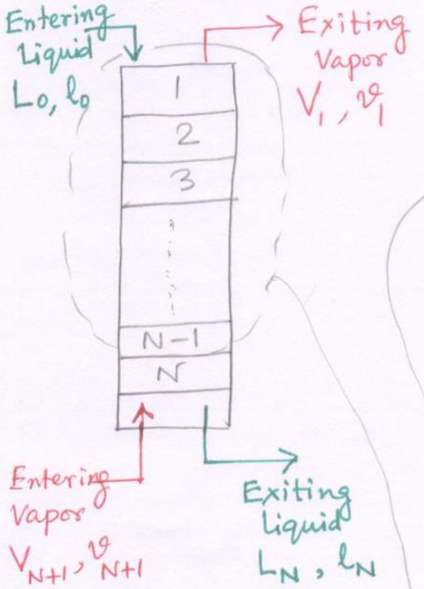
MULTICOMPONENT ABSORPTION by GROUP Method

An approximate Calculation Procedure! Detailed changes in temperature and compositions in the individual stages are not rigrously considered.

Consider countercurrent cascade of N adiabatic equilibrium stages for absorption of more than one species that ~~are~~ were present in the entering vapor.



v, l are component molar flow rates (the deduction focuses on one specific component of the many that are getting absorbed; v, l corresponds to molar flow rate of that specific component).

V, L are total molar flow rates

Subscripts (1, 0, N, N+1 etc.) refer to the stage from which the stream is leaving.

Assume that the components to be absorbed are not present in the entering liquid (i.e., absorbent is pure). $l_0 = 0$

Material balance for the specific component across stages 1 through N−1

$$v_N = v_1 + l_{N-1} + \cancel{l_0} \to 0$$

and for each stage
$$\left.\begin{aligned} v &= yV \\ l &= xL \end{aligned}\right\}$$

Again, y without subscript refers to mole fraction of specific component for which material balance is drawn in vapor phase. x corresponds to same in the liquid phase.

At N^{th} stage

$y_N = K_N x_N$ from equilibrium consideration.

$$\frac{v_N}{V_N} = K_N \frac{l_N}{L_N} \Rightarrow v_N = \frac{l_N}{\frac{L_N}{K_N V_N}} = \frac{l_N}{A_N} \quad \text{------ Equation 0}$$

$A = \dfrac{L}{KV}$ is Absorption factor (analogous to Extraction factor, E) for a given stage and component.

$$l_N = (l_{N-1} + v_1) A_N \quad \text{....... Equation 1}$$

Continue drawing material balance around stages 1 through N−2, the component balance equation becomes

$$l_{N-1} = (l_{N-2} + v_1) A_{N-1}$$

This follows from the pattern shown in Equation 1 in last page.

Substituting this expression of l_{N-1} to Equation 1 in last page,

$$l_N = l_{N-2} A_{N-1} A_N + v_1 (A_N + A_{N-1} A_N)$$

Continuing material balances around successively smaller sections of the top of cascade (i.e., balance around stages 1 through N−3, then around stages 1 through N−4, ...)

$$l_N = l_1 A_N A_{N-1} A_{N-2} \cdots A_2 + v_1 (A_N + A_{N-1} A_N + A_{N-2} A_{N-1} A_N + \cdots + A_2 A_3 A_4 \cdots A_N)$$

From Equation 0 of last page

$$l_1 = v_1 A_1$$

$$\Rightarrow l_N = v_1 (A_1 A_2 A_3 \cdots A_N + A_2 A_3 \cdots A_N + A_3 A_4 \cdots A_N + \cdots + A_N)$$

Material balance of the chosen component around stages 1 through N,

Since $l_0 = 0$

$$l_N = v_{N+1} - v_1$$

$$\Rightarrow v_{N+1} = l_N + v_1$$

$$= v_1 [A_1 A_2 A_3 \cdots A_N + A_2 A_3 \cdots A_N + \cdots + A_N + 1]$$

$$\Rightarrow v_1 = \frac{v_{N+1}}{[A_1 A_2 A_3 \cdots A_N + A_2 A_3 \cdots A_N + \cdots + A_N + 1]} = v_{N+1} \phi_A$$

$$\text{Here } \phi_A = \frac{1}{A_1 A_2 A_3 \cdots A_N + A_2 A_3 \cdots A_N + \cdots + A_N + 1}$$

is fraction of chosen ~~component~~ species in entering vapor that is not absorbed

