

Friday, September 05, 2003
 Chapter 3, Problem 35.

The wall of a refrigerator is constructed of fiberglass insulation ($k = 0.035 \text{ W/m} \cdot ^\circ\text{C}$) sandwiched between two layers of 1-mm-thick sheet metal ($k = 15.1 \text{ W/m} \cdot ^\circ\text{C}$). The refrigerated space is maintained at 3°C , and the average heat transfer coefficients at the inner and outer surfaces of the wall are $4 \text{ W/m}^2 \cdot ^\circ\text{C}$ and $9 \text{ W/m}^2 \cdot ^\circ\text{C}$, respectively. The kitchen temperature averages 25°C . It is observed that condensation occurs on the outer surfaces of the refrigerator when the temperature of the outer surface drops to 20°C . Determine the minimum thickness of fiberglass insulation that needs to be used in the wall in order to avoid condensation on the outer surfaces.

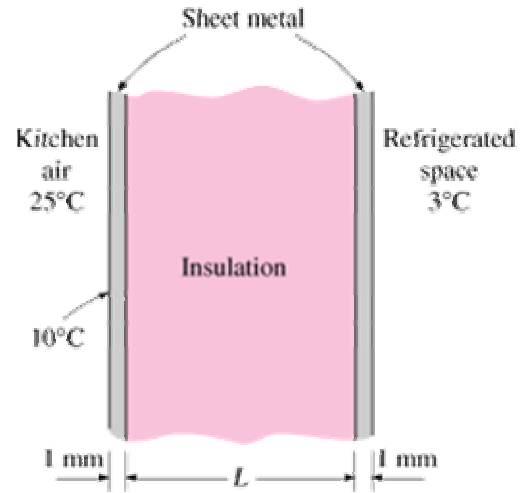


Figure P3-35.

Chapter 3, Solution 35

The wall of a refrigerator is constructed of fiberglass insulation sandwiched between two layers of sheet metal. The minimum thickness of insulation that needs to be used in the wall in order to avoid condensation on the outer surfaces is to be determined.

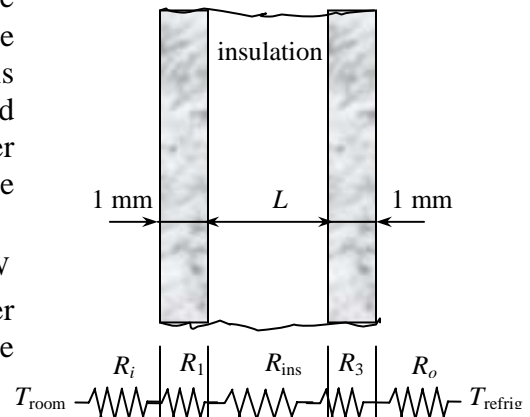
Assumptions 1 Heat transfer through the refrigerator walls is steady since the temperatures of the food compartment and the kitchen air remain constant at the specified values. 2 Heat transfer is one-dimensional. 3 Thermal conductivities are constant. 4 Heat transfer coefficients account for the radiation effects.

Properties The thermal conductivities are given to be $k = 15.1 \text{ W/m} \cdot ^\circ\text{C}$ for sheet metal and $0.035 \text{ W/m} \cdot ^\circ\text{C}$ for fiberglass insulation.

Analysis The minimum thickness of insulation can be determined by assuming the outer surface temperature of the refrigerator to be 10°C . In steady operation, the rate of heat transfer through the refrigerator wall is constant, and thus heat transfer between the room and the refrigerated space is equal to the heat transfer between the room and the outer surface of the refrigerator. Considering a unit surface area,

$$\dot{Q} = h_o A (T_{room} - T_{s,out}) = (9 \text{ W/m}^2 \cdot ^\circ\text{C})(1 \text{ m}^2)(25 - 20)^\circ\text{C} = 45 \text{ W}$$

Using the thermal resistance network, heat transfer between the room and the refrigerated space can be expressed as



Friday, September 05, 2003

$$\dot{Q} = \frac{T_{room} - T_{refrig}}{R_{total}}$$

$$\dot{Q} / A = \frac{T_{room} - T_{refrig}}{\frac{1}{h_o} + 2\left(\frac{L}{k}\right)_{metal} + \left(\frac{L}{k}\right)_{insulation} + \frac{1}{h_i}}$$

