



GAS ABSORPTION

Mass Transfer II 

Absorption is one of the important gas-liquid contact operations in which a gaseous mixture is contacted with a solvent to dissolve one or more components of the gas preferentially and provide a solution of them in the solvent.

Some of the applications of this operation are as follows;

- (i) Ammonia is removed from coke oven gas with water
- (ii) Benzene and toluene vapours are removed using hydrocarbon oil from the coke-oven gas.
- (iii) Hydrogen sulfide is removed from naturally occurring hydrocarbon gases with alkaline solutions.
- (iv) Ammonia and other water soluble harmful gases from air are removed using water.

Gas solubility in liquids at equilibrium

The rate at which a gaseous constituent of a mixture will dissolve in an absorbent liquid depends upon the departure from equilibrium which exists.

For two component system (single gas and nonvolatile liquid)

Equilibrium solubility of gas in liquid at prevailing temperature and pressure will increase with pressure for fixed temperature.

For example curve A in figure shows the solubility of ammonia in water at 30°C.

In a **multicomponent system**, mixture of gases is brought into contact with liquid, under certain conditions the equilibrium solubility's of each gas will be independent of the others. The equilibrium solubility is described in terms of the partial pressures in the gas mixture.

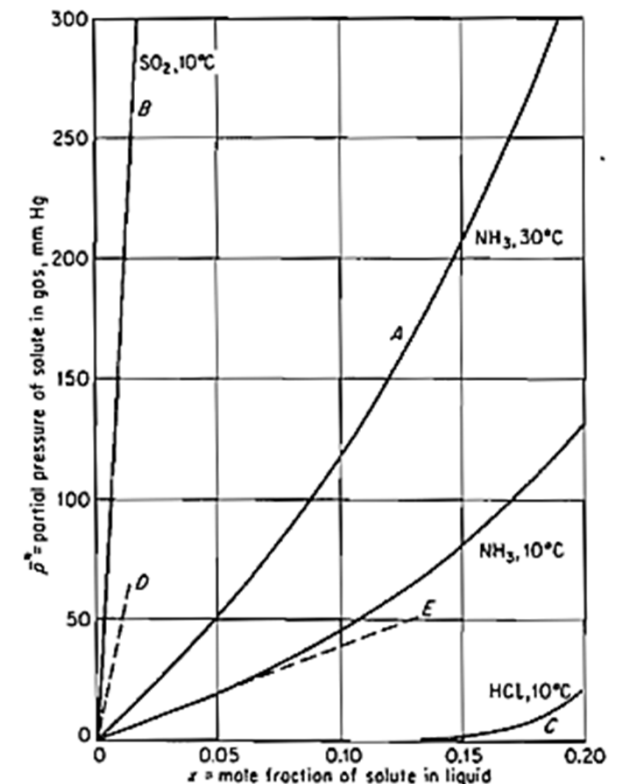
However, some of the system resulting solution of these gases are not ideal since, solubility of one gas affected by another gas.

For example: Solubility of ammonia in water can be expected to be influenced by the presence of methylamine.

The solubility of a gas will also be influenced by the presence of nonvolatile solute in the liquid, such as a salt in water solution, when such solutions are nonideal.

Ideal liquid solution, in reality there are no ideal solutions, and actual mixtures only approach ideality as a limit.

Practically, however, many solutions are so nearly ideal that for engineering purpose they can be considered .



For example: Solution of benzene in toluene, or paraffin hydrocarbon gases in paraffin oil can be considered as ideal solutions.

When the gas mixture in equilibrium with an ideal liquid solution also follows the ideal-gas law, the partial pressure \bar{p}^* of a solute gas A equals the product of its vapor pressure p at the same temperature and its mole fraction in the solution x .

$$\bar{p}^* = px$$

For **nonideal liquid solution**, Henry's law is seen to be applicable with different values of Henry constant m for each of the gases over at least a modest liquid-concentration range.

$$p_A^* = Hx_A$$

Usually H is dependent upon temperature but relatively independent of pressure at moderate levels. In solutions containing inorganic salts, H will also be a function of ionic strength.

