General information about mass transfer and extraction

Mass transfer

- It depends on concentration difference

$$Rateoftransfer = (\frac{Drivingforce}{resista\eta ce})$$

The driving force is the concentration difference for mass trafnsfer

- Fick’s law is dominant in mass transfer

$$J_B = -D_{BC}\frac{dC_B}{dx}$$

- Equilibrium and transfer

- There are three modes of mass transfer
  - molecular mass diffusion,
  - convective mass transfer and
  - mass transfer by change of phase.

- Many of daily experiences involve mass transfer.
- A lump of sugar added to a cup of tea eventually dissolves and then diffuses uniformly throughout the tea.
- You can smell the perfume, sprayed by a friend who is far away, due to diffusion of perfume molecules in air.

- Mass transfer has an important role in many areas of science and engineering.
- Many industrial processes such as leaching of sugar from sugar cane, distillation of alcoholic beverages, drying of apricots depend on mass transfer.

- Especially in food industry the following processes are leaded by mass transfer
  - Drying
  - Distillation
  - Evaporation
  - Extraction

- Extraction can be defined as a seperation process which depends on solubility difference.
- The aim is to remove the target component (solute) by using a convenient solvent.
- The extraction process can be grouped as;
  - Liquid liquid extraction
  - Solid liquid extraction (leaching)

General information about leaching:

- Leaching is a separation process in which the desired component, the solute, in a solid phase is separated by contacting the solid with a liquid, the solvent, in which the desired component is soluble.
- The desired component leaches from the solid into the solvent.
- Then the solid and the liquid phases are separated and the desired component is recovered from the liquid phase.

- Some common examples for leaching in food industry are;
  - extraction of soluble compounds from roasted and ground coffee in the soluble coffee production;
  - extraction of edible oils from oilseeds with organic solvents;
  - extraction of proteins from soybeans in the production of isolated soybean protein.

Solid–liquid extraction equilibrium

- Leaching can be grouped as single stage and multiple stage leaching according to its stage number.
- To analyze both leaching subgroups, an operating line equation or material balance relation and the equilibrium relations between the two streams are needed as in other separation processes.

- Rectangular diagram is used to interpret the equilibrium data of a three component system: solute (*A*), inert or leached solid (*B*) and solvent (*C*). The two phases are named as slurry and liquid. The concentration of inert or insoluble solid *B* in the slurry mixture can be given as;

