8-16 A 15-cm-diameter brass ball [$k = 111$ W/(m · °C), $\rho = 8520$ kg/m^3, $C_p = 0.38$ kJ/(kg · °C)] is observed to cool from 130°C to an average temperature of 70°C in 20 min in atmospheric air at 30°C. Determine (*a*) the total amount of heat transferred from the copper ball, (*b*) the average rate of heat transfer from the ball, (*c*) the average heat flux, and (*d*) the convection heat transfer coefficient at the beginning of the cooling process.

8-17 Consider steady heat transfer between two large parallel plates at constant temperatures of $T_1 = 290$ K and $T_2 = 150$ K that are $L = 2$ cm apart. Assuming the surfaces to be black (emissivity $\varepsilon = 1$), determine the rate of heat transfer between the plates per unit surface area, if the gap between the plates is (*a*) filled with atmospheric air, (*b*) evacuated, (*c*) filled with fiber glass insulation, and (*d*) filled with superinsulation that has an apparent thermal conductivity of 0.00015 W/(m · °C).

8-18 A logic chip used in a computer dissipates 3 W of power in an environment at 60°C, and has a heat transfer surface area of 0.34 cm^2. Assuming the heat transfer from the surface to be uniform, determine (*a*) the amount of heat this chip dissipates during an eight-hour work day, in kWh, and (*b*) the heat flux on the surface of the chip, in W/m^2.

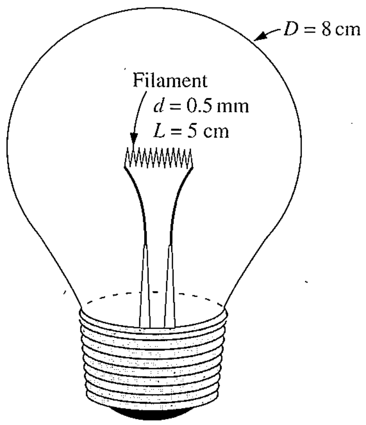

FIGURE P8-19

8-19 Consider a 150-W incandescent lamp. The filament of the lamp is 5 cm long and has a diameter of 0.5 mm. The diameter of the glass bulb of the lamp is 8 cm. Determine the heat flux, in W/m^2, (*a*) on the surface of the filament and (*b*) on the surface of the glass bulb, and (*c*) calculate how much it will cost per year to keep that light on for eight hours a day every day if the price of electricity is \$0.08/kWh.

8-20 A 35-cm-diameter watermelon is to be cooled from 25°C to 10°C in a refrigerator. Previous observations indicate that heat is removed from the watermelon at an average rate 200 kJ/h. Using the properties of water for the watermelon, determine (*a*) the average heat flux on the surface of the watermelon, in W/m^2, and (*b*) how long it will take to cool the watermelon. *Answers:* (*a*) 144 W/m^2, (*b*) 7 h

8-20E A 15-in-diameter watermelon is to be cooled from 75°F to 50°F in a refrigerator. Previous observations indicate that heat is removed from the watermelon at an average rate 200 Btu/h. Using the properties of water for the watermelon, determine (*a*) the average heat flux on the surface of the watermelon, in Btu/(h · ft^2), and (*b*) how long it will take to cool the watermelon. *Answers:* (*a*) 40.8 Btu/(h · ft^2), (*b*) 7.9 h

8-21 A 1200-W iron is left on the ironing board with its base exposed to the air. About 90 percent of the heat generated in the iron is dissipated through its base whose surface area is 150 cm^2, and the remaining 10 percent through other surfaces. Assuming the heat transfer from the surface to be uniform, determine (*a*) the amount of heat the iron dissipates during a two-hour period, in kWh, (*b*) the heat flux on the surface of the iron base, in W/m^2, and (*c*) the cost of electricity consumed during this two-hour period for an electricity price of \$0.07/kWh.

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thermal diffusivities are placed in a hot oven. Compare the heat conduction processes through each ball.

8-35 In a certain experiment cylindrical samples of diameter 4 cm and length 7 cm are used. The two thermocouples in each sample are placed 3 cm apart. After initial transients the electric heater is observed to draw 0.6 A at 110 V, and both differential thermometers read a temperature difference of 10°C. Determine the thermal conductivity of the sample.

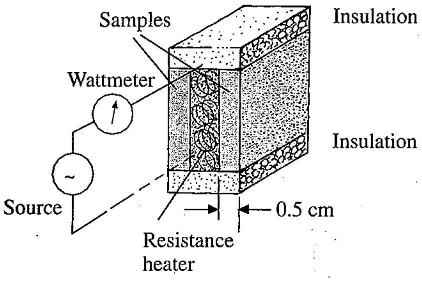

FIGURE P8-36

8-36 One way of measuring the thermal conductivity of a material is to sandwich an electric thermofoil heater between two identical rectangular samples of the material and to heavily insulate the four outer edges, as shown in Fig. P8-36. Thermocouples attached to the inner and outer surfaces of the samples record the temperature.

During an experiment, two 0.5-cm-thick samples 10 cm × 10 cm in size are used. When steady operation is reached, the heater is observed to draw 35 W of electric power, and the temperature of each sample is observed to drop from 82°C at the inner surface to 74°C at the outer surface. Determine the thermal conductivity of the material at the average temperature.

8-37 Repeat Prob. 8-36 for an electric power consumption of 20 W.

8-38 A heat flux meter attached to the inner surface of a 3-cm-thick refrigerator door indicates a heat flux of 25 W/m^2 through the door. Also, the temperatures of the inner and the outer surfaces of the door are measured to be 7°C and 15°C, respectively. Determine the average thermal conductivity of the refrigerator door.
Answer: 0.0938 W/(m · °C)

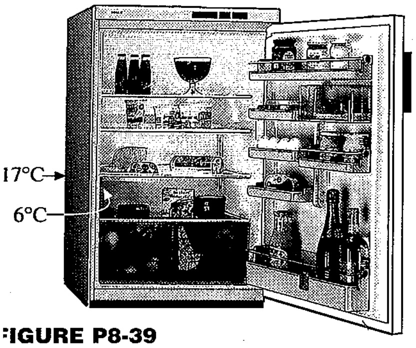

FIGURE P8-39

8-39 Consider a refrigerator whose dimensions are 1.8 m × 1.2 m × 0.8 m and whose walls are 3 cm thick. The refrigerator consumes 600 W of power when operating, and has a COP of 2.5. It is observed that the motor of the refrigerator remains on for 5 min and then off for 15 min periodically. If the average temperatures at the inner and outer surfaces of the refrigerator are 6°C and 17°C, respectively, determine the average thermal conductivity of the refrigerator walls. Also determine the annual cost of operating this refrigerator if the price of electricity is $0.06/kWh.

8-39E Consider a refrigerator whose dimensions are 6 ft × 4 ft × 3 ft and whose walls are 1 in. thick. The refrigerator consumes 600 W of power when operating, and has a COP of 2.5. It is observed that the motor of the refrigerator remains on for 5 min and then off for 15 min periodically. If the average temperatures at the inner and outer surfaces of the refrigerator are 50°F and 65°F, respectively, determine the average thermal conductivity of the refrigerator walls. Also determine the annual cost of operating this refrigerator if the price of electricity is $0.06/kWh.

Steady Heat Conduction in Plane Walls

8-40C Consider one-dimensional heat conduction through a cylindrical rod of diameter D and length L. What is the heat transfer area of the rod

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8-54C Consider steady heat transfer through an outer wall of a room in winter. The convection heat transfer coefficient at the outer surface of the wall is three times that of the inner surface as a result of the winds. On which surface of the wall do you think the temperature will be closer to the surrounding air temperature? Explain.

8-55C The bottom of a pan is made of a 4-mm-thick aluminum layer. In order to increase the rate of heat transfer through the bottom of the pan, someone proposes a design for the bottom which consists of a 3-mm-thick copper layer sandwiched between two 2-mm-thick aluminum layers. Will the new design conduct heat better? Explain. Assume perfect contact between the layers.

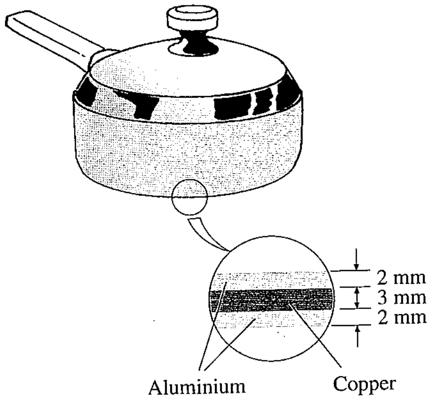


FIGURE P8-55C

8-56C Will the thermal contact resistance be greater for smooth or rough surfaces?

8-57 Consider a 4-m-high, 6-m-wide, and 0.3-m-thick brick wall whose thermal conductivity is $k = 0.8 \text{ W/(m} \cdot \text{°C)}$. On a certain day, the temperatures of the inner and the outer surfaces of the wall are measured to be 14°C and 6°C, respectively. Determine the rate of heat loss through the wall on that day.

8-58 Consider a 1.2-m-high and 2-m-wide glass window whose thickness is 6 mm and which has a thermal conductivity of $k = 0.78 \text{ W/(m} \cdot \text{°C)}$. Determine the steady rate of heat transfer through this glass window and the temperature of its inner surface for a day during which the room is maintained at 24°C while the temperature of the outdoors is −5°C. Take the convection heat transfer coefficients on the inner and outer surfaces of the window to be $h_1 = 10 \text{ W/(m}^2 \cdot \text{°C)}$ and $h_2 = 25 \text{ W/(m}^2 \cdot \text{°C)}$, and disregard any heat transfer by radiation.

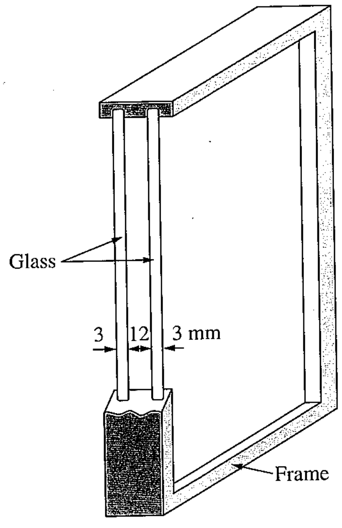


FIGURE P8-59

8-59 Consider a 1.2-m-high and 2-m-wide double-pane window consisting of two 3-mm-thick layers of glass [$k = 0.78 \text{ W/(m} \cdot \text{°C)}$] separated by a 12-mm-wide stagnant air space [$k = 0.026 \text{ W/(m} \cdot \text{°C)}$]. Determine the steady rate of heat transfer through this double-paned window and the temperature of its inner surface for a day during which the room is maintained at 24°C while the temperature of the outdoors is −5°C. Take the convection heat transfer coefficients on the inner and outer surfaces of the window to be $h_1 = 10 \text{ W/(m}^2 \cdot \text{°C)}$ and $h_2 = 25 \text{ W/(m}^2 \cdot \text{°C)}$, and disregard any heat transfer by radiation. *Answers:* 113 W, 19.2°C

8-60 Repeat Prob. 8-59, assuming the space between the two glass layers is evacuated.

