THAPAR INSTITUTE OF ENGINEERING & TECHNOLOGY (Deemed to be University)

Mass Transfer-I

Interphase Mass Transfer (Continue…)

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Interphase Mass Transfer (Continue…)

Overall mass transfer coefficient (Gas Phase)

The mass transfer flux of A in terms of mass transfer film coefficient for gas phase

$$N_A = K_y(y_{A,G} - y_A^*) = k_y\,(y_{A,G} - y_{Ai})$$

K_y is the overall mass transfer coefficient in Gas phase

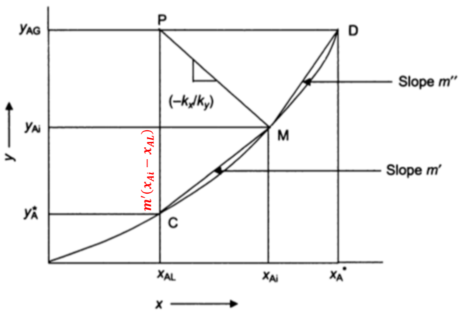
From the figure

$$y_{AG} - y_A^* = (y_{A,G} - y_{Ai}) + (y_{Ai} - y_A^*)$$

or

$$y_{AG} - y_A^* = (y_{A,G} - y_{Ai}) + m'(x_{Ai} - x_{AL})$$

Where m' is the slope of the chord MC



From rate expression $\frac{N_A}{K_y} = \frac{N_A}{k_y} + \frac{m' N_A}{k_x}$ ⟹ $\boxed{\frac{1}{K_y} = \frac{1}{k_y} + \frac{m'}{k_x}}$

Overall mass transfer coefficient (Liquid phase)

Similarly for liquid side,

$$N_A = K_x(x_A^* - x_{AL}) = k_x\,(x_{Ai} - x_{AL})$$

K_x is the overall mass transfer coefficient in liquid phase

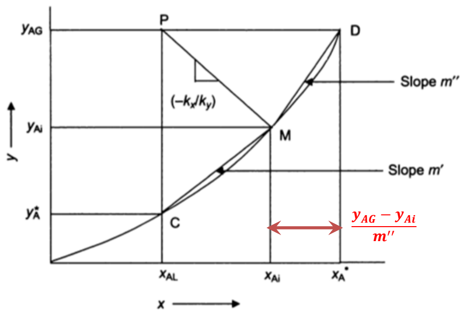
Again from the figure

$$x_A^* - x_{AL} = (x_A^* - x_{Ai}) + (x_{Ai} - x_{AL})$$

or

$$x_A^* - x_{AL} = \frac{y_{AG} - y_{Ai}}{m''} + (x_{Ai} - x_{AL})$$

Where m'' is the slope of the chord MD



From rate expression

$\frac{N_A}{K_x} = \frac{N_A}{m'' k_y} + \frac{N_A}{k_x}$ ⟹ $\boxed{\frac{1}{K_x} = \frac{1}{m'' k_y} + \frac{1}{k_x}}$

Cont…

1. Assuming that k_x and k_y are same and if m' is small

- Component A is highly soluble in liquid
- Equilibrium curve is flat
- The term $\frac{m'}{k_x}$ will be negligible as compares to $\frac{1}{k_y}$
- Resistance to the mass transfer lies in the Gas phase
- Entire mass transfer is controlled by gas phase
- Hence, $\frac{1}{K_y} \approx \frac{1}{k_y}$

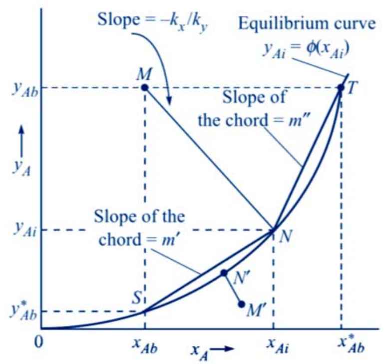
2. Assuming that m'' is very large

- Component A is relatively insoluble in liquid
- The term $\frac{1}{m''k_y}$ will be negligible as compares to $\frac{1}{k_x}$
- Resistance to the mass transfer lies in the liquid-phase
- Entire mass transfer is controlled by liquid phase
- Hence, $\frac{1}{K_x} \approx \frac{1}{k_x}$

Cont…

3. For cases where k_x and k_y are not nearly equal

"The relative size of the ratio $\left(\frac{k_x}{k_y}\right)$ and of m' or m'' will be determine the location of the controlling mass transfer resistance."