Substituting,

$$45 \text{ W/m}^2 = \frac{(25 - 3)^{\circ}\text{C}}{\frac{1}{9 \text{ W/m}^2 \cdot ^{\circ}\text{C}} + \frac{2 \times 0.001 \text{ m}}{15.1 \text{ W/m}^2 \cdot ^{\circ}\text{C}} + \frac{L}{0.035 \text{ W/m}^2 \cdot ^{\circ}\text{C}} + \frac{1}{4 \text{ W/m}^2 \cdot ^{\circ}\text{C}}}$$

Solving for L , the minimum thickness of insulation is determined to be

$$L = 0.0045 \text{ m} = \mathbf{0.45 \text{ cm}}$$

Friday, September 05, 2003

Chapter 3, Problem 55.

A 12-m-long and 5-m-high wall is constructed of two layers of 1-cm-thick sheetrock ($k = 0.17 \text{ W/m} \cdot ^\circ\text{C}$) spaced 12 cm by wood studs ($k = 0.11 \text{ W/m} \cdot ^\circ\text{C}$) whose cross section is 12 cm \times 5 cm. The studs are placed vertically 60 cm apart, and the space between them is filled with fiberglass insulation ($k = 0.034 \text{ W/m} \cdot ^\circ\text{C}$). The house is maintained at 20°C and the ambient temperature outside is 25°C . Taking the heat transfer coefficients at the inner and outer surfaces of the house to be 8.3 and $34 \text{ W/m}^2 \cdot ^\circ\text{C}$, respectively, determine (a) the thermal resistance of the wall considering a representative section of it and (b) the rate of heat transfer through the wall.

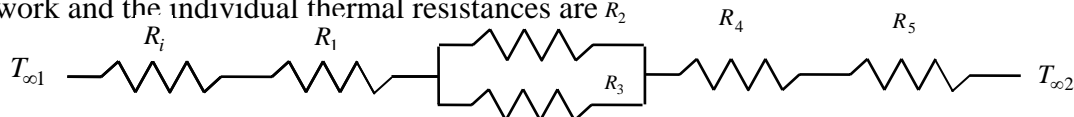
Chapter 3, Solution 55

A wall is constructed of two layers of sheetrock spaced by $5 \text{ cm} \times 12 \text{ cm}$ wood studs. The space between the studs is filled with fiberglass insulation. The thermal resistance of the wall and the rate of heat transfer through the wall are to be determined.

Assumptions 1 Heat transfer is steady since there is no indication of change with time. 2 Heat transfer through the wall is one-dimensional. 3 Thermal conductivities are constant. 4 Heat transfer coefficients account for the radiation heat transfer.

Properties The thermal conductivities are given to be $k = 0.17 \text{ W/m} \cdot ^\circ\text{C}$ for sheetrock, $k = 0.11 \text{ W/m} \cdot ^\circ\text{C}$ for wood studs, and $k = 0.034 \text{ W/m} \cdot ^\circ\text{C}$ for fiberglass insulation.

Analysis (a) The representative surface area is $A = 1 \times 0.65 = 0.65 \text{ m}^2$. The thermal resistance network and the individual thermal resistances are



$$R_i = \frac{1}{h_i A} = \frac{1}{(8.3 \text{ W/m}^2 \cdot ^\circ\text{C})(0.65 \text{ m}^2)} = 0.1854 \text{ }^\circ\text{C/W}$$

$$R_1 = R_4 = R_{sheetrock} = \frac{L}{kA} = \frac{0.01 \text{ m}}{(0.17 \text{ W/m} \cdot ^\circ\text{C})(0.65 \text{ m}^2)} = 0.0905 \text{ }^\circ\text{C/W}$$

$$R_2 = R_{stud} = \frac{L}{kA} = \frac{0.12 \text{ m}}{(0.11 \text{ W/m} \cdot ^\circ\text{C})(0.05 \text{ m}^2)} = 21.82 \text{ }^\circ\text{C/W}$$

$$R_3 = R_{fiberglass} = \frac{L}{kA} = \frac{0.12 \text{ m}}{(0.034 \text{ W/m} \cdot ^\circ\text{C})(0.60 \text{ m}^2)} = 5.882 \text{ }^\circ\text{C/W}$$

$$R_o = \frac{1}{h_o A} = \frac{1}{(34 \text{ W/m}^2 \cdot ^\circ\text{C})(0.65 \text{ m}^2)} = 0.0452 \text{ }^\circ\text{C/W}$$

