Fundamentals of Heat and Mass Transfer

Chapter 1

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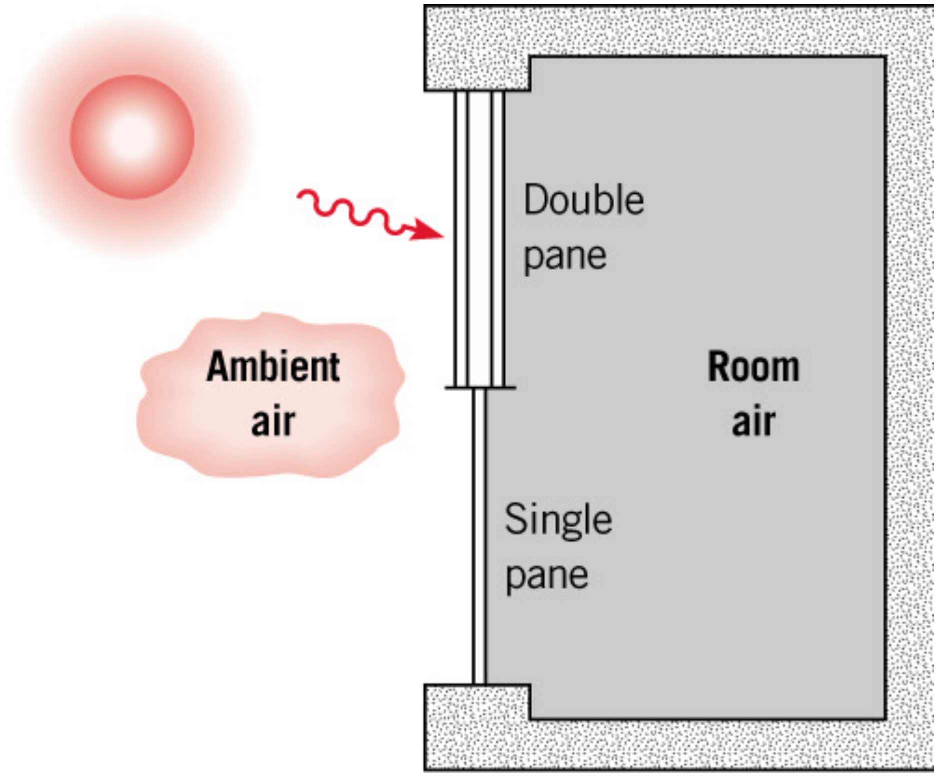
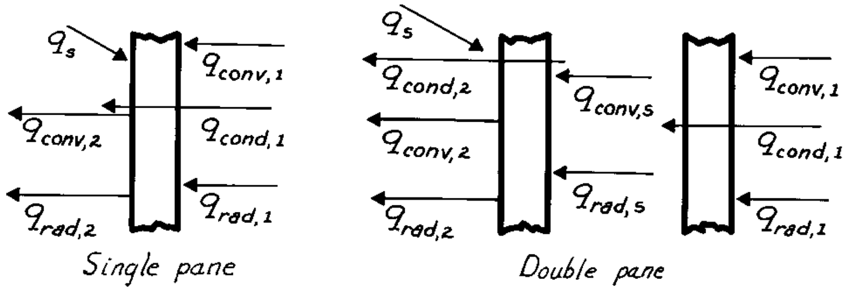
Problem: Process Identification

Problem 1.63(a): Process identification for single-and double-pane windows



Problem: Process Identification (2 of 2)



$q_{conv,1}$ Convection from room air to inner surface of first pane

$q_{rad,1}$ Net radiation exchange between room walls and inner surface of first pane

$q_{cond,1}$ Conduction through first pane

$q_{conv,s}$ Convection across airspace between panes

$q_{rad,s}$ Net radiation exchange between outer surface of first pane and inner surface of second pane (across airspace)

$q_{cond,2}$ Conduction through a second pane

$q_{conv,2}$ Convection from outer surface of single (or second) pane to ambient air

$q_{rad,2}$ Net radiation exchange between outer surface of single (or second) pane and surroundings such as the ground

q_s Incident solar radiation during day; fraction transmitted to room is smaller for double pane