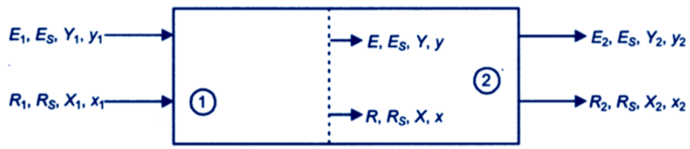


Mass transfer resistance

Mass transfer resistance	Gas-phase basis	Liquid-phase basis
Total resistance of the two phases	$\frac{1}{K_y}$	$\frac{1}{K_x}$
Individual gas-phase mass transfer resistance	$\frac{1}{k_y}$	$\frac{1}{m''k_y}$
Individual liquid-phase mass transfer resistance	$\frac{m'}{k_x}$	$\frac{1}{k_x}$
Fractional resistance offered by gas-phase	$\frac{1/k_y}{1/K_y}$	$\frac{1/(m''k_y)}{1/K_x}$
Fractional resistance offered by liquid-phase	$\frac{m'/k_x}{1/K_y}$	$\frac{1/k_x}{1/K_x}$

Steady state co-current Process

Let the two insoluble phases be identified as phase ***E*** and phase ***R*** considering only a single substance ***A*** diffuses from phase ***R*** to phase ***E*** during their contact. The other constituents of the phases solvents for the diffusing solutes is considered not to diffuse.



where E_1, E_2 are mass or molar flow rates of E stream at ① and ② position respectively, R_1, R_2 are mass or molar flow rates of R stream at ① and ② position respectively, E_S, R_S are solute free flow rates of streams, x_1, x_2, y_1, y_2 are concentration of solute in mass or mole fraction of streams at ① and ② position respectively and X_1, X_2, Y_1, Y_2 are mass or mole ratio of solute in streams at ① and ② position respectively.

Cont…

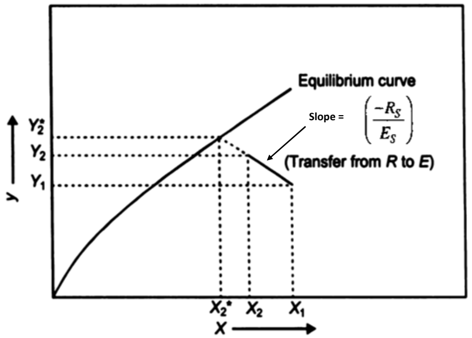
Making a component balance for solute, we get

$$R_1x_1 + E_1y_1 = R_2x_2 + E_2y_2$$

$$R_SX_1 + E_SY_1 = R_SX_2 + E_SY_2$$

$$R_S\,(X_1 - X_2) = E_S\,(Y_2 - Y_1)$$

$$\left(\frac{-R_S}{E_S}\right) = \frac{Y_2 - Y_1}{X_2 - X_1}$$



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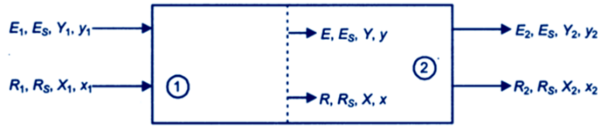
Cont…

This indicates a line passing through the points (X_1, Y_1) and (X_2, Y_2) which is called as operating line in the X vs. Y plot. The operating line also indicates the material balance in the operation.
Also,



$$R_SX_1 + E_SY_1 = R_SX + E_SY$$

$$\boxed{R_S\,(X_1 - X) = E_S\,(Y - Y_1)}$$

This represents the general equation of operating line in a co-current process.