$$\frac{1}{R_{mid}} = \frac{1}{R_2} + \frac{1}{R_3} = \frac{1}{21.82} + \frac{1}{5.882} \longrightarrow R_{mid} = 4.633 \text{ }^\circ\text{C/W}$$

$$R_{total} = R_i + R_1 + R_{mid} + R_4 + R_o = 0.15 + 0.09 + 4.63 + 0.09 + 0.08 = \mathbf{5.045 \text{ }^\circ\text{C/W}}$$
 (for a $1 \text{ m} \times 0.65 \text{ m}$ section)

$$\dot{Q} = \frac{T_{\infty 1} - T_{\infty 2}}{R_{total}} = \frac{[20 - (-5)]^\circ\text{C}}{5.045 \text{ }^\circ\text{C/W}} = 4.956 \text{ W}$$

(b) Then steady rate of heat transfer through entire wall becomes

Friday, September 05, 2003

$$\dot{Q}_{total} = (4.96 \text{ W}) \frac{(12 \text{ m})(5 \text{ m})}{0.65 \text{ m}^2} = 458 \text{ W}$$

Chapter 3, Problem 71.

Consider a 2-m-high electric hot water heater that has a diameter of 40 cm and maintains the hot water at 55°C. The tank is located in a small room whose average temperature is 27°C, and the heat transfer coefficients on the inner and outer surfaces of the heater are 50 and 12 W/m² · °C, respectively. The tank is placed in another 46-cm-diameter sheet metal tank of negligible thickness, and the space between the two tanks is filled with foam insulation (*k* = 0.03 W/m · °C). The thermal resistances of the water tank and the outer thin sheet metal shell are very small and can be neglected. The price of electricity is \$0.08/kWh, and the home owner pays \$280 a year for water heating. Determine the fraction of the hot water energy cost of this household that is due to the heat loss from the tank.

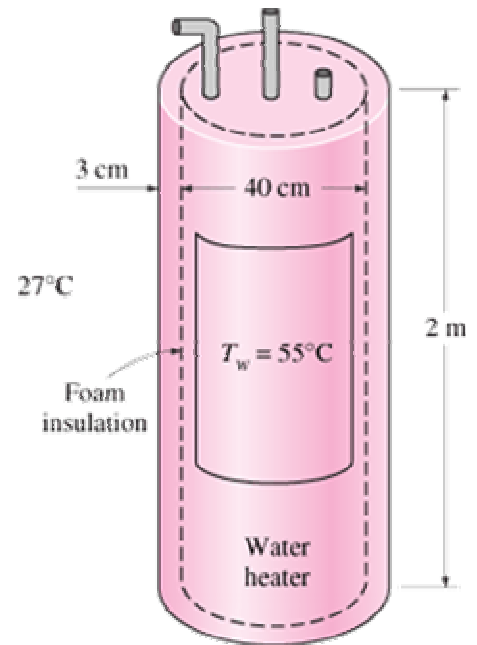


Figure P3-71

Hot water tank insulation kits consisting of 3-cm-thick fiberglass insulation (*k* = 0.035 W/m · °C) large enough to wrap the entire tank are available in the market for about \$30. If such an insulation is installed on this water tank by the home owner himself, how long will it take for this additional insulation to pay for itself? Answers: 17.5 percent, 1.5 years

Chapter 3, Solution 71

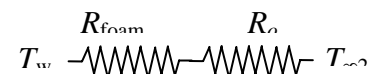
An electric hot water tank is made of two concentric cylindrical metal sheets with foam insulation in between. The fraction of the hot water cost that is due to the heat loss from the tank and the payback period of the do-it-yourself insulation kit are to be determined.

Assumptions 1 Heat transfer is steady since there is no indication of any change with time. 2 Heat transfer is one-dimensional since there is thermal symmetry about the center line and no variation in the axial direction. 3 Thermal conductivities are constant. 4 The thermal resistances of the water tank and the outer thin sheet metal shell are negligible. 5 Heat loss from the top and bottom surfaces is negligible.

