Absorption

Outcomes:

➤ Phase equilibrium curve

➤ Calculate flows and composition in single and multiple equilibrium contact stages by using both an equilibrium relationship and a material balance

➤ Use analytical and graphical techniques to calculate the number of stages needed for either an absorber or stripper

➤ Estimate tray efficiency from correlations of mass-transfer coefficients

➤ Using two-film theory State the differences between loading point and flooding point in a packed column

➤ Estimate the pressure drop across a trayed and packed column and column diameter

➤ Calculate, for a packed column, the number of theoretical plates/stages; then, explain its difference from the number of transfer units

What is Absorption (Gas)?

Gas absorption is a mass transfer operation in which one or more species (solute) is removed from a gaseous stream by dissolution in a liquid (solvent).

The insoluble component(s) present in the gas which is not absorbed is called the **carrier gas**.

Example: Removal of H_2S from natural gas using a suitable solvent such as an aqueous solution of an alkanolamine, H_2S is the solute, natural gas is the carrier and aqueous alkanolamine is the solvent.

In **stripping (desorption)**, a liquid mixture is contacted with a gas to selectively remove components by mass transfer from the **liquid to the gas phase**.
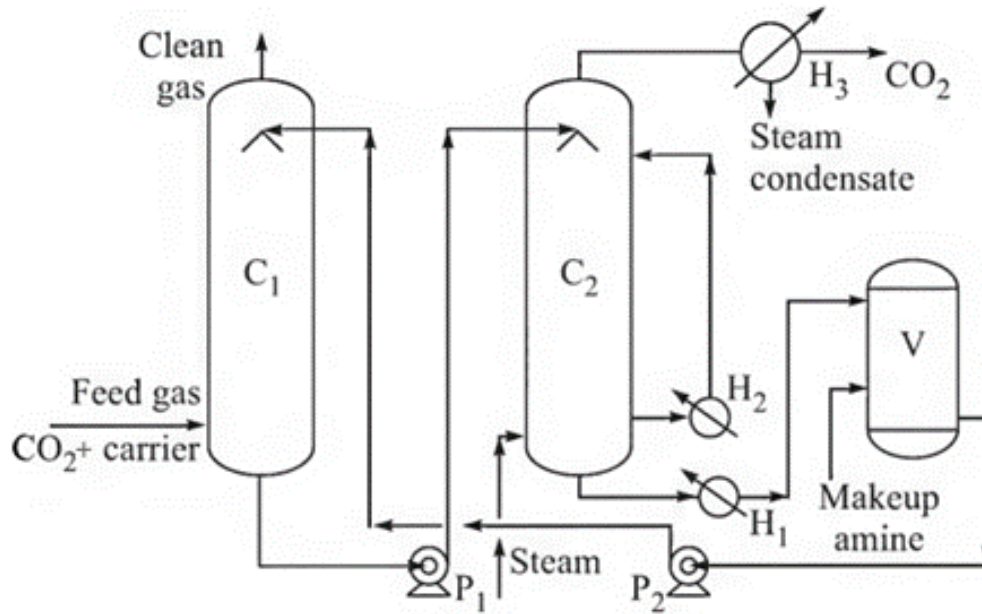

Absorption   Vs   Adsorption
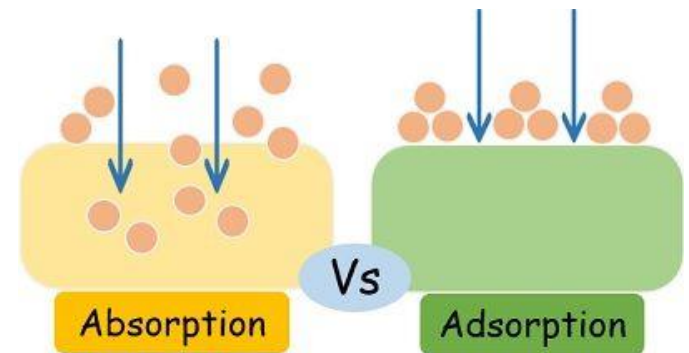
Examples:

Table 6.1 Examples of industrial gas absorption processes   **B.K.D chapter 6,**

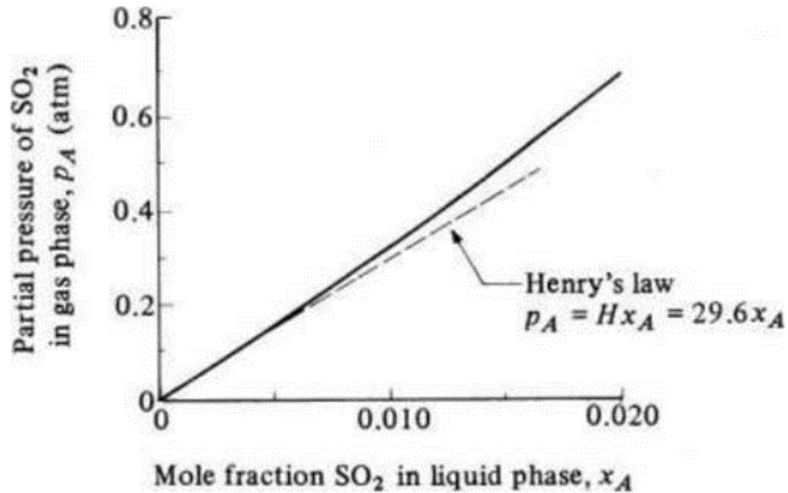|	Example	Industry/Purpose	Solvent
1.	Absorption of SO_3	Production of sulphuric acid and oleum	98% H_2SO_4/Concentrated H_2SO_4
2.	Absorption of H_2S	Treatment of sour natural gas	Mono- or diethanol amine
3.	Drying of a gas	Air for sulphur burning	Concentrated H_2SO_4
		Drying of natural gas	Di- and tri-ethylene glycol
4.	Absorption of ammonia	Ammoniation of brine in a soda ash plant	Brine
		Ammonia removal/recovery from the coke oven gas	Water or dilute H_2SO_4
5.	Absorption of SO_2 from flue gases	Pollution abatement	Lime slurry
6.	Absorption of NO_2	Nitric acid manufacture	Water
7.	Absorption of acrylonitrile	Manufacture of acrylonitrile by ammoxidation of propylene	Water
8.	Absorption of oxygen from air	Aerobic bioreactor	Fermentation broth, Waste water
9.	Absorption of ethylene oxide	Ethylene oxide manufacture	Water
10.	Absorption of HF	Pollution control in phosphoric acid and phosphatic fertilizer plants	Water, dilute alkali
11.	Absorption of HCl gas	Hydrochloric acid production	Water
12.	Absorption of CO_2	CO_2 removal from the synthesis gas in an ammonia plant	Aqueous alkanolamines, Sodium carbonate-bicarbonate buffer solution with a dissolved catalyst
13.	Absorption of light hydrocarbons	Refineries	Absorption oil
14.	Absorption of formaldehyde and methanol	Production of formaldehyde by air-oxidation of methanol	Water
15.	Absorption of aromatics (benzene, naphthalene, etc.)	Recovery of the substances from raw coal gas	Absorption oil

Example:

Clean gas

H_3 CO_2

Steam condensate

C_1

C_2

V

Feed gas
CO_2+ carrier

H_2

Makeup amine

P_1 Steam P_2

H_1

Equilibrium Between Phases:

Air + SO_2
y_A
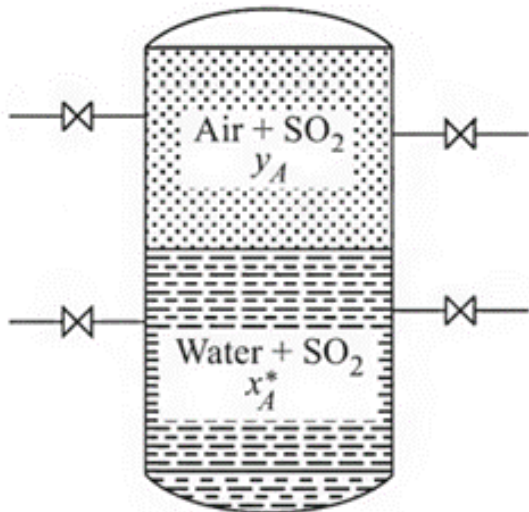
Water + SO_2
x_A^*

Phase rule:

$$F = C - P + 2$$

Equilibrium Curve

Equilibrium plot for SO_2–water system at 20°C

$$p_A = Hx_A = 29.6x_A$$

Henry's law
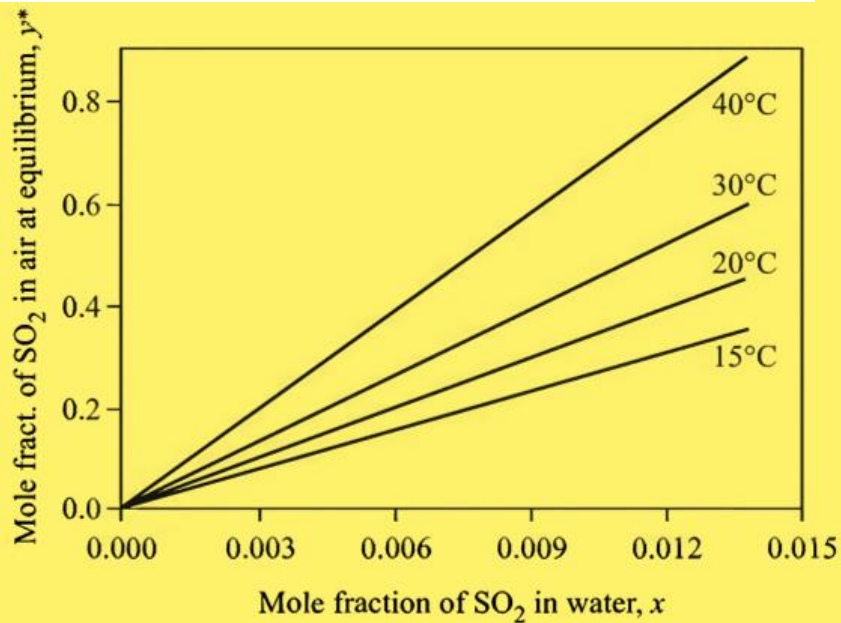
Equilibrium plot for SO_2–water system at different temperature
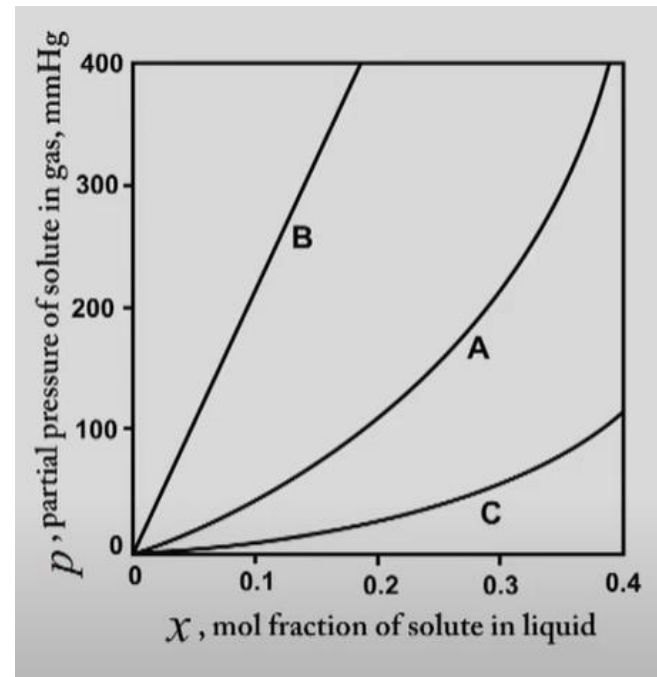
Solubility of Ammonia in water at 30 °C

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

$$p*_A = x_A P_A$$

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

A solution behaves ideally when

(a) the solute and the solvent molecules have similar sizes and similar intermolecular forces

(b) the excess volume of mixing is zero, and

(c) the heat of mixing is zero when both the solute and the solvent are liquids. When the solute is a gas, the heat of mixing is equal to the heat of condensation for a gas solute and liquid solvents.