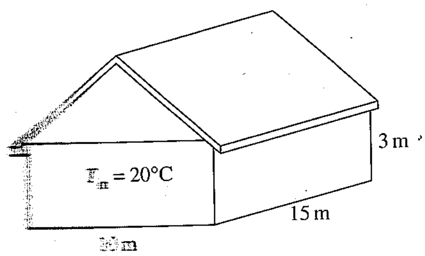


FIGURE P8-61

8-61 Consider an electrically heated brick house [$k = 0.69 \text{ W/(m} \cdot \text{°C)}$] whose walls are 3 m high and 0.3 m thick. Two of the walls of the house are 15 m long and the other two are 10 m long. The house is maintained at 20°C at all times, while the temperature of the outdoors varies. On a certain day, the temperature of the inner surface of the walls is measured to be at 14°C, while the average temperature of the outer surface is observed to remain at 10°C during the day for 10 h and at 6°C at night for 14 h. Determine the amount of heat lost from the house that day. Also determine the cost of that heat loss to the homeowner for an electricity price of \$0.075/kWh. *Answers:* 52.4 kWh, \$3.93

8-61E Consider an electrically heated brick house (k = 0.40 Btu/(h · ft · °F)] whose walls are 9 ft high and 1 ft thick. Two of the walls of the house are 40 ft long and the other two are 30 ft long. The house is maintained at 70°F at all times, while the temperature of the outdoors varies. On a certain day, the temperature of the inner surface of the walls is measured to be at 55°F, while the average temperature of the outer surface is observed to remain at 45°F during the say for 10 h and at 35°F at night for 14 h. Determine the amount of heat lost from the house that day. Also determine the cost of that heat loss to the homeowner for an electricity price of \$0.075/kWh.

8-62 A cyclindrical resistor element on a circuit board dissipates 0.15 W of power in an environment at 40°C. The resistor is 1.2 cm long and has a diameter of 0.3 cm. Assuming heat to be transferred uniformly from all surfaces, determine (*a*) the amount of heat this resistor dissipates during a 24-h period, (*b*) the heat flux on the surface of the resistor, in W/m^2, and (*c*) the surface temperature of the resistor for a combined convection and radiation heat transfer coefficient of 9 W/(m^2 · °C).

8-63 Consider a power transistor which dissipates 0.2 W of power in an in environment at 30°C. The transistor is 0.4 cm long, and has a diameter of 0.5 cm. Assuming heat to be transferred uniformly from all surfaces, determine (*a*) the amount of heat this resistor dissipates during a 24-h period, in kWh, (*b*) the heat flux on the surface of the transistor, in W/m^2, and (*c*) the surface temperature of the resistor for a combined convection and radiation heat transfer coefficient of 12 W/(m^2 · °C).

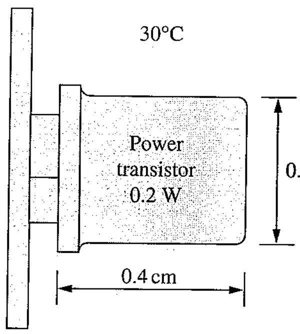


FIGURE P8-

8-64 A 12 cm × 18 cm circuit board houses 100 closely spaced logic chips, each dissipating 0.07 W, on its surface. The heat transfer from the back surface of the board is negligible. If the heat transfer coefficient on the surface of the board is 10 W/(m^2 · °C), determine (*a*) the heat flux on the surface of the circuit board, in W/m^2, (*b*) the surface temperature of the chips, and (*c*) the thermal resistance between the surface of the circuit board and the cooling medium, in °C/W.

8-65 Consider a naked person standing in a room at 20°C with an exposed surface area of 1.7 m^2. The deep body temperature of the human body is 37°C, and the thermal conductivity of the human tissue near the skin is about 0.3 W/(m · °C). The body is losing heat at a rate of 150 W by natural convection and radiation to the surroundings. Taking the body temperature 0.5 cm beneath the skin to be 37°C, determine the skin temperature of the person. *Answer:* 35.5°C

8-66 Water is boiling in a 25-cm-diameter aluminum pan [k = 237 W/(m · °C)] at 95°C. Heat is transferred steadily to the boiling water in the pan through its 0.5 cm thick flat bottom at a rate of 600 W. If the

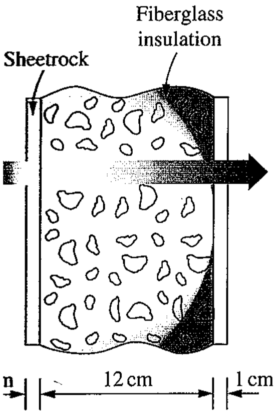


FIGURE P8-67

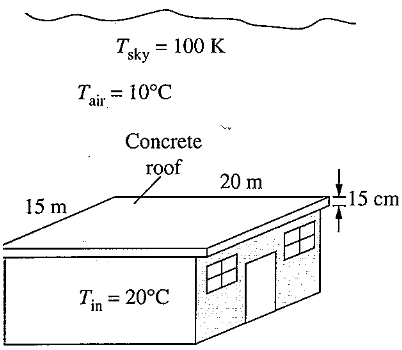


FIGURE P8-68

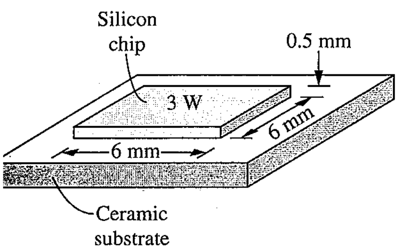


FIGURE P8-69

inner surface temperature of the bottom of the pan is 108°C, determine (*a*) the boiling heat transfer coefficient on the inner surface of the pan and (*b*) the outer surface temperature of the bottom of the pan.

8-67 A wall is constructed of two layers of 1-cm-thick sheetrock [k = 0.17 W/(m · °C)], which is a plasterboard made of two layers of heavy paper separated by a layer of gypsum, placed 12 cm apart. The space between the sheetrocks is filled with fiberglass insulation [k = 0.035 W/(m · °C)]. Determine (*a*) the thermal resistance of the wall and (*b*) its R-value of insulation in SI units.

8-67E A wall is constructed of two layers of 0.5-in.-thick sheetrock [k = 0.10 Btu/(h · ft · °F)], which is a plasterboard made of two layers of heavy paper separated by a layer of gypsum, placed 5 in. apart. The space between the sheetrocks is filled with fiberglass insulation [k = 0.020 Btu/(h · ft · °F)]. Determine (*a*) the thermal resistance of the wall and (*b*) its R-value of insulation in English units.

8-68 The roof of a house consists of 15-cm-thick concrete slab (k = 2 W/(m · °C)] that is 15 m wide and 20 m long. The convection heat transfer coefficients on the inner and outer surfaces of the roof are 5 and 12 W/(m^2 · °C), respectively. On a clear winter night, the ambient air is reported to be at 10°C, while the night sky temperature is 100 K. The house and the interior surfaces of the wall are maintained at a constant temperature of 20°C. The emissivity of both surfaces of the concrete roof is 0.9. Considering both radiation and convection heat transfers, determine the rate of heat transfer through the roof, and the inner surface temperature of the roof.

If the house is heated by a furnace burning natural gas with an efficiency of 80%, and the price of natural gas is $0.60/therm (1 therm = 105,500 kJ of energy content), determine the money lost through the roof that night during a 14-h period. *Answers:* 37,440 W, 7.3°C, $12.6

8-69 The heat generated in the circuitry on the surface of a silicon chip [k = 130 W/(m · °C)] is conducted to the ceramic substrate to which it is attached. The chip is 6 mm × 6 mm in size and 0.5 mm thick, and dissipates 3 W of power. Determine the temperature difference between the front and back surfaces of the chip in steady operation.

8-69E The heat generated in the circuitry on the surface of a silicon chip [k = 75 Btu/(h · ft · °F)] is conducted to the ceramic substrate to which it is attached. The chip is 0.25 in. × 0.25 in. in size and 0.02 in. thick, and dissipates 3 W of power. Determine the temperature difference between the front and back surfaces of the chip in steady operation.

8-70 A 2 m × 1.5 m section wall of an industrial furnace burning natural gas is not insulated, and the temperature at the outer surface of this section is measured to be 80°C. The temperature of the furnace room is 30°C, and the combined convection and radiation heat transfer coefficient at the surface of the outer furnace is 10 W/(m^2 · C). It is proposed to insulate this section of the furnace wall with glass wool insulation

[$k = 0.038$ W/(m · °C)] in order to reduce the heat loss by 90 percent. Assuming the outer surface temperature of the metal section still remains at about 80°C, determine the thickness of the insulation which needs to be used.

The furnace operates continuously, and has an efficiency of 78%. The price of the natural gas is \$0.55/therm (1 therm = 105,500 kJ of energy content). If the installation of the insulation will cost \$250 for materials and labor, determine how long it will take for the insulation to pay for itself from the energy it saves.

8-71 Consider a house whose walls are 4 m high and 12 m long. Two of the walls of the house have no windows, while each of the other two walls have four windows made of a 0.6-cm-thick glass [$k = 0.78$ W/(m · °C)], 1.2 m × 2 m in size. The walls are certified to have an R-value of 3.38 m² · °C/W. Disregarding any direct radiation gain or loss through the windows and taking the heat transfer coefficients at the inner and outer surfaces of the house to be 10 and 20 W/(m² · °C), respectively, determine the ratio of the heat transfer through the walls with and without windows. *Answer:* 6.24

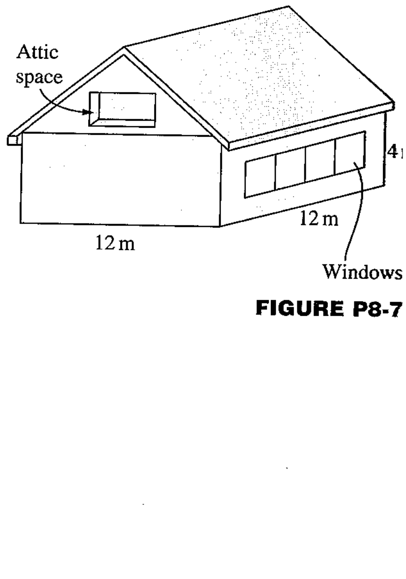


FIGURE P8-7

8-71E Consider a house whose walls are 12 ft high and 40 ft long. Two of the walls of the house have no windows, while each of the other two walls have four windows made of 0.25-in-thick glass [$k = 0.45$ Btu/(h · ft · °F)], 3 ft × 5 ft in size. The walls are certified to have an R-value of 19 (i.e., an L/k value of 19 h · ft² · °F/Btu). Disregarding any direct radiation gain or loss through the windows and taking the heat transfer coefficients at the inner and outer surfaces of the house to be 2 and 4 Btu/(h · ft² · °F), respectively, determine the ratio of the heat transfer through the walls with and without windows.

8-72 Consider a house that has a 10 m × 20 m base and a 4-m-high walls. All four walls of the house have an R-value of 2.31 m² · °C/W. The two 10 m × 4 m walls have no windows. The third wall has five windows made of 0.5-cm-thick glass [$k = 0.78$ W/(m · °C)], 1.2 m × 1.8 m in size. The fourth wall has the same size and number of windows, but they are double-paned with a 1.5-cm-thick stagnant air space [$k = 0.026$ W/(m · °C)] enclosed between two 0.5-cm-thick glass layers. The thermostat in the house is set at 22°C and the average temperature outside at that location is 5°C during the seven-month-long heating season. Disregarding any direct radiation gain or loss through the windows and taking the heat transfer coefficients at the inner and outer surfaces of the house to be 7 and 15 W/(m² · °C), respectively, determine the average rate of heat transfer through each wall.

