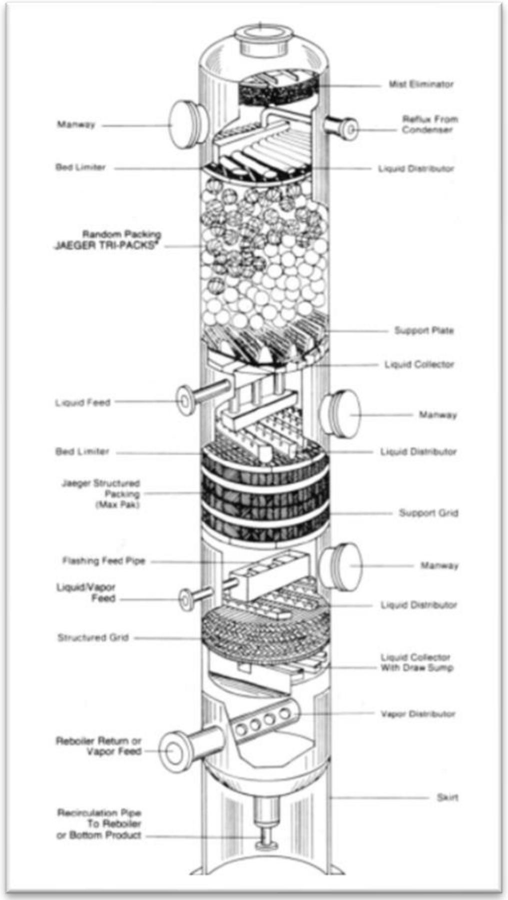
Packed Tower Design

OPERASI TEKNIK KIMIA III

Capaian Pembelajaran

Students are able to design packed columns using liquid film coefficients (k'x), gas filter coefficients (k'y) and overall film coefficients K'x, K'Y

Sistem Operasi *Packed Tower*



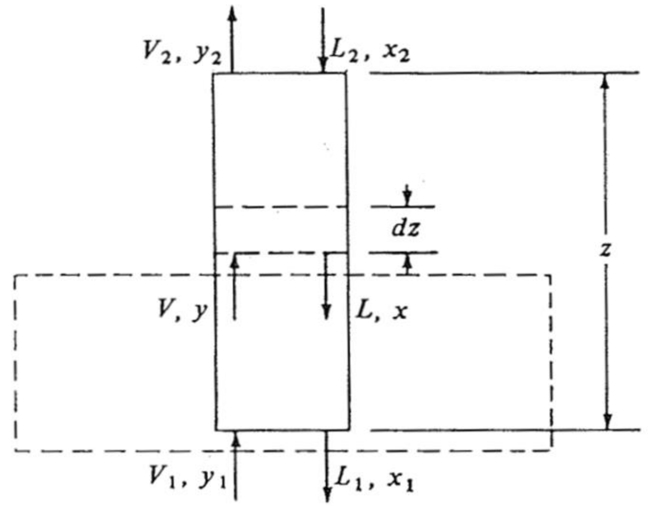


FIGURE 10.6-6. *Material balance for a countercurrent packed absorption tower.*

Operating-line derivation

In the case of solute A diffusing through the stagnant gas and then into the stagnant liquid, the overall material balance of component A in the drawings for an absorption tower is:

Over-all	$L'\frac{x_2}{(1-x_2)}+V'\frac{y_1}{(1-y_1)}=L'\frac{x_1}{(1-x_1)}+V'\frac{y_2}{(1-y_2)}$	10.6-4
Local	$L'\frac{x}{(1-x)}+V'\frac{y_1}{(1-y_1)}=L'\frac{x_1}{(1-x_1)}+V'\frac{y}{(1-y)}$	10.6-5

- L' and V' are constant
- The total flow rate L and V is not constant
- Equation 10.6-4 is OPERATING LINE EQUATION, which may be a curved line
- Operating line can also be written in terms of partial pressure of A
- For dilute L & V, $(1-x)$ and $(1-y)$ can be taken as 1, Eqn. (10.6-4) becomes a straight

Desain untuk laju pelarut minim L'min dan Rasio Optimal L'/V'

- Inlet gas conditions V1, y1 are known
- Exit concentration y2 is set
- Concentration x2 of the entering liquid is oftened fixed
- Entering liquid flow L2 or L' needs to be determined
- When the operating line has a minimum slope and touches the equilibrium line at point P, L is a minimum at L'min The value of x1 is a maximum at at L'min
- At point P, the driving forces are all zero
- To determine L'min the following operationg line equation can be used