❖ Most solutions are, however, non-ideal. There are some solutions which are nearly ideal in their behaviour. (Chlorobenzene and bromobenzene, benzene and toluene, n-butyl chloride and n-butyl bromide, methanol and ethanol)

Henry's Law: (Non-ideal gas-liquid system)

$$p^*_A = Hx_A$$

H is the Henry's law constant, atm/mole

Temp. ↑ - H ↑

$$y_A = H'x_A$$

H' is the Henry's law constant, gas mole fraction/ liquid mole fraction

H' depends on total pressure
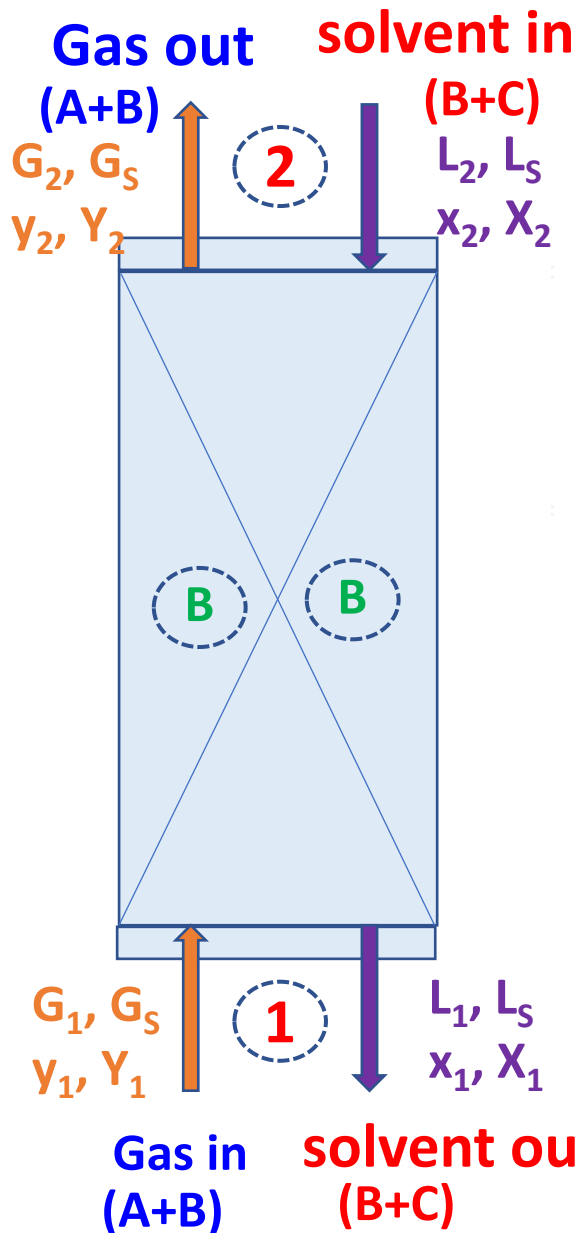
$$p^*_A = H^*C_A$$

Selection of Solvent

- Solubility
- Volatility
- Viscosity
- Corrosiveness
- Cost
- Hazard and toxicity
- Stability and inertness
- Low foaming proclivities
- Availability

Different type of Absorbent/Solvent

Solute	Absorbent	Type of Absorption
Acetone, Acrylonitrile, Ammonia, Ethanol, Formaldehydes,	Water	Physical
Hydrochloric acid, Hydrofluoric acid, Sulfur dioxide, Sulfur trioxide,	Water	Physical
Benzene, Toluene, Butadiene, Butanes, Propane, Naphthalene	Hydrocarbon oil	Physical
Hydrochloric acid, Hydrofluoric acid, Hydrocyanic acid, Hydrogen sulfide	Aqueous NaOH	Irreversible chemical
Chlorine	Water	Reversible chemical
Carbon monoxide	Aq. Cuprous Ammonium salt	Reversible chemical
CO_2 and H_2S	MEA or DEA	Reversible chemical
CO_2 and H_2S	DEG or TEG	Reversible chemical
Nitrogen oxides	Water	Reversible chemical

Counter current flow absorption:

Gas out (A+B)
G_2, G_S
y_2, Y_2

②

solvent in (B+C)
L_2, L_S
x_2, X_2

B **B**

G_1, G_S
y_1, Y_1

①

L_1, L_S
x_1, X_1

Gas in (A+B)

solvent out (B+C)

Assumption:
No solvent evaporation, isothermal process

Notations

G_1 = Rate of input of phase G at section 1, mol/time
G_2 = Rate of output of phase G at section 2, mol/time
G_s = Rate of flow of phase G on *solute-free basis*, mol/time
G = Rate of flow of phase G at any section, mol/time
y_1, y_2, y = Mole fractions of the solute in phase G at respective sections
Y_1, Y_2, Y = Mole ratios of the solute in phase G at respective sections
L_1 = Rate of output of phase L at section 1, mol/time
L_2 = Rate of output of phase L at section 2, mol/time
L_s = Rate of flow of phase L on *solute-free basis*, mol/time
L = Rate of flow of phase L at any section, mol/time
x_1, x_2, x = Mole fractions of the solute in phase L at respective sections
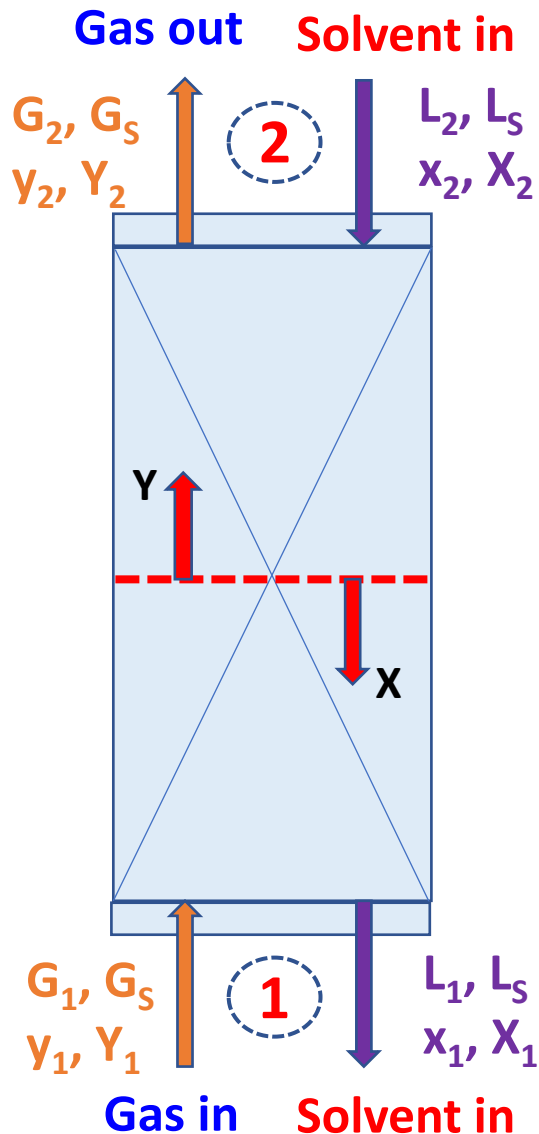X_1, X_2, X = Mole ratios of the solute in phase L at respective sections

$$Y = \frac{y}{1-y} \qquad X = \frac{x}{1-x}$$

$$G_s = \frac{G}{1+y} \qquad L_s = \frac{L}{1+x}$$

Operating line equation for counter current flow absorption:

Materials Balance:

$$G_s Y_1 + L_s X_2 = G_s Y_2 + L_s X_1$$

$$G_s(Y_1 - Y_2) = L_s (X_1 - X_2)$$

Slope

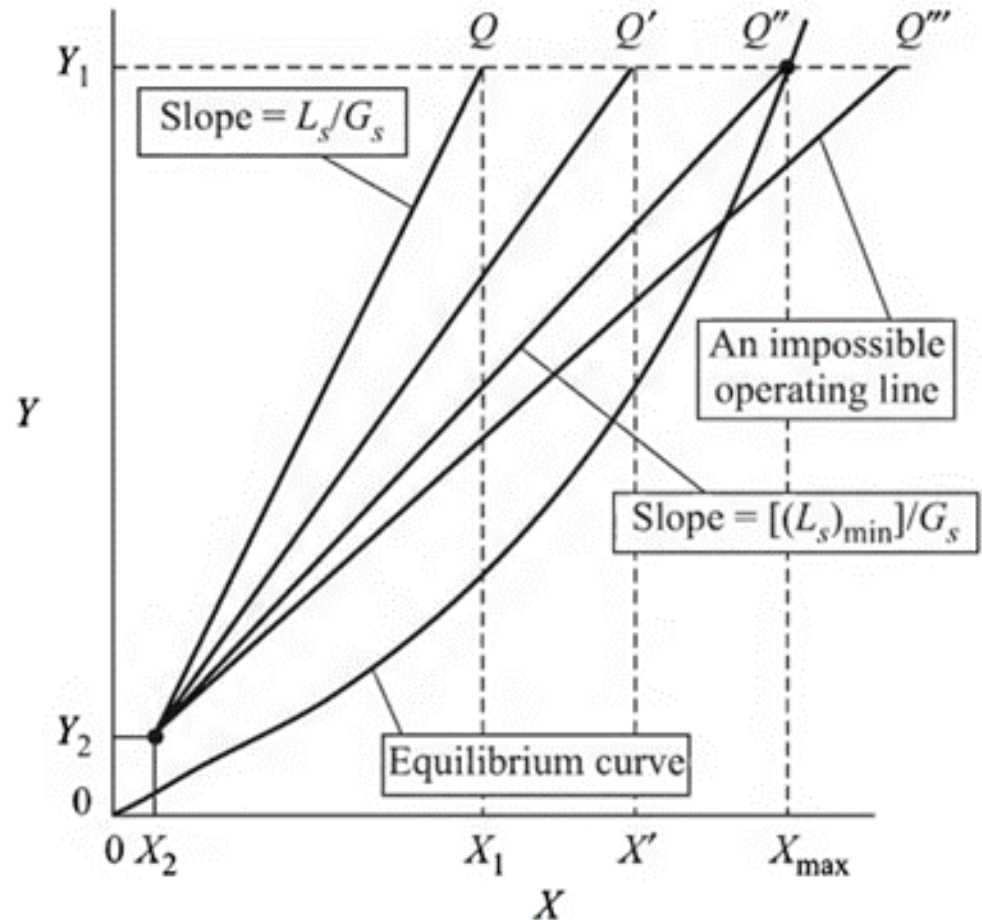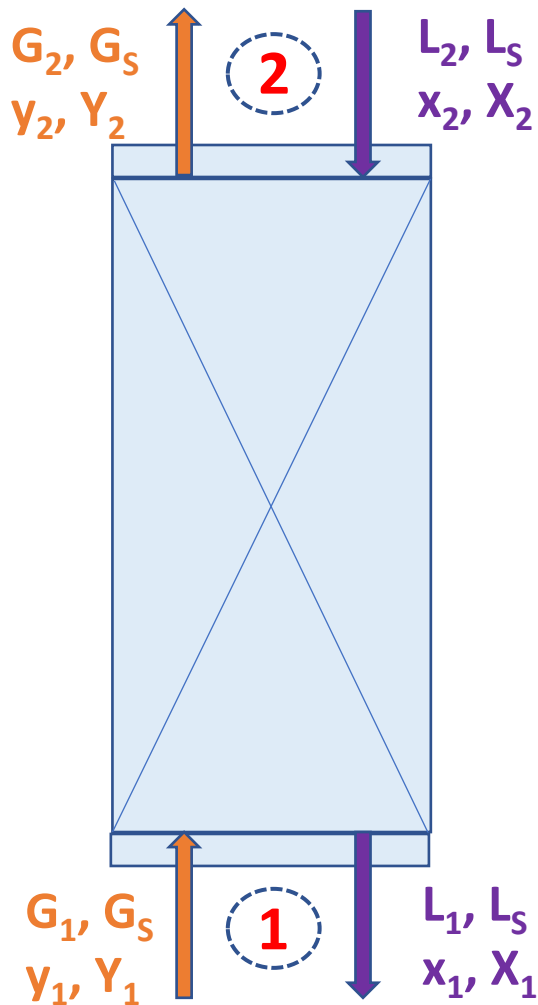$$Y_1 = \frac{L_s}{G_s}(X_1 - X_2) + Y_2$$

Operating line equation:

$$G_s(Y - Y_2) = L_s (X - X_2)$$

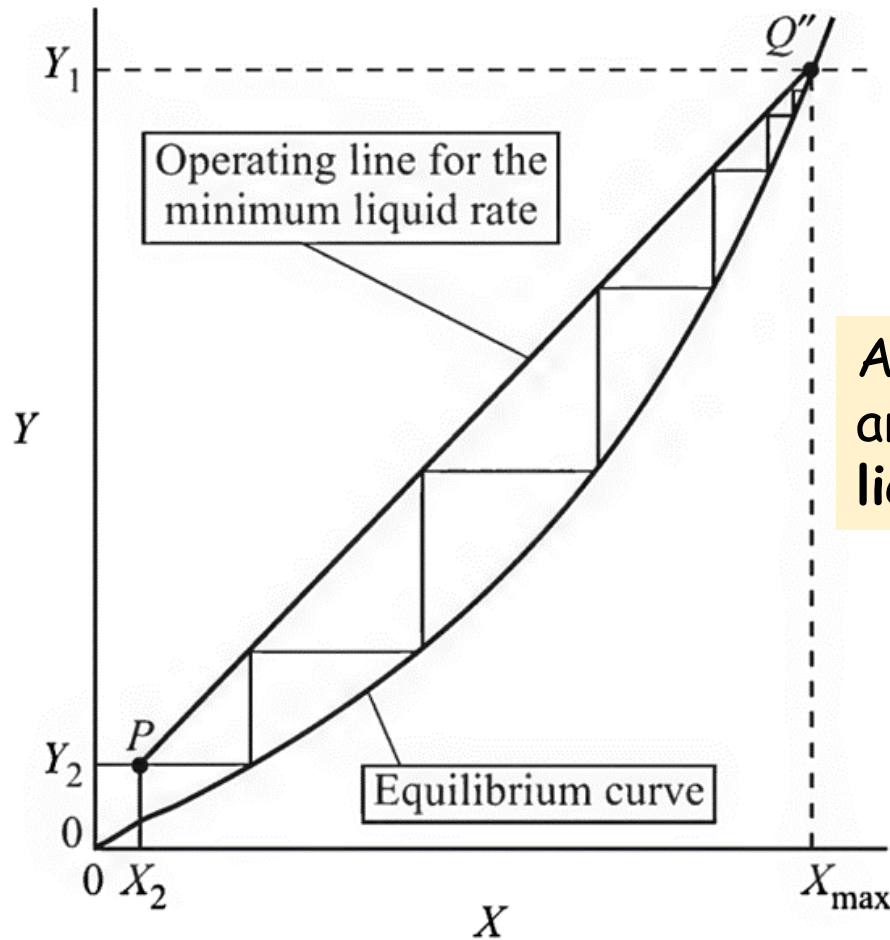$$Y = \frac{L_s}{G_s}(X - X_2) + Y_2$$

$$\text{Slope} = \frac{L_s}{G_s}$$

❖ **Significant:** It tells about the variation of composition at different position of the column

Graphical Representation of Operating line and Minimum Liquid Rate for Absorption
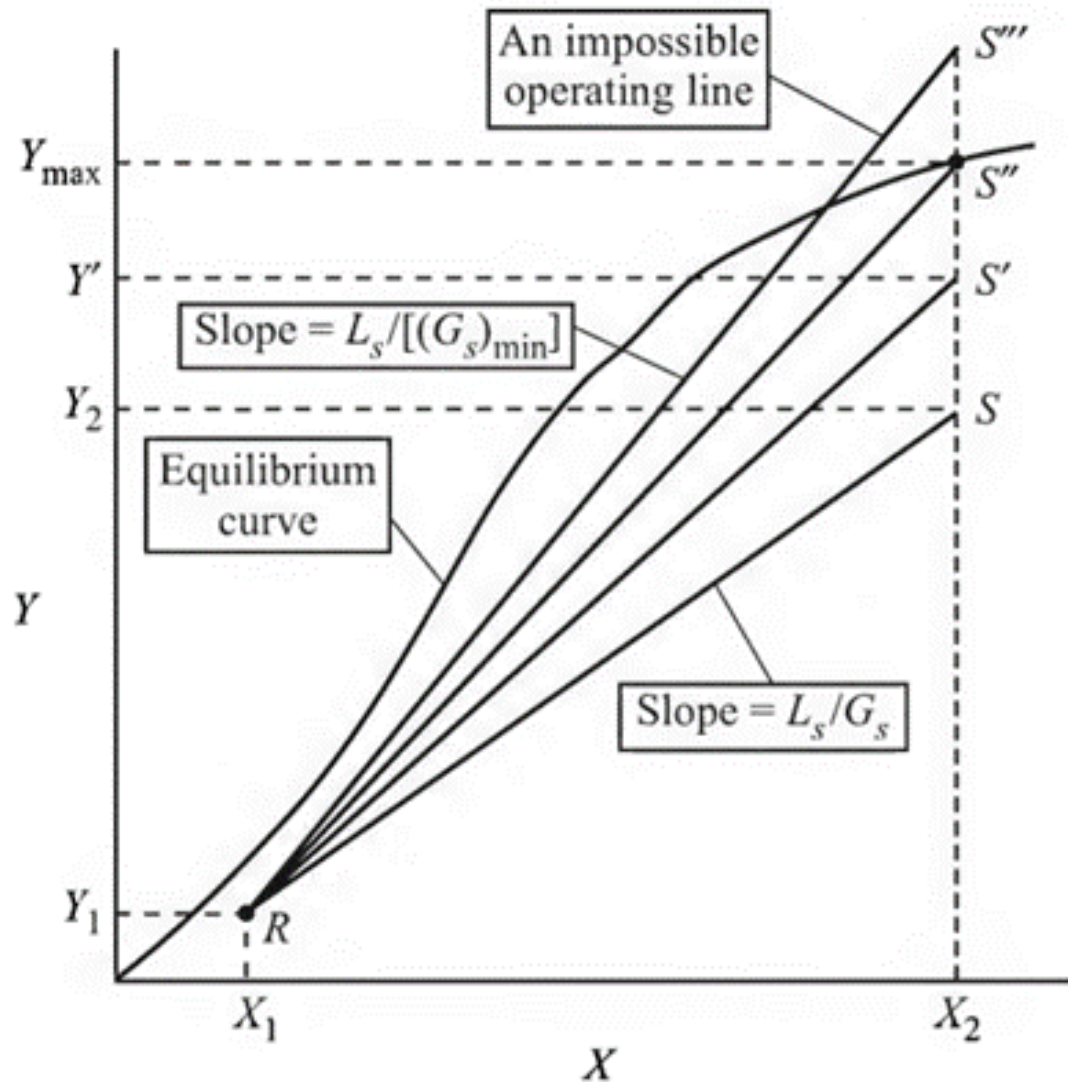
Graphical Representation of Operating line: Absorption

An **infinite number** of plates are required if **minimum liquid flow rate** is used

Graphical Representation of Operating line: Stripping

Problem 1:

A counter current absorption tower is design to remove 95% of component A from an incoming binary mixture using pure solvent B. the mole fraction of a in the inlet gas is 4%. The carrier gas flow rate is 50 Kmol/h. The equilibrium relation is given by Y = 2.2X, where Y and X are mole ratio of A in the gas and liquid. If the tower is operated at twice of minimum solvent rate then what should be the mole ration and mole fraction of A in the exit liquid?

