MODULE 4: ABSORPTION

LECTURE NO. 3

4.4. Design of packed tower based on overall mass transfer coefficient

From overall mass transfer equation, $N_A = K_y(y_{AG} - y_A^*)$ one can write for packed tower as

$N_A=K_y(y-y^*)$

Then,

$$dh = -\frac{G/dy}{K_y\,\bar{a}(1-y)(y-y^*)} \qquad (4.10)$$

where, y^* is solute concentration in gas phase that is capable of remaining in equilibrium with a liquid having a bulk concentration of x.

Therefore,

$$h_T = \int_0^{h_T} dh = \int_{y_2}^{y_1} \frac{G/dy}{K_y\,\bar{a}(1-y)(y-y^*)}$$

$$= \int_{y_2}^{y_1} \frac{G/dy}{k_G\,\bar{a}P(1-y)(y-y_i)}$$

$$= \int_{x_2}^{x_1} \frac{L/dx}{k_L\,\bar{a}(C_{av})(1-x)(x_i-x)} \qquad (4.11)$$

Graphical integration of right hand side of Equation (4.11):

Operating line AB is drawn in xy plane. Any point (x,y) is taken in operating line. A vertical line is drawn upto equilibrium line to get y^*.

$$h_T = \int_{x_2}^{x_1} \frac{L/dx}{K_x\,\bar{a}(1-x)(x^*-x)} = \int_{y_2}^{y_1} \frac{G/dy}{K_G\,\bar{a}P(1-y)(y-y^*)} = \int_{x_2}^{x_1} \frac{L/dx}{k_L\,\bar{a}(C_{av})(1-x)(x^*-x)} \qquad (4.12)$$

5.5. Design based on height of a transfer unit (HTU)

Equation 4.7 can be written as

$$h_T = \int_0^{h_T} dh = \int_{y_2}^{y_1} \frac{G/ y_{iBM}\, dy}{k_y \bar{a}\, y_{iBM}\, (1-y)(y-y_i)} = \int_{y_2}^{y_1} \frac{G/ (1-y)_{iM}\, dy}{k_y \bar{a}\, (1-y)_{iM}\, (1-y)(y-y_i)} \quad (4.13)$$

where, $y_{iBM} = (1-y)_{iM} = \frac{(1-y_i)-(1-y)}{ln\frac{(1-y_i)}{(1-y)}}$

$$h_T = \frac{G/}{k_y \bar{a}\, (1-y)_{iM}} \int_{y_2}^{y_1} \frac{(1-y)_{iM}\, dy}{(1-y)(y-y_i)} \quad (4.14)$$

As, $\frac{G/}{k_y \bar{a}\, (1-y)_{iM}}$ remains constant at the packing section though G/ varies. This quantity is called 'height if transfer units' (HTU) and designated as H_{tG}. It is important to measure the separation effectiveness of the particular packings for a particular separation process. It also describes the mass transfer coefficient. Larger mass transfer coefficient leads to the smaller value of HTU.

Hence,

$$H_{tG} = \frac{G/}{k_y \bar{a}\, (1-y)_{iM}} = \frac{G/}{k_y/ \bar{a}} \quad (4.15)$$

The integral part of Equation (4.14) is called number of gas phase transfer units as N_{tG}.

$h_T = H_{tG} \times N_{tG}$

When overall gas phase mass transfer coefficients are used, the height of the packing is as follows:

$$h_T = \int_{y_2}^{y_1} \frac{G/ dy}{K_y \bar{a}\, y^*_{BM}\, (1-y)(y-y^*)} = \frac{G/}{K_y \bar{a}\, y^*_{BM}} \int_{y_2}^{y_1} \frac{dy}{(1-y)(y-y^*)} = H_{toG} \times N_{toG} \quad (4.16)$$

where, $H_{toG} = \frac{G/}{K_y \bar{a}\, y^*_{BM}}$, $N_{toG} = \int_{y_2}^{y_1} \frac{dy}{(1-y)(y-y^*)}$ and $y^*_{BM} = (1-y)^*_{BM} = \frac{(1-y^*)-(1-y)}{ln\frac{(1-y^*)}{(1-y)}}$.

4.6. Design Equations based concentration in mole ratio unit

If k_x, k_y are individual gas phase mass transfer coefficients and K_Y is overall gas phase mass transfer coefficient, height of packed tower is expressed as:

$$h_T = \int_{Y_2}^{Y_1} \frac{G_s' dy}{k_y \bar{a}\,(Y - Y_i)} = \int_{Y_2}^{Y_1} \frac{G_s' dy}{K_y \bar{a}\,(Y - Y^*)} = \frac{G_s'}{K_y \bar{a}} \int_{Y_2}^{Y_1} \frac{dy}{(Y - Y^*)} = H_{toG} \times N_{toG} \qquad (4.17)$$

$$H_{toG} = \frac{G_s'}{K_y \bar{a}}$$

$$N_{toG} = \int_{Y_2}^{Y_1} \frac{dy}{(Y - Y^*)}$$

$$Slope\ of\ operating\ line = \frac{L_s'}{G_s'}$$

Overall gas-phase mass transfer coefficient, K_Y is correlated with individual mass transfer coefficients as follows:

$$\frac{1}{K_Y} = \frac{1}{k_Y} + \frac{\propto}{k_x}$$

Example Problem 4.1. Solute *A* is to be absorbed from a binary mixture containing 7.5% of *A* with solvent *B* in a packed tower. Based on flooding calculation, a tower diameter of 1.2 m is selected. Total gas flow rate is 60 kmol/h. The exit gas must not contain 0.2% of solute *A*. Solute free liquid *B* enters from the top of the tower at 40 kmol/h. The gas phase and liquid phase mass transfer coefficients based on mole ratio unit are: k_X =2.05 kmol/m^{2}h (*ΔX*) and k_Y =1.75 kmol/m^{2}h (*ΔY*). The equilibrium line Equation is *Y*=0.63*X*. Specific interfacial area of gas-liquid contact ($\bar{a}$) is 71 m^2/m^3. (a) Calculate packing height required for the desired separation. (b) For 99.5% solute *A* removal, what % increase in packed height is needed? (c) Determine slopes of operating line in each case.

Solution 4.1:

Gas flow rate, G_1 =60 kmol/h; y_1=0.075

Area of tower cross-section=$\frac{\pi}{4}(1.2)^2 = 1.131\ m^2$

$G_1^/$=53.05 kmol/m^2.h

$G_s^/$=53.05(1-0.075) kmol/m^2.h = 49.07 kmol/m^2.h

$Y_1 = \frac{0.075}{0.925} = 0.0811$

Solute concentration in exit gas is 0.2%.

Therefore, $Y_2 = \frac{0.2}{99.8} = 0.00204$

Liquid flow rate, L_s=40 kmol/h

$L_s^/ = \frac{40}{1.131} = 35.37$ kmol/m^2.h

X_2=0

Overall mass balance Equation for the solute concentration in exit liquid as follows:

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

49.07(0.011-0.00204) = 35.37(X_1-0)

X_1 = 0.1097

Overall gas-phase mass transfer coefficient, K_Y:

$$\frac{1}{K_Y} = \frac{1}{k_Y} + \frac{\propto}{k_x}$$

$$\frac{1}{K_Y} = \frac{1}{1.75} + \frac{0.63}{2.05}$$

K_Y=1.138 kmol/m^{2}h (ΔY)

$H_{toG} = \frac{G_s^/}{K_Y \bar{a}} = \frac{49.07}{1.138 \times 71} = 0.607\ m$,

$$N_{toG} = \int_{Y_2}^{Y_1} \frac{dY}{(Y - Y^*)}$$

Y^* can be expressed in terms of Y.

The operating line Equation can be expressed as:

$G_s^/(Y - Y_2) = L_s^/(X - X_2)$

49.07(Y-0.00204) = 35.37(X-0)

X=1.387(Y-0.00204)

We have

$Y^* = \alpha X$ = 0.63×1.387(Y-0.00204) = 0.874Y-0.00178

Therefore,

$$N_{toG} = \int_{0.00204}^{0.0811} \frac{dY}{[Y-(0.874Y-0.00178)]} = \int_{0.00204}^{0.0811} \frac{dY}{(0.126Y+0.00178)}$$

$$N_{toG} = \frac{1}{0.126} ln \frac{[(0.126\times0.0811)+0.00178]}{[(0.126\times0.00204)+0.00178]} = 13.9$$

(a) Packed height, $h_T = H_{toG} \times N_{toG}$=0.0607×13.9 m=8.46 m.

(b) For 99.5% solute removal, Y_2=0.0811×0.0005=4.05×10^{-4}.

$G_s^/(Y - Y_2) = L_s^/(X - X_2)$

49.07(Y-4.05×10^{-4}) = 35.37(X-0)

X = (1.387Y – 5.62×10^{-4})

Hence,

$Y^* = \alpha X$ = 0.63×(1.387Y – 5.62×10^{-4}) = 0.874Y-0.000354

Therefore,

$$N_{toG} = \int_{4.05\times10^{-4}}^{0.0811} \frac{dY}{[Y-(0.874Y-0.000354)]} = \int_{4.05\times10^{-4}}^{0.0811} \frac{dY}{(0.126Y+0.000354)}$$

$$N_{toG} = \frac{1}{0.126} ln \frac{[(0.126\times0.0811)+0.000354]}{[(0.126\times4.05\times10^{-4})+0.000354]} = 22$$

Required packed height, $h_T = H_{toG} \times N_{toG}$=0.0607×22 m=13.35 m.

$$\%increase\ in\ packing\ height = \frac{13.35 - 8.46}{8.46} \times 100 = 58\%$$

(c) For both the cases slope of the operating will remain same as $\frac{L_s^/}{G_s^/}$.

So,

$$Slope\ of\ operating\ line = \frac{L_s^/}{G_s^/} = \frac{35.37}{49.07} = 0.721.$$