If the house is electrically heated and the price of electricity is given to be \$0.09/kWh, determine the amount of money this household will save per heating season by converting the single pane windows to double pane windows.

8-73 The wall of a refrigerator is constructed of fiberglass insulation [$k = 0.035$ W/(m · °C)] sandwiched between two layers of 1-mm-thick

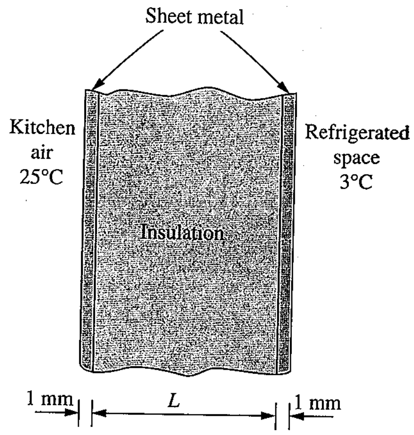


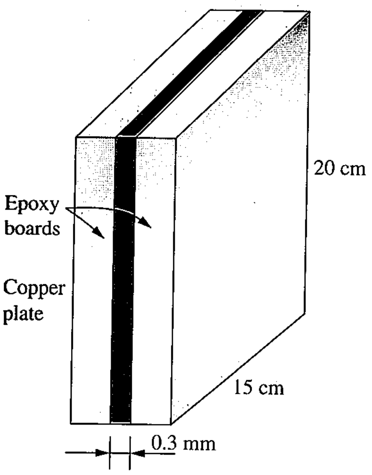
FIGURE P8-73

sheet metal [k = 15.1 W/(m · °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 W/(m² · °C) and 9 W/(m² · °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.

8-74 Repeat Prob. 8-73 for a condensation temperature of 15°C on the outer surfaces of the refrigerator when the kitchen temperature is 19°C.

8-75 Heat is to be conducted along a circuit board that has a copper layer on one side. The circuit board is 15 cm long and 15 cm wide, and the thicknesses of the copper and epoxy layers are 0.1 mm and 1.2 mm, respectively. Disregarding heat transfer from side surfaces, determine the percentages of heat conduction along the copper [k = 386 W/(m · °C)] and epoxy [k = 0.26 W/(m · °C)] layers. Also determine the effective thermal conductivity of the board.
Answers: 0.8%, 99.2%, and 29.9 W/(m · °C)

8-76 A 0.3-mm-thick copper plate [k = 386 W/(m · °C)] is sandwiched between two 4-mm-thick epoxy boards [k = 0.26 W/(m · °C)] that are 15 cm × 20 cm in size. Determine the effective thermal conductivity of the board along its 20-cm-long side. What fraction of the heat transferred along that side is conducted through copper?



IGURE P8-76

8-76E A 0.03-in.-thick copper plate [k = 223 Btu/(h · ft · °F)] is sandwiched between two 0.1-in.-thick epoxy boards [k = 0.15 Btu/(h · ft · °F)] that are 7 in. × 9 in. in size. Determine the effective thermal conductivity of the board along its 9-in.-long side. What fraction of the heat transferred along that side is conducted through copper?

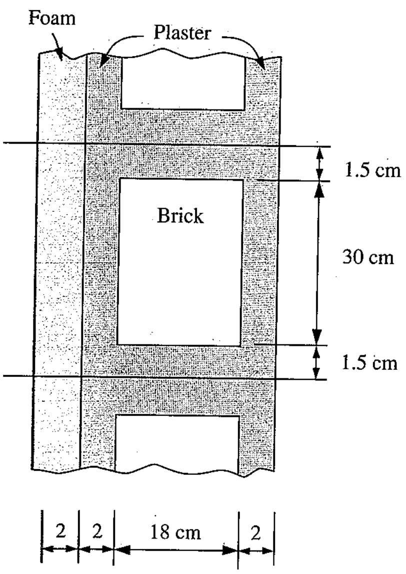
Generalized Thermal Resistance Networks

8-77C When plotting the thermal resistance network associated with a heat transfer problem, explain when two resistances are taken to be in series and when they are in parallel.

8-78C The thermal resistance networks can also be used approximately for multidimensional problems. For what kind of multidimensional problems will the thermal resistance approach give adequate results?

8-79C What are the two approaches used in the development of the thermal resistance network for two-dimensional problems?

8-80 A 4-m-high and 6-m-wide wall consists of long 18 cm × 30 cm cross-section horizontal bricks [k = 0.72 W/(m · °C)] separated by 3-cm-thick plaster layers [k = 0.22 W/(m · °C)]. There are also 2-cm-thick plaster layers on each side of the wall, and a 2-cm-thick rigid foam (k = 0.026 W/(m · °C)] on the inner side of the wall. The indoor and the



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outdoor temperatures are 22°C and −4°C, and the convection heat transfer coefficients on the inner and the outer sides are $h_1 = 10\ \text{W/(m}^2 \cdot °\text{C)}$ and $h_2 = 20\ \text{W/(m}^2 \cdot °\text{C)}$, respectively. Assuming one-dimensional heat transfer and disregarding radiation, determine the rate of heat transfer through the wall.

8-81 A 10-cm-thick wall is to be constructed with 2.5-m-long wood studs [$k = 0.11$ W/(m · °C)] that have a cross-section of 10 cm × 10 cm. At some point, the builder has run out of those studs, and started using pairs of 2.5-m-long wood studs that have a cross-section of 5 cm × 10 cm nailed to each other instead. The manganese steel nails [$k = 50$ W/(m · °C)] are 10 cm long, and have a diameter of 0.4 cm. A total of 50 nails are used to connect the two studs, which are mounted to the wall such that the nails cross the wall. The temperature difference between the inner and outer surfaces of the wall is 15°C. Assuming the thermal contact resistance between the two layers to be negligible, determine the rate of heat transfer (*a*) through a solid stud and (*b*) through a stud pair of equal length and width nailed to each other. (*c*) Also determine the effective conductivity of the nailed stud pair.

8-82 A 12-m-long and 5-m-high wall is constructed of two layers of 1-cm-thick sheetrock [$k = 0.17$ W/(m · °C)] spaced 12 cm by wood studs [$k = 0.11$ W/(m · °C)] whose cross-section is 12 cm × 5 cm. The studs are placed vertically 60 cm apart, and the space between them is filled with fiberglass insulation [$k = 0.034$ W/(m · °C)]. The house is maintained at 20°C and the ambient temperature outside is −5°C. Taking the heat transfer coefficients at the inner and outer surfaces of the house to be 8.3 and 34 W/(m² · 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.

8-83 A 22-cm-thick, 10-m-long, and 3.5-m-high wall is to be constructed using 20-cm-long solid bricks [$k = 0.7$ W/(m · °C)] of cross-section 16 cm × 16 cm, or identical size bricks with nine square air holes [$k = 0.026$ W/(m · °C)] that are 20 cm long and have a cross-section of 4 cm × 4 cm, as shown in Fig. P8-83. There is a 1-cm-thick plaster layer [$k = 0.22$ W/(m · °C)] between two adjacent bricks on all four sides, and on both sides of the wall. The house is maintained at 24°C and the ambient temperature outside is 2°C. Taking the heat transfer coefficients at the inner and outer surfaces of the wall to be 8 and 24 W/(m² · °C), respectively, determine the rate of heat transfer through the wall constructed of (*a*) solid bricks and (*b*) bricks with air holes.
Answers: (*a*) 1326 W, (*b*) 840 W

8-83E A 10-in.-thick, 30-ft-long, and a 10-ft-high wall is to be constructed using 9-in.-long solid bricks [$k = 0.40$ Btu/(h · ft · °F)] of cross-section 7 in. × 7 in., or identical size bricks with nine square air holes [$k = 0.015$ Btu/(h · ft · °F)] that are 9 in. long and have a cross-section of 1.5 in. × 1.5 in. There is a 0.5-in.-thick plaster layer [$k = 0.10$ Btu/(h · ft · °F)] between two adjacent bricks on all four sides, and on both

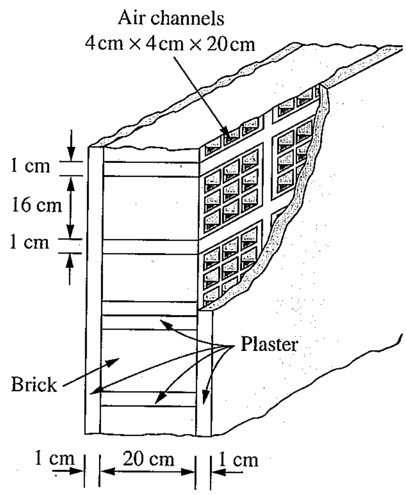


FIGURE P8-83

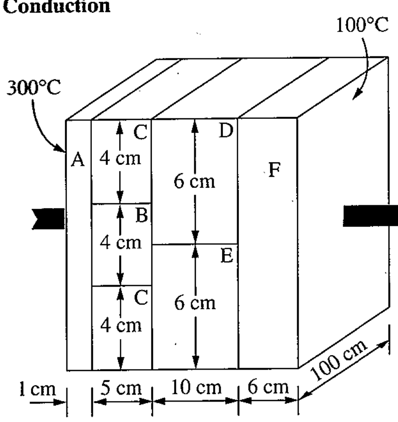


FIGURE P8-84

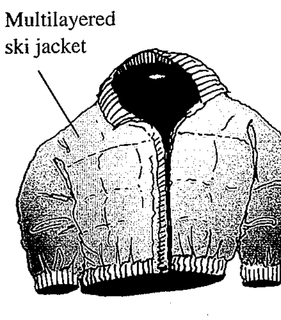


FIGURE P8-86

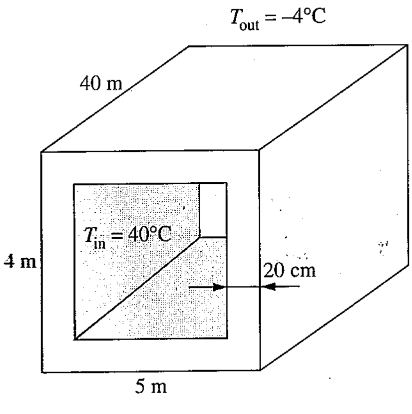


FIGURE P8-88

sides of the wall. The house is maintained at 75°F and the ambient temperature outside is 35°F. Taking the heat transfer coefficients at the inner and outer surfaces of the wall to be 1.5 and 4 Btu/(h · ft² · °F), respectively, determine the rate of heat transfer through the wall constructed of (*a*) solid bricks and (*b*) bricks with air holes.

8-84 Consider a 5-m-high, 8-m-long, and 0.22-m-thick wall whose representative cross-section is as given in Fig. P8-84. The thermal conductivities of various materials used, in W/(m · °C), are $k_A = k_F = 2$, $k_B = 8$, $k_C = 20$, $k_D = 15$, and $k_E = 35$. The left and right surfaces of the wall are maintained at uniform temperatures of 300°C and 100°C, respectively. Assuming heat transfer through the wall to be one-dimensional, determine (*a*) the rate of heat transfer through the wall, (*b*) the temperature at the point where the sections B, D, and E meet, and (*c*) the temperature drop across the section F. Disregard any contact resistances at the interfaces.