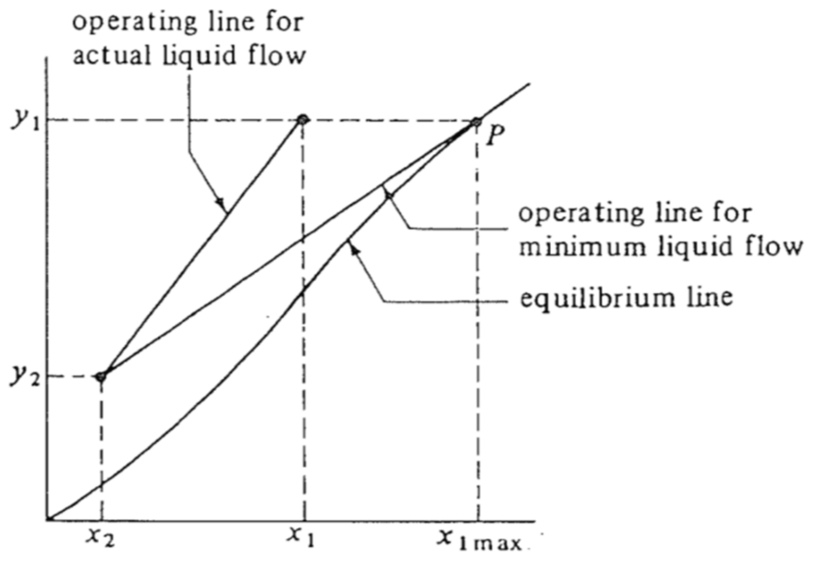


FIGURE 10.6-8. *Minimum liquid/gas ratio for absorption.*

If the equilibrium line is curved concavely downward, the minimum value of L is reached by the operating line becoming tangent to the equilibrium line instead of intersecting it.

$$L'_{min}\frac{x_2}{(1-x_2)}+V'\frac{y_1}{(1-y_1)}=L'_{min}\frac{x_{1max}}{(1-x_{1max})}+V'\frac{y_2}{(1-y_2)}$$

The choice of the optimum ratio (L/V) depends the economics. In absorption, too high a value requires a large liquid flow, and hence a large-diameter tower. The cost of recovering the solute from the liquid by distillation will be high. A small liquid flow results in a high tower, which is costly. As an approximation,the optimum liquid flow is obtained by using a value of about 1.5 for the ratio of the average slope of the operating line to that of the equilibrium line for absorption. This factor can vary depending on the value of the solute and tower type.

Design Equations

Defining a as interfacial area in m2 per m3 volume of packed section, the volume of packing in a height dz m (Fig. 10.6-6) is Sdz. Therefore,

$$dA = aS\,dz$$

where, S is cross-sectional area of tower. The volumetric film and overall mass transfer coefficients are k Since the mass exchange of solute takes place between L (=kg mol total liquid/s) and V (=kg m

$$N_A dA = d(Vy) = d(Lx) \qquad 10.6\text{-}10$$

Since,

$$N_A = \frac{k'_y}{(1-y_A)_{iM}}(y_{AG} - y_{Ai}) = \frac{k'_x}{(1-x_A)_{iM}}(x_{Ai} - x_{AL}) \qquad 10.4\text{-}8$$

$$N_A dA = \frac{k'_y a}{(1-y_A)_{iM}}(y_{AG} - y_{Ai})S\,dz = \frac{k'_x a}{(1-x_A)_{iM}}(x_{Ai} - x_{AL})S\,dz \qquad 10.6\text{-}11$$

$$d(Vy_{AG}) = \frac{k'_y a}{(1-y_A)_{iM}}(y_{AG} - y_{Ai})S\,dz \quad 10.6\text{-}12$$

$$d(Lx_{AL}) = \frac{k'_x a}{(1-x_A)_{iM}}(x_{Ai} - x_{AL})S\,dz \quad 10.6\text{-}13$$

$$d(Vy_{AG}) = d\left(\frac{V'}{(1-y_{AG})}y_{AG}\right) = V'd\left(\frac{y_{AG}}{(1-y_{AG})}\right) = \frac{V'dy_{AG}}{(1-y_{AG})^2} = \frac{Vdy_{AG}}{(1-y_{AG})} \quad 10.6\text{-}14$$

$$\frac{Vdy_{AG}}{(1-y_{AG})} = \frac{k'_y a}{(1-y_A)_{iM}}(y_{AG} - y_{Ai})S\,dz \quad 10.6\text{-}15$$

$$\frac{Ldx_{AL}}{(1-x_{AL})} = \frac{k'_x a}{(1-x_A)_{iM}}(x_{Ai} - x_{AL})S\,dz \quad 10.6\text{-}16$$

$$z = \int_0^z dz = \int_{y_2}^{y_1} \frac{V dy_{AG}}{\frac{k'_y aS}{(1 - y_A)_{iM}} (1 - y_{AG})(y_{AG} - y_{Ai})}$$

$$= \int_{y_2}^{y_1} \frac{V dy_{AG}}{\frac{K'_y aS}{(1 - y_A)_{*M}} (1 - y_{AG})(y_{AG} - y_A^*)}$$

$$z = \int_0^z dz = \int_{x_2}^{x_1} \frac{L dx_{AL}}{\frac{k'_x aS}{(1 - x_A)_{iM}} (1 - x_{AL})(x_{Ai} - x_{AL})}$$

$$= \int_{x_2}^{x_1} \frac{L dx_{AL}}{\frac{K'_x aS}{(1 - x_A)_{*M}} (1 - x_{AL})(x_A^* - x_{AL})}$$