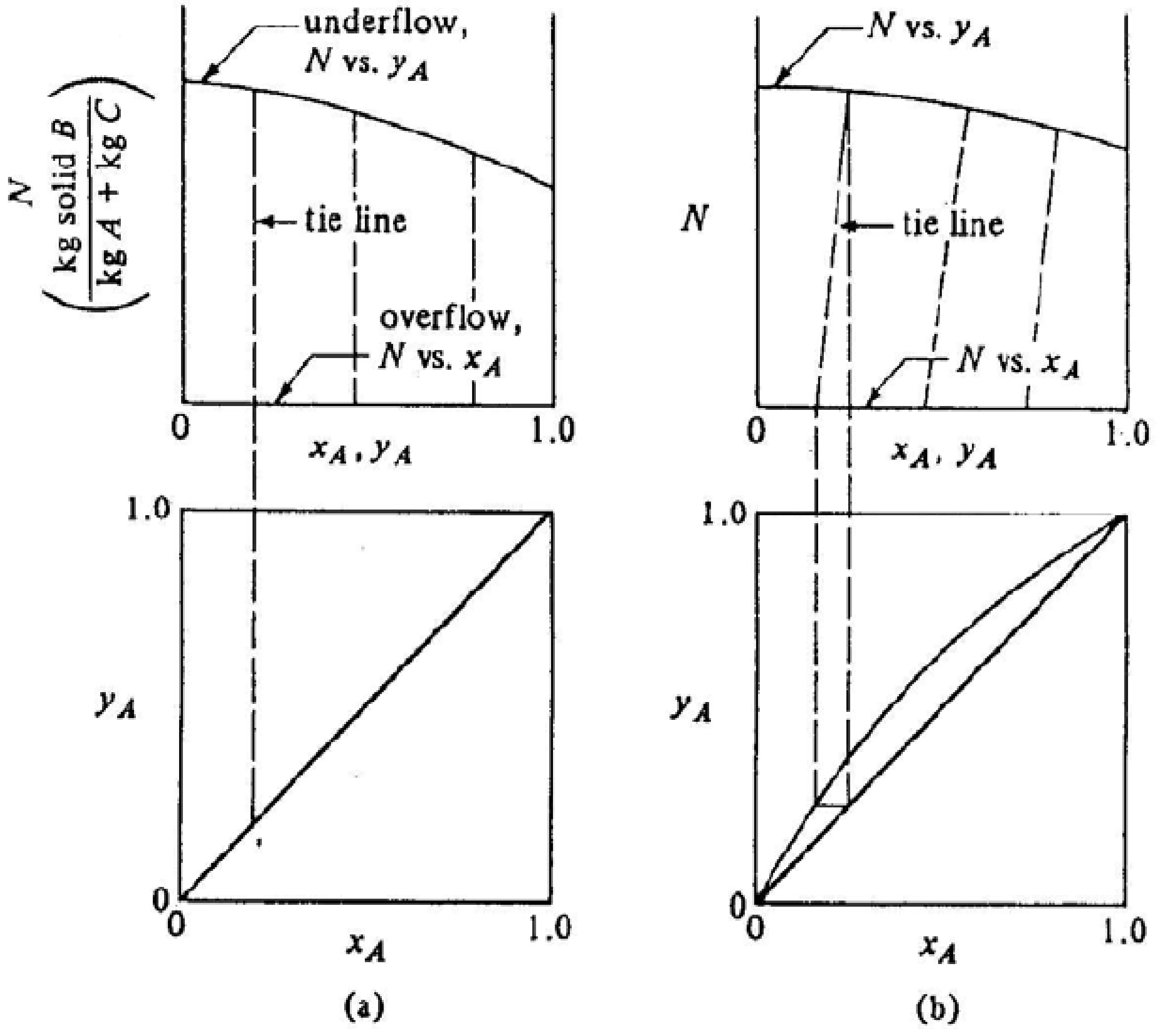
$$N = \frac{kgB}{kgA + kgC} = \frac{kg\ \ solid}{kg\ \ solution}$$

- The concentration of solute A in the liquid can be determined as:

$$x_A = \frac{kgA}{kgA + kgC} = \frac{kg\ \ solute}{kg\ \ solution} \qquad (overflow\ liquid)$$

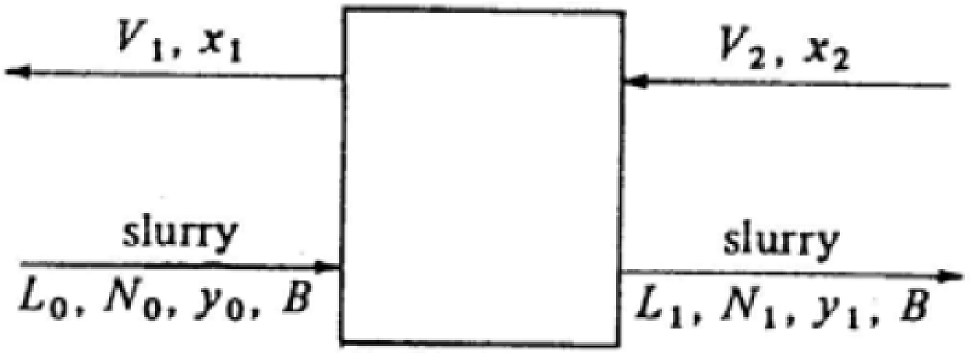
$$y_A = \frac{kgA}{kgA + kgC} = \frac{kg\ \ solute}{kg\ \ solution} \qquad (liquid\ \ in\ \ slurry)$$

where x_A is the weight fraction of solute *A* in the overflow liquid and y_A is the weight fraction of *A* on a solid-*B*-free basis in the liquid in slurry phase.

