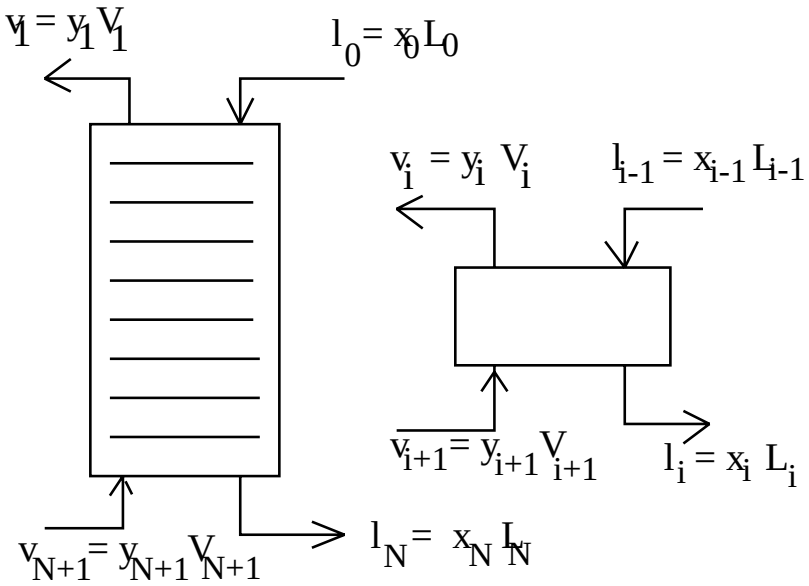
Gas Absorption with Plate Absorbers

Gas Absorption

Absorption represents a vapor recovery operation where the desired component is transferred from a gas to the liquid phase through countercurrent mass transfer.

- This unit operation is modeled as a cascade of equilibrium stages
- The assumption of equilibrium is weak and is corrected by the use of tray efficiencies



- Given a vapor feed, there are 4 degrees of freedom:
  1. Pressure (P)
  2. Number of equilibrium stages (N) for a desired recovery of key component (or vice versa)
  3. Temperature (T_0) of the absorbing liquid stream
  4. Flowrate (L_0) of the absorbing liquid stream

Given these 4 specifications, we can derive the mass balance relations
The liquid and vapor streams leaving a stage are at equilibrium. Thus

$$\frac{v_i}{V_i} = K_i \frac{l_i}{L_i}$$

If we define an absorption factor $A_i = \dfrac{L_i}{K_i V_i}$, we can write the above equation as

$$l_i = A_i v_i$$

For each stage, the absorption factor A_i will be different. If we assume a constant absorption factor A_E for all the stages, we get simplified mass balance equations.

For the first stage, we have:

$$\begin{aligned} l_1 + v_1 &= l_0 + v_2 \\ \text{or} \quad v_2 &= (A_E + 1)v_1 - l_0 \end{aligned}$$

For each subsequent stage, we have:

$$\begin{aligned} v_{i+1} &= l_i + v_i - l_{i-1} \\ v_{i+1} &= (A_E + 1)v_i - A_E v_{i-1} \end{aligned}$$

Writing the above balance from tray 1 to tray N relates the vapor flow at the bottom, v_{N+1} to the vapor flow at the top, v_1 and the liquid flow at the top, l_0.

$$v_{N+1} = \sum_{i=0}^{N} (A_E)^i \, v_1 - \sum_{i=0}^{N-1} (A_E)^i \, l_0$$

Define

$$\beta_N = \sum_{i=0}^{N} (A_E)^i$$

Multiplying both sides of the above equation by $(1 - A_E)$ results in:

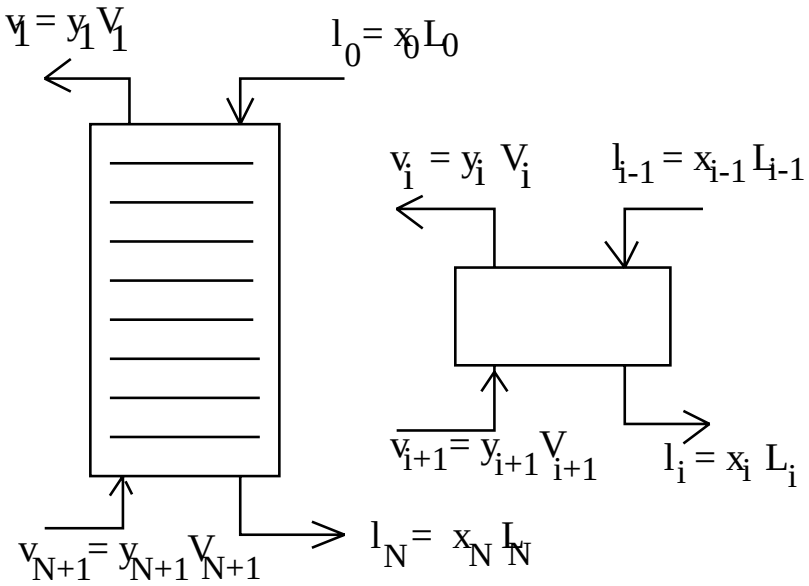
$$(1 - A_E)\beta_N = \sum_{i=0}^{N} (A_E)^i - \sum_{i=1}^{N+1} (A_E)^i$$

which implies

$$\beta_N = \frac{1 - A_E^{N+1}}{1 - A_E}$$

which simplifies the relationship for v_{N+1} to:

$$v_{N+1} = \beta_N v_1 - \beta_{N-1} l_0$$



$$v_{N+1} = \beta_N v_1 - \beta_{N-1} l_0$$

The liquid flow rate at the bottom can be calculated from an overall mass balance to yield:

$$l_N = v_{N+1} + l_0 - v_1$$

The above equations are valid for any component k in the column.

Calculation of Number of Stages

We define a recovery fraction, r, for the key component n as follows:

$$v_1^n = (1-r)v_{N+1}^n$$

Substituting this in the mass balance equations in the previous slide, we get

$$v_{N+1}^n = \beta_N(1-r)v_{N+1}^n - \beta_{N-1}l_0^n$$

Substituting for β_N in terms of A_E, and solving for N results in the Kremser equation:

$$N = \frac{ln\left\{\dfrac{l_0^n + (r-A_E)v_{N+1}^n}{l_0^n - A_E(1-r)v_{N+1}^n}\right\}}{ln\{A_E\}}$$

If none of the key component appears in the liquid feed ($l_0^n = 0$), the above equation simplifies to

$$N = \frac{ln\left\{\frac{(r - A_E)}{A_E(r-1)}\right\}}{ln\{A_E\}}$$

We choose 4 degrees of freedom:

- r, the recovery of the key component, n
- Overhead column pressure
- Solvent temperature (assume isothermal operation)
- The absorption factor $A_E = 1.4$ (choose this as initial guess) which fixes the liquid flow rate

Absorption Algorithm

- Select key component n, fix recovery (typically $r = 0.99$), fix P and solvent temperature.
- Calculate L_0 from

$$\begin{aligned} A_E &= \frac{L_0}{V_{N+1} K_n} = 1.4 \\ L_0 &= 1.4 V_{N+1} \frac{P_N^0(T)}{P} \end{aligned}$$

- Calculate the number of stages from the Kremser equation

$$N = \frac{ln\left\{\dfrac{l_0^n + (r - A_E) v_{N+1}^n}{l_0^n - A_E(1-r) v_{N+1}^n}\right\}}{ln\{A_E\}}$$

- Calculate absorption factors for non-key components

$$A^k = \frac{L_0}{V_{N+1}} \frac{P}{P_k^0(T)} \quad k \neq n$$

$$\text{or} \quad A^k = \frac{1.4}{\alpha_{k/n}}$$

- Calculate aggregate terms (β values) for non-key components

$$\beta_N^k = \frac{\left[1 - (A^k)^{N+1}\right]}{1 - A^k}$$

$$\beta_{N-1}^k = \frac{\left[1 - (A^k)^{N}\right]}{1 - A^k}$$

- Complete the mass balance for all components

$$
\begin{aligned}
v_1^k &= \frac{v_{N+1}^k}{\beta_N^k} + \frac{\beta_{N-1}^k}{\beta_N^k} l_0^k \\
l_N^k &= \left(1 - \frac{\beta_{N-1}^k}{\beta_N^k}\right) l_0^k + \left(1 - \frac{1}{\beta_N^k}\right) v_{N+1}^k
\end{aligned}
$$

- If necessary, readjust P and T and return to step 1 under the following conditions
  1. If the temperature of l_N is too high, increase L_0 (check with bubble point equation).
  2. If too much solvent vaporizes in v_1, increase P or decrease T.
  3. If too many undesirable components are absorbed, increase T, decrease P, or select a more suitable solvent for absorption.