8-85 Repeat Prob. 8-84 assuming that the thermal contact resistance at the interfaces D–F and E–F is 0.00012 m² · °C/W.

8-86 Clothing made of several thin layers of fabric with trapped air in between, often called ski clothing, is commonly used in cold climates because it is light, fashionable, and a very effective thermal insulator. So it is no surprise that such clothing has largely replaced thick and heavy old-fashioned coats.

Consider coat made of five layers of 0.1-mm-thick synthetic fabric [$k = 0.13$ W/(m · °C)] with 1.5-mm-thick air space [$k = 0.026$ W/(m · °C)] between the layers. Assuming the inner surface temperature of the jacket to be 28°C and the surface area to be 1.1 m², determine the rate of heat loss through the jacket when the temperature of the outdoors is −5°C and the heat transfer coefficient at the outer surface is 25 W/(m² · °C).

What would your response be if the jacket were made of a single layer of 0.5-mm-thick synthetic fabric? What should the thickness of a wool fabric [$k = 0.035$ W/(m · °C)] be if the person is to achieve the same level of thermal comfort wearing a thick wool coat instead of a ski jacket?

8-87 Repeat Prob. 8-86 assuming that the layers of the jacket are made of cotton fabric [$k = 0.06$ W/(m · °C)].

8-88 A 5-m-wide, 4-m-high, and 40-m-long kiln used to cure concrete pipes is made of 20-cm-thick concrete walls and ceiling [$k = 0.9$ W/(m · °C)]. The kiln is maintained at 40°C by injecting hot steam into it. The two ends of the kiln, 4 × 5 m in size, are made of a 3-mm-thick sheet metal covered with 2-cm-thick styrofoam [$k = 0.033$ W/(m · °C)]. The convection heat transfer coefficients on the inner and the outer surfaces of the kiln are 3000 W/(m² · °C) and 25 W/(m² · °C), respectively. Disregarding any heat loss through the floor, determine the rate of heat loss from the kiln when the ambient air is at −4°C.

8-89 Consider a 15 cm × 18 cm epoxy glass laminate [k = 0.26 W/(m · °C)] whose thickness is 1.4 mm. In order to reduce the thermal resistance across its thickness, cylindrical copper fillings [k = 386 W/(m · °C)] of 1 mm diameter are to be planted throughout the board, with a center-to-center distance of 3 mm. Determine the new value of the thermal resistance of the epoxy board for heat conduction across its thickness as a result of this modification.
Answer: 0.00153 °C/W

8-89E Consider a 6 in. × 8 in. epoxy glass laminate [k = 0.10 Btu/(h · ft · °F)] whose thickness is 0.05 in. In order to reduce the thermal resistance across its thickness, cylindrical copper fillings [k = 223 Btu/(h · ft · °F)] of 0.02 in diameter are to be planted throughout the board, with a center-to-center distance of 0.06 in. Determine the new value of the thermal resistance of the epoxy board for heat conduction across its thickness as a result of this modification.
Answer: 0.00065 h · °F/Btu

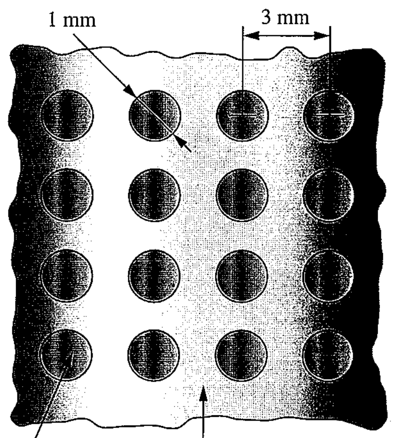


FIGURE P8-89

Heat Conduction in Cylinders and Spheres

8-90C Consider one-dimensional heat conduction through a plane wall, a long cylinder, and a sphere. For which of these geometries is the heat transfer area constant, and for which of them is variable? Explain.

8-91C What is an infinitely long cylinder? When is it proper to treat an actual cylinder as being infinitely long, and when is it not?

8-92C Consider a short cylinder whose top and bottom surfaces are insulated. The cylinder is initially at a uniform temperature T_i, and is subjected to convection from its side surface to a medium at temperature T_∞, with a heat transfer coefficient of h. Is the heat transfer in this short cylinder one- or two-dimensional? Explain.

8-93C Can the thermal resistance concept be used for a solid cylinder or sphere in steady operation? Explain.

8-94 A 5-m internal diameter spherical tank made of 1.5-cm-thick stainless steel [k = 15 W/(m · °C)] is used to store iced water at 0°C. The tank is located in a room whose temperature is 20°C. The walls of the room are also at 20°C. The outer surface of the tank is black (emissivity ε = 1), and heat transfer between the outer surface of the tank and the surroundings is by natural convection and radiation. The convection heat transfer coefficients at the inner and the outer surfaces of the tank are 80 W/(m² · °C) and 10 W/(m² · °C), respectively. Determine (*a*) the rate of heat transfer to the iced water in the tank and (*b*) the amount of ice at 0°C that melts during a 24-h period. The heat of fusion of water at atmospheric pressure is h_{if} = 333.7 kJ/kg.

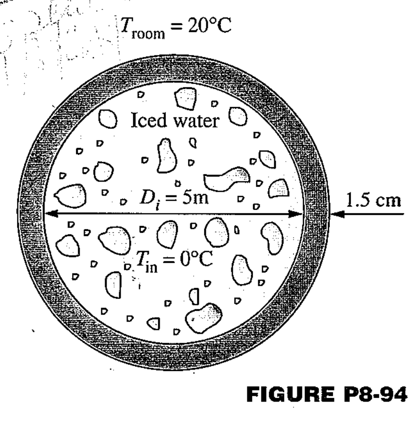


FIGURE P8-94

8-95 Steam at 320°C flows in a stainless steel pipe [k = 15 W/(m · °C)] whose inner and outer diameters are 5 cm and 5.5 cm, respectively. The pipe is covered with 3-cm-thick glass wool insulation [k = 0.038 W/(m · °C)]. Heat is lost to the surroundings at 5°C by natural

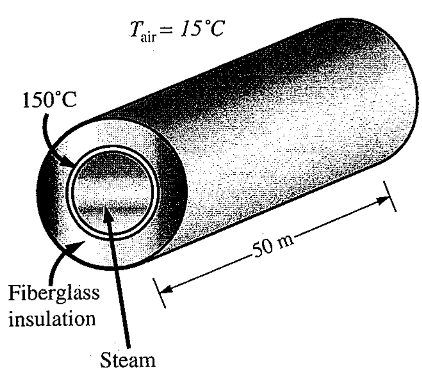


FIGURE P8-96

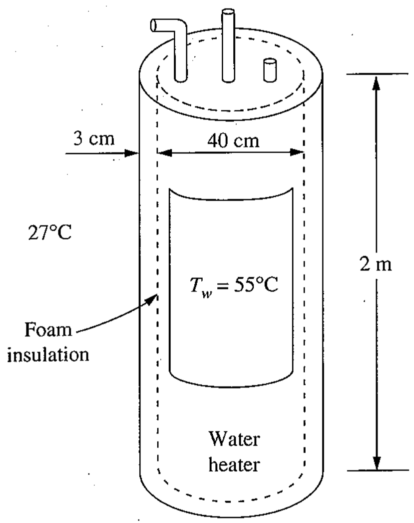


FIGURE P8-97

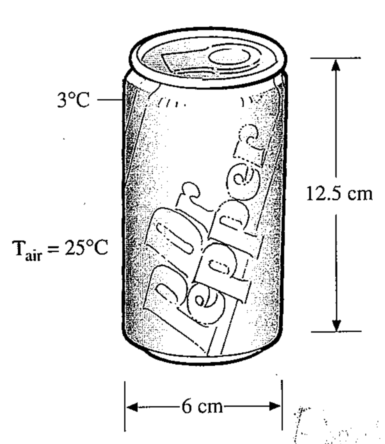


FIGURE P8-98

convection and radiation, with a combined natural convection and radiation heat transfer coefficient of $15\ \mathrm{W/(m^2 \cdot C)}$. Taking the heat transfer coefficient inside the pipe to be $80\ \mathrm{W/(m^2 \cdot °C)}$, determine the rate of heat loss from the steam per unit length of the pipe. Also determine the temperature drops across the pipe shell and the insulation.

8-96 A 50-m-long section of a steam pipe whose outer diameter is 10 cm passes through an open space at 15°C. The average temperature of the outer surface of the pipe is measured to be 150°C. If the combined heat transfer coefficient on the outer surface of the pipe is $20\ \mathrm{W/(m^2 \cdot °C)}$, determine (*a*) the rate of heat loss from the steam pipe, (*b*) the annual cost of this energy lost if steam is generated in a natural gas furnace that has an efficiency of 75 percent, and the price of natural gas is \$0.52/therm (1 therm = 105,500 kJ), and (*c*) the thickness of fiberglass insulation [$k = 0.035\ \mathrm{W/(m \cdot °C)}$] needed in order to save 90 percent of the heat lost. Assume the pipe temperature to remain constant at 150°C.

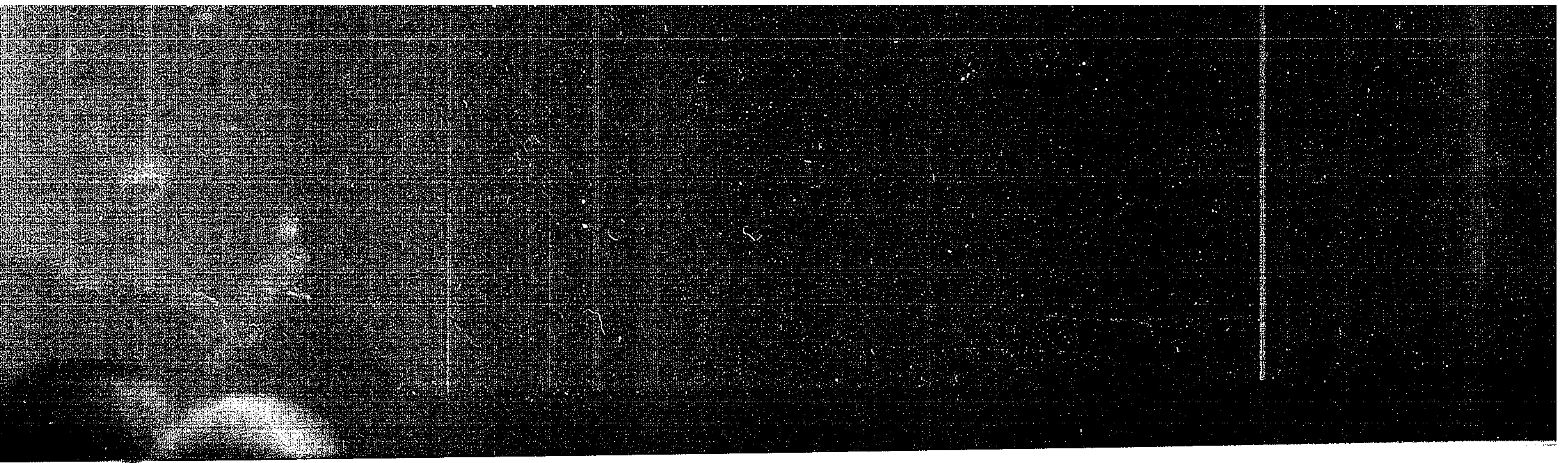
8-96E A 150-ft-long section of a steam pipe whose outer diameter is 4 in. passes through an open space at 60°F. The average temperature of the outer surface of the pipe is measured to be 300°F. If the combined heat transfer coefficient on the outer surface of the pipe is $3.5\ \mathrm{Btu/(h \cdot ft^2 \cdot °F)}$, determine (*a*) the rate of heat loss from the steam pipe, (*b*) the annual cost of this energy lost if steam is generated in a natural gas furnace that has an efficiency of 75 percent, and the price of natural gas is \$0.52/therm (1 therm = 100,000 Btu), and (*c*) the thickness of fiberglass insulation [$k = 0.020\ \mathrm{Btu/(h \cdot ft \cdot °F)}$] needed in order to save 90 percent of the heat lost. Assume the pipe temperature to remain constant at 300°F.