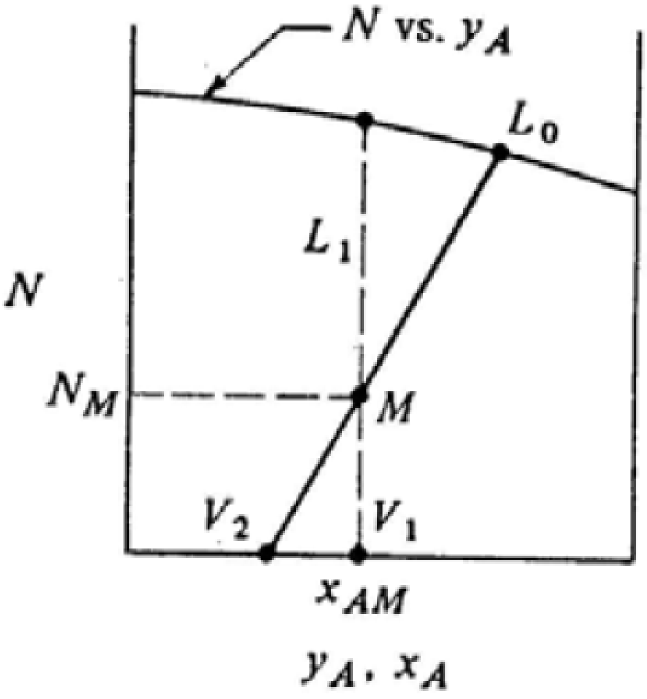


Typical equilibrium diagrams (a) for $x_A = y_A$, (b)for $x_A \neq y_A$

Single stage leaching



(a)



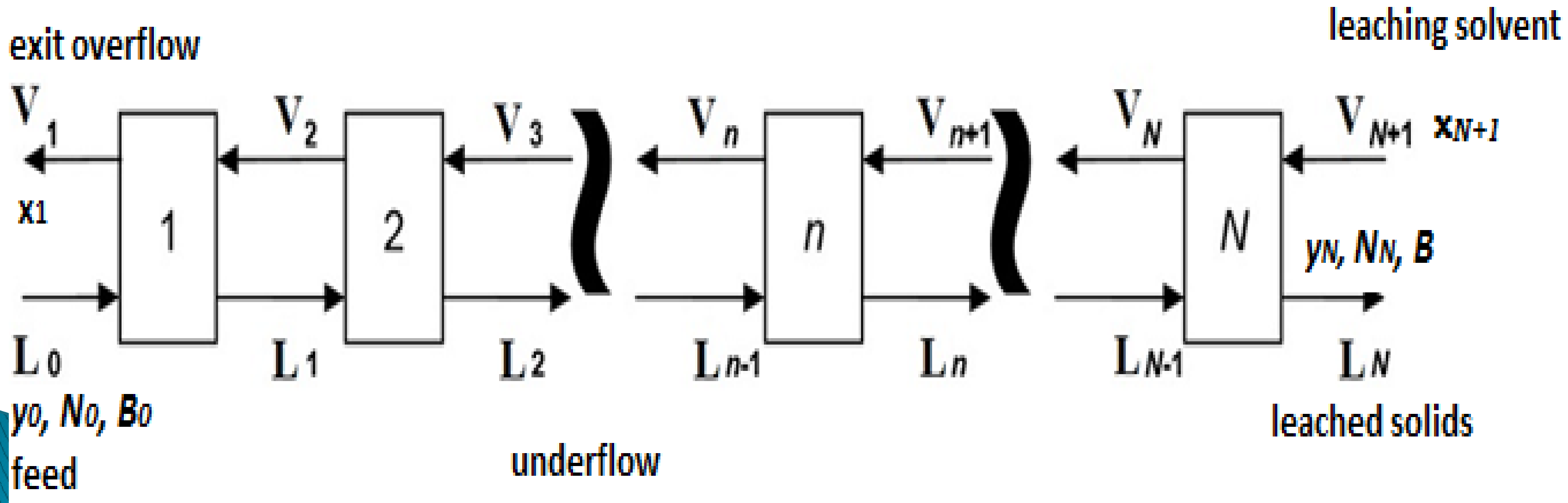
(b)

