Principles of Chemical Engineering

Mass Transfer

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July 8, 2021

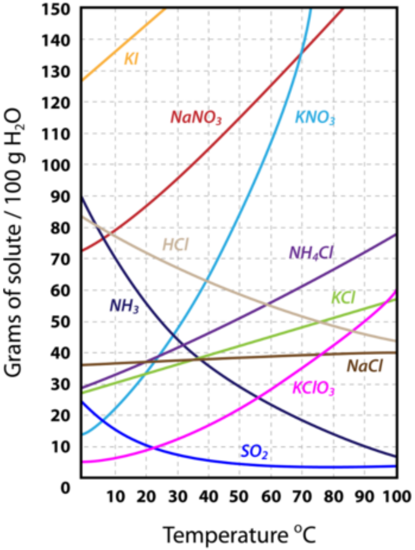
Syllabus Contents

Equilibrium curves.
Mass transfer operation in multiple stages.

Objectives

- To introduce about equilibrium curve in a typical mass transfer operation.
- To introduce about the need for multiple stages in mass transfer equipments.

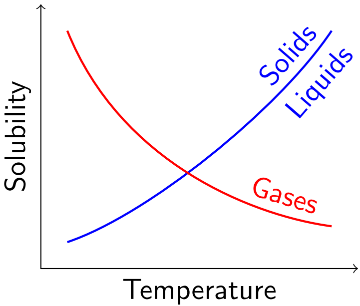
Solubility



- Solubility is the amount of solute that can dissolve in a given amount of solvent at a given temperature.
- Solubility curves can be used to determine if a given solution is saturated or unsaturated.

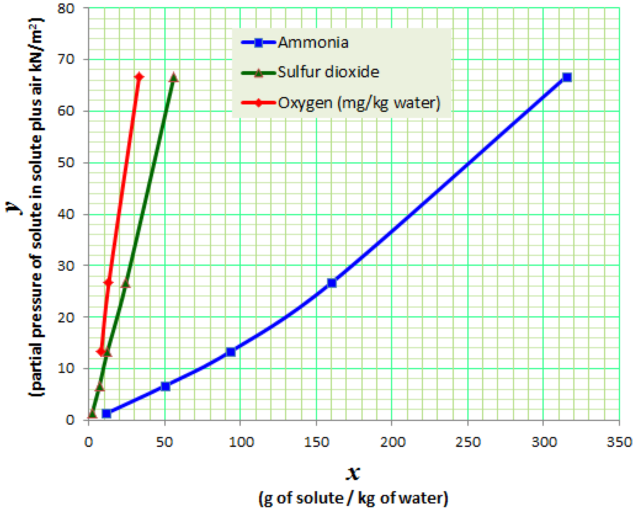
(Image source:
www.ck12.org/book/ck-12-chemistry-concepts---intermediate/r25/section/16.4/)

Solubility



- With solid or liquid solutes, increasing the temperature increases its solubility. For example, solubility of sugar is more in hot water than in cold water.
- If the solute is a gas, increasing the temperature decreases its solubility. For example, oxygen's solubility is lesser in warm water than in cold water.

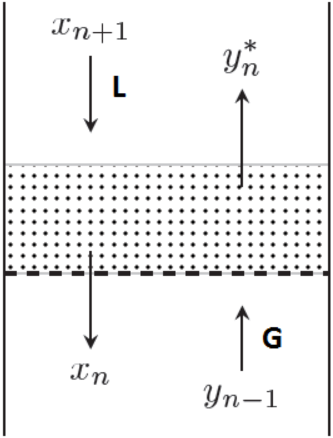
Equilibrium Curve for a Solute in Gas and Liquid Phases



At 30°C.

Data Source: Coulson & Richardson's Chemical Engineering - Vol. 2, pp. 657.

Equilibrium Stage



Bringing two phases in intimate contact, and allowing for a long time, will lead to attainment of equilibrium concentration.

The ideal stage is one, from which the materials leaving are in equilibrium with each other.

Here, y_n^* is in equilibrium with x_n, related by the expression such as $y_n^* = mx_n$.

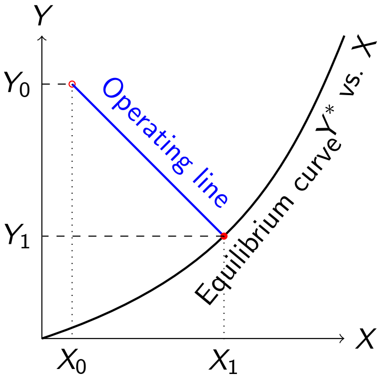
Single Stage Contact

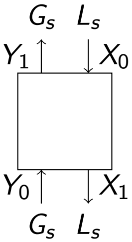
Streams leaving a stage are in equilibrium with each other.

$$G_s(Y_0 - Y_1) = L_s(X_1 - X_0) \quad \Longrightarrow \quad Y_0 - Y_1 = \frac{-L_s}{G_s}(X_0 - X_1)$$

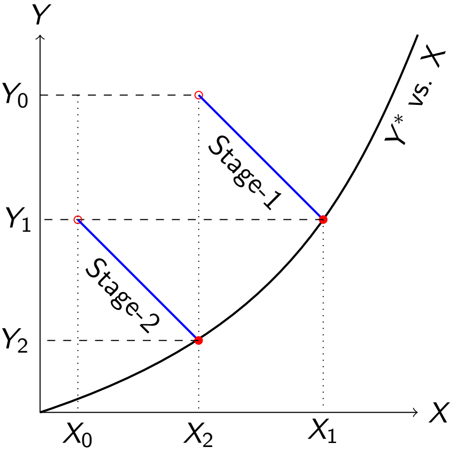
The compositions X_i, and Y_i are in terms of mole ratios. L_s and G_s are molar flow rate of liquid and gas on solute free basis.

