

PED notes
HTC = heat transfer coefficient
per unit area per unit time

Mass transfer

- Diffusion ✓
- Convection ✓
- Crystallisation ✓
- Distillation ✓
- Absorption ✓
- Gas- liquid contactor ✓
- Extraction ✓
- humidification
- leaching ✓
- Membrane separation

MOLECULAR DIFFUSION (stagnant layer or laminar flow)

- molecules of species move from a region of higher conc to lower to make conc uniform
- Turbulent medium - eddy diffusion
- Decantation :-
- Water is used to separate dissolved gas from a mixture with another gas by absorption.

Fick's law

$$J_A \propto \frac{dc_A}{dx}$$

$$J_A = -D_A \frac{dc_A}{dx}$$

rate of diffusion \propto

a substance across
unit area \propto conc
conc gradient

$$\rightarrow N_A = (N_A + N_B) C_A = D_A \frac{dc_A}{dx}$$

$$c \propto \frac{dc_A}{dx}$$

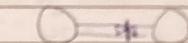
convective flux

diffusive flux

- ① A diffusing, B non-diffusing ② Equilibration ③ Non-equilibration

Gas phase diffusion coefficient measurement

- ① Tunnels method -



- ② Stofan tube → A diffusing, a non-diffusing

MTC, MTC definition?

cell left no heat transfer occurs

Pumps

2/3. 1/4

Molecular diffusion in liquids

liquid phase coefficient

① diaphragm cell

→ Knudsen diffusion:

movement is governed by molecular velocity and as well as collision with other molecules.

$$\text{Diffusivity } D_k = \frac{2}{3} \frac{\gamma_p v T}{r} \quad \rightarrow \text{avg. velocity}$$

↓
radius
of capillary

→ surface diffusions

→ Transport in porous media occurs by molecular diffusion

CONVECTIVE MASS TRANSFER

→ forced convection mass transfer

→ free convection: - the motion in the medium is caused by density difference. (cone causes density difference)

→ heat transfer - temp causes density difference

→ Mass transfer coeff (MTC) → rate const that relates mass transfer rate of mass transfer or conc. diff. rate, mass transfer area, cone. (driving force)

$$W_a \propto a \Delta C \frac{mol}{m^2}$$
$$W_a = k_c a \Delta C$$

real/s. $\rightarrow m/s.$

k_c = Mass transfer resistance

→ advection?

1/1

→ Sherwood number = convective flux

conductive flux (diffusion) / stagnant film

$$Sh = \frac{k_c L}{D_{AB}} = f(Re, Sc)$$

$Sc = \text{Soret number} = \frac{k}{D_{AB}}$ → momentum diffusivity

controls relative thickness of momentum and mass transfer BL

→ Mass transfer coefficient $k_c = f(v, \rho, \mu, L, D_{AB})$

→ Walled wall column: Used to find MTC for falling film of liquid

Film theory:

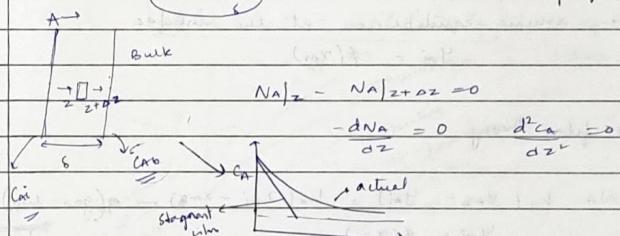
Assumptions: ① Purely diffusion through stagnant fluid layer

② Steady state:

S-L boundary ③ $(Na + Nb)Ca$ is low.

$$k_c = D_{AB}$$

[linear conc profile]



Penetration theory: unsteady state

$$k_c = \sqrt{\frac{D_{AB}}{\pi t}}$$

gas | O_2 vapor

Surface renewal theory

$$k_s = \sqrt{D_{\text{gas}} S}$$

↑ fractional rate of surface renewal.

Boundary layer theory

Correlations → $Sh \propto$

- Drying of air is done in contact with concentrated H_2SO_4 in a packed column
- interphase mass transfer
- At equilibrium chemical potential of solutes must be equal

Roult's law (to find vapor pressure)

$$P_n^* = x_n P_a \rightarrow \text{ideal system} \quad (\text{vapour-liquid}) \rightarrow \Delta V_{\text{mix}} = 0$$

↓ mole fraction in vapour phase.

