A 160 mol/h liquid stream (99 mole percent mineral oil, 1 mole percent octane) is to be stripped by countercurrent contact with air to reduce the octane mole fraction to 0.05 mole percent in the exiting liquid. The tower is to be packed with 2 in. ceramic Intalox saddles. Air enters pure. Operation is isothermal at 68 °C and atmospheric pressure. As per usual assumptions, you may neglect any evaporation of mineral oil as well as dissolution of air in the liquid.

$P^{sat}_{octane\ @\ 68C} = 0.15$ atm

(a) What would be the minimum required air flow rate in mol/h, corresponding to an infinitely tall tower?

The stripping process actually will be carried out with 1215 mol/h of entering air. (Incidentally, this implies that your answer for part (a) had better come out to be less than 1215 mol/h.)

(b) What is the vapor phase mass velocity for flooding, $G_{y,\ flooding}$ in lb_m/ft^2s, based on conditions at the top of the tower?

The final column design should have the vapor phase mass velocity G_y equal to 0.15 lb_m/ft^2s. (Incidentally, this implies that your answer for part (b) had better come out to be more than 0.15 lb_m/ft^2s.)

(c) What is the required column diameter?

(d) A reasonable estimate for H_x is 0.7 ft. Calculate H_y and then H_{Oy}. Given the diluteness of the solutions involved and to save time, you may base the calculation of H_y on just the flow rates at the top of the tower instead of average flow rates.

(e) What is the required packed height Z_T?

(f) What are the liquid- and gas-phase interfacial mole fractions of octane, x_i and y_i, at the top ("a" end) of the column?

The liquid density ρ_x can be approximated by the density of the pure oil, which is 0.85 g/cm^3. The liquid viscosity μ_x can be approximated by the viscosity of the pure oil, which is 3 cP. The Schmidt number N_{Sc} for octane in air is 2.62. Additional data you may or may not need are given on the attached sheets.

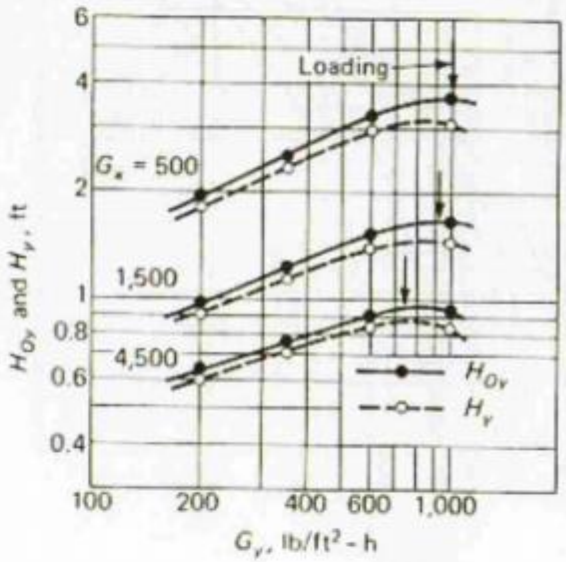
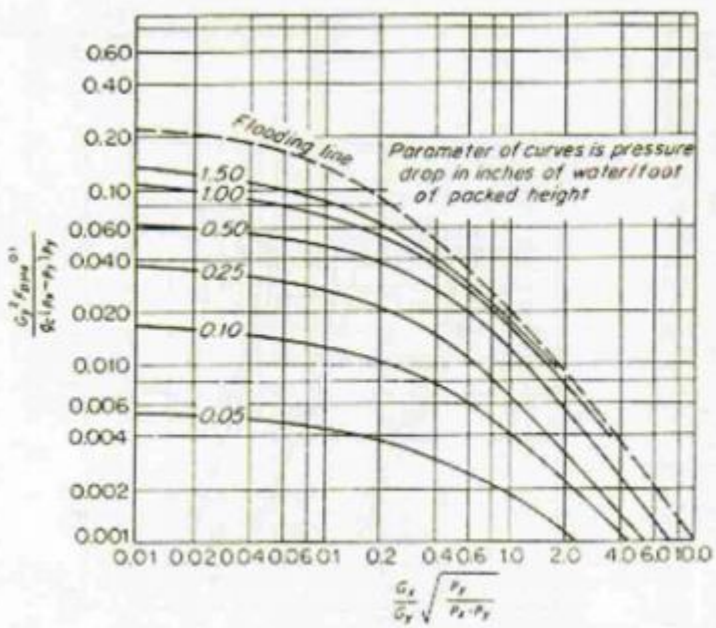


FIGURE 22.20
Height of a transfer unit for the absorption of ammonia in water with $1\frac{1}{2}$-in. ceramic Raschig rings.