Over wide concentration range Henry law is not applicable due to chemical interaction with the liquid or electrolytic dissociation.

A more general way of expressing solubilities is through the vapor-liquid equilibrium constant K , defined by

$$Y = KX$$

A common alternate notation replaces K by m

$$Y = mX$$

K values are widely employed to represent hydrocarbon vapor-liquid equilibria in absorption and distillation calculations.

Choice of Solvent for Absorption

If the principal purpose of the absorption operation is to produce a specific solution, the solvent is specified by the nature of the product.

If the principal purpose is to remove some constituent from the gas than following properties are important considerations:

- (i) Solubility: solubility of the solute to be absorbed in solvent should be relatively high, but it should not dissolve the carrier gas.

sometimes there may be more than one solute of similar chemical nature, but it may be desirable to remove only one of them. In such a case, a solvent which is 'selective' for the particular solute is preferred.

For example:

Natural gas contains both CO_2 and H_2S as undesirable constituents. While CO_2 need not to be removed when the gas is used for certain purposes, H_2S has to be. A common solvent like aqueous ethanolamine absorbs both CO_2 and H_2S . However, N-methyl diethanolamine preferentially absorbs H_2S ; only a little of CO_2 is absorbed.

(ii) Volatility: a good solvent should have a low volatility or vapor pressure so that the solvent loss with the carrier gas because of vaporization remains small.

(iii) Viscosity: a solvent should have a low viscosity so that it flows easily. Viscous solvent causes large pumping cost and flooding at lower liquid and gas flow rates.

(iv) Corrosiveness: use of a non-corrosive or less corrosive solvent reduces the material cost of the equipment as well as its maintenance cost.

(v) Cost: A solvent should not be very expensive so that vaporization and other losses are not significant in terms of economy.

(vi) Hazard and toxicity: A solvent should not be hazardous or toxic. It should preferably be non-inflammable.

Single Stage –One Component Transferred-Counter current and Isothermal Operation

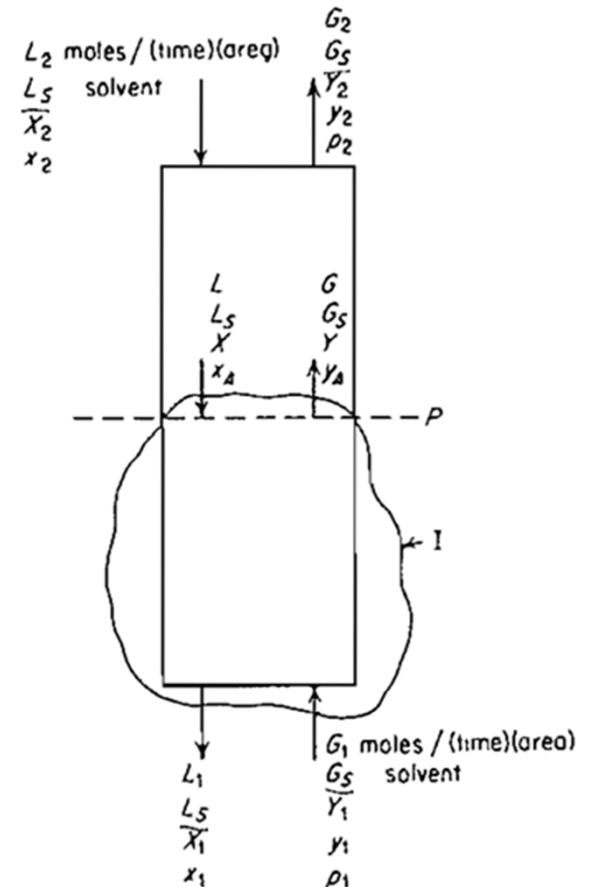
Considering a single stage isothermal absorber shown in figure. Gaseous mixture entering the absorber at the bottom is contacted counter currently with liquid solvent, entering from the top.