As per the schematic drawing of last page, v_1 is the molar flow rate of selected component ~~at the~~ exiting from the top of the column, where as v_{N+1} is the molar in-flow rate of the same at the bottom. Thus $\frac{v_1}{v_{N+1}}$ signifies fraction of the selected species that remains unabsorbed, and is referred as recovery fraction.

An assumption in the group method is to replace individual 'A's by a single ~~value~~ parameter i.e., an average effective absorption factor 'A_e' such that the recovery fraction ϕ_A can be expressed as

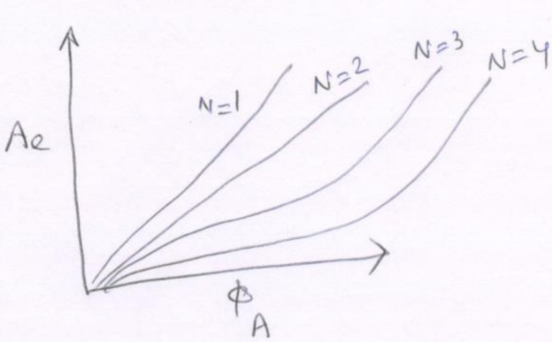
$$\phi_A = \frac{1}{A_e^N + A_e^{N-1} + A_e^{N-2} + \cdots + A_e + 1}$$

Multiplying numerator and denominator by $(A_e - 1)$

$$\phi_A = \frac{A_e - 1}{A_e\left[A_e^N + A_e^{N-1} + \cdots + A_e + 1\right] - \left[A_e^N + A_e^{N-1} + \cdots + A_e + 1\right]}$$

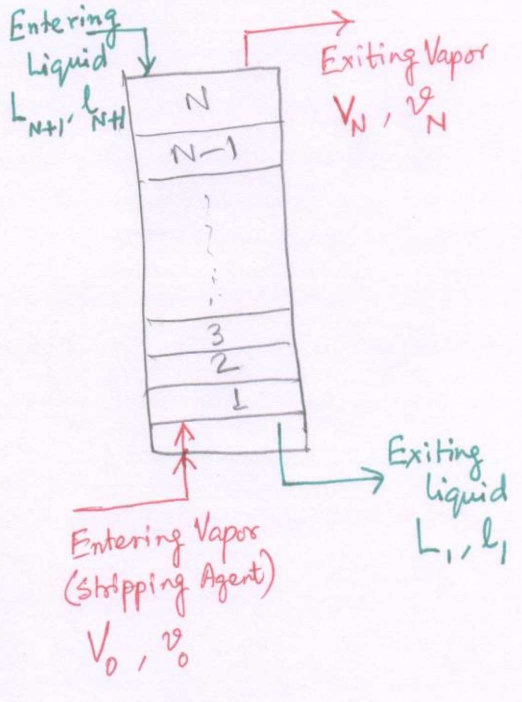
$$= \frac{A_e - 1}{A_e^{N+1} - 1}$$

The above is true for the species on which material balance is performed. A varies from stage to stage since pressure, temperature, and composition very from stage to stage. A_e is an average that can replace A values of individual stages i.e., $A_1, A_2, \ldots, A_N$ by a single parameter A_e and still gives the same recovery fraction. A_e and ϕ_A can be plotted as follows



Absorbers are frequently coupled with stripper. The purpose of the stripper is to separate out the absorbed component from the absorbent. The process is reverse of "absorption" where the volatile components are drawn out from the loaded absorbent using a stripping agent (gas). The regenerated absorbent is recycled to the absorption column. Alternative way to regenerate the absorbent is distillation.

Application of Group method for countercurrent STRIPPING



Exactly similar treatment, as was done for Absorption.

Assumptions: ① Components, stripped from the liquid are absent in the entering vapor.

i.e., $v_0 = 0$ (in case of Absorption $l_0 = 0$).

