

MODULE 4: ABSORPTION

LECTURE NO. 2

Design of packed tower

The cross sectional view of the packed tower is shown in Figure 4.5.

Design of packed tower may be

- (I) on the basis of individual mass transfer coefficients or
- (II) on the basis of overall mass transfer coefficient.

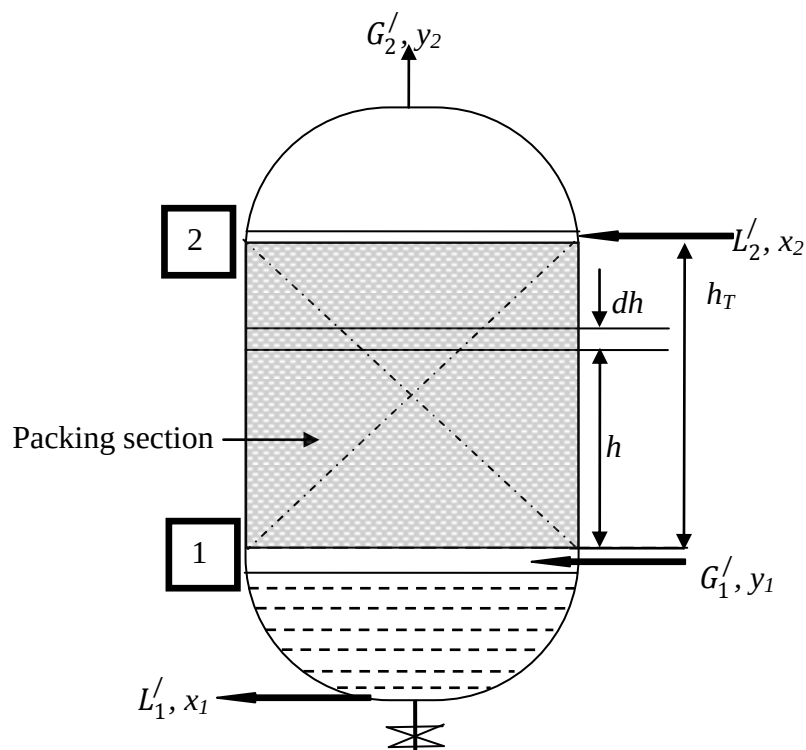


Figure 4.5: Cross sectional view of packed tower.

The column is packed with packing materials (any type) to provide more contact between gas and liquid.

Let, G' and L' are gas and liquid flow rate per unit area basis, mol/h.m². $\bar{a}$ is specific interfacial contact area between gas and liquid, m²/m³. The mole fraction of solute in gas is y .

Hence, solute flow rate in gas = $G'y$ mol/h.m²

The decrease in solute flow rate over the thickness

$$dh = d(G'y) \quad (4.1)$$

For a unit cross-sectional area (1m²), volume of differential section = $1 \times dh$ m³ and interfacial area of contact in differential section = $\bar{a} \times 1 \times dh$ m²

If N_A is solute flux and k_y is individual gas-phase mass transfer coefficient, solute transfer through differential section = $\bar{a} \times dh \times N_A$.

Therefore,

$$-[G'dy + y dG'] = \bar{a} \times dh \times N_A \quad (4.2)$$

$$-G'dy - y dG' = \bar{a} \times dh \times N_A \quad (4.3)$$

The change in total gas flow rate (dG') is equal to rate of solute transfer ($\bar{a} \times dh \times N_A$) as carrier gas is not soluble, i.e.,

$$-dG' = \bar{a} \times dh \times N_A \quad (4.4)$$

Putting the value of $-dG'$ in Equation 4.3, we have,

$$-G'dy + \bar{a} \times dh \times N_A y = \bar{a} \times dh \times N_A$$

$$(4.5)$$

$$-G'dy = \bar{a} \times dh \times N_A (1-y)$$

$$dh = -\frac{G'dy}{\bar{a}(1-y)N_A} = -\frac{G'dy}{\bar{a}(1-y)k_y(y-y_i)} \quad (4.6)$$

Boundary conditions:

$$h=0; y=y_1$$

$$h=h_T; y=y_2$$

Integration of Equation 4.6 gives the height of packed column as follows:

$$h_T = \int_0^{h_T} dh = -\int_{y_1}^{y_2} \frac{G'dy}{\bar{a}(1-y)k_y(y-y_i)} = \int_{y_2}^{y_1} \frac{G'dy}{\bar{a}(1-y)k_y(y-y_i)} \quad (4.7)$$

Interfacial solute concentration, y_i is not known; hence the integration of the right hand side of Equation 4.7 is complicated.