Generalized correlation for flooding and pressure drop in packed columns. (*After Eckert.*[2])

(1 hour late because Elroy says so, and what Elroy wants Elroy gets)

(i) Preliminaries

Entering liquid: $L_a = 160$ mol total

$L_C = (0.99)(160 \text{ mol}) = 158.400 \text{ mol}$

$L_a x_a = (L_{out})_a = (0.01)(160 \text{ mol}) = 1.600 \text{ mol}$

$x_a = 0.01$

Exiting liquid: $x_b = 0.0005 = \dfrac{(L_{out})_b}{158.4 \text{ mol} + (L_{out})_b}$

$\Rightarrow (L_{out})_b = 0.079 \text{ mol}$

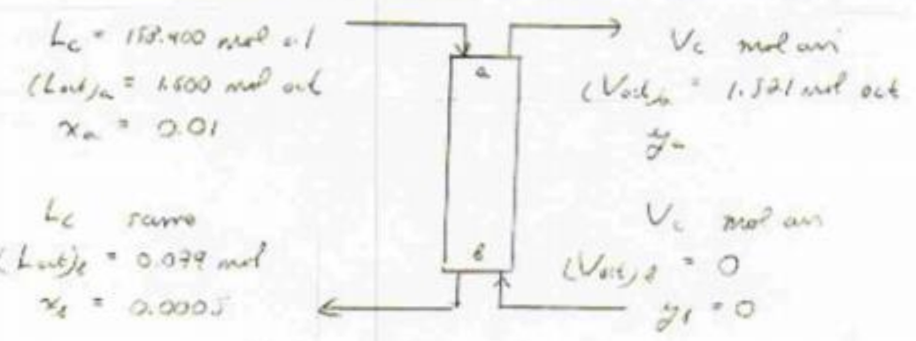
Entering air: $y_b = 0$, $(V_{out})_b = 0$ (air enters pure)

Exiting air: $V_a y_a = (V_{out})_a = (L_{out})_a + (V_{out})_b - (L_{out})_b$

$= 1.600 \text{ mol} + 0 \text{ mol} - 0.079 \text{ mol}$

$= 1.521 \text{ mol}$

$y_a = \dfrac{1.521 \text{ mol}}{V_C + 1.521 \text{ mol}}$

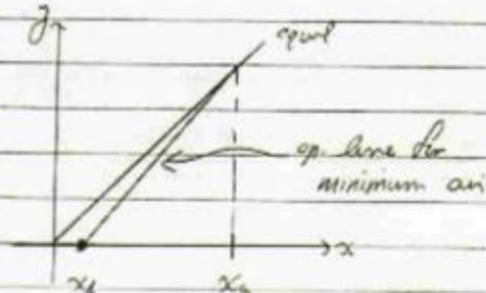


(ii) Equil. relation

Assuming validity of Raoult's law, equil. rel is

$$y = (p_{act}^{sat} / P)\,x = (0.15 \text{ atm} / 1 \text{ atm})\,x = 0.15\,x$$

(iii) Minimum air



$$(y_a)_{min\ air} = (0.15)\,x_a = 0.0015 = \frac{1.521 \text{ mol}}{(V_c)_{min} + 1.521 \text{ mol}}$$

(x_a, y_a) satisfies equil. relation

$$\Longrightarrow \boxed{(V_c)_{min} = 1012 \text{ mol/h air}}$$

answer (a)

(iv) Actual operation – mole numbers + compositions

Use V_c = 1215 mol air (this is $1.2 \times (V_c)_{min}$). Then

$$y_a = \frac{1.521}{1215 + 1.521} = 0.00125$$

(v) Flooding velocity

(Use mole numbers at top of tower where flow rates are highest.)