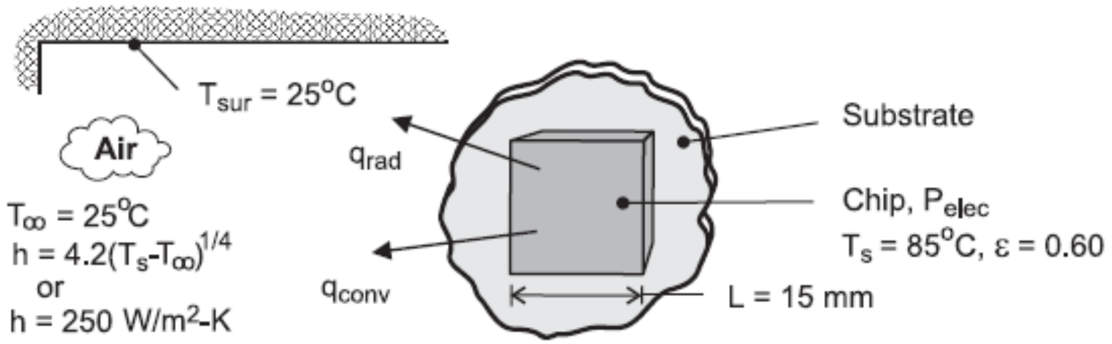
Problem: Electronic Cooling (1 of 3)

Problem 1.35: Power dissipation from chips operating at a surface temperature of $85^\circ C$ and in an enclosure whose walls and air are at $25^\circ C$ for (a) free convection and (b) forced convection.

Schematic:

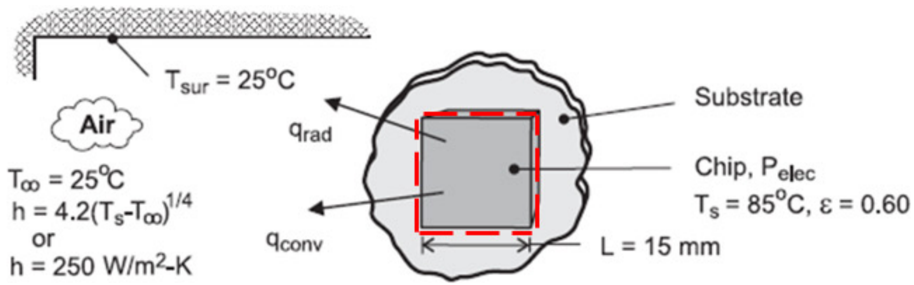
Free convection →

Forced convection →



Assumptions: (1) Steady-state conditions, (2) Radiation exchange between a small surface and a large enclosure, (3) $a = \varepsilon$, (4) Negligible heat transfer from sides of chip or from back of chip by conduction through the substrate.

Problem: Electronic Cooling (2 of 3)



Analysis:

$$P_{\text{elec}} = q_{\text{conv}} + q_{\text{rad}} = hA\left(T_s - T_\infty\right) + \varepsilon A\sigma\left(T_s^4 - T_{\text{sur}}^4\right)$$

$$A = L^2 = (0.015\text{m})^2 = 2.25\times10^{-4}\text{m}^2$$

(a) If heat transfer is by free convection,

$$q_{\text{conv}} = CA\left(T_s - T_\infty\right)^{5/4} = 4.2\text{W/m}^2\cdot\text{K}^{5/4}\left(2.25\times10^{-4}\text{m}^2\right)(60\text{K})^{5/4} = 0.158\text{W}$$

$$q_{\text{rad}} = 0.60\left(2.25\times10^{-4}\text{m}^2\right)5.67\times10^{-8}\text{W/m}^2\cdot\text{K}^4\left(358^4 - 298^4\right)\text{K}^4 = 0.065\text{W}$$

$$P_{\text{elec}} = 0.158\text{W} + 0.065\text{W} = 0.223\text{W}$$

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Problem: Electronic Cooling (3 of 3)

(b) If heat transfer is by forced convection,

$$q_{\text{conv}} = hA\left(T_s - T_\infty\right) = 250\,\text{W/m}^2 \cdot \text{K}^4 \left(2.25 \times 10^{-4}\,\text{m}^2\right)\left(60\,\text{K}\right) = 3.375\,\text{W}$$

$$P_{\text{elec}} = 3.375\,\text{W} + 0.065\,\text{W} = 3.44\,\text{W} \qquad <$$

Problem: Electronic Cooling

An uninsulated steam pipe passes through a room in which the air and walls are at 25°C. The outside diameter of the pipe is 70 mm, and its surface temperature and emissivity are 200°C and 0.8, respectively. What are the surface emissive power and irradiation? If the coefficient associated with free convection heat transfer from the surface to the air is $15\ W/m^2 \cdot K$, what is the rate of heat loss from the surface per unit length of pipe?