STEP-BY-STEP PROCEDURE

- (1) For a particular gas-liquid system, draw equilibrium curve on X-Y plane.
- (2) Draw operating line in X-Y plane (PQ) using material balance Equation. Lower terminal Q (X_2 , Y_2) and upper terminal P (X_1 , Y_1) are placed in x-y plane. Overall mass balance Equation for the absorption tower is as follows:

$$G_s(Y_1 - Y_2) = L_s(X_1 - X_2)$$

$$G_s \left(\frac{y_1}{1-y_1} - \frac{y_2}{1-y_2} \right) = L_s \left(\frac{x_1}{1-x_1} - \frac{x_2}{1-x_2} \right) \quad (4.8)$$

If liquid mass flow rate, L_s is not known, minimum liquid mass flow rate $(L_s)_{min}$ is to be determined. L_s is generally 1.2 to 2 times the $(L_s)_{min}$.

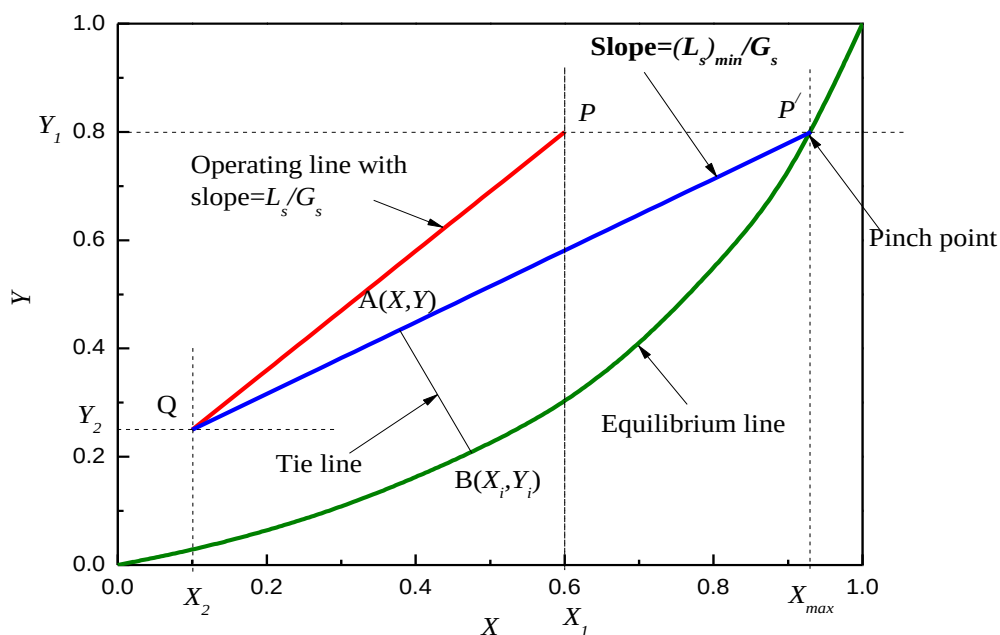


Figure 4.6: Graphical determination of $(L_s)_{min}$ for absorption.

In Figure 4.6, lower terminal of absorption tower is represented by Q (X_2 , Y_2); i.e., bottom of the tower. Operating line is PQ. If liquid rate is decreased, slope of operating line (L_s/G_s) also decreases and operating line shifts from PQ to P'Q, when touches equilibrium line. This operating line is tangent to equilibrium line.

$$\text{Slope of } P/Q = \frac{(L_s)_{\min}}{G_s}$$

The driving force for absorption is zero at P' and is called “PINCH POINT”.

(3) A point $A(x, y)$ is taken on the operating line. From the known value of k_x and k_y or $k_x \bar{a}$ and $k_y \bar{a}$, a line is drawn with slope of k_x / k_y to equilibrium line, $B(x_i, y_i)$. Line AB is called “TIE LINE” and x_i and y_i are known for a set of values of x and y .

(4) Step (3) is repeated for other points in the operating line to get several (x_i, y_i) sets for $y_1 \geq y \geq y_2$.

(5) Calculate flow rate of gas G (kg/h) at each point as $G = G_s(1+y)$.

(6) Calculate height of the packing h_T of Equation 4.7 graphically or numerically.

The height of the ‘stripping column’ is also obtained in a similar way. For stripping, $y_2 > y_1$ and driving force is $(y_i - y)$. The corresponding design Equation will be

$$h_T = \int_{y_1}^{y_2} \frac{G/dy}{\bar{a}(1-y)k_y(y_i-y)} \quad (4.9)$$