(total solution) $L_0 + V_2 = L_1 + V_1 = M$

(A): $L_0 y_{A0} + V_2 x_{A2} = L_1 y_{A1} + V_1 x_{A1} = M x_{AM}$

$B = N_0 L_0 + 0 = N_1 L_1 + 0 = N_M M$

The liquid phase, which is composed of solvent and solute, is named as V phase. It overflows countercurrent to the solid phase. The solute dissolves as it moves along. On the other hand, the slurry phase, which is composed of inert solid and a liquid phase of A and C, is named as L phase. It underflows from each stage.



- The major assumption of multistage leaching is insoluble solid B which results in no loss in the liquid V phase. The other assumption is constant flow rate of the solids through the stages. The terms are similar with the ones for single stage leaching:

-V is kg/h of overflow solution and

-L is kg/h of liquid solution in the slurry retained by the solid.

- The operating line equation can be derived by using an overall balance and component balance on solute A. If these balances are made over n stages;

$$L_0 + V_{n+1} = L_n + V_1$$

$$L_0 y_0 + V_{n+1} x_{n+1} = L_n y_n + V_1 x_1$$

- If this equation is solved for x_{n+1}, the operating line equation can be obtained.

$$x_{n+1} = \frac{1}{1+\left(V_1 - L_0\right)/L_n}\, y_n + \frac{L_0 y_0 + V_1 x_1}{L_n + V_1 - L_0}$$

- This operating line passes through the terminal points (x_1, y_0) and (x_{n+1}, y_n).

- If the viscosity and density of the solution change with the solute (A) concentration, the liquid retained in the solid underflow will change and so will the overflow and the slope of the operating line vary. This is called variable underflow. If the amount of solution *Ln* retained by the solid is constant and independent of concentration, then we will have constant underflow.