8-97 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 $12\ \mathrm{W/(m^2 \cdot °C)}$, 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 [$k = 0.03\ \mathrm{W/(m \cdot °C)}$]. 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 homeowner 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.

Hot water tank insulation kits consisting of 3-cm-thick fiber glass insulation [$k = 0.035\ \mathrm{W/(m \cdot °C)}$] 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 homeowner himself, how long will it take for this additional insulation to pay for itself?

Answers: 17.5 percent, 1.5 year

8-98 Consider an aluminum cold drink can that is initially at a uniform temperature of 3°C. The can is 12.5 cm high and has a diameter of 6 cm.



If the combined convection/radiation heat transfer coefficient between the can and the surrounding air at 25°C is 10 W/(m^2 · C), determine how long it will take for the average temperature of the drink to rise to 10°C.

In an effort to slow down the warming of the cold drink a person puts the can in a perfectly fitting 1-cm-thick cylindrical rubber insulation [k = 0.13 W/(m · °C)]. Now how long will it take for the average temperature of the drink to rise to 10°C? Assume the top of the can is not covered.

8-99 Repeat Prob. 8-98, assuming a thermal contact resistance of 0.00008 m^2 · °C/W between the can and the insulation.

8-100 Steam at 300°C is flowing through a steel pipe [k = 15.1 W/(m · °C)] whose inner and outer diameters are 8 and 8.8 cm, respectively, in an environment at 15°C. The pipe is insulated with 3-cm-thick fiberglass insulation [k = 0.035 W/(m · °C)]. If the heat transfer coefficients on the inside and the outside of the pipe are 150 and 25 W/(m^2 · °C), respectively, determine the rate of heat loss from the steam per meter length of the pipe. What is the error involved in neglecting the thermal resistance of the steel pipe in calculations?

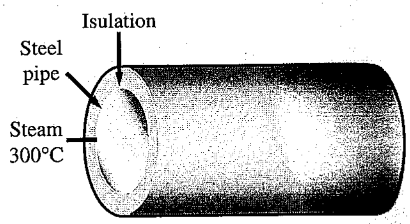


FIGURE P8-100

8-100E Steam at 600°F is flowing through a steel pipe [k = 8.7 Btu/(h · ft · °F)] whose inner and outer diameters are 3.5 and 4.0 in., respectively, in an environment at 60°F. The pipe is insulated with 2-in.-thick fiberglass insulation [k = 0.020 Btu/(h · ft · °F)]. If the heat transfer coefficients on the inside and the outside of the pipe are 30 and 5 Btu/(h · ft^2 · °F), respectively, determine the rate of heat loss from the steam per foot length of the pipe. What is the error involved in neglecting the thermal resistance of the steel pipe in calculations?

8-101 Hot water at an average temperature of 90°C is flowing through a 15-m section of a cast iron pipe [k = 52 W/(m · °C)] whose inner and outer diameters are 4 and 4.6 cm, respectively. The outer surface of the pipe, whose emissivity is 0.7, is exposed to the cold air at 10°C in the basement, with a heat transfer coefficient of 15 W/(m^2 · °C). The heat transfer coefficient at the inner surface of the pipe is 120 W/(m^2 · °C). Taking the walls of the basement to be 10°C also, determine the rate of heat loss from the hot water. Also determine the average velocity of the water in the pipe if the temperature of the water drops by 3°C as it passes through the basement.

8-102 Repeat Prob. 8-101 for a pipe made of copper [k = 386 W/(m · °C)] instead of cast iron.

X **8-103** Steam exiting the turbine of a steam power plant at 35°C is to be condensed in a large condenser by cooling water flowing through copper pipes [k = 386 W/(m · °C)] of inner diameter 1 cm and outer diameter 1.4 cm at an average temperature of 20°C. The heat of vaporization of water at 35°C is 2419 kJ/kg. The heat transfer coefficients are 8000 W/(m^2 · °C) on the steam side and 160 W/(m^2 · °C) on the water side. Determine the length of the tube required to condense steam at a rate of 200 kg/h. *Answer:* 1773 m

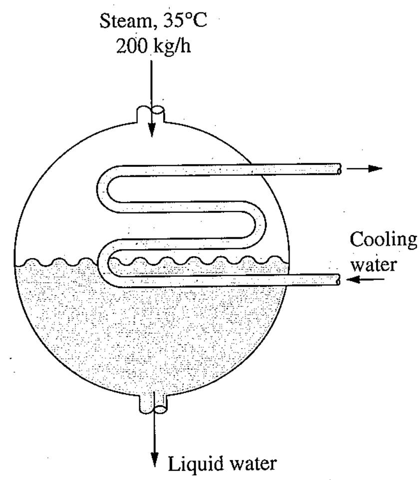


FIGURE P8-103

10-15C What does the friction coefficient represent in flow over a flat plate? How is it related to the drag force acting on the plate?

10-16C For flow over a flat plate, how does the flow in the thermal boundary layer differ than the flow outside the thermal boundary layer?

10-17C Consider laminar flow over a flat plate. Will the friction coefficient change with position? How about the heat transfer coefficient?

10-18C How are the average friction and heat transfer coefficients determined in flow over a flat plate?

10-19 Engine oil at 80°C flows over a 6-m-long flat plate whose temperature is 30°C with a velocity of 3 m/s. Determine the total drag force and the rate of heat transfer over the entire plate per unit width.

10-20 The local atmospheric pressure in Denver, Colorado (elevation 1610 m) is 83.4 kPa. Air at this pressure and 30°C flows with a velocity of 6 m/s over a 2.5 m × 8 m flat plate whose temperature is 120°C. Determine the rate of heat transfer from the plate if the air flows parallel to the (*a*) 8-m-long side and (*b*) the 2.5-m side.

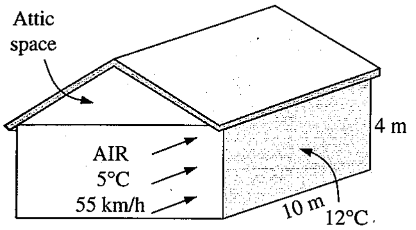


FIGURE P10-21

10-21 During a cold winter day, wind at 55 km/h is blowing parallel to a 4-m-high and 10-m-long wall of a house. If the air outside is at 5°C and the surface temperature of the wall is 12°C, determine the rate of heat loss from that wall by convection. What would your answer be if the wind velocity has doubled? *Answers:* 9212 W, 16,408 W

10-21E During a cold winter day, wind at 40 mph is blowing parallel to a 12-ft-high and 30-ft-long wall of a house. If the air outside is at 40°F and the surface temperature of the wall is 55°F, determine the rate of heat loss from that wall by convection. What would your answer be if the wind velocity has doubled? *Answers:* 36,018 Btu/h, 64,152 Btu/h

10-22 Air at 17°C flows over a 3-m-long flat plate at 2 m/s. Determine the local friction and heat transfer coefficients at intervals of 25 cm, and plot the results against the distance from the leading edge.

10-22E Air at 65°F flows over a 10-ft-long flat plate at 7 ft/s. Determine the local friction and heat transfer coefficients at intervals of 1 ft, and plot the results against the distance from the leading edge.

10-23 Consider a hot automotive engine, which can be approximated as a 0.5-m-high, 0.40-m-wide, and 0.8-m-long rectangular block. The bottom surface of the block is at a temperature of 80°C and has an emissivity of 0.95. The ambient air is at 30°C, and the road surface is at 25°C. Determine the rate of heat transfer from the bottom surface of the engine block by convection and radiation as the car travels at a velocity of 80 km/h. Assume the flow to be turbulent over the entire surface because of the constant agitation of the engine block.

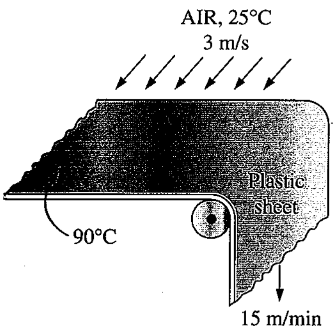


FIGURE P10-24

10-24 The forming section of a plastics plant puts out a continuous sheet of plastic that is 1.2 m wide and 2 mm thick at a rate of 15 m/min. The

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temperature of the plastic sheet is 90°C when it is exposed to the surrounding air, and the sheet is subjected to air flow at 25°C at a velocity of 3 m/s on both sides along its surfaces normal to the direction of motion of the sheet. The width of the air cooling section is such that a fixed point on the plastic sheet passes through that section in 2 s. Determine the rate of heat transfer from the plastic sheet to the air and the drag force the air exerts on the plastic sheet in the direction of air flow.

10-25 The top surface of the passenger car of a train moving at a velocity of 70 km/h is 2.8 m wide and 8 m long. The top surface is absorbing solar radiation at a rate of 200 W/m^2, and the temperature of the ambient air is 30°C. Assuming the roof of the car to be perfectly insulated and the radiation heat exchange with the surroundings to be small relative to convection, determine the equilibrium temperature of the top surface of the car. *Answer:* 35°C

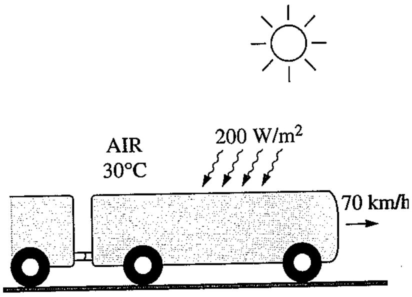

FIGURE P10-25

10-25E The top surface of the passenger car of a train moving at a velocity of 60 mph is 9 ft wide and 25 ft long. The top surface is absorbing solar radiation at a rate of 70 Btu/(h · ft^2), and the temperature of the ambient air is 80°F. Assuming the roof of the car to be perfectly insulated and the radiation heat exchange with the surroundings to be small relative to convection, determine the equilibrium temperature of the top surface of the car. *Answer:* 87.6°F

10-26 A 15 cm × 15 cm circuit board dissipating 15 W of power uniformly is cooled by air, which approaches the circuit board at 50°C with a velocity of 5 m/s. Disregarding any heat transfer from the back surface of the board, determine the surface temperature of the electronic components (*a*) at the leading edge and (*b*) at the end of the board. Assume the flow to be turbulent, since the electronic components are expected to act as turbulators.

10-27 The weight of a thin flat plate 50 cm × 50 cm in size is balanced by a counterweight that has a mass of 2 kg, as shown in Fig. P10-27. Now a fan is turned on, and air at 25°C flows downwards over both surfaces of the plate with a free-stream velocity of 10 m/s. Determine the mass of the counterweight that needs to be added in order to balance the plate in this case. Also determine the initial rate of heat transfer to the plate if the plate was initially at a uniform temperature of 10°C.