② Condensation or absorption of stripping agent is ignored.

(in case of Absorption, the vaporization of absorbent was also ignored — to be noted).

Stages are numbered in the reverse order to make same treatment on v, as was done on l, and thus utilize the derivation steps of Absorption.

Following the same methods, as before:

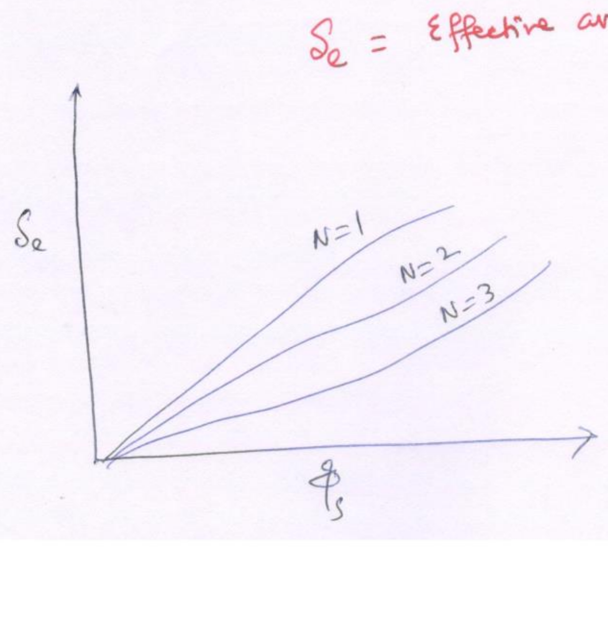
$$l_1 = l_{N+1}\,\phi_S$$

Equivalent form for Absorption $v_1 = v_{N+1}\,\phi_A$

where $\phi_S = \dfrac{S_e - 1}{S_e^{N+1} - 1}$ = fraction of species in entering liquid that is not stripped

and $S = \dfrac{KV}{L} = \dfrac{1}{A}$ = Stripping Factor

S_e = Effective average stripping factor



Exactly same shape of curves, as observed for A_e vs. ϕ_A in case of Absorption

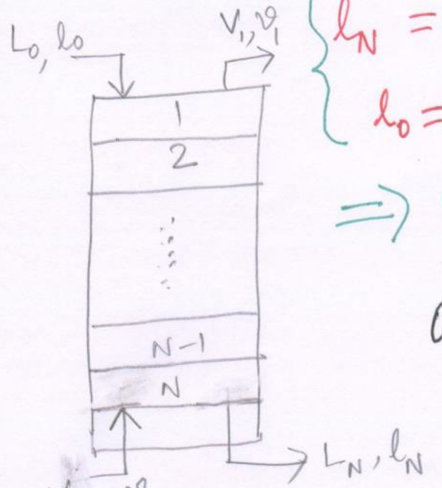
General Absorber Equation

- Typically, Absorption and Stripping occur simultaneously.
- Recycled absorbent contains remnants (from previous cycle) of species present in the vapor entering the absorber.
- Vapor passing up through the absorber can also strip some part of absorbent.

A general absorber equation can be obtained by combining the Absorption and Stripping equation. However, the numbering of stages has to be consistent in both cases.

Stripping Equation was found to be $\boxed{l_1 = l_{N+1}\,\phi_S}$ in last page

when the stage numbering is Reversed to make it consistent with what was there in Absorption, the equation gets modified as



$$\begin{cases} l_N = l_0\,\phi_S \\ l_0 = v_1 + l_N - \cancel{v_{N+1}}^{\,0} \end{cases}$$

(Material balance of chosen species across stages 1 through N)

$$\Rightarrow v_1 = l_0(1-\phi_S)$$

On the other hand, the Absorption equation was

$$v_1 = v_{N+1}\,\phi_A$$

(derived before)

Therefore, for a component that appears in both entering vapor and entering liquid, the cumulative effect of Absorption and Stripping would be the sum

$$\boxed{v_1 = v_{N+1}\,\phi_A + l_0(1-\phi_S)}$$

This has to be generally applied to each component in the vapor, entering the absorber.