Simplified Design Methods for Absorption of Dilute Gas Mixtures in Packed Towers

For solute A concentration in L & V streams less than 10%, the flows will vary by less than 10% and the mass-transfer coefficients by considerably less than this. As a result, the average values of the flows V and L and the mass-transfer coefficients at the top and bottom of the tower can be taken outside the integral. Likewise, the following terms can be taken outside, and average values of the values at the top and bottom of the tower used.

$$\frac{(1-y_{AG})}{(1-y_A)_{iM}}, \frac{(1-y_{AG})}{(1-y_A)_{*M}}, \frac{(1-x_{AL})}{(1-x_A)_{iM}}, \frac{(1-x_{AL})}{(1-x_A)_{*M}}$$

$$z = \int_{y_2}^{y_1} \frac{V dy_{AG}}{\frac{k'_y aS}{(1-y_A)_{iM}}(1-y_{AG})(y_{AG}-y_{Ai})} = \int_{y_2}^{y_1} \frac{V dy_{AG}}{\frac{K'_y aS}{(1-y_A)_{*M}}(1-y_{AG})(y_{AG}-y_A^*)}$$

$$z = \left[\frac{V}{k'_y aS}\frac{(1-y_A)_{iM}}{(1-y_{AG})}\right]_{av} \int_{y_2}^{y_1} \frac{dy_{AG}}{(y_{AG}-y_{Ai})} = \left[\frac{V}{K'_y aS}\frac{(1-y_A)_{*M}}{(1-y_{AG})}\right]_{av} \int_{y_2}^{y_1} \frac{dy_{AG}}{(y_{AG}-y_A^*)}$$

For dilute soln.,	$\frac{(1-y_A)_{iM}}{(1-y_{AG})} \cong \frac{(1-y_A)_{*M}}{(1-y_{AG})} \cong 1$
gives,	$z = \left[\frac{V}{k'_y aS}\right]_{av} \int_{y_2}^{y_1} \frac{dy}{(y-y_i)} = \left[\frac{V}{K'_y aS}\right]_{av} \int_{y_2}^{y_1} \frac{dy}{(y-y^*)}$
Approximation of integration	$z = \left[\frac{V}{k'_y aS}\right]_{av} \frac{(y_1-y_2)}{(y-y_i)_M} = \left[\frac{V}{K'_y aS}\right]_{av} \frac{(y_1-y_2)}{(y-y^*)_M}$

where,	$$(y-y_i)_M = \frac{(y_1-y_{i1})-(y_2-y_{i2})}{\ln[(y_1-y_{i1})/(y_2-y_{i2})]}$$ $$(y-y^*)_M = \frac{(y_1-y_1^*)-(y_2-y_2^*)}{\ln[(y_1-y_1^*)/(y_2-y_2^*)]}$$

$\left[\frac{kg\ mol\ A\ absorbed}{s \cdot m^2}\right]$	$\frac{V}{S}(y_1-y_2) = k'_y az(y-y_i)_M = K'_y az(y-y^*)_M$
	$\frac{L}{S}(x_1-x_2) = k'_x az(x_i-x)_M = K'_x az(x^*-x)_M$

Design Procedure for Dilute Solutions

- Determine compositions of steams x1,y1,x2,y2 and draw the oprating line. Material balance equation may be needed.
- Use thermodynamic eqilibrium data to draw the equilibrium line.
- Obtain mass tranfer coefficients either from experimental values or empirical correlations,
- From point P1, draw line P1M1 with slope

$$-\frac{k_x}{k_y} = -\frac{\left[\frac{k'_x a}{(1-x)_{iM}}\right]}{\left[\frac{k'_y a}{(1-y)_{iM}}\right]}$$

- Since interface concentration are unknow, use following for dilute solution for slope

$$= -\frac{\left[\frac{k'_x a}{(1-x_1)}\right]}{\left[\frac{k'_y a}{(1-y_1)}\right]}$$