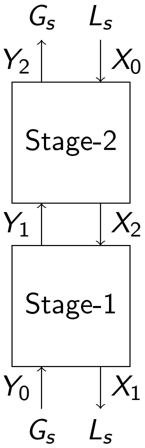
Operating line is the representation of material balance.





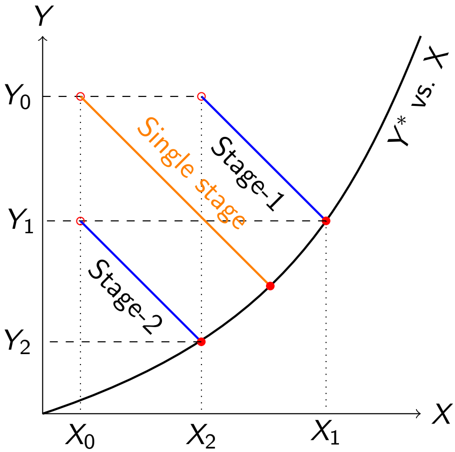
Countercurrent Contact (Two Stages)

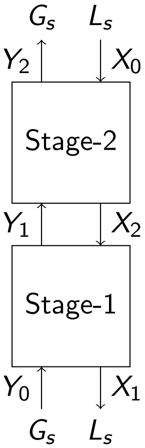




Countercurrent Contact (Two Stages)

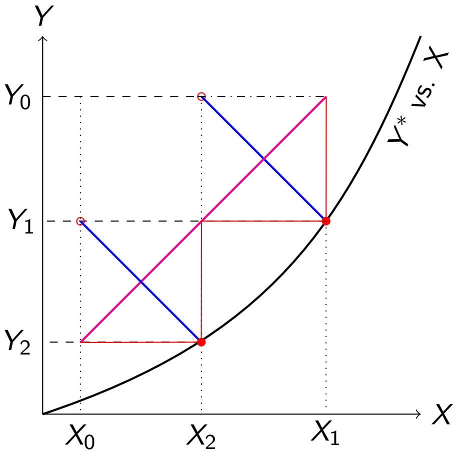
Countercurrent flow of streams with contact in multiple stages provides more amount of separation for a given liquid-to-gas ratio. Note the increase in concentration of solute in leaving solvent, and the decrease of solute concentration in the leaving gas stream.

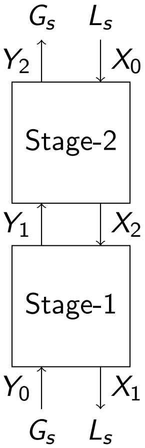




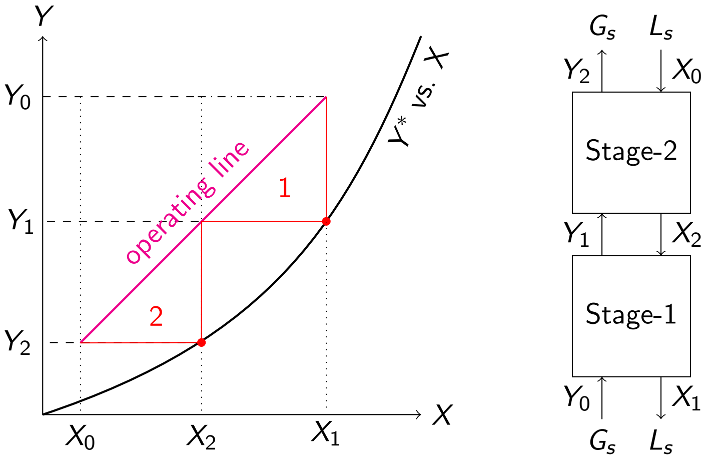
Countercurrent Contact (Two Stages)

End concentrations can be connected to make the operating line for the countercurrent cascades. Step construction between the operating line of cascade and equilibrium curve will give the count of number of stages.





Countercurrent Contact (Two Stages)



The operating line indicates the relation between the gas and liquid concentration at any level in the tower.

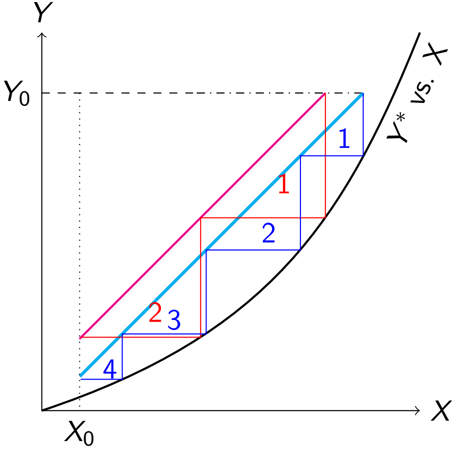
Countercurrent Contact

$$G_s(Y_0 - Y_2) = L_s(X_1 - X_0) \quad \Longrightarrow \quad Y_0 - Y_2 = \frac{L_s}{G_s}(X_1 - X_0)$$

Slope of operating line of countercurrent cascades is given by L_s/G_s.

Effect of Multiple Stages

For the same L/G ratio, separation can be improved with multiple stages; i.e., reduction in concentration of solute in the gas phase; and, increase in concentration of solute in liquid phase.



Effect of L/G Ratio

- Increasing the L/G leads to decrease in number of stages required.
- Increasing the L/G leads to increase in operating cost.
- Increasing the number of stages, increases the initial (fixed) cost.