The gas stream at any point in the tower consists of G total mol/(area of tower cross section)(time), made up of diffusing solute A of mole fraction y , partial pressure p , or mole ratio Y , and non-diffusing, essentially insoluble gas G_S mol/(area)(time). The relationship between these is

$$Y = \frac{y}{1 - y} = \frac{\bar{p}}{p_t - \bar{p}}$$

$$G_S = G(1 - y) = \frac{G}{1 + Y}$$

Similarly the liquid stream consists of L total mol/(area)(time), Containing x mole fraction soluble gas, or mole ratio X , and essentially nonvolatile solvent L_S mol/(area)(time)



$$X = \frac{x}{1-x}$$

$$L_S = L(1-x) = \frac{L}{1+X}$$

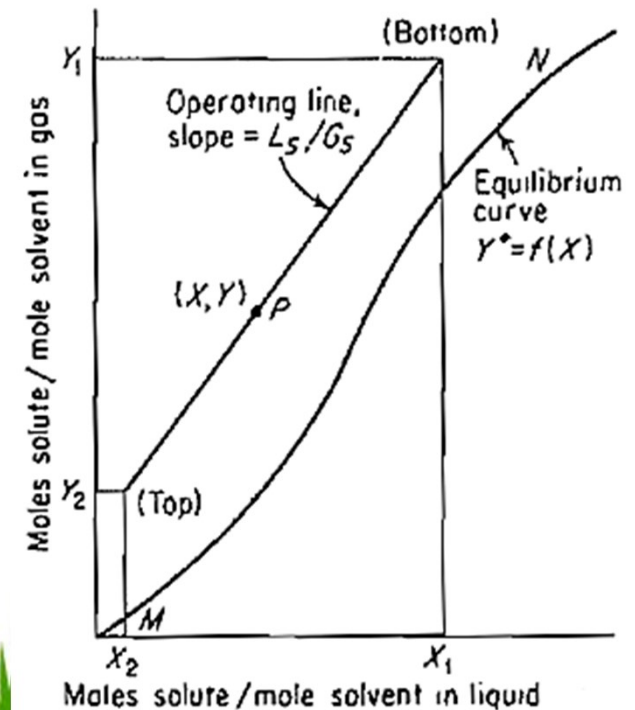
Since the solvent gas and solvent liquid are essentially unchanged in quantity as they pass through the tower, it is convenient to express the material balance in terms of these.

A solute balance about the lower part of the tower (envelop I)

$$G_S(Y_1 - Y) = L_S(X_1 - X)$$

This is the equation of a straight line (the operating line) on X, Y coordinates, of slope L_S/G_S , which passes through (X_1, Y_1) . Substitution of X_2 and Y_2 for X and Y shows the line to pass through (X_2, Y_2) as on figure for an absorber.

This line indicates the relation between the liquid and gas concentration at any level in the tower, as at point p.



The equilibrium-solubility data for the solute gas in the solvent liquid plotted in terms of these concentration units represented by the curve MN.