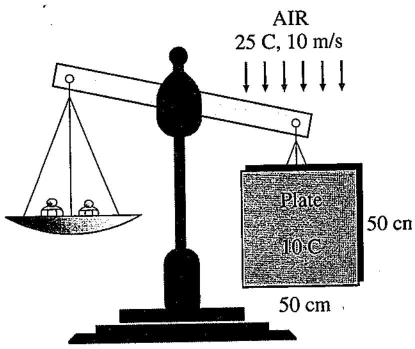

FIGURE P10-2

10-28 Consider laminar flow of a fluid over a flat plate maintained at a constant temperature. Now the free-stream velocity of the fluid is doubled. Determine the change in the drag force on the plate and the rate of heat transfer between the fluid and the plate. Assume the flow to remain laminar.

10-29 Consider a refrigeration truck traveling at 85 km/h at a location where the air temperature is 30°C. The refrigerated compartment of the truck can be considered to be a 2.6-m-wide, 2.4-m-high, and 7-m-long rectangular box. The refrigeration system of the truck can provide 3 tons of refrigeration (i.e., it can remove heat at a rate of 633 kJ/min). The

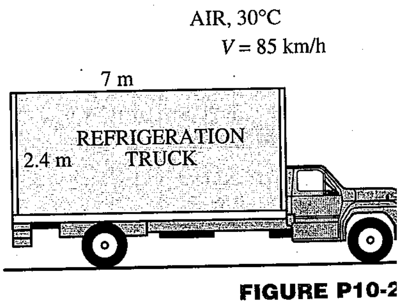

FIGURE P10-2

outer surface of the truck is coated with a low-emissivity material, and thus radiation heat transfer is very small. Determine the average temperature of the outer surface of the refrigeration compartment of the truck if the refrigeration system is observed to be operating at half the capacity. Assume the air flow over the entire outer surface to be turbulent, and the heat transfer coefficient at the front and rear surfaces to be equal to that on side surfaces.

10-29E Consider a refrigeration truck traveling at 55 mph at a location where the air temperature is 80°F. The refrigerated compartment of the truck can be considered to be a 9-ft-wide, 8-ft-high, and 20-ft-long rectangular box. The refrigeration system of the truck can provide 3 tons of refrigeration (i.e., it can remove heat at a rate of 600 Btu/min). The outer surface of the truck is coated with a low-emissivity material, and thus radiation heat transfer is very small. Determine the average temperature of the outer surface of the refrigeration compartment of the truck if the refrigeration system is observed to be operating at half the capacity. Assume the air flow over the entire outer surface to be turbulent, and the heat transfer coefficient at the front and rear surfaces to be equal to that on side surfaces.

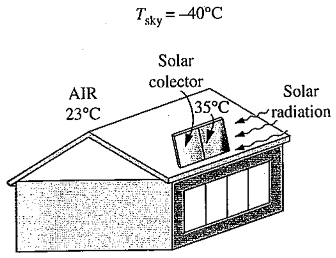

FIGURE P10-30

10-30 Solar radiation is incident on the glass cover of a solar collector at a rate of 700 W/m². The glass transmits 88 percent of the incident radiation, and has an emissivity of 0.90. The entire hot water needs of a family in summer can be met by two collectors 1.2 m high and 1 m wide. The two collectors are attached to each other on one side so that they appear like a single collector 1.2 m × 2 m in size. The temperature of the glass cover is measured to be 35°C on a day when the surrounding air temperature is 23°C and the wind is blowing at 30 km/h. The effective sky temperature for radiation exchange between the glass cover and the open sky is −40°C. Water enters the tubes attached to the absorber plate at a rate of 1 kg/min. Assuming the backsurface of the absorber plate to be heavily insulated and the only heat loss occurs through the glass cover, determine (*a*) the total rate of heat loss from the collector, (*b*) the collector efficiency, which is the ratio of the amount of heat transferred to the water to the solar energy incident on the collector, and (*c*) the temperature rise of water as it flows through the collector.
Answers: (*a*) 1262 W, (*b*) 0.15, (*c*) 3.1°C

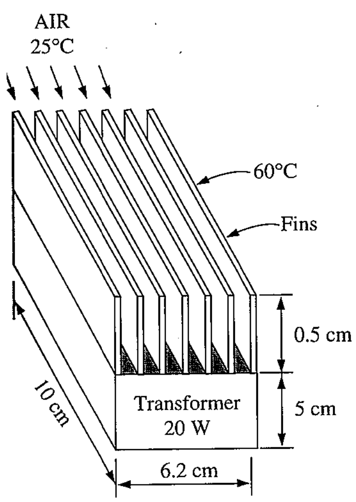

FIGURE P10-31

10-31 A transformer that is 10 cm long, 6.2 cm wide, and 5 cm high is to be cooled by attaching a 10 cm × 6.2 cm wide polished aluminum heat sink (emissivity = 0.03) to its top surface. The heat sink has seven fins, which are 5 mm high, 2 mm thick, and 10 cm long. A fan blows air at 25°C parallel to the passages between the fins. The heat sink is to dissipate 20 W of heat and the base temperature of the heat sink is not to exceed 60°C. Assuming the fins and the base plate to be nearly isothermal and the radiation heat transfer to be negligible, determine the minimum free-stream velocity the fan needs to supply to avoid overheating.

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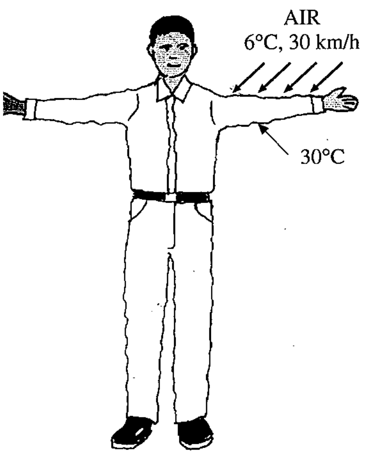
10-40C Which car is more likely to be more fuel-efficient: the one with sharp corners, or the one that is contoured to resemble an ellipse? Why?

10-41C Consider laminar flow of air across a hot circular cylinder. At what point on the cylinder will the heat transfer be highest? What would your answer be if the flow were turbulent?

10-42 A long 8-cm-diameter steam pipe whose external surface temperature is 90°C passes through some open area that is not protected against the winds. Determine the rate of heat loss from the pipe per unit of its length when the air is at 1 atm pressure and 7°C and the wind is blowing across the pipe at a velocity of 50 km/h.

10-43 A stainless steel ball [ρ = 8055 kg/m^3, C_p = 480 J/(kg · °C)] of diameter D = 15 cm is removed from the oven at a uniform temperature of 350°C. The ball is then subjected to the flow of air at 1-atm pressure and 30°C with a velocity of 6 m/s. The surface temperature of the ball eventually drops to 250°C. Determine the average convection heat transfer coefficient during this cooling process, and estimate how long this process has taken.



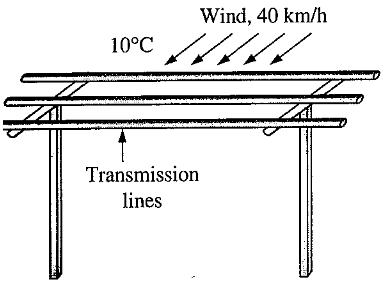
IGURE P10-44

10-44 A person extends his uncovered arms into the windy air outside at 6°C and 30 km/h in order to feel nature closely. Initially, the skin temperature of the arm is 30°C. Treating the arm as a 60-cm-long and 7.5-cm-diameter cylinder, determine the rate of heat loss from the arm.

10-44E A person extends his uncovered arms into the windy air outside at 40°F and 20 mph in order to feel nature closely. Initially, the skin temperature of the arm is 86°F. Treating the arm as a 2-ft-long and 3-in-diameter cylinder, determine the rate of heat loss from the arm.

10-45 An average person generates heat at a rate of 84 W while resting. Assuming one-quarter of this heat is lost from the head and disregarding radiation, determine the average surface temperature of the head when it is not covered and is subjected to winds at 10°C and 35 km/h. The head can be approximated as a 30-cm-diameter sphere. *Answer:* 12.7°C

10-46 Consider the flow of a fluid across a cylinder maintained at a constant temperature. Now the free-stream velocity of the fluid is doubled. Determine the change in the drag force on the cylinder and the rate of heat transfer between the fluid and the cylinder.



IGURE P10-47

10-47 A 6-mm-diameter electrical transmission line carries an electric current of 50 A and has a resistance of 0.002 ohm per meter length. Determine the surface temperature of the wire during a windy day when the air temperature is 10°C and the wind is blowing across the transmission line at 40 km/h. Also determine the drag force exerted on the wire by the wind.

10-47E A 0.25-in-diameter electrical transmission line carries an electric current of 50 A and has a resistance of 0.001 ohm per ft length. Determine the surface temperature of the wire during a windy day when the air

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temperature is 50°F and the wind is blowing across the transmission line at 30 mph. Also determine the drag force exerted on the wire by the wind.

10-48 A heating system is to be designed to keep the wings of an aircraft cruising at a velocity of 900 km/h above freezing temperatures during flight at 12,200-m altitude where the standard atmospheric conditions are −55.4°C and 18.8 kPa. Approximating the wing as a cylinder of elliptical cross-section whose minor axis is 30 cm and disregarding radiation, determine the average convection heat transfer coefficient on the wing surface and the average rate of heat transfer per unit surface area.

10-49 A long aluminum wire of diameter 3 mm is extruded at a temperature of 350°C. The wire is subjected to cross air flow at 35°C at a velocity of 6 m/s. Determine the rate of heat transfer from the wire to the air per meter length when it is first exposed to the air.

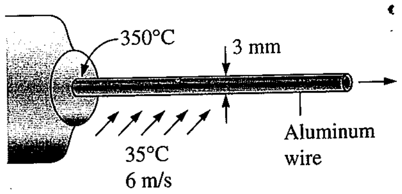

FIGURE P10-49

10-50 Consider a person who is trying to keep cool in a hot summer day by turning a fan on and exposing his entire body to air flow. The air temperature is 30°C and the fan is blowing air at a velocity of 2 m/s. If the person is doing light work and generating sensible heat at a rate of 100 W, determine the average temperature of the outer surface (skin or clothing) of the person. The average human body can be treated as a 30-cm-diameter cylinder with an exposed surface area of 1.7 m². Disregard any heat transfer by radiation. What would your answer be if the air velocity were doubled? *Answers:* 33.8°C, 32.2°C

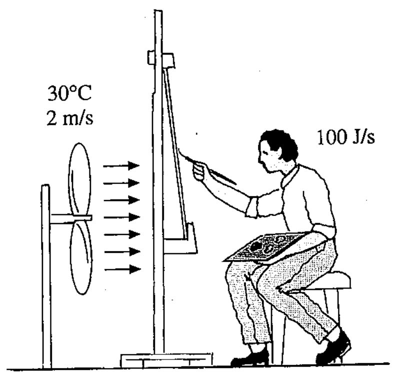

FIGURE P10-50

10-50E Consider a person who is trying to keep cool in a hot summer day by turning a fan on and exposing his entire body to air flow. The air temperature is 85°F and the fan is blowing air at a velocity of 6 ft/s. If the person is doing light work and generating sensible heat at a rate of 300 Btu/h, determine the average temperature of the outer surface (skin or clothing) of the person. The average human body can be treated as a 1-ft-diameter cylinder with an exposed surface area of 18 ft². Disregard any heat transfer by radiation. What would your answer be if the air velocity were doubled? *Answers:* 91.7°F, 88.9°F

10-51 An incandescent light bulb is an inexpensive but a highly inefficient device which converts electrical energy into light. It converts about 10 percent of the electrical energy it consumes into light while converting the remaining 90 percent into heat. (A fluorescent light bulb will give the same amount of light while consuming only one-fourth of the electrical energy, and it will last 10 times longer than an incandescent light bulb). The glass bulb of the lamp heats up very quickly as a result of absorbing all that heat and dissipating it to the surroundings by convection and radiation.