$$(SG_x)_a = \Big[(158.4 \text{ mol oil/h})\left(\frac{200\ g}{mol}\right) + (1.100 \text{ mol octane/h})\left(\frac{114.2232}{mol}\right)\Big] \times \frac{1\ lb}{453.59237\ g} \times \frac{1\ h}{3600\ s}$$

$$= 0.0951\ lbm/s$$

$$(SG_y)_a = \Big[(1215 \text{ mol air/h})\left(\frac{28.85\ g}{mol}\right) + (1.121 \text{ mol octane/h})\left(\frac{114.2232}{mol}\right)\Big] \times \frac{1\ lbm}{453.59237\ g} \times \frac{1\ h}{3600\ s}$$

$$= 0.02157\ lbm/s$$

$$\rho_x \approx (\rho_x)_{oil} = 0.85\ \frac{g}{cm^3} \times \frac{1\ lbm}{453.59237\ g} \times \frac{(30.48\ cm)^3}{1\ ft^3}$$

$$= 53.06\ lbm/ft^3$$

$$\rho_y = \rho_M \bar{M} = \frac{P}{RT}\left[y M_{oct} + (1-y) M_{air}\right]$$

x negligible

$$= \frac{101325\ \frac{J}{m^3}}{(8.314\ \frac{J}{mol\,K})(341.15\ K)}\Big[(0.00125)(114.232\ \tfrac{g}{mol}) + (1-0.00121)(28.85\ g/mol)\Big] \times \frac{1\ lbm}{453.59237\ g} \times \frac{(0.3048\ m)^3}{(1\ ft)^3}$$

$$= 0.0658\ lbm/ft^3$$

$$\frac{G_x}{G_y}\sqrt{\frac{\rho_y}{\rho_x-\rho_y}} = \frac{SG_x}{SG_y}\sqrt{\frac{\rho_y}{\rho_x-\rho_y}}$$

$$= \frac{0.01951}{0.02157}\sqrt{\frac{0.06458}{57.05-0.06458}}$$

$$= 0.032 \quad \text{abscissa}$$

$\Longrightarrow$ ordinate from flooding correlation ≈ 0.195

$$\therefore \quad G_y = \sqrt{\frac{g_c(\rho_x-\rho_y)\rho_y}{F_p\,\mu_x^{0.1}}(0.195)}$$

$$= \sqrt{\frac{(32.174)(57.05-0.06458)(0.06458)}{40\;(3)^{0.1}}(0.195)}$$

from Table 22.1 for 2 in ceramic Intalox saddles

answer (b)

$$\boxed{G_y = 0.5935 \;\text{lbm/ft}^2\text{s for flooding}}$$

(c) <u>Column diameter</u>

Operate with $G_y = 0.15$ lbm/ft^{2}s
(this is 0.25 $G_{y,\text{flooding}}$).

$$S = \text{tower cross-sectional area} = \frac{SG_y}{G_y}$$

$$= \frac{0.02157\ \text{lbm/s}}{0.15\ \text{lbm/ft}^2\text{s}} = 0.1438\ \text{ft}^2$$

$$\text{diam.} = \sqrt{\frac{4S}{\pi}} = \sqrt{\frac{4\,(0.1438\ \text{ft}^2)}{\pi}}$$

$$\boxed{\text{diam.} = 0.428\ \text{ft}}$$ answer (c)

Alternate method for part (b)

$$(\Delta P)_{flood} = \begin{cases} 0.115\ F_p^{\,0.7} & 10 \le F_p \le 60 \\ 2 & 60 \le F_p \end{cases}$$

in H_2O / ft of packing

abcissa = 0.032

$$(\Delta P)_{flood} = (0.115)(40)^{0.7} = 1.52 \text{ in } H_2O/\text{ft} \approx 1.5 \frac{\text{in } H_2O}{\text{ft}}$$

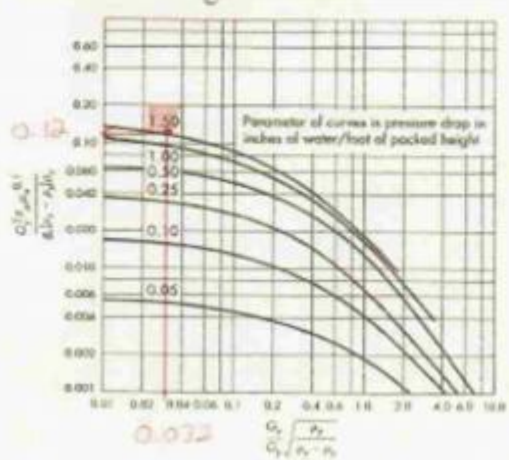
$$\Longrightarrow \text{ ordinate } \approx \boxed{0.12} = \frac{G_y^2 F_p \mu_x^{0.1}}{g_c(\rho_x - \rho_y)\rho_y}$$