Properties The thermal conductivities are given to be *k* = 0.03 W/m·°C for foam insulation and *k* = 0.035 W/m·°C for fiber glass insulation

Analysis We consider only the side surfaces of the water heater for simplicity, and disregard the top and bottom surfaces (it will make difference of about 10 percent). The individual thermal resistances are

$$A_o = \pi D_o L = \pi(0.46 \text{ m})(2 \text{ m}) = 2.89 \text{ m}^2$$



Friday, September 05, 2003

$$R_o = \frac{1}{h_o A_o} = \frac{1}{(12 \text{ W/m}^2 \cdot \text{°C})(2.89 \text{ m}^2)} = 0.029 \text{ °C/W}$$

$$R_{foam} = \frac{\ln(r_2 / r_1)}{2\pi k L} = \frac{\ln(23 / 20)}{2\pi(0.03 \text{ W/m}^2 \cdot \text{°C})(2 \text{ m})} = 0.37 \text{ °C/W}$$

$$R_{total} = R_o + R_{foam} = 0.029 + 0.37 = 0.40 \text{ °C/W}$$

The rate of heat loss from the hot water tank is

$$\dot{Q} = \frac{T_w - T_{\infty 2}}{R_{total}} = \frac{(55 - 27) \text{ °C}}{0.40 \text{ °C/W}} = 70 \text{ W}$$

The amount and cost of heat loss per year are

$$Q = \dot{Q} \Delta t = (0.07 \text{ kW})(365 \times 24 \text{ h / yr}) = 613.2 \text{ kWh / yr}$$

$$\text{Cost of Energy} = (\text{Amount of energy})(\text{Unit cost}) = (613.2 \text{ kWh})(\$0.08 / \text{kWh}) = \$49.056$$

$$f = \frac{\$49.056}{\$280} = 0.1752 = \mathbf{17.5\%}$$

If 3 cm thick fiber glass insulation is used to wrap the entire tank, the individual resistances becomes

$$A_o = \pi D_o L = \pi(0.52 \text{ m})(2 \text{ m}) = 3.267 \text{ m}^2$$

$$R_o = \frac{1}{h_o A_o} = \frac{1}{(12 \text{ W/m}^2 \cdot \text{°C})(3.267 \text{ m}^2)} = 0.026 \text{ °C/W}$$

$$R_{foam} = \frac{\ln(r_2 / r_1)}{2\pi k_1 L} = \frac{\ln(23 / 20)}{2\pi(0.03 \text{ W/m}^2 \cdot \text{°C})(2 \text{ m})} = 0.371 \text{ °C/W}$$

$$R_{fiberglass} = \frac{\ln(r_3 / r_2)}{2\pi k_2 L} = \frac{\ln(26 / 23)}{2\pi(0.035 \text{ W/m}^2 \cdot \text{°C})(2 \text{ m})} = 0.279 \text{ °C/W}$$

$$R_{total} = R_o + R_{foam} + R_{fiberglass} = 0.026 + 0.371 + 0.279 = 0.676 \text{ °C/W}$$

The rate of heat loss from the hot water heater in this case is

$$\dot{Q} = \frac{T_w - T_{\infty 2}}{R_{total}} = \frac{(55 - 27) \text{ °C}}{0.676 \text{ °C/W}} = 41.42 \text{ W}$$

The energy saving is

$$\text{saving} = 70 - 41.42 = 28.58 \text{ W}$$

The time necessary for this additional insulation to pay for its cost of \$30 is then determined to be

$$\text{Cost} = (0.02858 \text{ kW})(\text{Time period})(\$0.08 / \text{kWh}) = \$30$$

Then, Time period = 13,121 hours = **547 days ≈ 1.5 years**

Friday, September 05, 2003

Chapter 3, Problem 81.

The boiling temperature of nitrogen at atmospheric pressure at sea level (1 atm pressure) is -196°C . Therefore, nitrogen is commonly used in low-temperature scientific studies since the temperature of liquid nitrogen in a tank open to the atmosphere will remain constant at -196°C until it is depleted. Any heat transfer to the tank will result in the evaporation of some liquid nitrogen, which has a heat of vaporization of 198 kJ/kg and a density of 810 kg/m^3 at 1 atm.

Consider a 3-m-diameter spherical tank that is initially filled with liquid nitrogen at 1 atm and -196°C . The tank is exposed to ambient air at 15°C , with a combined convection and radiation heat transfer coefficient of $35\text{ W/m}^2 \cdot ^{\circ}\text{C}$. The temperature of the thin-shelled spherical tank is observed to be almost the same as the temperature of the nitrogen inside. Determine the rate of evaporation of the liquid nitrogen in the tank as a result of the heat transfer from the ambient air if the tank is (a) not insulated, (b) insulated with 5-cm-thick fiberglass insulation ($k = 0.035\text{ W/m} \cdot ^{\circ}\text{C}$), and (c) insulated with 2-cm-thick superinsulation which has an effective thermal conductivity of $0.00005\text{ W/m} \cdot ^{\circ}\text{C}$.