Consider a 10-cm diameter 100-W light bulb cooled by a fan that blows air at 25°C to the bulb at a velocity of 2 m/s. The surrounding surfaces are also at 25°C, and the emissivity of the glass is 0.9. Assuming

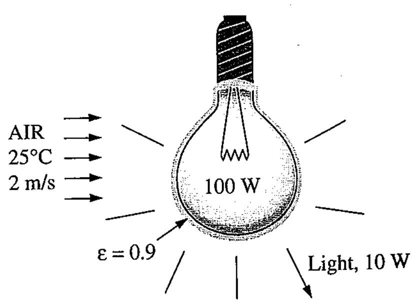

FIGURE P10-51

10 percent of the energy passes through the glass bulb as light with negligible absorption and the rest of the energy is absorbed and dissipated by the bulb itself, determine the equilibrium temperature of the glass bulb.

10-52 Consider a 3-mm-diameter raindrop at 8°C that is falling freely in atmospheric air at 20°C. Determine the terminal velocity of the raindrop, which is the velocity at which the drag force equals the weight of the drop, and the rate of heat transfer by convection as the raindrop descends at the teminal velocity. Assume there is no evaporation or condensation.

10-53 During a plant visit, it was noticed that 12-m-long section of a 10-cm-diameter steam pipe is completely exposed to the ambient air. The temperature measurements indicate that the average temperature of the outer surface of the steam pipe is 82°C when the ambient temperature is 5°C. There are also light winds in the area at 10 km/h. The emissivity of the outer surface of the pipe is 0.8, and the average temperature of the surfaces surrounding the pipe, including the sky, is estimated to be 0°C. Determine the amount of heat lost from the steam during a 10-h-long work day.

Steam is supplied by a gas-fired steam generator that has an efficiency of 80 percent, and the plant pays $0.54/therm of natural gas (1 therm = 105,500 kJ). If the pipe is insulated and 90 percent of the heat loss is saved, determine the amount of money this facility will save a year as a result of insulating the steam pipes. Assume the plant operates every day of the year for 10 h. State your assumptions.

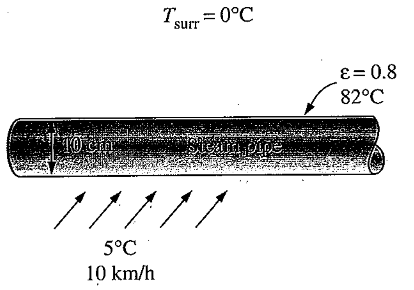

FIGURE P10-53

10-54 Reconsider Prob. 10-53. There seems to be some uncertainty about the average temperature of the surfaces surrounding the pipe used in radiation calculations, and you are asked to determine if it makes any significant difference in overall heat transfer. Repeat the calculations in Prob. 10-53 for average surrounding surface temperatures of −20°C and 25°C, and determine the change in the values obtained.

10-55 A 4-m-long 1.5-kW electrical resistance wire is made of 0.25-cm-diameter stainless steel [k = 15.1 W/(m · °C)]. The resistance wire operates in an environment at 30°C. Determine the surface temperature of the wire if it is cooled by a fan blowing air at a velocity of 7 m/s.

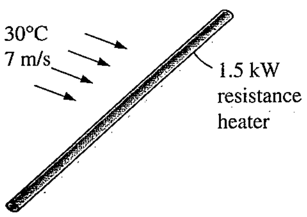

FIGURE P10-55

10-55E A 12-ft-long 1.5-kW electrical resistance wire is made of 0.1-in-diameter stainless steel [k = 8.7 Btu/(h · ft · °F)]. The resistance wire operates in an environment at 85°F. Determine the surface temperature of the wire if it is cooled by a fan blowing air at a velocity of 20 ft/s.

10-56 The components of an electronic system are located in a 1.5-m-long horizontal duct whose cross-section is 20 cm × 20 cm. The components in the duct are not allowed to come into direct contact with cooling air, and thus are cooled by air at 30°C flowing over the duct with a velocity of 200 m/min. If the surface temperature of the duct is not to exceed 65°C, determine the total power rating of the electronic devices that can be mounted into the duct. *Answer:* 643 W

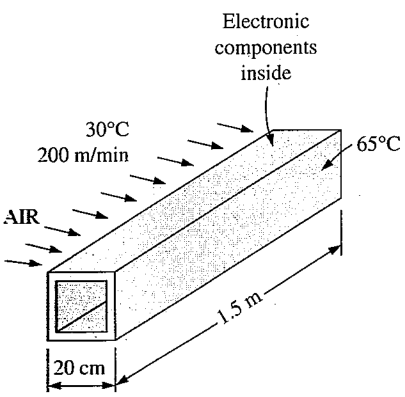

FIGURE P10-56

remains constant. What is the appropriate temperature difference for use in Newton's law of cooling with an average heat transfer coefficient?

10-68C What is the physical significance of the number of transfer units NTU = $hA/\dot{m}C_p$? What does a small and a large NTU tell the heat transfer engineer about a heat transfer system?

10-69C How is the friction factor for flow in a tube related to the pressure drop? How is the pressure drop related to the pumping power requirement for a given mass flow rate?

10-70C What does the logarithmic mean temperature difference represent for flow in a tube whose surface temperature is constant? Why do we use the logarithmic mean temperature instead of the arithmetic mean temperature?

10-71C How is the hydrodynamic entry length defined for flow in a tube? How about the thermal entry length? In what region is the flow in a tube fully developed?

10-72C Consider laminar forced convection in a circular tube. Will the friction factor be higher near the inlet of the tube or near the exit? Why? What would your response be if the flow were turbulent?

10-73C Consider laminar forced convection in a circular tube. Will the heat flux be higher near the inlet of the tube or near the exit? Why?

10-74C Consider turbulent forced convection in a circular tube. Will the heat flux be higher near the inlet of the tube or near the exit? Why?

10-75C How does surface roughness effect the pressure drop and the heat transfer in a tube if the fluid flow is turbulent? What would your response be if the flow in the tube were laminar?

10-76 Water is to be heated from 12°C to 70°C as it flows through a 2-cm internal-diameter 7-m-long tube. The tube is equipped with an electric resistance heater, which provides uniform heating throughout the surface of the tube. The outer surface of the heater is well insulated, so that in steady operation all the heat generated in the heater is transferred to the water in the tube. If the system is to provide hot water at a rate of 8 L/min, determine the power rating of the resistance heater. Also estimate the inner surface temperature of the pipe at the exit.

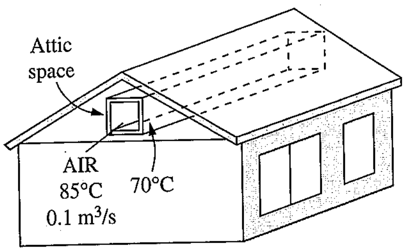

FIGURE P10-77

10-77 Hot air at atmospheric pressure and 85°C enters a 10-m-long uninsulated square duct of cross-section 0.15 m × 0.15 m that passes through the attic of a house at a rate of 0.10 m³/s. The duct is observed to be nearly isothermal at 70°C. Determine the exit temperature of the air and the rate of heat loss from the duct to the air space in the attic.
Answers: 75.6°C, 946 W

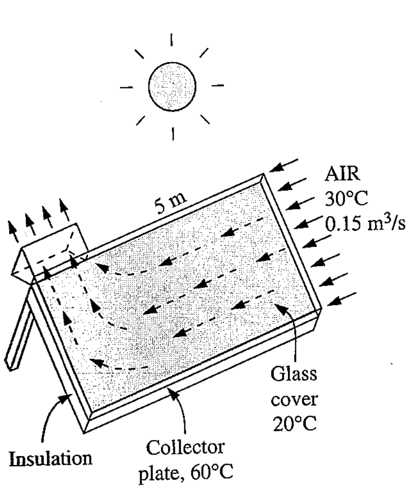

FIGURE P10-78

10-78 Consider an air solar collector that is 1 m wide and 5 m long and has a constant spacing of 3 cm between the glass cover and the collector plate. Air enters the collector at 30°C at a rate of 0.15 m³/s through the forced

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11-15C Consider laminar natural convection from a vertical hot plate. Will the heat flux be higher at the top or at the bottom of the plate? Why?

11-16 An 8-m-long section of a 6-cm-diameter horizontal hot water pipe passes through a large room whose temperture is 22°C. If the temperature and the emissivity of the outer surface of the pipe are 65°C and 0.8, respectively, determine the rate of heat loss from the pipe by (*a*) natural convection and (*b*) radiation.

11-17 Consider a wall-mounted power transistor that dissipates 0.18 W of power in an environment at 35°C. The transistor is 0.45 cm long, and has a diameter of 0.4 cm. The emissivity of the outer surface of the transistor is 0.1, and the average temperature of the surrounding surfaces is 25°C. Disregarding any heat transfer from the base surface, determine the surface temperature of the transistor. *Answer:* 60°C

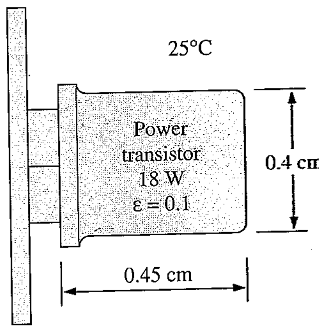

FIGURE P11-1

11-18 Consider a 0.8 m × 0.8 m thin square plate in a room at 25°C. One side of the plate is maintained at a temperature of 60°C, while the other side is insulated. Determine the rate of heat transfer from the plane by natural convection if the plate is (*a*) vertical, (*b*) horizontal with hot surface facing up, an (*c*) horizontal with hot surface facing down.

11-18E Consider a 2 ft × 2 ft thin square plate in a room at 75°F. One side of the plate is maintained at a temperature of 130°F, while the other side is insulated. Determine the rate of heat transfer from the plate by natural convection if the plate is (*a*) vertical, (*b*) horizontal with hot surface facing up, and (*c*) horizontal with hot surface facing down.

11-19 A 500-W cylindrical resistance heater is 1 m long and 0.5 cm in diameter. The resistance wire is placed horizontally in a fluid at 20°C. Determine the outer surface temperature of the resistance wire in steady operation if the fluid is (*a*) air and (*b*) water. Ignore any heat transfer by radiation. For water take $\beta = 0.000365\ K^{-1}$.