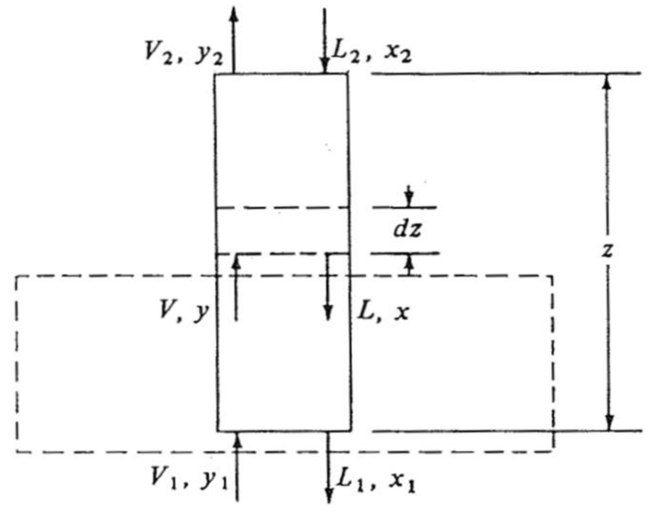


FIGURE 10.6-6. *Material balance for a countercurrent packed absorption tower.*

Design Procedure for Dilute Solutions

- Determine the M1 (x1i,y1i) on the equilibrium line

And determine the M₁ (x_{1i}, y_{1i}) on the equilibrium line

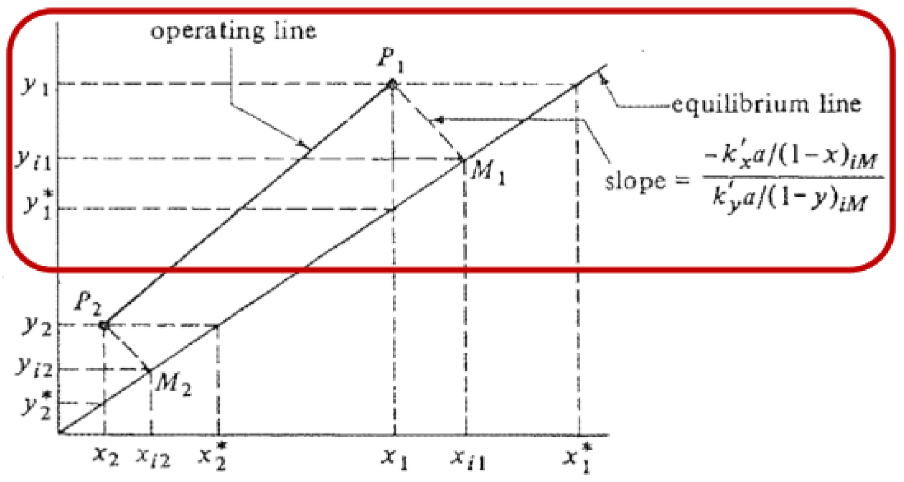


FIGURE 10.6-9. *Operating-line and interface compositions in a packed tower for absorption of dilute gases.*

Design Procedure for Dilute Solutions

- Similarly, draw line P2M2 with slope

$$-\left[\frac{k'_x a}{(1-x_2)}\right] \Big/ \left[\frac{k'_y a}{(1-y_2)}\right]$$

And determine the M_2 (x_{2i}, y_{2i}) on the equilibrium line

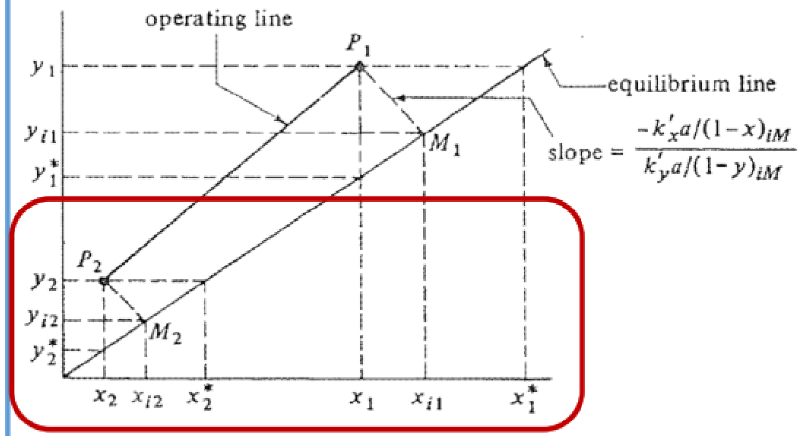


FIGURE 10.6-9. *Operating-line and interface compositions in a packed tower for absorption of dilute gases.*

Design Procedure for Dilute Solutions

- Compute average values for V and L streams, and

$$(y - y_i)_M = \frac{(y_1 - y_{i1}) - (y_2 - y_{i2})}{\ln[(y_1 - y_{i1})/(y_2 - y_{i2})]}$$

- Compute height of the absorption column using,

$$\frac{V_{av}}{S}(y_1 - y_2) = k'_y a \mathbf{z} (y - y_i)_M$$