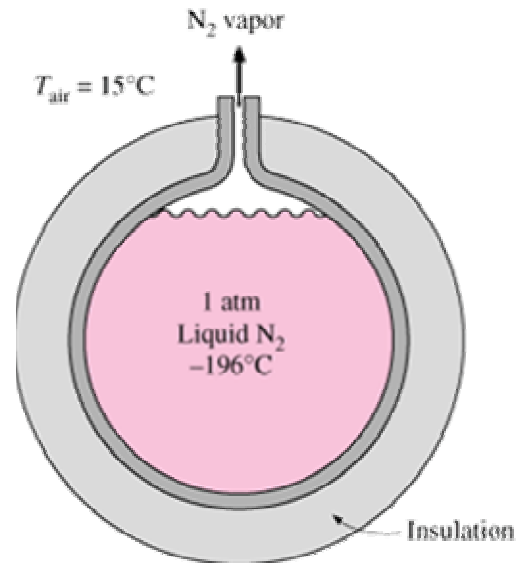


Figure P3-81

Chapter 3, Solution 81

A 3-m diameter spherical tank filled with liquid nitrogen at 1 atm and -196°C is exposed to convection and radiation with the surrounding air and surfaces. The rate of evaporation of liquid nitrogen in the tank as a result of the heat gain from the surroundings for the cases of no insulation, 5-cm thick fiberglass insulation, and 2-cm thick superinsulation are to be determined.

Assumptions 1 Heat transfer is steady since the specified thermal conditions at the boundaries do not change with time. 2 Heat transfer is one-dimensional since there is thermal symmetry about the midpoint. 3 The combined heat transfer coefficient is constant and uniform over the entire surface. 4 The temperature of the thin-shelled spherical tank is said to be nearly equal to the temperature of the nitrogen inside, and thus thermal resistance of the tank and the internal convection resistance are negligible.

Properties The heat of vaporization and density of liquid nitrogen at 1 atm are given to be 198 kJ/kg and 810 kg/m^3 , respectively. The thermal conductivities are given to be $k = 0.035\text{ W/m} \cdot ^{\circ}\text{C}$ for fiberglass insulation and $k = 0.00005\text{ W/m} \cdot ^{\circ}\text{C}$ for super insulation.

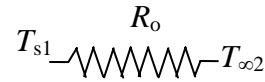
Analysis (a) The heat transfer rate and the rate of evaporation of the liquid without insulation are

Friday, September 05, 2003

$$A = \pi D^2 = \pi(3 \text{ m})^2 = 28.27 \text{ m}^2$$

$$R_o = \frac{1}{h_o A} = \frac{1}{(35 \text{ W/m}^2 \cdot ^\circ\text{C})(28.27 \text{ m}^2)} = 0.00101 \text{ } ^\circ\text{C/W}$$

$$\dot{Q} = \frac{T_{s1} - T_{\infty 2}}{R_o} = \frac{[15 - (-196)]^\circ\text{C}}{0.00101 \text{ } ^\circ\text{C/W}} = 208,910 \text{ W}$$

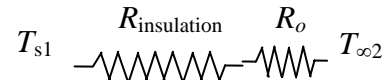


$$\dot{Q} = \dot{m} h_{fg} \longrightarrow \dot{m} = \frac{\dot{Q}}{h_{fg}} = \frac{208.910 \text{ kJ/s}}{198 \text{ kJ/kg}} = \mathbf{1.055 \text{ kg/s}}$$

(b) The heat transfer rate and the rate of evaporation of the liquid with a 5-cm thick layer of fiberglass insulation are

$$A = \pi D^2 = \pi(3.1 \text{ m})^2 = 30.19 \text{ m}^2$$

$$R_o = \frac{1}{h_o A} = \frac{1}{(35 \text{ W/m}^2 \cdot ^\circ\text{C})(30.19 \text{ m}^2)} = 0.000946 \text{ } ^\circ\text{C/W}$$



$$R_{insulation} = \frac{r_2 - r_1}{4\pi k r_1 r_2} = \frac{(1.55 - 1.5) \text{ m}}{4\pi(0.035 \text{ W/m} \cdot ^\circ\text{C})(1.55 \text{ m})(1.5 \text{ m})} = 0.0489 \text{ } ^\circ\text{C/W}$$

$$R_{total} = R_o + R_{insulation} = 0.000946 + 0.0489 = 0.0498 \text{ } ^\circ\text{C/W}$$