Henry's law (non-ideal)

$$P_n^* = H x_n$$

evolving
vapour

- we assume equilibrium at the interface

$$Y_{ni} = \phi(x_{ni})$$

Two film theory:

$$N_A = k_y (Y_{ab} - Y_{ai}) = k_x (x_{ai} - x_{ab}) \rightarrow q \quad (\text{gas-liquid})$$

↑ separation

$$Y_{ai} = \phi(x_{ai})$$

- Interfacial conc. cannot be measured directly.

∴ overall MTC comes into picture.

b → bulk
i → interface.

$$N_A = k_y (Y_{ab} - Y_{ai}^*) = k_x (x_{ab}^* - x_{ai})$$

↑ overall gas-phase ↑ overall liquid phase

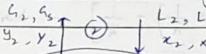
MTC

$$Y_{ab}^* = \phi(x_{ab})$$

$$x_{ab}^* = \phi(Y_{ab})$$

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

(gas-liquid contacting (for counter current))



$$L_g, L_s \rightarrow \text{solute free basis}$$

$$Y, Y_1, Y_s \rightarrow \text{mole ratio of solute in liquid}$$

$$Y, Y_1, Y_s \rightarrow \text{mole fraction of solute in gas}$$

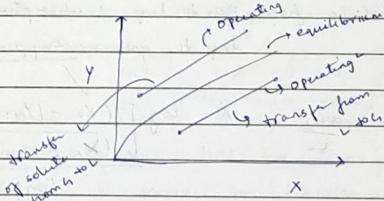
$$G_s = G \quad Y = \frac{Y}{1+Y}$$

$$G_l = G_1, G_s \quad L_1, L_s$$

$$Y_1, Y_s \quad X_1, X_s$$

L, G → immiscible

$$L_s X_2 + G_s Y = L_s X + G_s Y_2 \rightarrow \text{eqn of operating}$$



$$G_s Y + L_s X_2 = L_s Y_2 + G_s X \rightarrow \text{operating curve}$$

ideal trays?
why not ideal?

- Counter current is preferred when compared to co-current because much greater amount of solute can be transferred for same solvent used.
- catalytic hydro-desulphurization of petroleum products in trickle bed reactor → co-current is used.

Stage wise contact (Tay tower) (absorption)

$$G_a(Y_{N+1} - Y_1) = L_a(X_1 - X_0)$$

$$N = \log \left[\frac{(Y_{N+1} - \alpha X_0)}{Y_1 - \alpha X_0} \right] \left(1 - \frac{1}{\bar{A}} \right) + \frac{1}{\bar{A}} \rightarrow \text{Krausen equation}$$

no. of
ideal
stages

log \bar{A}

$$\bar{A} = \frac{L_s}{\alpha G_a}$$

$$\begin{aligned} &\text{absorption factor} \\ &Y = \text{---} X \rightarrow \text{equilibrium} \\ &(\bar{A} + 1) \end{aligned}$$

→ for stripping = \bar{A}

→ $\bar{A} = 1 \rightarrow$ operating line and equilibrium line coincide / parallel

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

→ Transfer of solute from gas to liquid → absorption
liquid to gas → stripping

$$\bar{A} = \frac{1}{n} = \frac{\alpha G_a}{L_s}$$

stripping factor

$$N = \log \left[\frac{(X_0 - (Y_{N+1}/\alpha)(1 - \bar{A})) + \bar{A}}{(X_N - (Y_{N+1}/\alpha))} \right]$$

log $(1/\bar{A})$

→ V-L equilibrium → Under a given set of conditions, the equilibrium vapour composition is related to liquid composition.

→ gas-liquid → absorption, stripping, distillation, water cooling, humidification

→ liquid-liquid → extraction

→ gas-solid → adsorption, drying

→ liquid-solid → leaching, crystallization, ion exchange

gas is dispersed in the form of bubbles: - tray tower, bubble column, agitated vessel

liquid is dispersed in the form of droplets: - spray tower, packed tower, or discontinuous venturi scrubbers

Tay column

gas-liquid dispersion (bubbles)

→ Downcomer is the region where gas-liquid disengagement occurs

Components:

① Shell: - material should be selected on the basis of corrosiveness of the fluids, temp and pressure conditions.

