

# Solutions Manual

to accompany

# Unit Operations of Chemical Engineering

Seventh Edition

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## Chapter 2

2-1. Use Eq. (2-10) noting that

$1 \text{ g/cm}^3 = 1000 \text{ kg/m}^3$ . Quantities needed are:

$g = 9.80665 \text{ m/s}^2$  (Eq. (1-13))  $R_m = 0.2 \text{ m}$

$$\begin{aligned} P_a - P_b &= 9.80665 \times 0.2 (13.6 - 1.6) 1000 \\ &= 23536 \text{ kg} \cdot \text{m/m}^2 \cdot \text{s}^2 = 23536 \text{ N/m}^2 \end{aligned}$$

2-2. Find a relation between temperature and elevation.

From the given conditions:

$$\frac{dT}{dz} = - \frac{5}{1000} = - 0.005$$

Integrating between limits, setting  $T = 288\text{K}$  at  $Z = 0$  gives

$$T = 288 - 0.005Z$$

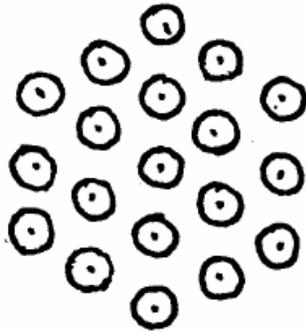
Substituting for  $T$  in Eq. (2-6) and integrating gives

$$\int_{P_a}^{P_b} \frac{dp}{P} = - \frac{gM}{R} \int_{z_a}^{z_b} \frac{dz}{288 - 0.005Z}$$

Since  $z_a = 0$

$$\ln \frac{P_a}{P_b} = \frac{gM}{0.005R} \ln \frac{288}{288 - 0.005z_b}$$

13.3



Assume orientation  
of tubes as shown

Maximum capacity of condenser will be based on a very large flow of cooling water, so  $h_i$  is infinite and the exit water temperature is  $70^\circ\text{F}$ .

$$D_o = 1.5/12 = 0.125 \text{ ft}$$

$$\bar{D}_L = 1/12[(1.5 - 1.3)/(\ln 1.5/1.3)] = 0.1165 \text{ ft}$$

Resistance of metal wall:

$$\frac{x_w D_o}{k_m D_L} = \frac{0.1 \times 0.125}{12 \times 26 \times 0.1165} = 0.00034$$

Estimate surface temperature  $T_{w0}$  to be  $73^\circ\text{F}$  (found by trial).  $T_o = 82 - 73 = 9^\circ\text{F}$

$$T_f = 82 - (0.75 \times 9) = 75.3^\circ\text{F}$$

$$\mu_f = 0.11 \times 2.42 = 0.266 \text{ lb/ft-h (Appendix 9)}$$

$$k_f = 0.29 \text{ Btu/h-f-}^\circ\text{F (Appendix 13)}$$

$$\rho_f = (1/0.00165)/16.0185 = 37.84 \text{ lb/ft}$$

( Perry, 7<sup>th</sup> ed., p. 2-214)

$$\lambda = 500 \text{ Btu/lb}$$

From Eq. (13.17), for each stack of tubes,

27.5. From Eq. (27.23) the growth rate is  

$$G = B^{\circ}/n^{\circ} = 1.84/1.46 \times 10^6$$

$$= 1.26 \times 10^{-6} \text{ cm/s or } 0.0454 \text{ mm/h}$$

From Eq. (27.25) , since  $B^{\circ}/n^{\circ}G = 1$ ,

$$K_N = \frac{t_{T0}}{u_T^2 \rho_c (G\tau)^5}$$

$$= \frac{35}{1350^2 \times 2.163 \times (0.0454 \times 1.80)^5}$$

$$= 2.436$$

27.6. (a) Assume  $Sh = 2.0$  or  $k_c = 2D_v/D_p$

The rate of change of mass is:

$$\frac{d(\rho_s \pi D_p^3 / 6)}{dt} = -\pi D_p^2 k_c \Delta C$$

$$3\rho_s D_p^2 dD_p / 6 = - D_p^2 (2D_v / D_p) \Delta C$$

$$\int D_p dD_p = - \int \frac{4D_v \Delta C}{\rho_s} dt$$

$$D_p^2 / 2 = - 4D_v \Delta C t / \rho_s$$

For complete dissolution

$$-\Delta D_p^2 = D_p^2 = 8D_v \Delta C t / \rho_s$$

$$\rho_s = 1.988 \text{ g/cm}^3$$

Use Eq. (17.24) and Table 17.1 with  $\lambda$  for  $K^+$  and  $Cl^-$ . For dilute solutions at 25°C,