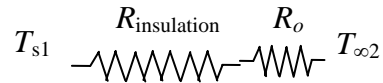
$$\dot{Q} = \frac{T_{s1} - T_{\infty 2}}{R_{total}} = \frac{[15 - (-196)]^\circ\text{C}}{0.0498 \text{ } ^\circ\text{C/W}} = 4233 \text{ W}$$

$$\dot{Q} = \dot{m} h_{fg} \longrightarrow \dot{m} = \frac{\dot{Q}}{h_{fg}} = \frac{4.233 \text{ kJ/s}}{198 \text{ kJ/kg}} = \mathbf{0.0214 \text{ kg/s}}$$

(c) The heat transfer rate and the rate of evaporation of the liquid with 2-cm thick layer of superinsulation is

$$A = \pi D^2 = \pi(3.04 \text{ m})^2 = 29.03 \text{ m}^2$$

$$R_o = \frac{1}{h_o A} = \frac{1}{(35 \text{ W/m}^2 \cdot ^\circ\text{C})(29.03 \text{ m}^2)} = 0.000984 \text{ } ^\circ\text{C/W}$$



$$R_{insulation} = \frac{r_2 - r_1}{4\pi k r_1 r_2} = \frac{(1.52 - 1.5) \text{ m}}{4\pi(0.00005 \text{ W/m} \cdot ^\circ\text{C})(1.52 \text{ m})(1.5 \text{ m})} = 13.96 \text{ } ^\circ\text{C/W}$$

$$R_{total} = R_o + R_{insulation} = 0.000984 + 13.96 = 13.96 \text{ } ^\circ\text{C/W}$$

$$\dot{Q} = \frac{T_{s1} - T_{\infty 2}}{R_{total}} = \frac{[15 - (-196)]^\circ\text{C}}{13.96 \text{ } ^\circ\text{C/W}} = 15.11 \text{ W}$$

$$\dot{Q} = \dot{m} h_{fg} \longrightarrow \dot{m} = \frac{\dot{Q}}{h_{fg}} = \frac{0.01511 \text{ kJ/s}}{198 \text{ kJ/kg}} = \mathbf{0.000076 \text{ kg/s}}$$

Friday, September 05, 2003

Chapter 3, Problem 111.

Consider a stainless steel spoon ($k = 8.7 \text{ Btu/h} \cdot \text{ft} \cdot ^\circ\text{F}$) partially immersed in boiling water at 200°F in a kitchen at 75°F . The handle of the spoon has a cross section of $0.08 \text{ in.} \times 0.5 \text{ in.}$, and extends 7 in. in the air from the free surface of the water. If the heat transfer coefficient at the exposed surfaces of the spoon handle is $3 \text{ Btu/h} \cdot \text{ft}^2 \cdot ^\circ\text{F}$, determine the temperature difference across the exposed surface of the spoon handle. State your assumptions. Answer: 124.6°F

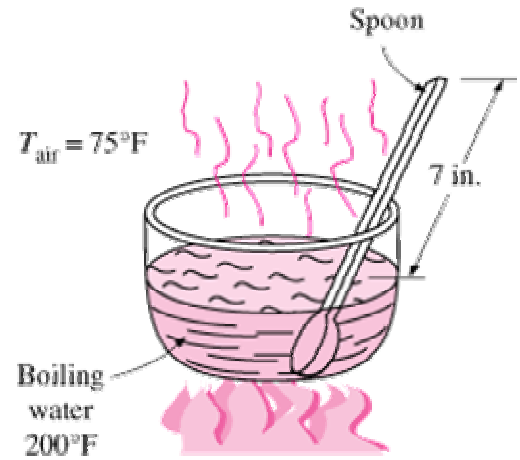


Figure P3-111

Chapter 3, Solution 111

The handle of a stainless steel spoon partially immersed in boiling water extends 7 in. in the air from the free surface of the water. The temperature difference across the exposed surface of the spoon handle is to be determined.

Assumptions 1 The temperature of the submerged portion of the spoon is equal to the water temperature. 2 The temperature in the spoon varies in the axial direction only (along the spoon), $T(x)$. 3 The heat transfer from the tip of the spoon is negligible. 4 The heat transfer coefficient is constant and uniform over the entire spoon surface. 5 The thermal properties of the spoon are constant. 6 The heat transfer coefficient accounts for the effect of radiation from the spoon.