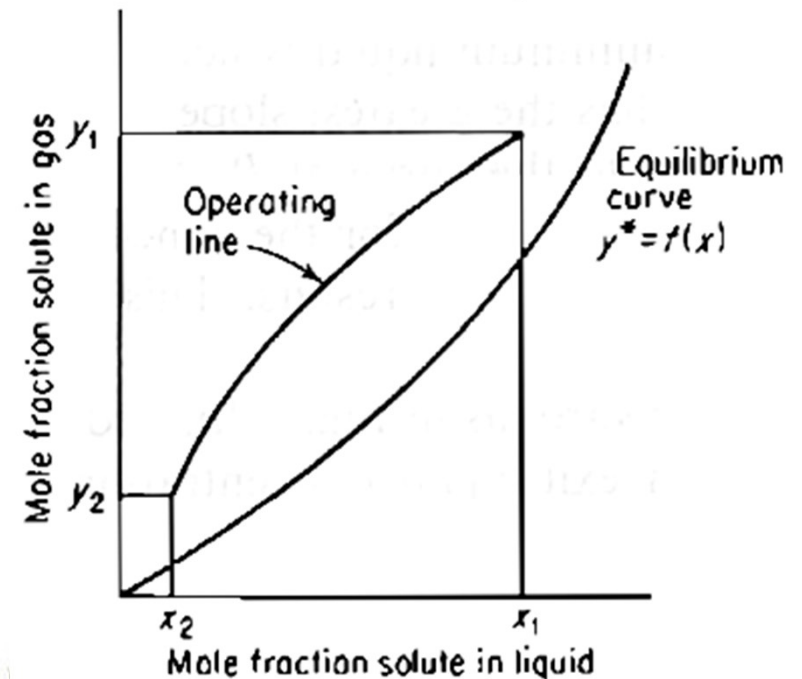
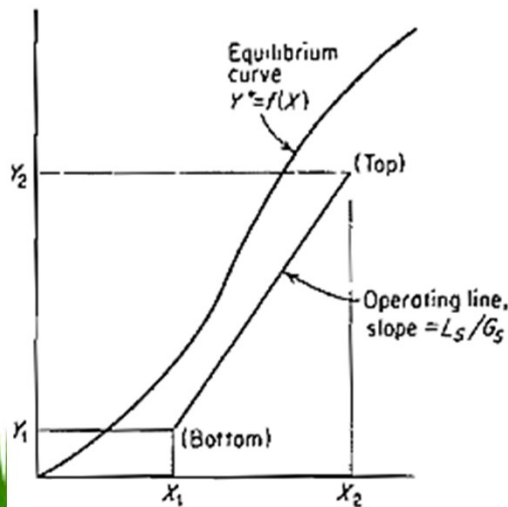
For an absorber (mass transfer from gas to liquid) the operating line always lies above the equilibrium-solubility curve, while for a stripper (mass transfer from liquid to gas) the line is always below.

The operating line is straight only when plotted in terms of the mole-ratio units. In terms of mole fractions or partial pressures the line is curved shown in figure.

The equation of the line is then

$$G_S \left(\frac{y_1}{1-y_1} - \frac{y}{1-y} \right) = G_S \left(\frac{\bar{p}_1}{p_t - \bar{p}_1} - \frac{\bar{p}}{p_t - \bar{p}} \right)$$