Table 6.2 summarizes the expressions for the various forms of HTUs and NTUs.

Table 6.2 Expressions for HTUs and NTUs

Driving force	Height of a Transfer Unit (HTU)			Number of Transfer Units (NTU)	
	Symbol	DANB	ECD	Symbol	
$y - y_i$	H_{tG}	$\dfrac{G'}{k_y\,\bar{a}\,(1-y)_{iM}}$	$\dfrac{G'}{k_y'\,\bar{a}}$	N_{tG}	$\displaystyle\int_{y_2}^{y_1}\dfrac{(1-y)_{iM}\,dy}{(1-y)(y-y_i)}$
$y - y^{*}$	H_{tOG}	$\dfrac{G'}{K_y\,\bar{a}\,(1-y)_M^{*}}$	$\dfrac{G'}{K_y'\,\bar{a}}$	N_{tOG}	$\displaystyle\int_{y_2}^{y_1}\dfrac{(1-y)_M^{*}\,dy}{(1-y)(y-y^{*})}$
$Y - Y^{*}$	H_{tOG}	$\dfrac{G_s'}{K_Y\,\bar{a}}$	$\dfrac{G_s'}{K_Y\,\bar{a}}$	N_{tOG}	$\displaystyle\int_{Y_2}^{Y_1}\dfrac{dY}{(Y-Y^{*})}$
$x_i - x$	H_{tL}	$\dfrac{L'}{k_x\,\bar{a}\,(1-x)_{iM}}$	$\dfrac{L'}{k_x'\,\bar{a}}$	N_{tL}	$\displaystyle\int_{x_2}^{x_1}\dfrac{(1-x)_{iM}\,dx}{(1-x)(x_i-x)}$
$x^{*} - x$	H_{tOL}	$\dfrac{L'}{K_x\,\bar{a}\,(1-x)_M^{*}}$	$\dfrac{L'}{K_x'\,\bar{a}}$	N_{tOL}	$\displaystyle\int_{x_2}^{x_1}\dfrac{(1-x)_M^{*}\,dx}{(1-x)(x^{*}-x)}$
$X^{*} - X$	H_{tOL}	$\dfrac{L_s'}{K_X\,\bar{a}}$	$\dfrac{L_s'}{K_X\,\bar{a}}$	N_{tOL}	$\displaystyle\int_{X_2}^{X_1}\dfrac{dX}{(X^{*}-X)}$

$$(1-y)_{iM} = \frac{(1-y_i)-(1-y)}{\ln[(1-y_i)/(1-y)]}; \qquad (1-y)_M^{*} = \frac{(1-y^{*})-(1-y)}{\ln[(1-y^{*})/(1-y)]}$$

$$N_A = k_y(y_{Ab} - y_{Ai}) = k_x(x_{Ai} - x_{Ab}) = K_x(x_{Ab}^* - x_{Ab})$$

i.e.
$$(x_{Ab}^* - x_{Ab}) = \frac{N_A}{K_x}$$

and
$$(x_{Ab}^* - x_{Ab}) = \frac{(x_{Ab}^* - x_{Ai})}{(y_{Ab} - y_{Ai})}(y_{Ab} - x_{Ai}) + (x_{Ai} - x_{Ab})$$

$$= \frac{1}{m''}(y_{Ab} - y_{Ai}) + (x_{Ai} - x_{Ab})$$

From Eqs. (4.20), (4.19) and [4.16(a),(b)],

$$\frac{N_A}{K_x} = \frac{N_A}{m'' k_y} + \frac{N_A}{k_x} \qquad \Rightarrow \qquad \frac{1}{K_x} = \frac{1}{m'' k_y} + \frac{1}{k_x}$$

$$\frac{1}{K_y} = \frac{1}{k_y} + \frac{m'}{k_x}$$

Problem:

A packed tower is to be designed to absorbed 95% of SO_2 from an air-SO_2 mixture using pure water. The entering feed gas mixture contains 15 mol % SO_2 and 85 mol % air at 303 K and 101.3 kPa total pressure. The feed gas rate is 1000 kg/h. the solvent rate is 3000 kg/h. The tower cross sectional area is 1 m². Given that k'_xa = 1.1 kmol/m³.s.mol and k'_ya = 0.07 kmol/m³.s.mol fraction. Calculate the height of the packed tower using height of transfer unit. Equilibrium data are given in the table or $Y = 1.4X$

Condition 2

x	0	0.000056	0.00014	2.80E-04	4.21E-04	8.42E-04	1.40E-03	1.97E-03	2.79E-03	4.00E-03
y	0	7.90E-04	2.23E-03	6.20E-03	1.07E-02	2.59E-02	4.73E-02	6.85E-02	1.04E-01	1.60E-01

Determination of Packed Bed Height (HTU, NTU Method)

Interfacial area, $a = \dfrac{dA}{dV}$

$dA = a.\,dV = a.\,A_{cs}.\,\Delta Z$

Mass balance over cross sectional area

[rate of mass in] – [rate of mass out] =

[Accumulation] + [rate of mass generation]   **0**

[rate of mass out] – [rate of mass in] +

[Accumulation] = 0

$G_S\,|_{z+\Delta z}.\,dY - G_S|_z.\,dY = -N_B.\,\mathbf{dA}$

$= -N_B.\,a.\,A_{cs}.\,\Delta Z$

$= -K_Y.\,(Y - Y_i).\,a.\,A_{cs}.\,\Delta Z$

Gas out   Solvent in

$G_2,\ G_S$ **2** $L_2,\ L_S$
$y_2,\ Y_2$ $x_2,\ X_2$

ΔZ

Z

$G_1,\ G_S$ **1** $L_1,\ L_S$
$y_1,\ Y_1$ $x_1,\ X_1$

Gas in   Solvent in
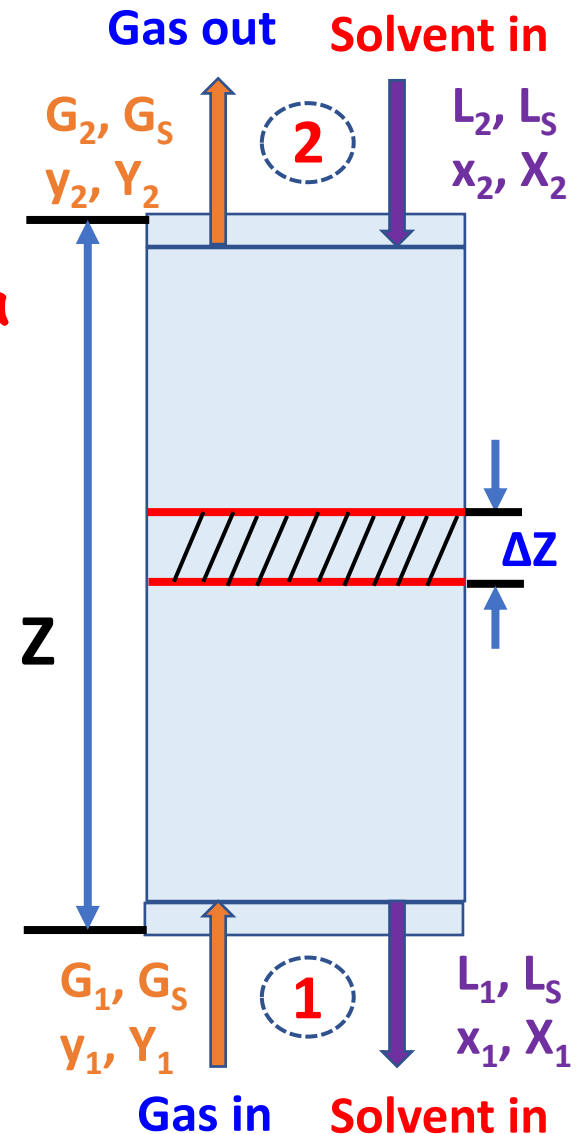
Determination of Packed Bed Height (HTU, NTU Method)

$$(G_S|_{z+\Delta z}.dY - G_S|_z.dY)/\Delta Z = -K_Y.(Y - Y_i).a.A_{cs}$$

$$\frac{dG_S}{dZ}dY = K_Y.(Y - Y_i).a.A_{cs}$$

$$\int_0^{G_S} dG_S \int_{Y_1}^{Y_2} \frac{dY}{Y - Y_i} = -K_Y.a.A_{cs}\int_o^Z dZ$$

$$Z = \frac{G_S}{K_Y.a.A_{cs}} \int_{Y_2}^{Y_1} \frac{dY}{Y - Y_i}$$

HTU   **NTU**

Gas out   Solvent in
G_2, G_S L_2, L_S
y_2, Y_2 ② x_2, X_2

Z ΔZ

G_1, G_S L_1, L_S
y_1, Y_1 ① x_1, X_1
Gas in   Solvent in
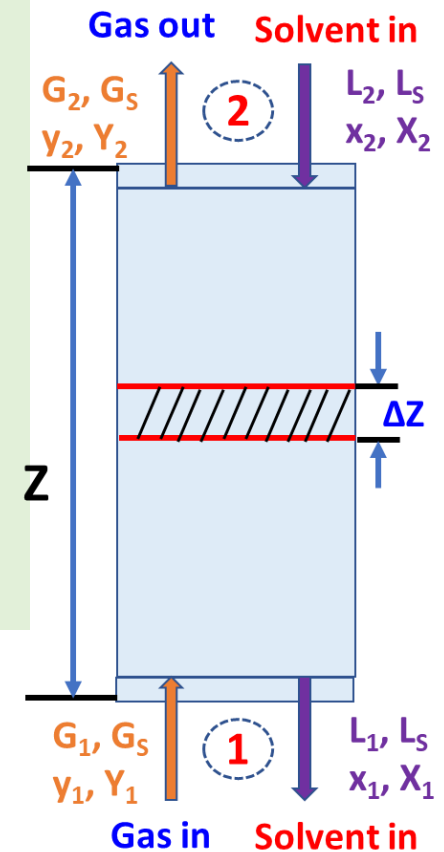
HTU = Height of transfer unit based on overall mass transfer coefficient on gas side

NTU = Number of transfer unit based on overall mass transfer coefficient on gas side

Determination of Packed Bed Height (HTU, NTU Method)