$$D_v = \frac{2 \times 8.314 \times 298}{(1/73.5 + 1/76.3)96,500^2}$$

$$= 1.99 \times 10^{-5} \text{ cm}^2/\text{s}$$

Correct to 130°F or 54.4°C, using  $T/\mu$  ratios for water (see Appendix 6):

$$\text{At } 20^{\circ}\text{C}, \bar{V} = 0.265 (293/273) = 0.284 \text{ m/s}$$

$$\mu = 0.018 \text{ cP} = 1.8 \times 10^{-5} \text{ Pa}\cdot\text{s}; \rho = 1.206 \text{ kg/m}^3$$

$$\text{Re} = \frac{300 \times 10^{-6} \times 0.284 \times 1.206}{1.8 \times 10^{-5}} = 5.71$$

Use Eq. (5.20) for laminar flow, in differential form,

$$\frac{dP}{dL} = \frac{32\bar{V}\mu}{D^2}$$

Assume a constant permeation rate over the fiber length.

$$\bar{V} = \bar{V}_{\text{exit}} \frac{L}{L_T}$$

$$dP = \frac{32\bar{V}_{\text{exit}}\mu L}{D^2 L_T} dL$$

$$\text{By integration, } \Delta P = \frac{32\bar{V}_{\text{exit}}\mu L_T^2}{2D^2 L_T}$$

$$\text{For } L_T = 1, \Delta P = \frac{16 \times 0.284 \times 1.8 \times 10^{-5}}{(300 \times 10^{-6})^2} = 909 \text{ Pa} = 9.09 \times 10^{-3} \text{ bar}$$

(b) For 150- x 300- $\mu\text{m}$  fibers, the permeate flux per fiber would be half as great, but the cross-sectional area is reduced by four, so  $\bar{V}$  is two times greater.  $\Delta P$  depends on  $\bar{V}/D^2$ . So  $\Delta P$  changes to:

$$909 \times 2 \times 4 = 7270 \text{ Pa} = 0.073 \text{ bar.}$$

$$26.12(a) \quad R = 0.05 = P_1/P_2 \quad \text{Let } P_1 = 20 \text{ atm}, P_2 = 1 \text{ atm}$$

Basis:  $F = 100$ ,  $x_F = 0.01$ ,  $y = 0.049$ . Stage cut = 19 percent

$$V = 0.19F, \quad F = 19, \quad L = F - V = 81$$

Check CFC balance. In:  $100(0.01) = 1$

$$\text{Out: } 19(0.049) + 81(0.001) = 1.012. \text{ OK.}$$

For CFC at inlet end,  $p_{1, \text{CFC}} = 20(0.01) = 0.2 \text{ atm}$

$$p_{2, \text{CFC}} = 1(0.049) = 0.049 \text{ atm}$$

$$\Delta p_{\text{CFC}} = 0.2 - 0.049 = 0.151 \text{ atm}$$

At the residue end,  $p_{1, \text{CFC}} = 20(0.001) = 0.02 \text{ atm}$

In 10 seconds, transfer  $10 \times \frac{9.12 \times 10^{-10}}{4.36 \times 10^{-8}} \times 100 = 21\%$  of  $O_2$  in bubble

If  $P$  is the same, the bubble size is reduced to  $1 \times (0.79)^{1/3} = 0.92$  mm .

However, in 10 seconds the bubble might rise 120 cm or 4 ft and  $P$  would be  $\left(\frac{30}{34}\right)^{+1} = 1.88$  atm. The corrected bubble size is  $(0.79 \times 2/1.88)^{1/3} \times 1 = 0.94$  mm .

A numerical solution would be needed to allow for the change in bubble size, area, oxygen concentration and mass transfer coefficient as the bubble rises in a quiescent liquid. In a stirred tank, small bubbles could be carried downward in some regions and have more time to dissolve.

The bubble rise velocity is reduced to  $\sim 0.92(12) = 11$  cm/s , but the mass transfer coefficient is almost the same.

$$Re = \frac{0.092(11)1.0}{0.01} = 101$$

$$Sh = 49.9$$

$$k_c = 0.0106 \text{ cm/s}$$

When 90% of the  $O_2$  has been absorbed,

$$D = 1.0(0.1)^{1/3} = 0.464 \text{ mm}, \quad u_r \cong 5.6 \text{ cm/s}$$

$$Re = \frac{0.0464(56)1}{0.01} = 26.0$$

$$Sh = 26.3$$

$$k_c = 0.0113 \text{ cm/s}$$