Problem: Electronic Cooling

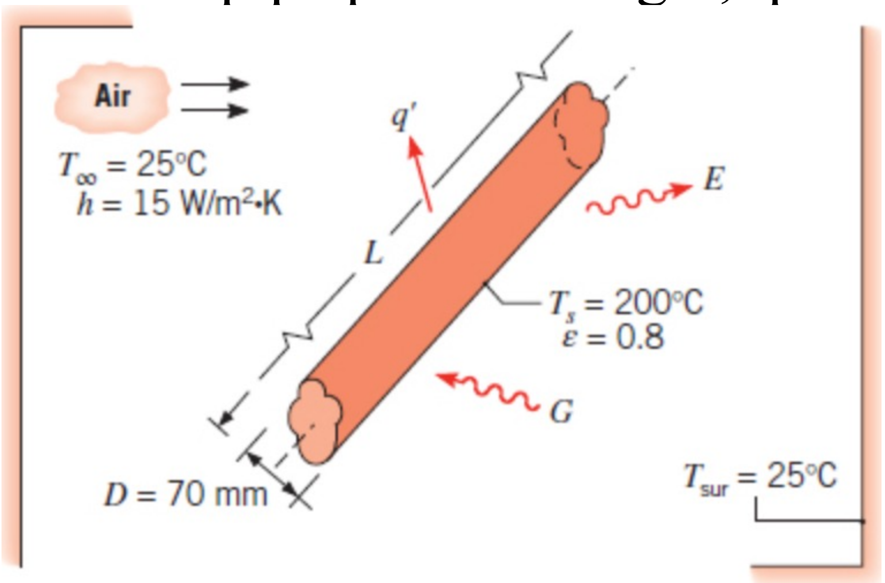
SOLUTION

Known: Uninsulated pipe of prescribed diameter, emissivity, and surface temperature in a room with fixed wall and air temperatures.

Find:

1. Surface emissive power and irradiation.
2. Rate of heat loss from pipe per unit length, q′.

Schematic:



Assumptions:

1. Steady-state conditions.
2. Radiation exchange between the pipe and the room is between a small surface and a much larger enclosure.
3. The surface emissivity and absorptivity are equal.

Analysis:

1. The surface emissive power and the irradiation are evaluated as the following:

$$E = \varepsilon\sigma T_s^4 = 0.8(5.67 \times 10^{-8}\ \mathrm{W/m^2 \cdot K^4})(473\ \mathrm{K})^4 = 2270\ \mathrm{W/m^2}$$

$$G = \sigma T_{\mathrm{sur}}^4 = 5.67 \times 10^{-8}\ \mathrm{W/m^2 \cdot K^4}(298\ \mathrm{K})^4 = 447\ \mathrm{W/m^2}$$

2. Heat loss from the pipe is by convection to the room air and by radiation exchange with the walls. Hence, q = qconv + qrad,

$$q = h(\pi DL)(T_s - T_\infty) + \varepsilon(\pi DL)\sigma(T_s^4 - T_{sur}^4)$$

The rate of heat loss per unit length of pipe is then:

$$q' = \frac{q}{L} = 15\ \mathrm{W/m^2 \cdot K}(\pi \times 0.07\ \mathrm{m})(200 - 25)^\circ\mathrm{C}$$
$$+0.8(\pi \times 0.07\ \mathrm{m})\ 5.67 \times 10^{-8}\ \mathrm{W/m^2 \cdot K^4}(473^4 - 298^4)\ \mathrm{K^4}$$

$$q' = 577\ \mathrm{W/m} + 421\ \mathrm{W/m} = 998\ \mathrm{W/m} \quad \triangleleft$$

Comments:

1. Note that temperature may be expressed in units of °C or K when evaluating the temperature difference for a convection (or conduction) heat transfer rate. However, temperature must be expressed in kelvins (K) when evaluating a radiation transfer rate.

2. The net rate of radiation heat transfer from the pipe may be expressed as

$$q'_{\text{rad}} = \pi D(E - \alpha G)$$

$$q'_{\text{rad}} = \pi \times 0.07\ \text{m}\ (2270 - 0.8 \times 447)\ \text{W/m}^2 = 421\ \text{W/m}$$

3. In this situation, the radiation and convection heat transfer rates are comparable because Ts is large compared to Tsur and the coefficient associated with free convection is small. For more moderate values of Ts and the larger values of h associated with forced convection, the effect of radiation may often be neglected. The radiation heat transfer coefficient may be computed. For the conditions of this problem, its value is hr = 11 W/m2 · K.