HTU measure the absorption/separation effectiveness of the particular packing for a particular separation process. It is packing materials characteristic.
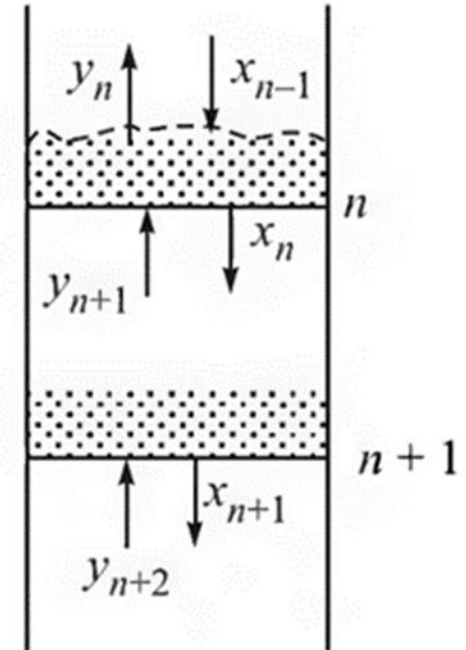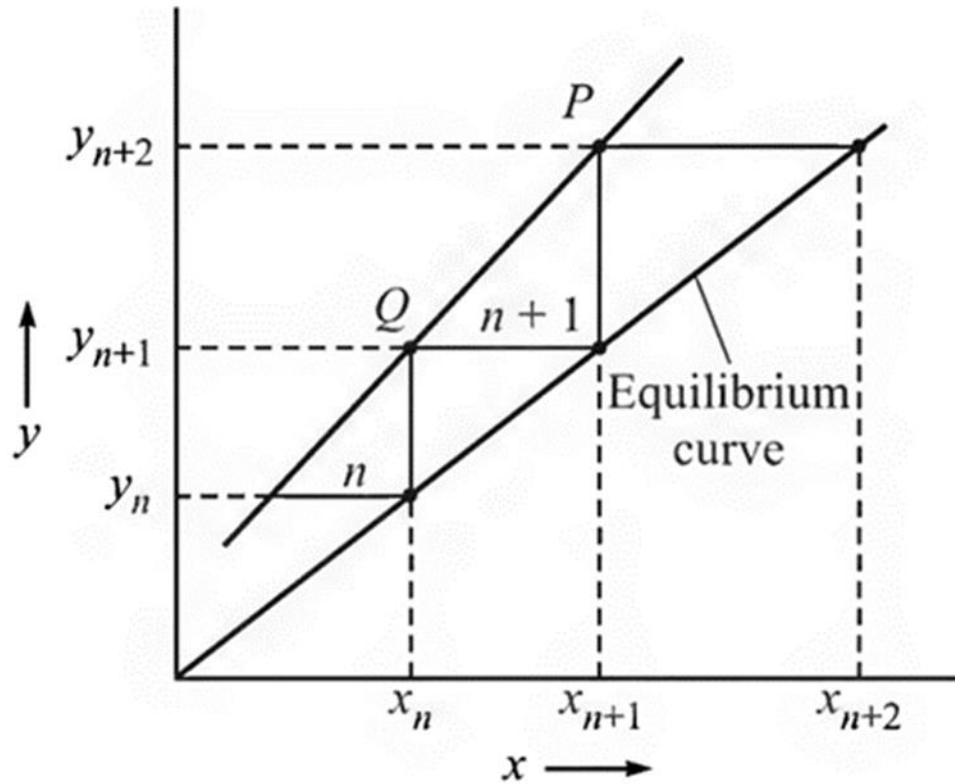
NTU tells about Number of theoretical tray for the try column.

$$Z = \underbrace{\frac{G_S}{Ko_Y . a . A_{cs}}}_{\textbf{HTU}_{OG}} \underbrace{\int_{Y_2}^{Y_1} \frac{dY}{Y - Y_i}}_{\textbf{NTU}_{OG}}$$

HTU_{OG} = Height of transfer unit based on overall mass transfer coefficient on gas side

NTU_{OG} = Number of transfer unit based on overall mass transfer coefficient on gas side. $(Y - Y_i)$ = driving force
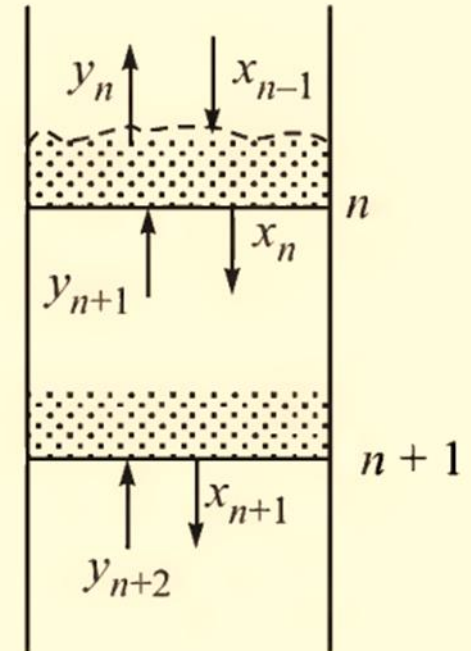
Height Equivalent To A Theoretical Plate (HETP)

HETP is the height of packed section that will bring about the same change in composition (separation to the same extend) as that achieved in a theoretical or ideal plate.
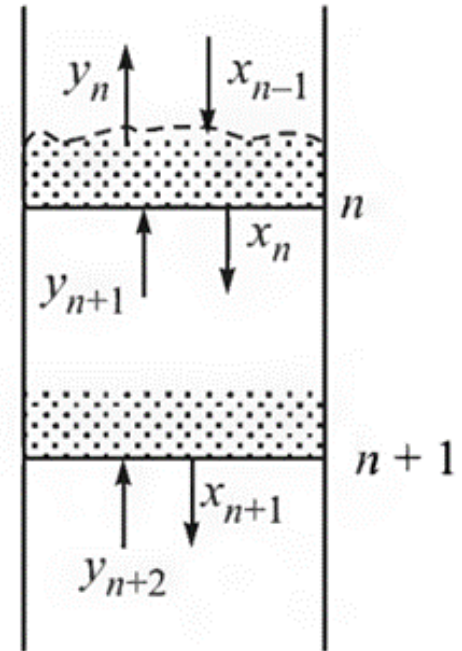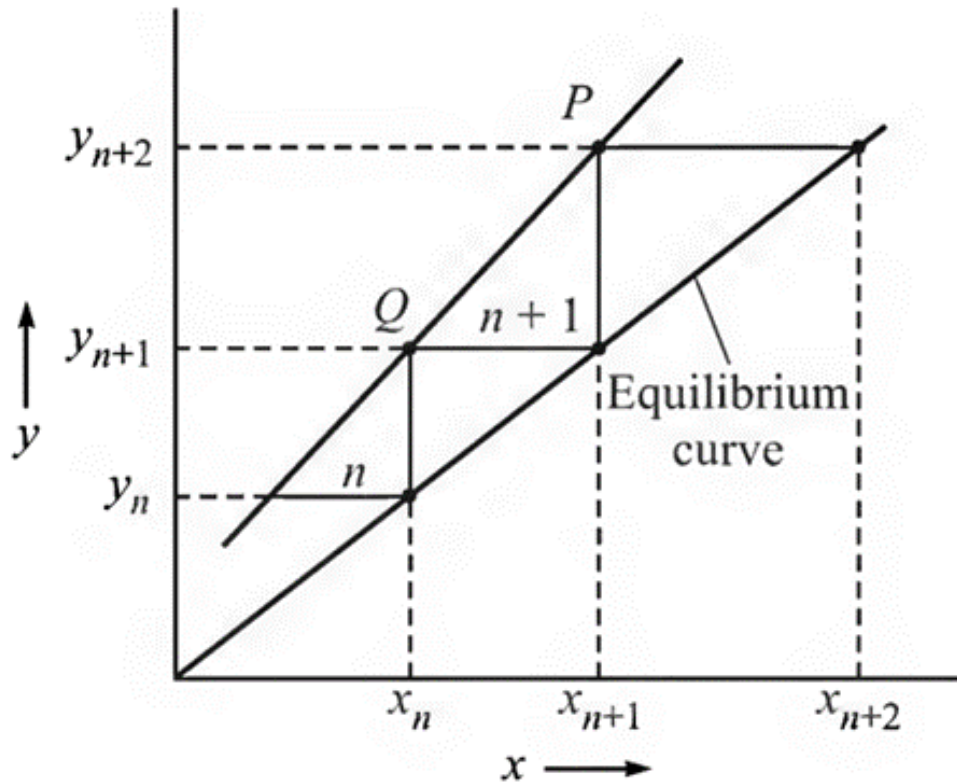
$$HETP = h_T/N_T$$

h_T = height of packing, and
N_T = number of ideal trays required to do the same separation

Rate of mass transfer $= G'(y_{n+2} - y_{n+1}) = L'(x_{n+1} - x_n)$

Height Equivalent To A Theoretical Plate (HETP)

$$\text{HETP} = H_{tOG} * \frac{ln(\frac{1}{A})}{(\frac{1}{A} - 1)}$$

3.2.1 Diffusion of A Through Non-diffusing B

Mass transfer in the gas phase: $N_A = k_G(p_{A1} - p_{A2}) = k_y(y_{A1} - y_{A2}) = k_c(C_{A1} - C_{A2})$ (3.3)

Mass transfer in the liquid phase: $N_A = k_x(x_{A1} - x_{A2}) = k_L(C_{A1} - C_{A2})$ (3.4)

Here k_G, k_y, and k_c are the gas-phase mass transfer coefficients, and k_x and k_L are the liquid-phase mass transfer coefficients; the subscripts 1 and 2 refer to two positions in a medium. The units of the mass transfer coefficients can be obtained from the definitions above. For example, a unit of k_y is $(\text{kmol})/(\text{m}^2)(\text{s})(\Delta y)$, where Δy stands for the driving force in mole fraction unit. If the gas phase is ideal, the concentration term in Eq. (3.3) is given by $C_A = p_A/RT$, where p_A is the partial pressure of A. Supposing that the distance between the two locations 1 and 2 is δ (the *film thickness*), the expressions for the mass transfer coefficients can be obtained by comparing Eq. (3.3) with Eq. (2.27) and Eq. (3.4) with Eq. (2.59).

