

SOLUTIONS MANUAL

to accompany

**TRANSPORT PHENOMENA
IN MATERIALS PROCESSING**

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$$b. \text{Eq. (1.13)} \quad \bar{v} = \left[\frac{8k_B T}{\pi m} \right]^{1/2}; \quad (k_B T)^{1/2} = \left(\frac{\pi m}{8} \right)^{1/2} \bar{v}$$

$$\text{Eq. (1.13)} \quad n = \frac{2}{3\pi^{1/2}} \frac{m^{1/2} (k_B T)^{1/2}}{d^2}; \quad (k_B T)^{1/2} = \frac{3\pi^{1/2}}{2} \frac{n d^2}{m^{1/2}}$$

$$n = \frac{2}{3\pi^{1/2}} \frac{m^{1/2} \left(\frac{\pi m}{8} \right)^{1/2} \bar{v}}{d^2} = \frac{m \bar{v}}{3\sqrt{2} \pi^{1/2} d^2}$$

$$c. \quad C = \frac{3\sqrt{2}}{8} \pi^{1/2} \frac{R^3 d^2}{L m} \bar{v}$$

5.5 Compare the conductance for viscous flow in a long straight tube (from Problem 5.4c) to the conductance for molecular flow.

- How does each vary with \bar{v} ?
- How does each vary with temperature?
- For nitrogen at 300 K, what is the mean free path (see Eq. (1.5)) at normal atmospheric pressure (760 torr).

$$\text{Viscous flow: } C = \frac{3\sqrt{2}}{8} \pi^{1/2} \frac{R^3 d^2}{L m} \bar{v}$$

$$\text{Molecular flow: Eq. (5.50)} \quad C = \frac{\pi D^3}{12 L} \bar{v}$$

a. They each vary linearly with \bar{v}

$$b. \quad \bar{v} = \left[\frac{8k_B T}{\pi m} \right]^{1/2}$$

They each vary with $T^{1/2}$

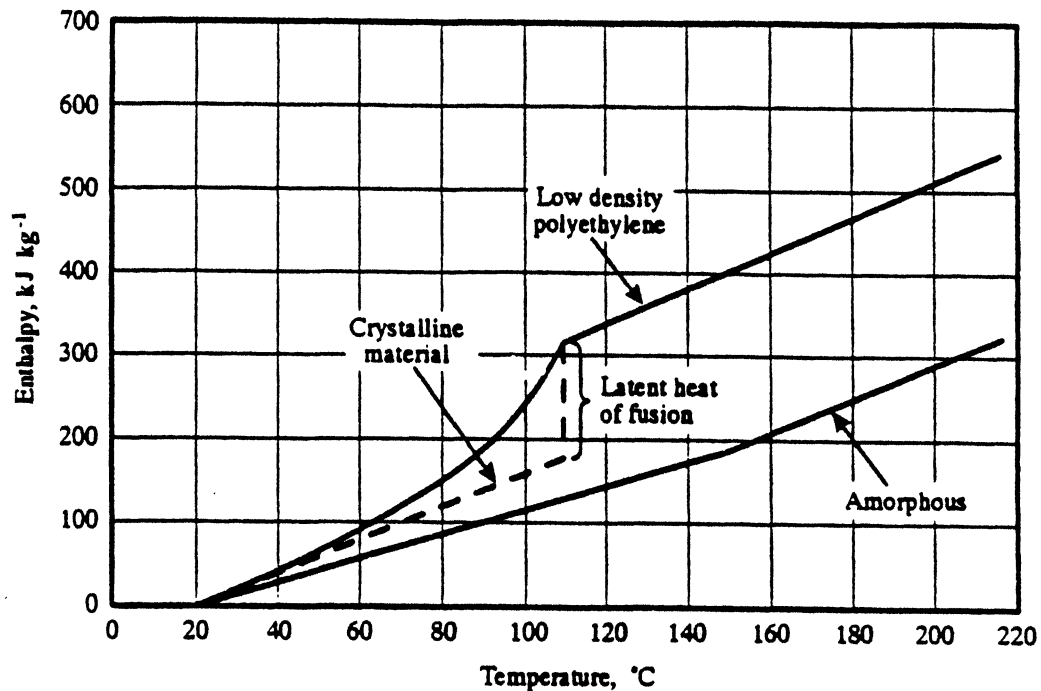
c. Eq. (1.5) $\lambda = \left(\frac{1}{\sqrt{2}} \right) \left(\frac{1}{\pi d^2 n} \right)$; Assume ideal gas

$$PV = NkT; \quad n = \frac{N}{V} = \frac{P}{kT} = \frac{1.01 \times 10^5 \text{ N/m}^2}{1.38 \times 10^{-23} \text{ J} \cdot 300 \text{ K}} = 2.44 \times 10^{25} \text{ molecules m}^{-3}$$

$$\lambda = \frac{1}{\sqrt{2} \pi} \frac{1}{(3.80 \times 10^{-10})^2 \text{ m}^2} \frac{1}{2.44 \times 10^{25} \text{ mol}^{-1}} = 6.39 \times 10^{-8} \text{ m}$$

$$\text{where } d \approx \sigma = 3.798 \text{ \AA} \text{ (Table 1.1)}; \quad d = \frac{3.798 \text{ \AA}}{10^{10} \frac{\text{\AA}}{\text{m}}} = 3.80 \times 10^{-10} \text{ m}$$