$$= L_S \left(\frac{x_1}{1-x_1} - \frac{x}{1-x} \right)$$



Minimum Liquid-Gas Ratio For Absorber

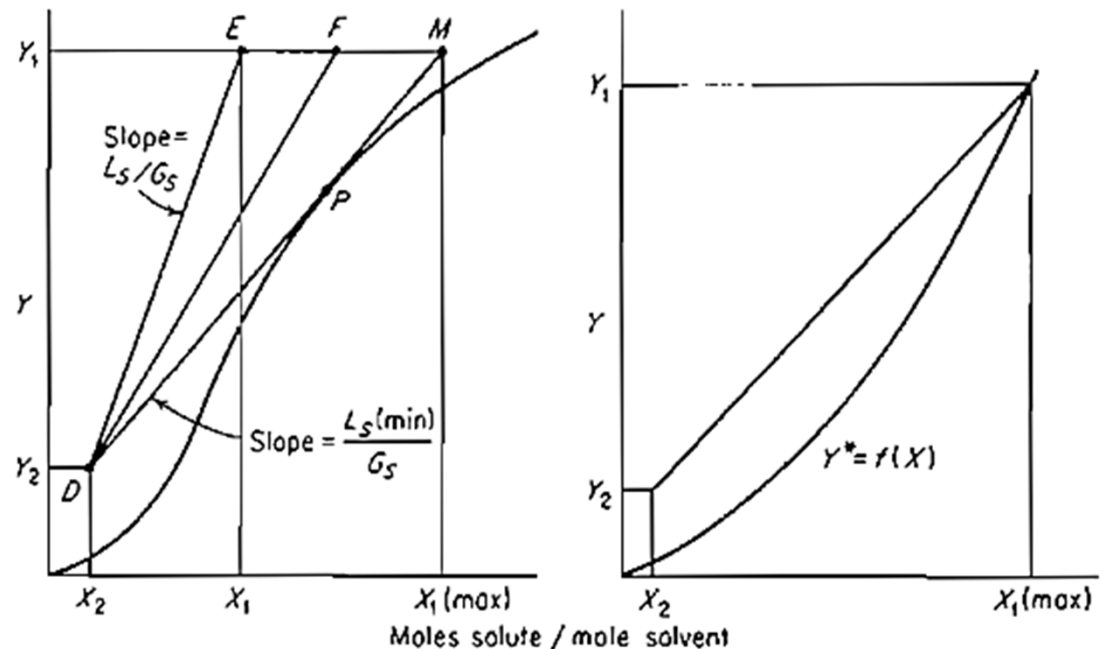
In the design of absorber, the quantity of gas to be treated G or G_S , the terminal concentrations Y_1 and Y_2 , and the composition of the entering liquid X_2 are ordinarily fixed by process requirements, but the quantity of liquid to be used is subject to choice.

Figure shows that the operating line must pass through point D and must end at the ordinate Y_1 .

If such a quantity of liquid is used to give operating line DE , the exit liquid will have the composition X_1 .

If less liquid is used, the exit liquid composition will clearly be greater, as at point F , but

since the driving forces for diffusion are less, the absorption is more difficult. The time of contact between gas and liquid must then be greater, and the absorber must be correspondingly taller.



The minimum liquid which can be used corresponds to the operating line DM, which has the greatest slope for any line touching the equilibrium curve and is tangent to the curve at P.

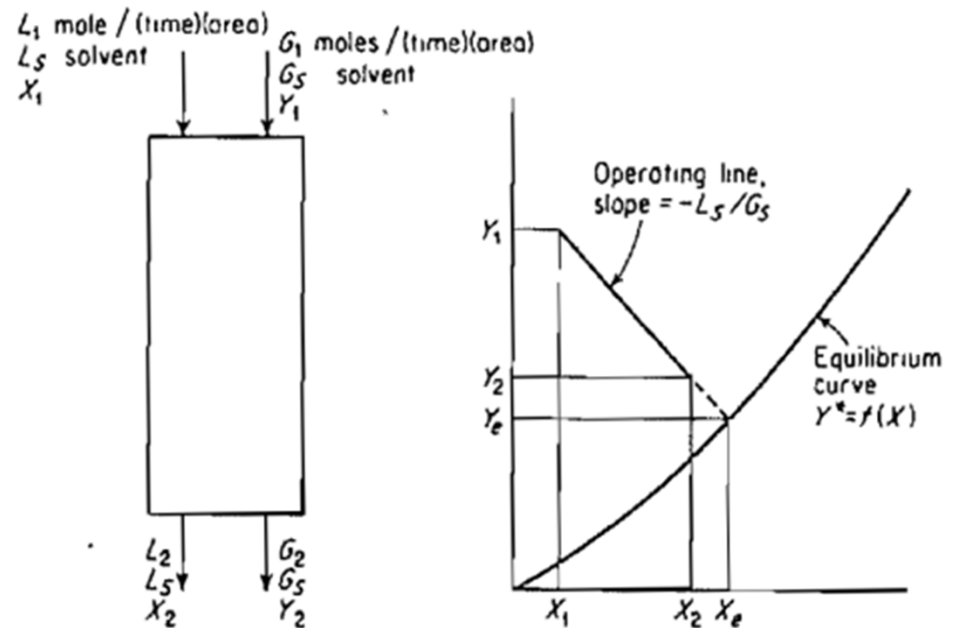
At P the diffusional driving force is zero, the required time of contact for the concentration change desired is infinite, and infinitely tall tower results. This then represents the limiting liquid-gas ratio.