Gas phase: $\qquad k_G = \dfrac{D_{AB}P}{RT\delta p_{BM}}$; $\qquad k_y = \dfrac{D_{AB}P^2}{RT\delta p_{BM}}$; $\qquad k_c = \dfrac{D_{AB}P}{\delta p_{BM}}$ $\qquad$ (3.5a)

Liquid phase: $\qquad k_x = \dfrac{D_{AB}(\rho/M)_{av}}{\delta x_{BM}}$; $\qquad k_L = \dfrac{D_{AB}}{\delta x_{BM}}$ $\qquad$ (3.5b)

The relations among the three types of gas-phase mass transfer coefficients (i.e. k_G, k_y, and k_c) can be easily obtained from [Eq. 3.5(a)]. Similarly, the relation between the two types of liquid-phase mass transfer coefficients, k_x and k_L, can be obtained from Eq. [3.5(b)].

$$k_c = RTk_G; \qquad k_y = Pk_G; \qquad k_x = (\rho/M)_{av}k_L \qquad (3.6)$$

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Tray Efficiency:

An **ideal stage** provides quite an efficient contact between the phases so that they attain equilibrium. Or, in other words, the phases leaving an ideal stage are at equilibrium irrespective of the inlet concentrations.

However, the performance of a real stage will expectedly be different from that of an ideal stage.

The **tray efficiency** is an indicator of how closely the performance of a real tray approaches that of an ideal tray.

Point Efficiency:

$$E_{OG} = \frac{y_{n,\,\text{local}} - y_{n+1,\,\text{local}}}{y_{n,\,\text{local}}^* - y_{n+1,\,\text{local}}}$$

Murphree Efficiency:

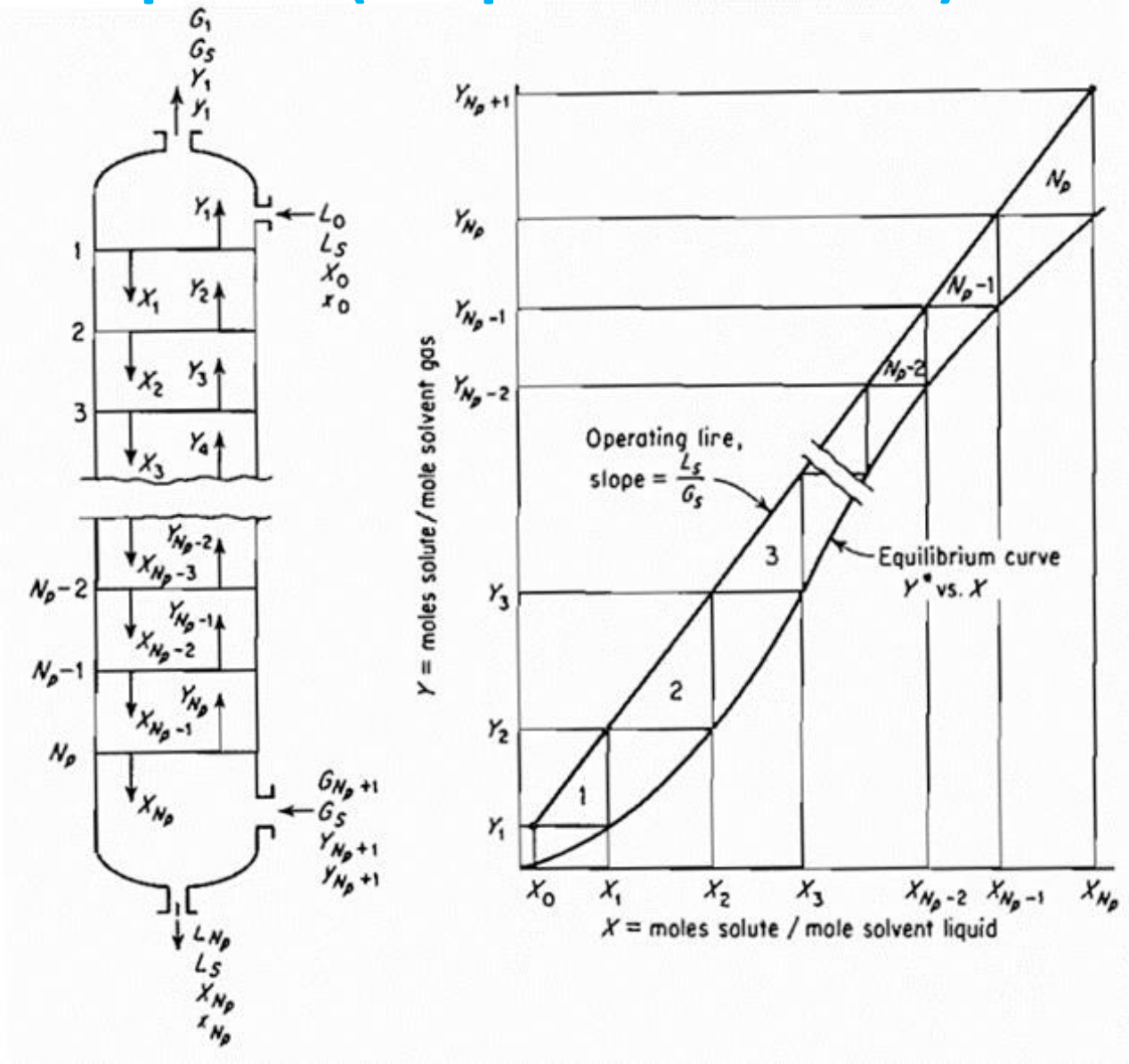$$E_{MG} = \frac{y_n - y_{n+1}}{y_n^* - y_{n+1}}$$

$$E_{MG} = \frac{L'}{m\,G'}\left[\exp\left(\frac{mG'E_{OG}}{L'}\right) - 1\right]$$
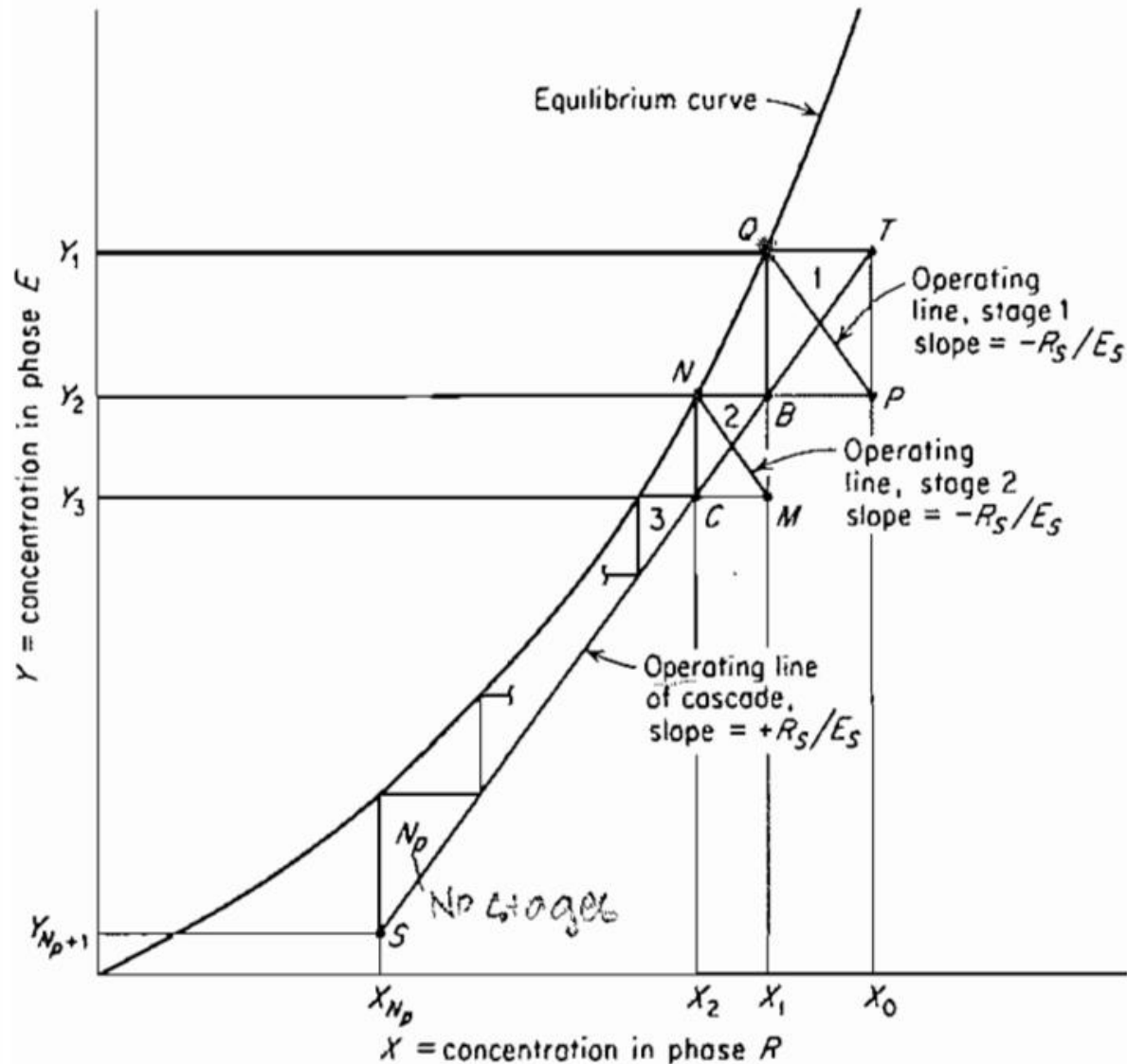
Overall Tray Efficiency:

$$E_O = \frac{\text{number of ideal trays}}{\text{number of real trays}}$$

$$E_O = \frac{\ln\left[1 + E_{MG}\left(\frac{mG'}{L'} - 1\right)\right]}{\ln\left(\frac{mG'}{L'}\right)}$$

Determination of the Number of Stages in Counter current Absorption: (Graphical Method)

Determination of the Number of Stages in Counter current Stripping: (Graphical Method)