Properties The thermal conductivity of the spoon is given to be $k = 8.7 \text{ Btu/h} \cdot \text{ft} \cdot ^\circ\text{F}$.

Analysis Noting that the cross-sectional area of the spoon is constant and measuring x from the free surface of water, the variation of temperature along the spoon can be expressed as

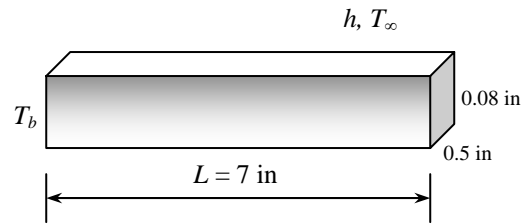
$$\frac{T(x) - T_\infty}{T_b - T_\infty} = \frac{\cosh a(L - x)}{\cosh aL}$$

where

$$p = 2(0.5/12 \text{ ft} + 0.08/12 \text{ ft}) = 0.0967 \text{ ft}$$

$$A_c = (0.5/12 \text{ ft})(0.08/12 \text{ ft}) = 0.000278 \text{ ft}^2$$

$$a = \sqrt{\frac{hp}{kA_c}} = \sqrt{\frac{(3 \text{ Btu/h} \cdot \text{ft}^2 \cdot ^\circ\text{F})(0.0967 \text{ ft})}{(8.7 \text{ Btu/h} \cdot \text{ft} \cdot ^\circ\text{F})(0.000278 \text{ ft}^2)}} = 10.95 \text{ ft}^{-1}$$



Noting that $x = L = 7/12 = 0.583 \text{ ft}$ at the tip and substituting, the tip temperature of the spoon is determined to be

$$T(L) = T_\infty + (T_b - T_\infty) \frac{\cosh a(L - L)}{\cosh aL}$$

$$= 75^\circ\text{F} + (200 - 75) \frac{\cosh 0}{\cosh(10.95 \times 0.583)} = 75^\circ\text{F} + (200 - 75) \frac{1}{296} = 75.4^\circ\text{F}$$

Therefore, the temperature difference across the exposed section of the spoon handle is

$$\Delta T = T_b - T_{\text{tip}} = (200 - 75.4)^\circ\text{F} = \mathbf{124.6^\circ\text{F}}$$

Friday, September 05, 2003
Chapter 3, Problem 116.

A hot surface at 100°C is to be cooled by attaching 3-cm-long, 0.25-cm-diameter aluminum pin fins ($k = 237 \text{ W/m} \cdot ^{\circ}\text{C}$) to it, with a center-to-center distance of 0.6 cm. The temperature of the surrounding medium is 30°C , and the heat transfer coefficient on the surfaces is $35 \text{ W/m}^2 \cdot ^{\circ}\text{C}$. Determine the rate of heat transfer from the surface for a $1\text{-m} \times 1\text{-m}$ section of the plate. Also determine the overall effectiveness of the fins.

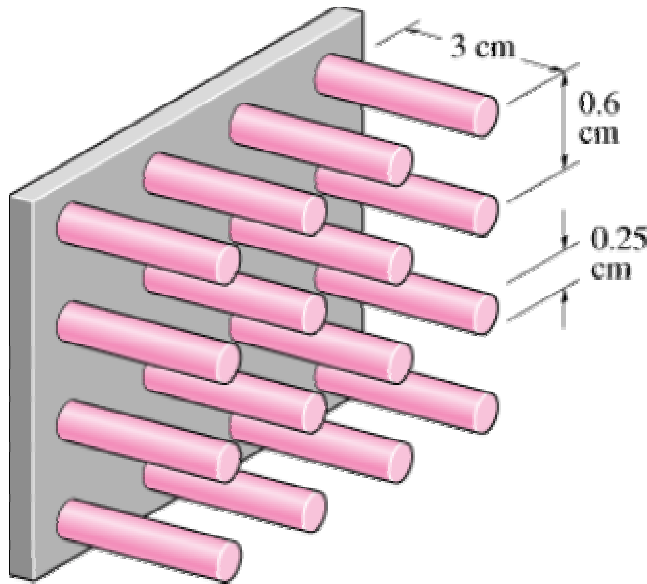


Figure P3-116

Chapter 3, Solution 116

A hot plate is to be cooled by attaching aluminum pin fins on one side. The rate of heat transfer from the 1 m by 1 m section of the plate and the effectiveness of the fins are to be determined.