on $\Delta P = 1.5$ curve

$$G_y = \sqrt{\frac{g_c(\rho_x - \rho_y)\rho_y}{F_p \mu_x^{0.1}}(0.12)}$$

$$= 0.5440 \text{ lbm/ft}^2\text{ s for flooding}$$

Probably more reliable



(vii) <u>Height of a transfer unit</u>

$$G_y = \frac{0.15\ \text{lbm}}{\text{ft}^2 \cdot \text{s}} \times \frac{3600\ \text{s}}{1\ \text{h}} = 540\ \frac{\text{lbm}}{\text{ft}^2 \cdot \text{h}}$$

$$G_x = \frac{(SG_x)}{S} = \frac{(0.01951\ \text{lbm/s})}{(0.1438\ \text{ft}^2)} \times \frac{3600\ \text{s}}{1\ \text{h}}$$

$$= 488\ \text{lbm/ft}^2 \cdot \text{h} \approx 500\ \text{lbm/ft}^2 \cdot \text{h}$$

From graph, $H_y \Big|_{NH_3,\ 1.5\text{ in Raschig rings}} \approx 2.8\ \text{ft}$

$\therefore$

$$H_y = (2.8\ \text{ft})\left(\frac{2.62}{0.66}\right)^{1/2} \frac{1}{(1.0)}$$

$f_p = 1.0$ for 2-in ceramic Intalox saddles

$$\boxed{H_y = 5.58\ \text{ft}}$$

answer (d)

Then

$$H_{oy} = H_y + m \frac{V}{L} H_x$$

$$= 5.58\ \text{ft} + (0.15)(7.60)(0.7\ \text{ft})$$

$$\boxed{H_{oy} = 6.38\ \text{ft}}$$

$$V/L \approx (V/L)_a = \frac{(1215 + 1.521)\ \text{mol}}{160\ \text{mol}} = 7.60$$

or

$$\frac{V}{L} \approx \frac{x_a - x_b}{y_a - y_b} = \frac{0.01 - 0.0005}{0.00125 - 0} = 7.60 \quad \checkmark \text{same}$$

(viii) <u>Packed height</u>

$$y_a = 0.00125$$

$$y_a^* = (0.15)(x_a) = (0.15)(0.01) = 0.0015$$

$$y_a - y_a^* = -0.00025$$

$$y_t = 0$$

$$y_t^* = (0.15)(x_t) = (0.15)(0.0005) = 0.000075$$

$$y_t - y_t^* = 0 - 0.000075 = -0.000075$$

$$\overline{(y-y^*)}_L = \frac{(y_a - y_a^*) - (y_t - y_t^*)}{\ln\left(\frac{y_a - y_a^*}{y_t - y_t^*}\right)} = \frac{-0.00025 - (-0.000075)}{\ln\left(\frac{-0.00025}{-0.000075}\right)}$$

$$= -0.0001454$$

$$N_{oy} = \frac{y_t - y_a}{\overline{(y-y^*)}_L} = \frac{0 - 0.00125}{-0.0001454}$$

$$N_{oy} = 8.60$$

Then $Z_T = \underbrace{(8.60)}_{N_{oy}}\underbrace{(6.38\ ft)}_{H_{oy}}$

$$\boxed{Z_T = 54.9\ ft}$$ answer (e)

(ix) <u>Interfacial concentrations</u> at top of tower ($x = x_a$, $y = y_a$)

$$k_x(x - x_i) = k_y(y_i - y) = \text{flux (liquid} \to \text{gas) of octane}$$

2.11

Also, $y_i = m\, x_i$ because have equil. @ interface $\therefore$

$$k_x x - k_x x_i = k_y m x_i - k_y y$$

or

$$x_i = \frac{x k_x + y k_y}{k_x + m k_y} = \frac{x\left(\frac{k_x}{k_y}\right) + y}{\left(\frac{k_x}{k_y}\right) + m}$$

Now $$\frac{k_x}{k_y} = \frac{V/S}{k_{ya}} \; \frac{k_x a}{L/S} \; \frac{L}{V} = \frac{H_y}{H_x (V/L)}$$

$$= \frac{5.58 \text{ ft}}{(0.75 \text{ ft})(7.10)} = 1.049$$

Then $$x_i = \frac{(0.01)(1.049) + 0.00125}{1.049 + 0.15}$$

$$\boxed{x_i = 0.00979}$$

answer (f)

and

$$\boxed{y_i = m x_i = 0.00147}$$