Countercurrent multistage leaching with variable underflow

$$L_0 + V_{N+1} = L_N + V_1 = M$$

$$L_0 y_{A0} + V_{N+1} x_{A,N+1} = L_N y_{A,N} + V_1 x_{A1} = M x_{AM}$$

$$B = L_0 N_0 = L_N N_N = M N_M$$

$$L_0 - V_1 = L_1 - V_2 = \ldots = L_n - V_{n+1} = L_N - V_{N+1} = \Delta$$

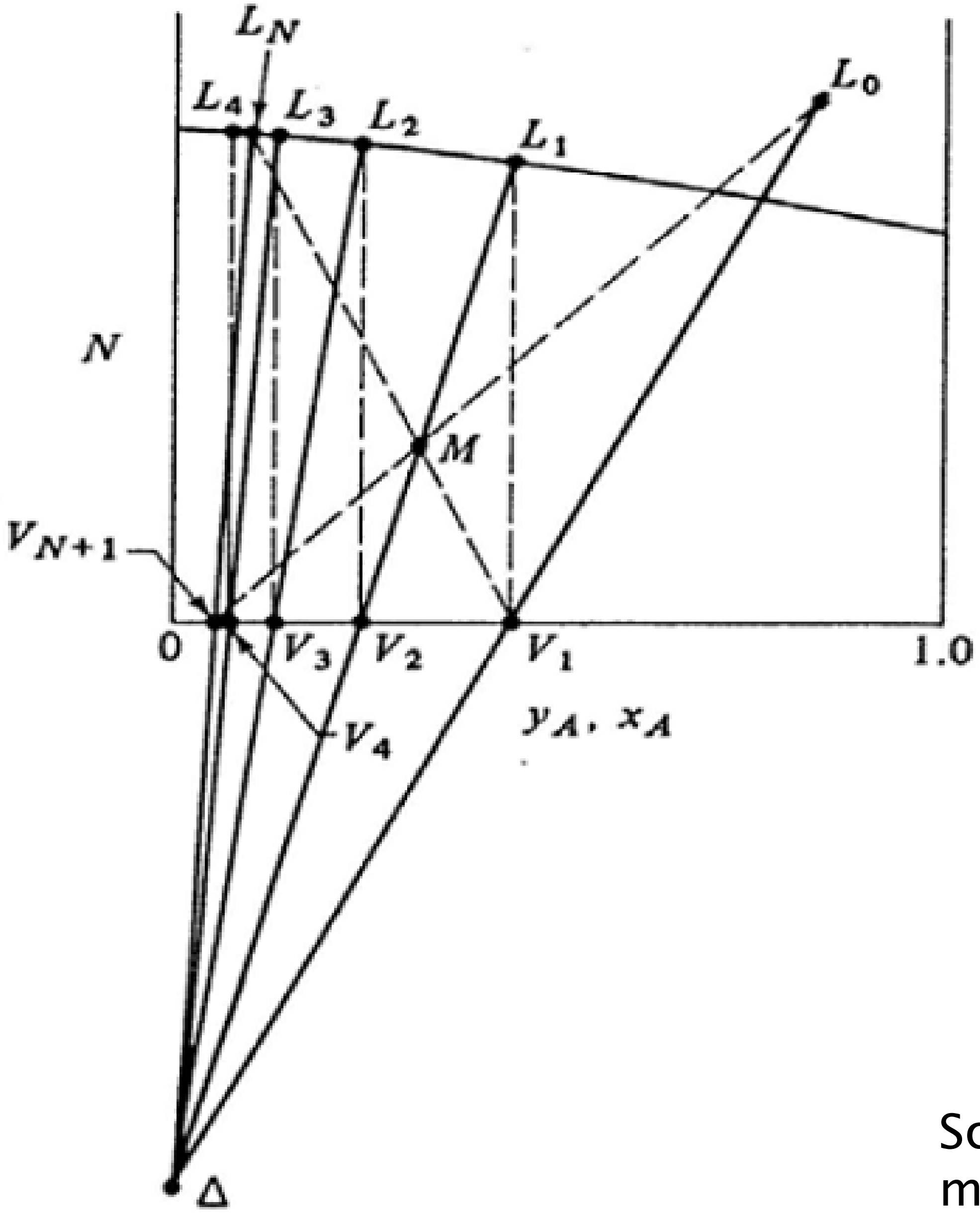
$$L_0 y_{A0} - V_1 x_{A1} = \ldots L_N y_{AN} - V_{N+1} x_{A,N+1} = \Delta x_{A\Delta}$$

$$B = L_0 N_0 = \ldots = L_N N_N = \Delta N_\Delta$$

$$x_{A\Delta} = \frac{L_0 y_{A0} - V_1 x_{A1}}{L_0 - V_1} = \frac{L_N y_{AN} - V_{N+1} x_{A,N+1}}{L_N - V_{N+1}}$$

$$N_\Delta = \frac{B}{L_0 - V_1} = \frac{L_0 N_0}{L_0 - V_1}$$

- This operating point Δ can also be located graphically as the intersection of lines L_0V_1 and L_NV_{N+1}



Schematic representation of the method to determine the coordinates of operating point graphically

- The number of stages can be determined by using the following procedure;

–The point L_0 should be located in the process graph.

–A linefrom$L_0$to Δ should be drawn to locate V_1.

–An equilibrium tie line through V_1 locates L_1.

–Line L_1 Δ is drawn to obtain V_2.

–A tie line from V_2 gives L_2.

–This is continued until the desired L_N is reached.