② Tay: - (a) allows gas to pass through the holes. g-L dispersion is formed. Tay holds the dispersion

(b) Mass transfer occurs on the tay. Performance of column will depend on the tay

Bubble cap tray, sieve tray, valve tray

When to use what? (pg 189) → BK delta

③ Downcomer: Passage through which liquid flows down from one tray to next. Gas-liquid disengagement sufficient residence time must be provided for disengagement

④ Nozzles

⑤ Mist eliminator

Entrainment of liquid in upflowing gas may occur. To remove liquid demister is used

absorption / scrubbing → same.

— / —

Flow regimes:-

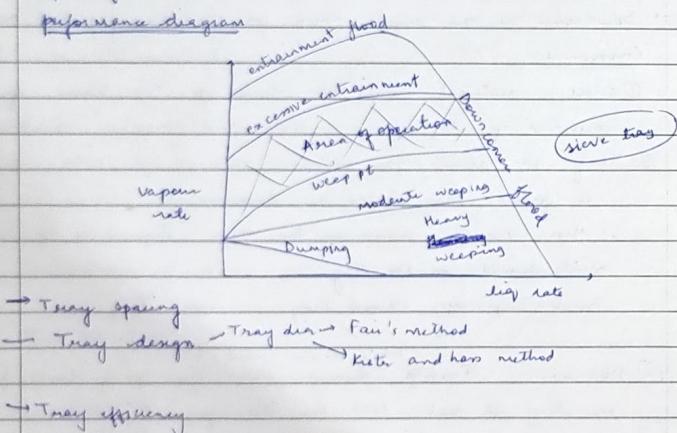
- (1) Emulsion
 - (2) Foath
 - (3) Spray
- gas flow
through tray at
low rates
large tray
rate to prevent spraying
high vapour velocities
in between
emulsion and
spraying

→ Flooding, weeping, entrainment, dumping

Downcomer flooding:-

When liquid flow rate is high, rate of flow of g-l dispersion into the downcomer also becomes high. If the downcomer cannot accommodate, disengagement does not occur properly.

Performance diagram



Agitated vessel

agitator shaft with impeller

Bubble column

Spray tower

Venturi scrubber

Packed column

Packings are used to increase the interfacial area (through pores), increase the contact time.

→ When we have a convective fluid, we can use packed column instead of tray tower

tray towers → (Packed v/s tray) ✓

Packing characteristics:- large surface area, uniform flow of gas and liquid, void volume, mechanical strength and fouling resistance

→ Flooding / loading characteristics

↓ accumulation of liquid just starts upon increasing the gas flow rate
If gas flow rate is further ↑, liquid accumulation rate increases sharply almost preventing the flow of gas

→ Sherwood plot for predicting pressure drop

→ packing factor: void fraction, area, two packing properties

→ Tray column v/s Packed (Pg 242)

→ Both are used for distillation, gas absorption, stripping, extraction

→ Pg 258 ✓

Absorption

Solvent properties :-

- (1) Solubility :- solute should be highly soluble, but it should not dissolve carrier gas.
- (2) low volatility
- (3) low viscosity
- (4) non-concave
- (5) non-toxic
- (6) low cost

Design of packed tower

- (1) selection of solvent
- (2) selection of packing
- (3) determination of min and actual solvent rate
- (4) column dia
- (5) redistributor --

$$H_t = H_{t_e} N_t$$

~~H_t~~ → of height

H_{t_e} = ht of individual transfer units

N_t = no. of transfer units

→ Scrubbing :- same as absorption → for removal of waste
↳ waste gas treatment

→ Ideal tray equilibrium is attained : tray efficiency comes into Picture

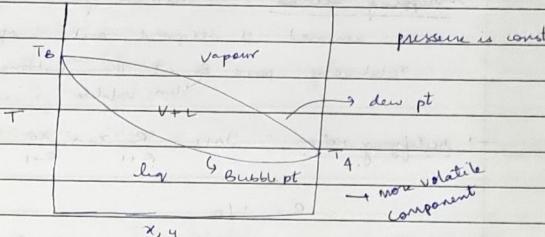
→ Murphree efficiency

mass transfer based on thermal energy more volatile heat of vapourization less absorb. vapour heat and become less volatile component condense \rightarrow x_1 .