Determination of the Number of Stages in Counter current Absorption (Kremser Equation)
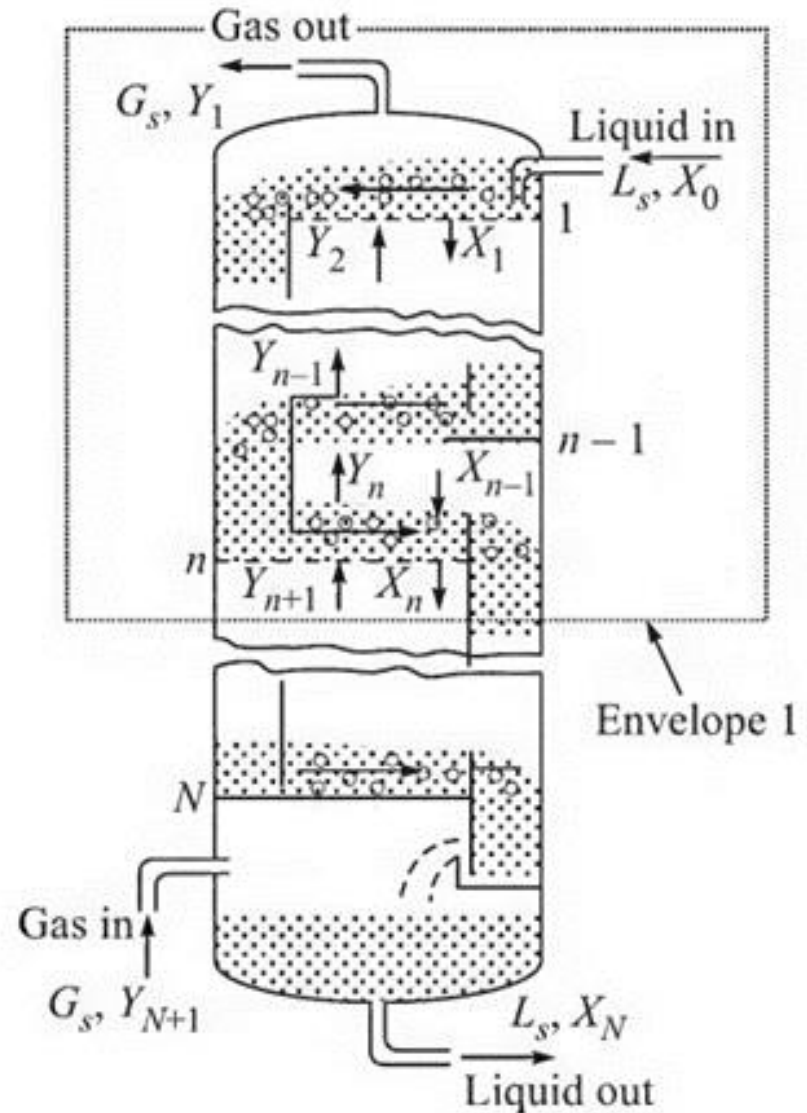
Assumption:

o Isothermal system

o Isobaric system

o When both operating line and equilibrium line are linear/straight

Equilibrium line equation:

$$Y_n = mX_n$$

Operating Line Equation:

$$G_s(Y_{n+1} - Y_1) = L_s(X_n - X_0)$$

Determination of the Number of Stages in Counter current Absorption (Kremser Equation)
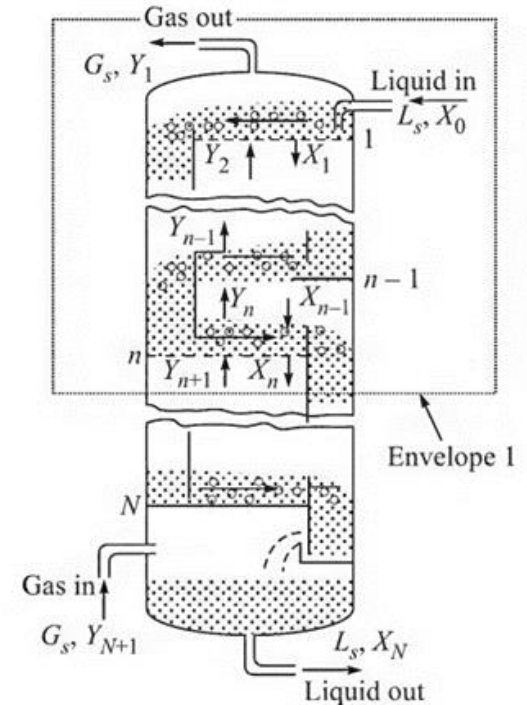
$$(Y_{n+1} - Y_1) = \frac{L_s}{G_s}(X_n - X_0)$$

Absorption factor, $A = \dfrac{L_s}{mG_s}$ So, $\dfrac{L_s}{G_s} = mA$

$$(Y_{n+1} - Y_1) = mA(X_n - X_0)$$

$$\boxed{Y_n = mX_n}$$

Rearranging the above equation:

$$\boxed{(Y_{n+1} - AY_n) = (Y_1 - mAX_0)}$$

First order non-homogeneous linear differential equation

Determination of the Number of Stages in Counter current Absorption (Kremser Equation)

$$Y_{N+1} = \frac{mX_0 - Y_1}{(1-A)} * A^{N+1} + \frac{Y_1 - mAX_0}{(1-A)}$$

$$A^N = \frac{Y_{N+1}\left(\frac{1}{A} - 1\right) - \left(\frac{Y_1}{A} - 1\right)}{(mX_0 - Y_1)}$$

$$N = \frac{\log\left[\left(\frac{Y_{N+1} - mX_0}{Y_1 - mX_0}\right)\left(1 - \frac{1}{A}\right) + \frac{1}{A}\right)\right]}{\log A}$$

For **A = 1**

$$\frac{N}{N+1} = \frac{Y_{N+1} - Y_1}{Y_{N+1} - mX_0}$$

$$N = \frac{Y_{N+1} - Y_1}{Y_1 - mX_0}$$

Kremser equation or Kremser-Brown-Souder Equation

Determination of the Number of Stages in Counter current **Stripping** (Kremser Equation)

$$X_N = (X_0 - \frac{Y_{N+1}/m - AXN}{(1-A)})A^N + \frac{Y_{N+1}/m - AX_N}{(1-A)}$$

For **A = 1**

$$\frac{X_0 - X_N}{X_0 - Y_{N+1}/m} = \frac{(\frac{1}{A})^{N+1} - \frac{1}{A}}{(\frac{1}{A})^{N+1} - 1}$$

$$\frac{X_0 - X_N}{X_0 - Y_{N+1}/m} = \frac{N}{N+1}$$

$$N = \frac{Log\left[\left(\dfrac{X_0 - \dfrac{Y_{N+1}}{m}}{X_N - \dfrac{Y_{N+1}}{m}}\right)(1-A)+A)\right]}{Log(\frac{1}{A})}$$

$$N = \frac{X_0 - X_N}{X_N - Y_{N+1}/m}$$
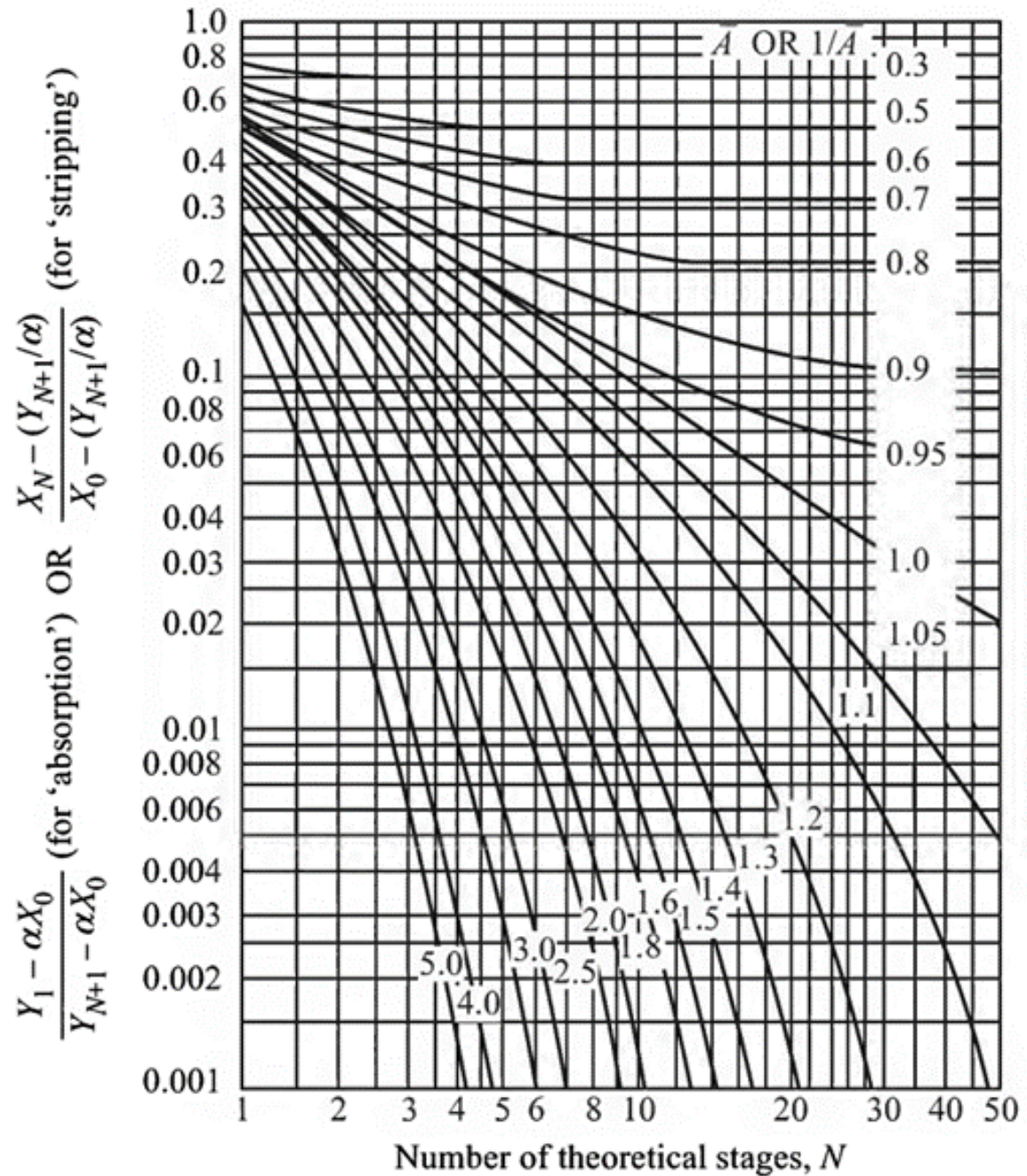
Kremser equation or Kremser-Brown-Souder Equation
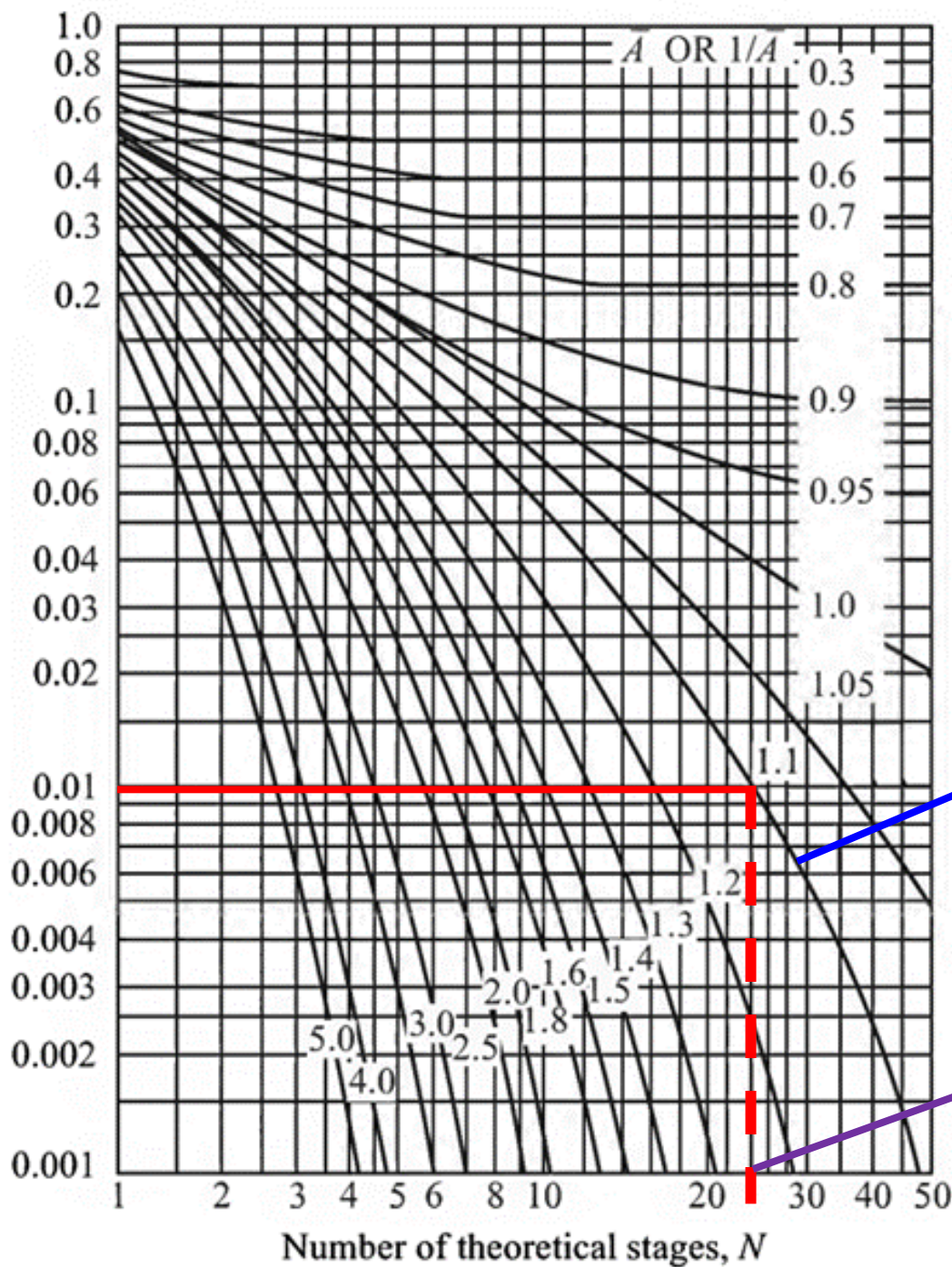
Kremser Chart:

Problem:

It is required to remove 99% of the solute C from a solution of C in G by using a 'pure' solvent L in a counter-current cascade. The feed containing 12% C in the mixture enters the column at the bottom at the rate of 6000 kg/h. The solvent enters at the top at a rate of 7685 kg/h. Write down the equation of the operating line. Determine the number of trays required to perform the separation if the overall tray efficiency is 40%. The equilibrium relation is linear, $Y = 1.32X$, where $Y = $ kg C per kg C-free G, and $X = $ kg C per kg C-free L.

Kremser Chart:

$$\overline{A} = 1.103$$

$$\frac{Y_1 - \alpha X_0}{Y_{N+1} - \alpha X_0}$$

$$= \frac{0.00136 - 0}{0.136} = 0.01$$

A = 1.1

23.8

Y-axis: $\frac{Y_1 - \alpha X_0}{Y_{N+1} - \alpha X_0}$ (for 'absorption') OR $\frac{X_N - (Y_{N+1}/\alpha)}{X_0 - (Y_{N+1}/\alpha)}$ (for 'stripping')

X-axis: Number of theoretical stages, N

$\overline{A}$ OR $1/\overline{A}$

Problem:

When a certain of moist soap is exposed to air at 75 °C, 1 std atm pressure, the equilibrium distribution of moisture between the air and soap is as follows

Wt% moisture in soap	0	2.4	3.76	4.76	6.1	7.83	9.90	12.63	15.4	19.02
Partial pressure water in air mmHg	0	9.66	19.2	28.4	37.2	46.4	55.0	63.2	71.9	79.5

a) 10 kg of wet soap containing 16.7% moisture by weight is placed in a vessel containing 10 m³ moist air whose initial moisture content correspond to a water-vapor partial pressure of 12 mmHg. After the soap has reached a moisture content of 13%, the air in the vessel entirely replaced by fresh air of the original moisture content and the system is then allowed to reach equilibrium. The total pressure and temperature are maintained at 1 std atm and 75 °C respectively. What will be ultimate moisture contend of the soap?

b) It is desired to dry the soap from 16.7 to 4% moisture continuously in a countercurrent stream of air whose initial water-vapour partial pressure is 12 mmHg. The pressure and temperature will be maintained through at 1 std atm and 75 °C. For 1 kg initial wet soap per hour. What is the minimum amount of air required per hr?

c) If 30% more air than that determine in part (b) is used, what will be the moisture content of the air leaving the drier? To how many equilibrium stages will be process be equivalent?

Absorption with Chemical Reaction:

Assumption:

No solvent evaporation, isothermal process, homogeneous reaction

Liquid Film

A

Bulk liquid

ΔZ

C_{Ai}

Z

C_{Ab} C_{Ab}

$Z = 0$ $Z = \delta$
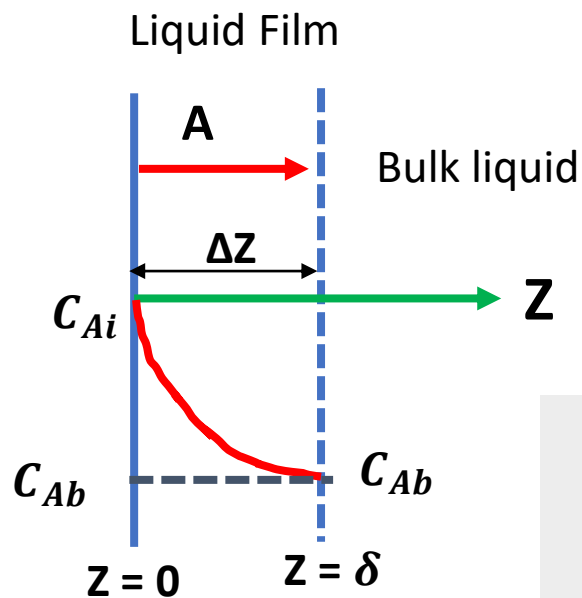
C_{Ai} = concentration at interphase
C_{Ab} = concentration at bulk

$$\boxed{A + B \rightarrow Product}$$

❖ Consider steady state process with no accumulation

[rate of in] – [rate of out] = [rate of depletion due to chemical reaction]

$$N_A|_z - N_A|_{z+\Delta z} = r_A. \, dV = r_A. \, A_{cs}. \, \Delta Z$$

For unit cross sectional area

$$N_A|_z - N_A|_{z+\Delta z} = r_A. \, \Delta Z$$
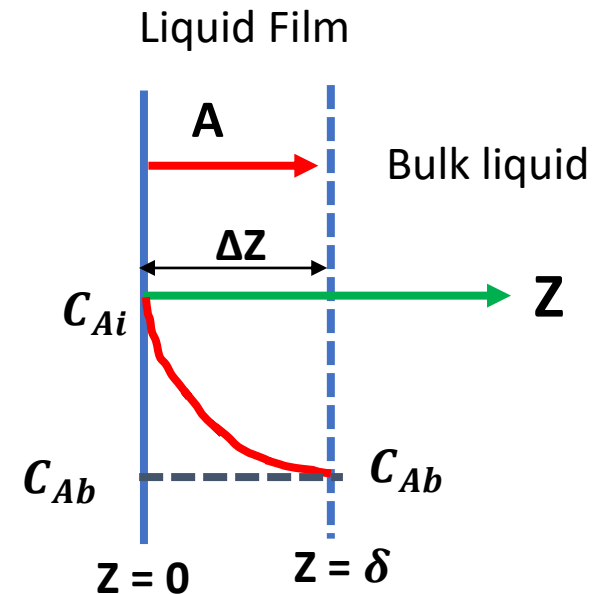
$$N_A = -D_A \frac{dC_A}{dZ}$$

Absorption with Chemical Reaction:

$$D_A \frac{d^2 C_A}{dZ^2} = r_A = K_1 C_A \quad \text{(for first order reaction)}$$

$$D_A \frac{d^2 C_A}{dZ^2} - K_1 C_A = 0$$

Liquid Film

A → Bulk liquid

ΔZ

C_{Ai}

C_{Ab} C_{Ab}

Z = 0   Z = δ

Boundary condition

Z = 0; $C_A = C_{Ai}$

Z = δ; $C_A = C_{Ab}$ or $N_A = 0$, $\frac{dC_A}{dZ} = 0$

$$\frac{C_A}{C_{Ai}} = \frac{\cosh[(\frac{K_1 \delta^2}{D_A})^{\frac{1}{2}} (1 - \frac{Z}{\delta})]}{\cosh(\frac{K_1 \delta^2}{D_A})^{\frac{1}{2}}}$$

Absorption with Chemical Reaction:

$$\varphi^2 = \frac{K_1 \delta^2}{D_A} = \text{Thiele Modulus}$$

$$= \frac{K_1 \delta}{D_A/\delta} = \frac{Maximum\ rate\ of\ reaction\ of\ A}{Maximum\ rate\ of\ physical\ mass\ transfer\ (diffusion)of\ A}$$

$$\frac{K_1 \delta C_{Ai}}{D_A/\delta(C_{Ai} - 0)} = \frac{Characteristic\ time\ for\ diffusion\ (\frac{1}{\frac{D_A}{\delta(C_{Ai} - 0)}})}{Characteristic\ time\ for\ reaction\ (\frac{1}{K_1 C_{Ai}})}$$

❖ φ^2 is large process is diffusion control

❖ φ^2 is small process is reaction control

❖ *Reaction is fast;* $\boldsymbol{\varphi}$ > 2

❖ *Reaction is slow;* $\boldsymbol{\varphi}$ < 0.3

φ is called Hatta Number

If the process is both diffusion and reaction control then
2 < φ < 0.3