10.9 Low density polyethylene is injected into a water-cooled copper mold. The temperature of the melt entering the mold is 465 K. The polyethylene is molded to form a plate that is 10 mm thick. Estimate the time required for all of the polyethylene reach less than 335 K, when it can be safely ejected from the mold. Assume that the heat transfer coefficient at the polyethylene-copper interface is relatively high ($h = 4000 \text{ W m}^{-2} \text{ K}^{-1}$) because cooling occurs while the molding is under pressure. The enthalpy of polyethylene is given below. Other properties of low density polyethylene are $k = 0.26 \text{ W m}^{-1} \text{ K}^{-1}$ and $\rho = 920 \text{ kg m}^{-3}$.



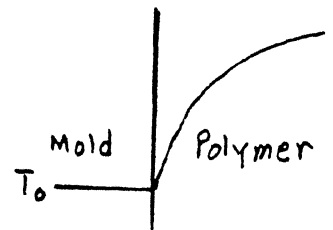
In this case the "casting" is a poor conductor whereas the mold is a good conductor. Hence we can assume that the major resistance is within the polymer and the mold is at a uniform and constant temperature.

Let H_2 = enthalpy at 465 K (T_2)

H_1 = enthalpy at 335 K (T_1)

$$\bar{c}_p \approx \frac{H_2 - H_1}{T_2 - T_1} = \frac{490 - 95}{465 - 335} = 3.039 \text{ kJ kg}^{-1} \text{ K}^{-1}$$

$$= 3.039 \times 10^3 \text{ J kg}^{-1} \text{ K}^{-1}$$



$$\alpha = \frac{0.26}{(920)(3.039 \times 10^3)} = 9.30 \times 10^{-8} \text{ m}^2 \text{ s}^{-1}$$

b. \dot{n} is proportional to the spacing between the sheets. so if we reduce the spacing from 2 cm to 5 mm, then when $\bar{v} = 1 \text{ ms}^{-1}$,

$$x = \frac{1.5}{4} \text{ m} = 0.375 \text{ m}$$

15.4 Assume that the initial thickness of an oxide layer on silicon is 10 nm. Determine the thickness of the oxide after oxidation in dry oxygen at 1350 K for 7000 s.

$$\delta_i = 10 \text{ nm} = 10 \times 10^{-9} \text{ m}$$

$$\text{Eq. (15.34) where } A = 1.18 \times 10^{-10} \exp\left(\frac{8840}{1350}\right) = 8.236 \times 10^{-8} \text{ m}$$

$$B = 1.81 \times 10^{-13} \exp\left(\frac{-14050}{1350}\right) = 5.463 \times 10^{-18} \text{ m}$$

$$\tau = \frac{(10 \times 10^{-9})^2 + (8.236 \times 10^{-8})(10 \times 10^{-9})}{5.463 \times 10^{-18}} = 168.9 \text{ s}$$

$$\delta = \frac{8.236 \times 10^{-8}}{2} \left[\left(1 + \frac{(4)(5.463 \times 10^{-18})(7000 + 168.9)}{(8.236 \times 10^{-8})^2} \right)^{1/2} - 1 \right] = 1.61 \times 10^{-7} \text{ m} = 161 \text{ nm}$$

15.5 The standard free energy of formation of $\text{SiO}_2(\text{s})$ is

$$\Delta G^\circ = -215\,600 + 41.5 T, \text{ cal mol}^{-1},$$

for $700 \leq T \leq 1700 \text{ K}$. Suppose the pure oxygen in Problem 15.4 is replaced with 90% Ar-10% O_2 . Would this appreciably change the oxidation kinetics?

$$\text{Eq. (15.36a): } j = \frac{P_{\text{O}_2}^\infty}{\frac{k_a T}{K_M} + \frac{1}{K_r K} + \frac{S}{D K}}$$

$P_{\text{O}_2}^\infty$ is 1 atm in Prob. 15.4 whereas it is 0.1 atm now. Hence, we can expect the flux to be only 10% of that in Example 15.4.

15.6 The vapor pressure of $\text{Zn}(\text{s})$ is

$$\log_{10} P(\text{mm Hg}) = -\frac{6850}{T} - 0.755 \log_{10} T + 11.24.$$

(Note: 760 mm Hg = 1 standard atm = $1.0133 \times 10^5 \text{ N m}^{-2}$.) Thermodynamic data at 1200 K give

$$\frac{\ln \gamma_{\text{Zn}}}{(1 - X_{\text{Zn}})} = 3.875 X_{\text{Zn}} - 3.425.$$