DISTILLATION separation of mixture by distillation is based on V - L equilibrium

→ Pg 321 Table

Vapour liquid equilibrium



- Bubble pt :- temp at which 1st bubble of vapour is formed
- dew pt : 1st drop of gaseous mixture condenses
- azeotropes :- const boiling points : vapour has same composition as liq.

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

Flash vapourization :- (pressure redn)

If hot liq mixture is throttled into a vessel, a part of it will vapourise

steam distillation

Process in which live steam is blown through a liq containing the mixture

Batch distillation / raggeal distillation

$$\ln(F_x F_w x_w) = \alpha \ln \frac{F_l - x_F}{w(1-x_w)}$$

unit operation v/s unit process

1/1

Continuous counter current

rectifying section :- cone of more volatile component is larger than the feed. Vapor is enriched.

stripping section :- below the feed tray, more volatile component is removed or stripped out of liquid to get relatively pure B at the bottom less volatile.

→ rectifying section :- $y_{n+1} = R \frac{x_n + x_0}{R+1}$

$$R = 1/D$$

higher R, less trays \rightarrow more purification

→ stripping section :- $y_{n+1} = \frac{1}{1-W} x_n - \frac{W}{1-W} x_0$

$$\text{boilup ratio} = R_w = \frac{V}{W}$$

→ Feed line :-

$$Y = \frac{y}{y-1} x - \frac{z_f}{y-1}$$

$$\gamma = \text{feed quality} \rightarrow \gamma = 1 \text{ liquid}$$

$$0 < \gamma < 1 \text{ - mix}$$

→ McCabe Thiele method is used to find no. of ideal trays Assumption: Equilibrium is attained

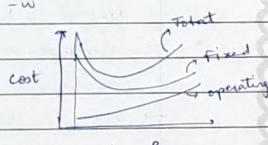
No heat loss
constant molar overflow

→ Smid's eqn : no. of ideal trays

Total reflux : $R = \infty \rightarrow$ minimum no. of trays.
↳ Fenske eqn

minimum Reflux : max no. of trays.

Optimum reflux: ✓



→ Murphree efficiency ✓

→ Ponchon Savart method ✓

enthalpy v/s x, y plot

→ Distillation in packed tower

(a) Vacuum or low pressure

(b) low capacity or feed rate

(c) small pressure drop

(d) corrosive.

→ Partial reboiler

Total reboiler

acts as additional equilibrium stage
less stage

(less all other conditions)
less pressure drop

→ Total condenser

The entire vapour leaving the top of the column is condensed.

→ reflux must be liquid

Partial \rightarrow if it contains undesirable material

Part of vapour is condensed and returned as reflux. It is assumed to be an equilibrium stage. This is assumed v-l containing stage.

Provides a stage for l no. of stages containing for rectification is 1 less.

→ BP of a mixture does not make sense.

→ EXTRACTION VM notes

Crystallization

- It gives products in an acceptable and granular form
- The process of formation of crystals or prodn of crystals from a solution or melt.
- Concentration of solution is more than solubility Then it is supersaturation
- S-L equilibrium
- opposite to dissolution
- Extent of supersaturation is the driving force.

$$h \left(\frac{c}{c_s} \right) = \frac{2 \sigma M_w}{R T P_c \gamma}$$

Nusselt number

It is the ratio of convective to conductive heat transfer

how much heat is transferred by convection $Nu = \frac{hL}{k}$

v/s conduction

$$\left(V = hL \right) \quad \alpha = \frac{k}{P_c \rho}$$

Prahlal number $= \frac{\gamma}{\alpha}$ → relation between momentum transport and thermal transport

Schmidt (Sc) :- $\frac{\gamma}{\alpha}$ → momentum v/s mass diffusion convection D_{AB}

