-50%)**, C3 acetylene and C4 acetylenes

Entrainer (Solvent):

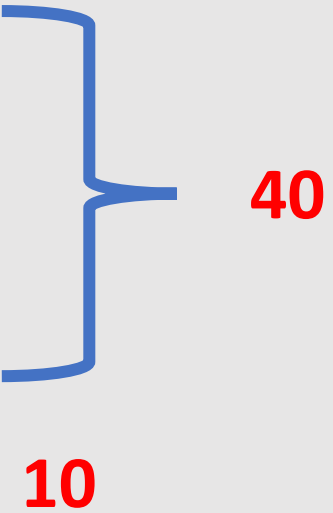
- N –methyl–2–pyrrolidone (NMP), acetonitrile, dimethylacetamide, dimethyl-formamide



Comparison between Extractive Distillation and Azeotropic Distillation:

Extractive Distillation	Azeotropic Distillation
It is a method used to separate the mixture which component boiling point is very close to each other	It is a method used to separate azeotropic mixture
Solvent with higher boiling point is used to create a difference of relative volatility between the component mixture	Entrainer used to form a new lower boiling azeotrope with one or more component of the feed
Helps to enhance the separation of components with similar boiling point that may not form azeotrope	The primary objective is to break the azeotrope
More versatile and can be used to improve the separation of wide range of mixtures with components having similar boiling point	Specially design for azeotropic mixtures and may not be as versatile when applied to other type of mixtures
Example- Butadiene extraction from butane, butene and other unsaturated hydrocarbon	Example- dehydration of ethanol

End Semester Syllabus (50 marks)

- Gas-liquid Contactors
 - Absorption
 - Distillation
 - Crystallization
- 
- 40
- 10

Thank You