If equilibrium curve is frequently concave upward as in figure, and the minimum liquid-gas ratio then corresponds to an exit-liquid concentration in equilibrium with the entering gas.

Cocurrent Flow

When **gas and liquid flow cocurrently** as shown in figure. The **operating line has a negative slope $-L_S/G_S$** .

There is **no limit on this ratio**, but an **infinitely tall tower would produce an exit liquid and gas in equilibrium**, as at (X_e, Y_e) .



Cocurrent flow may be used when an exceptionally tall tower is built in two sections as shown in figure.

Second section operated in cocurrent flow to save investment in large diameter gas pipe connecting the two section.

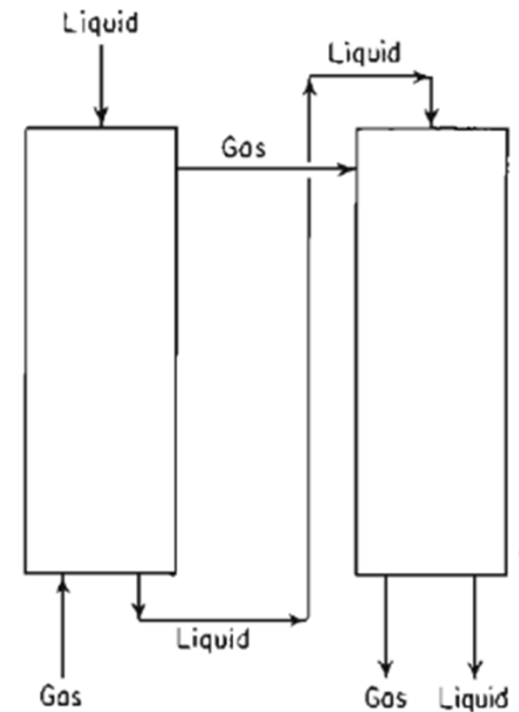
Cocurrent flow may also be used if gas to be dissolved in the liquid is a pure substance, or if rapid, irreversible chemical reaction with the dissolved solute occurs in the liquid.

Multistage Countercurrent Operation; One Component Transferred

Tray towers and similar device have stepwise contact of liquid and gas and are therefore multistage countercurrent cascades.

For example in a sieve tray tower gas and liquid brought into intimate contact and separated on each tray and tray thus constitutes a stage.

Theoretical or ideal tray is defined as one where the average composition of all the gas leaving the tray is in equilibrium with the average composition of all the liquid leaving the tray.