Shaword :- mass transfer by convection $= \frac{kL}{D_{AB}}$

Reynold's number :- inertial force $= \frac{\rho V D}{\mu}$

Lewis number $= \frac{\alpha}{D_{AB}}$

Reynold's analogy

$$\frac{4}{2} \frac{Re_L}{2} = Nu = sh$$

$$St = Nu \\ Re Pr$$

$$\frac{f}{2} = St = St_m$$

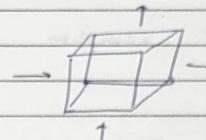
6 Stanton numbers

Colburn j - factor

$$j_H = j_m = \frac{f}{2}$$

$$j_H = St^{1/2} \quad \text{or} \quad j_m = St_m Sc^{2/3}$$

Derivation



in :- $n_{x,z} \alpha y_0 z_0 + n_{y,z} \alpha z_0 x_0 + n_{z,x} \alpha y_0 x_0$

out :- $n_{x,z+dx} \alpha y_0 z_0 + n_{y,z+dy} \alpha z_0 x_0 + n_{z,x+dz} \alpha y_0 x_0$

generation :- $\gamma_a \alpha x_0 y_0 z_0$

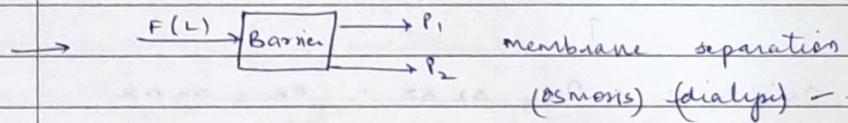
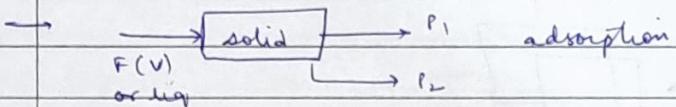
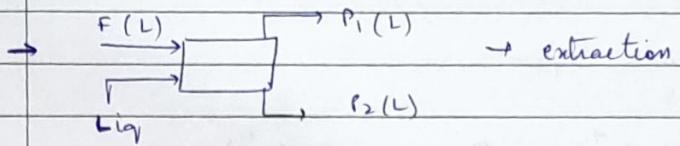
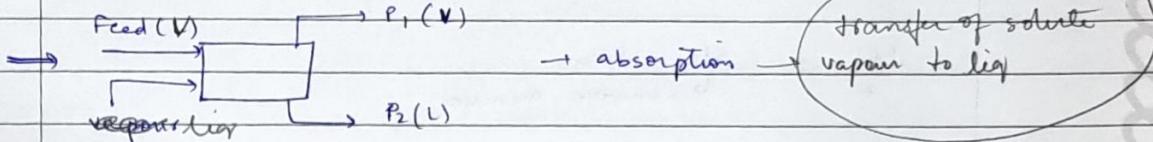
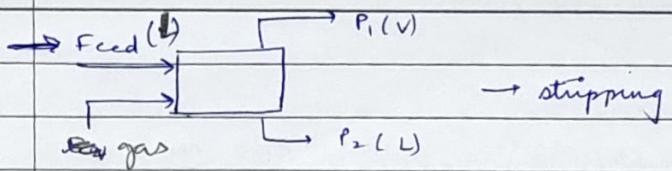
accumulation $= \frac{\partial (C_a \alpha y_0 z_0)}{\partial t}$

$$In - Out + gen = acc$$

$$- \frac{\partial n_{x,z}}{\partial x} - \frac{\partial n_{y,z}}{\partial y} - \frac{\partial n_{z,x}}{\partial z} + \gamma_a = \frac{\partial C_a}{\partial t}$$

$$n_{x,z} = - D_{AB} \frac{\partial C_a}{\partial x} + \gamma_a$$

$$\frac{\partial C_a}{\partial t} + \frac{U_x C_a}{\partial x} + \frac{V_y C_a}{\partial y} + \frac{W_z C_a}{\partial z} = D_{AB} \left[\frac{\partial^2 C_a}{\partial x^2} + \frac{\partial^2 C_a}{\partial y^2} + \frac{\partial^2 C_a}{\partial z^2} \right] + \gamma_a$$



BC

① Equality of conc at the interface

② impervious surface $\frac{dc}{dx} = 0$

③ convective flux = conductive

$$-\Delta A_B \frac{dc_A}{dx} \Big|_{x=x_0} = h_m(C_A - C_{A0})$$