Assumptions 1 Steady operating conditions exist. 2 The temperature along the fins varies in one direction only (normal to the plate). 3 Heat transfer from the fin tips is negligible. 4 The heat transfer coefficient is constant and uniform over the entire fin surface. 5 The thermal properties of the fins are constant. 6 The heat transfer coefficient accounts for the effect of radiation from the fins.

Properties The thermal conductivity of the aluminum plate and fins is given to be $k = 237 \text{ W/m} \cdot ^{\circ}\text{C}$.

Analysis Noting that the cross-sectional areas of the fins are constant, the efficiency of the circular fins can be determined to be

Friday, September 05, 2003

$$a = \sqrt{\frac{hp}{kA_c}} = \sqrt{\frac{h\pi D}{k\pi D^2/4}} = \sqrt{\frac{4h}{kD}} = \sqrt{\frac{4(35 \text{ W/m}^2 \cdot \text{°C})}{(237 \text{ W/m} \cdot \text{°C})(0.0025 \text{ m})}} = 15.37 \text{ m}^{-1}$$

$$\eta_{\text{fin}} = \frac{\tanh aL}{aL} = \frac{\tanh(15.37 \text{ m}^{-1} \times 0.03 \text{ m})}{15.37 \text{ m}^{-1} \times 0.03 \text{ m}} = 0.935$$

The number of fins, finned and unfinned surface areas, and heat transfer rates from those areas are

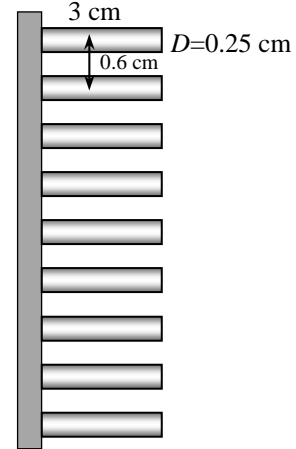
$$n = \frac{1 \text{ m}^2}{(0.006 \text{ m})(0.006 \text{ m})} = 27,777$$

$$A_{\text{fin}} = 27777 \left[\pi DL + \frac{\pi D^2}{4} \right] = 27777 \left[\pi(0.0025)(0.03) + \frac{\pi(0.0025)^2}{4} \right] = 6.68 \text{ m}^2$$

$$A_{\text{unfinned}} = 1 - 27777 \left(\frac{\pi D^2}{4} \right) = 1 - 27777 \left[\frac{\pi(0.0025)^2}{4} \right] = 0.86 \text{ m}^2$$

$$\begin{aligned} \dot{Q}_{\text{finned}} &= \eta_{\text{fin}} \dot{Q}_{\text{fin,max}} = \eta_{\text{fin}} h A_{\text{fin}} (T_b - T_\infty) \\ &= 0.935(35 \text{ W/m}^2 \cdot \text{°C})(6.68 \text{ m}^2)(100 - 30)^\circ\text{C} \\ &= 15,300 \text{ W} \end{aligned}$$

$$\begin{aligned} \dot{Q}_{\text{unfinned}} &= h A_{\text{unfinned}} (T_b - T_\infty) = (35 \text{ W/m}^2 \cdot \text{°C})(0.86 \text{ m}^2)(100 - 30)^\circ\text{C} \\ &= 2107 \text{ W} \end{aligned}$$



Then the total heat transfer from the finned plate becomes

$$\dot{Q}_{\text{total,fin}} = \dot{Q}_{\text{finned}} + \dot{Q}_{\text{unfinned}} = 15,300 + 2107 = 1.74 \times 10^4 \text{ W} = \mathbf{17.4 \text{ kW}}$$

The rate of heat transfer if there were no fin attached to the plate would be

$$A_{\text{no fin}} = (1 \text{ m})(1 \text{ m}) = 1 \text{ m}^2$$

$$\dot{Q}_{\text{no fin}} = h A_{\text{no fin}} (T_b - T_\infty) = (35 \text{ W/m}^2 \cdot \text{°C})(1 \text{ m}^2)(100 - 30)^\circ\text{C} = 2450 \text{ W}$$

Then the fin effectiveness becomes

$$\varepsilon_{\text{fin}} = \frac{\dot{Q}_{\text{fin}}}{\dot{Q}_{\text{no fin}}} = \frac{17,400}{2450} = \mathbf{7.10}$$