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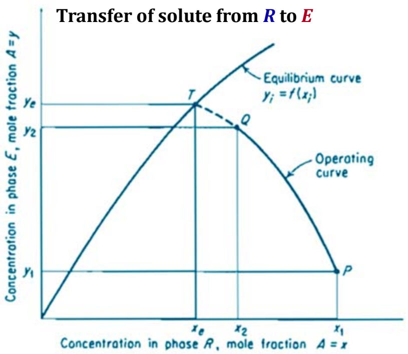
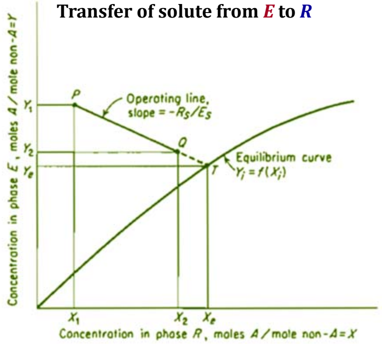
Cont…

Transfer of solute from R to E



Transfer of solute from E to R



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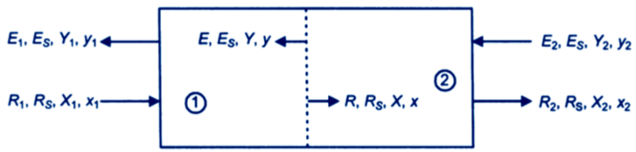
Steady state counter-current Process



where E_1, E_2 are mass or molar flow rates of E stream at ① and ② position respectively, R_1, R_2 are mass or molar flow rates of R stream at ① and ② position respectively, E_S, R_S are solute free flow rates of streams, x_1, x_2, y_1, y_2 are concentration of solute in mass or mole fraction of streams at ① and ② position respectively and X_1, X_2, Y_1, Y_2 are mass or mole ratio of solute in streams at ① and ② position respectively.

Cont…

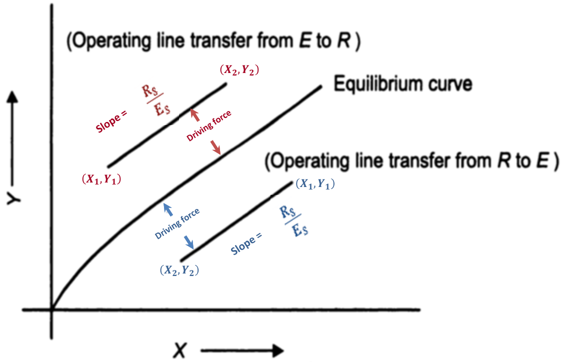
Making a component balance for solute yields

$$E_2 y_2 + R_1 x_1 = E_1 y_1 + R_2 x_2$$

$$E_S Y_2 + R_S X_1 = E_S Y_1 + R_S X_2$$

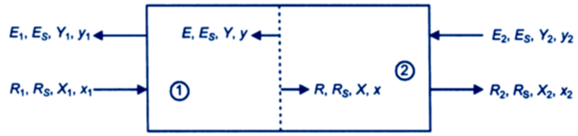
$$R_S (X_1 - X_2) = E_S (Y_1 - Y_2)$$

$$\frac{R_S}{E_S} = \frac{Y_1 - Y_2}{X_1 - X_2}$$



Cont…

This represents the equation of a line passing through the coordinates (X_1, Y_1) and (X_2, Y_2) with a slope of R_S/E_S in a plot of X vs Y.
Similarly another balance gives,



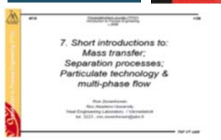
$$\boxed{E_S Y + R_S X_1 = E_S Y_1 + R_S X}$$

This represents the general equation of operating line

References

Mass Transfer
Theories for Mass Transfer Coefficients
Lecture 9, 15.11.2017, Dr. K. Wegner

MASS TRANSFER OPERATIONS: ABSORPTION AND EXTRACTION
José Coca, Salvador Ordóñez, and Eva Diaz
Department of Chemical Engineering and Environmental Technology, University of Oviedo, Oviedo, SPAIN



7. Short introductions to:
Mass transfer;
Separation processes;
Particulate technology &
multi-phase flow

- Lecture notes/ppt of Dr. Yahya Banat (ybanat@qu.edu.qa)