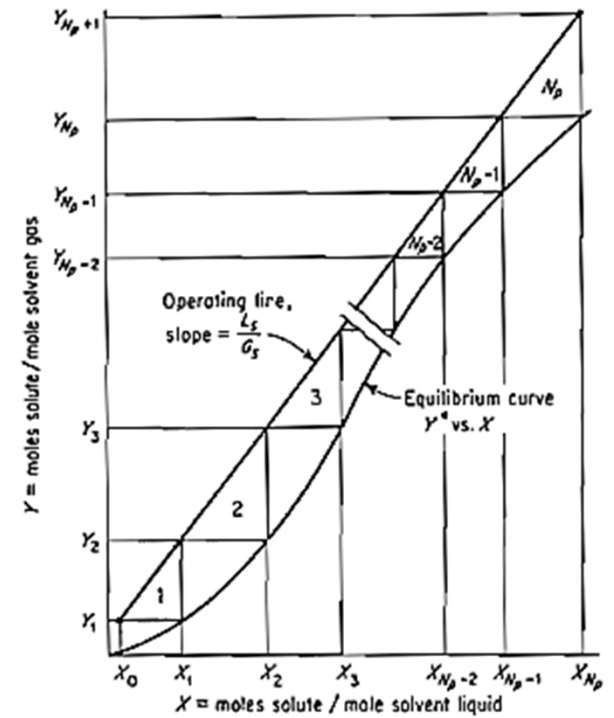
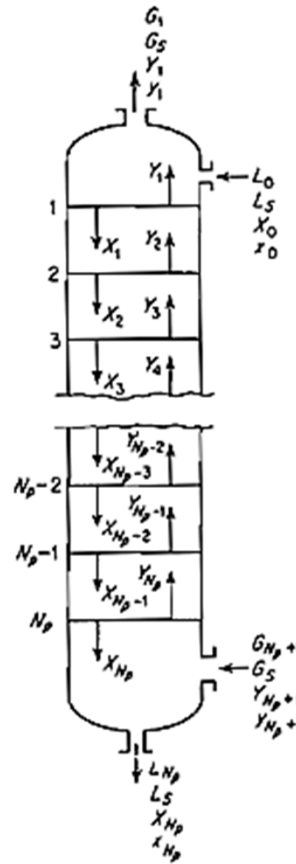
The number of ideal trays required to bring about a given change in composition of the liquid or the gas (either absorbers or strippers) can be determined graphically shown in figure for absorber.

Here liquid and gas composition corresponding to each tray are marked on the operating diagram.

The nearer the operating line to the equilibrium curve the more steps will be required.

If two curve touch at any point corresponding to minimum L_S/G_S ratio the number of steps will be infinite.

In the tray tower flow rates L and G define in mol/h



Dilute Gas Mixtures

for the **case of relatively dilute gas and liquid mixtures**, where both **operating line and equilibrium curve can be considered straight**.

Henry's law often applies to dilute solutions, for example if the quantity of gas absorbed is small, the total flow of liquid entering and leaving the absorber remains substantially constant, $L_O \approx L_{N_P} \approx L$ total mol/(area)(time), and similarly the total flow of gas is substantially constant at G total mol/(area)(time).

The Absorption Factor A

The absorption factor $A = L/mG$ is the ratio of the **slope of the operating line to that of the equilibrium curve**.

For values of **A less than unity**, corresponding to **convergence of the operating line and equilibrium curve for the lower end of the absorber**.

On the other hand, for **A greater than unity**, **any degree of absorption is possible** if sufficient trays are provided.

For a fixed degree of absorption from a fixed amount of gas, as A increases beyond unity, the absorbed solute is dissolved in more and more liquid and becomes therefore less valuable. At the same time, the number of tray decreases, so the equipment cost decreases.

As a rule of thumb for purpose of rapid estimates, it has been found that most economical A will be in the range from 1.25 to 2.

The reciprocal of absorption factor is called the stripping factor.

Absorption:

$$\frac{y_{N_p+1} - y_1}{y_{N_p+1} - mx_0} = \frac{A^{N_p+1} - A}{A^{N_p+1} - 1}$$

$$N_p = \frac{\log \left[\frac{y_{N_p+1} - mx_0}{y_1 - mx_0} \left(1 - \frac{1}{A} \right) + \frac{1}{A} \right]}{\log A}$$

Stripping:

$$\frac{x_0 - x_{N_p}}{x_0 - y_{N_p+1}/m} = \frac{S^{N_p+1} - S}{S^{N_p+1} - 1}$$

$$N_p = \frac{\log \left[\frac{x_0 - y_{N_p+1}/m}{x_{N_p} - y_{N_p+1}/m} \left(1 - \frac{1}{S} \right) + \frac{1}{S} \right]}{\log S}$$

where $A = L/mG$, and $S = mG/L$.