11-20 Water is boiling in a 12-cm-deep pan that has an outer diameter of 25 cm placed on top of a stove. The ambient air and the surrounding surfaces are at a temperature of 25°C, and the emissivity of the outer surface of the pan is 0.95. Assuming the entire pan to be at an average temperature of 98°C, determine the rate of heat loss from the cylindrical side surface of the pan to the surroundings by (*a*) natural convection and (*b*) radiation. (*c*) If water is boiling at a rate of 2 kg/h at 100°C, determine the ratio of the heat lost from the side surfaces of the pan to that by the evaporation of water. The heat of vaporization of water at 100°C is 2257 kJ/kg. *Answers:* 50 W, 56.1 W, 0.085

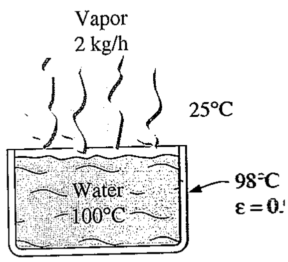

FIGURE P11-2

11-21 Repeat Prob. 11-20 for a pan whose outer surface is polished and has an emissivity of 0.1.

11-22 In a plant that manufactures canned aerosol paints, the cans are temperature-tested in water baths at 55°C before they are shipped to ensure that they will withstand temperatures up to 55°C during transportation and shelving. The cans, moving on a conveyor, enter the open hot

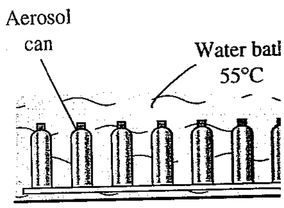

FIGURE P11-

11-43C Consider a double-pane window consisting of two glass sheets separated by a 1-cm-wide air space. Someone suggests inserting a thin vinyl sheet in the middle of the two glasses to form two 0.5-cm-wide compartments in the window in order to reduce natural convection heat transfer through the window. From heat transfer point of view, would you be in favor of this idea to reduce heat losses through the window?

11-44C What does the effective conductivity of an enclosure represent? How is the ratio of the effective conductivity to thermal conductivity related to the Nusselt number?

11-45 Show that the thermal resistance of a rectangular enclosure can be expressed as $R = \delta/(Ak\,\text{Nu})$, where k is the thermal conductivity of the fluid in the enclosure.

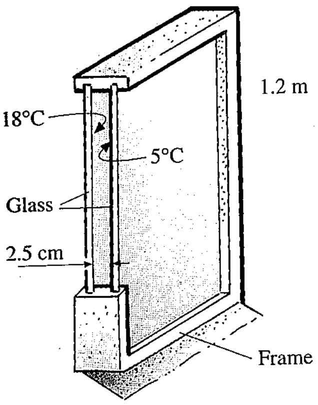

FIGURE P11-46

11-46 A vertical 1.2-m-high and 2-m-wide double-pane window consists of two sheets of glass separated by a 2.5-cm air gap at atmospheric pressure. If the glass surface temperatures across the air gap are measured to be 18°C and 5°C, determine the rate of heat transfer through the window by (*a*) natural convection and (*b*) radiation. Also determine the effective thermal conductivity of the air space of this double-paned window, which also accounts for the radiation effect. The effective emissivity for use in radiation calculations between two large parallel glass plates can be taken to be 0.82.
Answers: (*a*) 49.6 W, (*b*) 134 W, 0.147 W/(m · °C)

11-46E A vertical 4-ft-high and 6-ft-wide double-pane window consists of two sheets of glass separated by a 1-in air gap at atmospheric pressure. If the glass surface temperatures across the air gap are measured to be 65°F and 40°F, determine the rate of heat transfer through the window by (*a*) natural convection and (*b*) radiation. Also determine the *R*-value of insulation of this window such that multiplying the inverse of the *R*-value by the surface area and the temperature difference gives the total rate of heat transfer through the window. The effective emissivity for use in radiation calculations between two large parallel glass plates can be taken to be 0.82.

11-47 Two concentric spheres of diameters D_1 = 15 cm and D_2 = 25 cm are separated by air at 1-atm pressure. The surface temperatures of the two spheres enclosing the air are T_1 = 350 K and T_2 = 275 K, respectively. Determine the rate of heat transfer from the inner sphere to the outer sphere by natural convection.

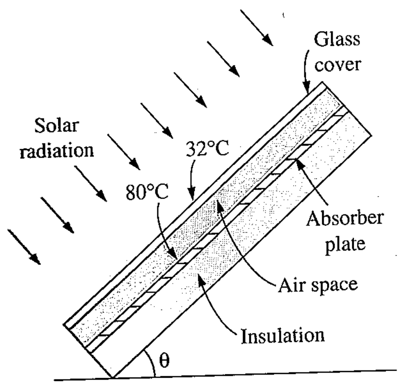

FIGURE P11-48

11-48 Flat-plate solar collectors are often tilted up towards the sun in order to intercept a greater amount of direct solar radiation. The tilt angle from the horizontal also effects the rate of heat loss from the collector. Consider a 2-m-high and 3-m-wide solar collector that is tilted at an angle θ from the horizontal. The distance between the glass cover and the absorber plate is 3 cm, and the back side of the absorber is heavily insulated. The absorber plate and the glass cover, which are spaced 2.5 cm from each other, are maintained at temperatures of 80°C

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pane is as given in Fig. P12-37. Determine the average transmissivity of this pane for solar radiation ($T \approx 5800$ K) and radiation coming from surfaces at room temperatue ($T \approx 300$ K). Also determine the amount of solar radiation transmitted through the pane for incident solar radiation of 650 W/m^2. *Answers:* 0.848, 0.00015, 551.1 W/m^2

Atmospheric and Solar Radiation

12-38C What is the solar constant? How is it used to determine the effective surface temperature of the sun? How would the value of the solar constant change if the distance between the earth and the sun doubled?

12-39C What changes would you notice if the sun emitted radiation at an effective temperature of 2000 K instead of 5762 K?

12-40C Explain why the sky is blue and the sunset is yellow-orange.

12-41C When the earth is closest to the sun, we have winter in the northern hemisphere. Explain why. Also explain why we have summer in the northern hemisphere when the earth is farthest away from the sun.

12-42C What is the effective sky temperature?

12-43C You have probably noticed warning signs on the highways stating that bridges may be icy even when the roads are not. Explain how this can happen.

12-44C Unless you live in a warm southern state, you have probably had to scratch ice from the windshield and windows of your car many mornings. You may have noticed, with frustration, that the thickest layer of ice always forms on the windshield instead of the side windows. Explain why this is the case.

12-45C Explain why surfaces usually have quite different absorptivities for solar radiation and for radiation originating from the surrounding bodies.

12-46 A surface has an absorptivity of $\alpha_s = 0.85$ for solar radiation and an emissivity of $\varepsilon = 0.5$ at room temperature. The surface temperature is observed to be 350 K when the direct and the diffuse components of solar radiation are $G_D = 350$ and $G_d = 400$ W/m^2, respectively, and the direct radiation makes a 30° angle with the normal of the surface. Taking the effective sky temperature to be 280 K, determine the net rate of radiation to the surface at that time.

12-47 Solar radiation is incident on the outer surface of a spaceship at a rate of 1320 W/m^2. The surface has an absorptivity of $\alpha_s = 0.10$ for solar radiation and an emissivity of $\varepsilon = 0.8$ at room temperature. The outer surface radiates heat into space at 0 K. If there is no net heat transfer into the spaceship, determine the equilibrium temperature of the surface.
Answer: 232.3 K

12-47E Solar radiation is incident on the outer surface of a spaceship at a rate of 400 Btu/(h · ft²). The surface has an absorptivity of $\alpha_s = 0.10$ for solar radiation and an emissivity of $\varepsilon = 0.8$ at room temperature. The outer surface radiates heat into space at 0 R. If there is no net heat transfer into the spaceship, determine the equilibrium temperature of the surface. *Answer:* 413.3 R

12-48 The air temperature on a clear night is observed to remain at about 4°C. Yet water is reported to have frozen that night. Taking the convection heat transfer coefficient to be 10 W/(m² · °C), determine the value of the effective sky temperature that night.

12-49 The absorber surface of a solar collector is made of aluminum coated with black chrome ($\alpha_s = 0.87$ and $\varepsilon = 0.09$). Solar radiation is incident on the surface at a rate of 600 W/m². The air and the effective sky temperatures are 25°C and 15°C, respectively, and the convection heat transfer coefficient is 10 W/(m² · °C). For an absorber surface temperature of 60°C, determine the net rate of solar energy delivered by the absorber plate to the water circulating behind it.

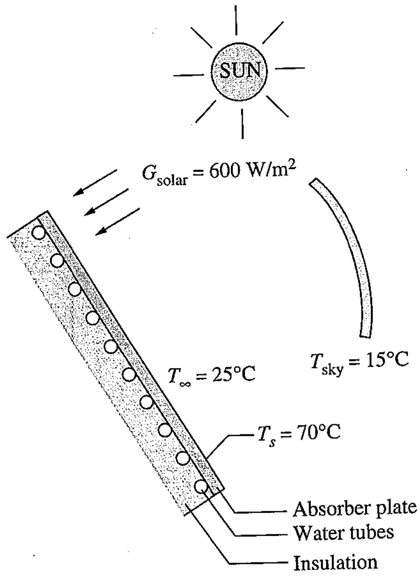


FIGURE P12-49

12-49E The absorber surface of a solar collector is made of aluminum coated with black chrome ($\alpha_s = 0.87$ and $\varepsilon = 0.09$). Solar radiation is incident on the surface at a rate of 200 Btu/(h · ft²). The air and the effective sky temperatures are 75°F and 60°F, respectively, and the convection heat transfer coefficient is 2 Btu/(h · ft² · °F). For an absorber surface temperature of 140°F, determine the net rate of solar energy delivered by the absorber plate to the water circulating behind it.

12-50 Determine the equilibrium temperature of the absorber surface in Prob. 12-49 if the back side of the absorber is insulated.

View Factors

12-51C What does the view factor represent? When is the view factor from a surface to itself not zero?

12-52C How can you determine the view factor F_{12} when the view factor F_{21} is available?

12-53C What are the summation rule and the superposition rule for view factors?

12-54C What is the crossed-strings method? For what kind of geometries is the crossed-strings method applicable?

12-55 Consider an enclosure consisting of seven surfaces. How many view factors does this geometry involve? How many of these view factors can be determined by the application of the reciprocity and the summation rules?

12-56 Consider an enclosure consisting of five surfaces. How many view factors does this geometry involve? How many of these view factors can be determined by the application of the reciprocity and summation rules?

12-57 Consider an enclosure consisting of 12 surfaces. How many view factors does this geometry involve? How many of these view factors can be determined by the application of the reciprocity and the summation rules? *Answers:* 144, 78

12-58 Determine the view factors F_{13} and F_{23} between the rectangular surfaces shown in Fig. P12-58.

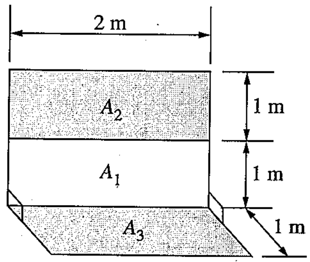


FIGURE P12-58

12-59 Consider a cylindrical enclosure whose height is twice the diameter of its base. Determine the view factor from the side surface of this cylindrical enclosure to its base surface.

12-60 Consider a hemispherical furnace with a flat circular base of diameter D. Determine the view factor from the dome of this furnace to its base. *Answer:* 0.5

12-61 Determine the view factors F_{12} and F_{21} for the very long ducts shown in Fig. P12-61 without using any view factor tables or charts. Neglect end effects.

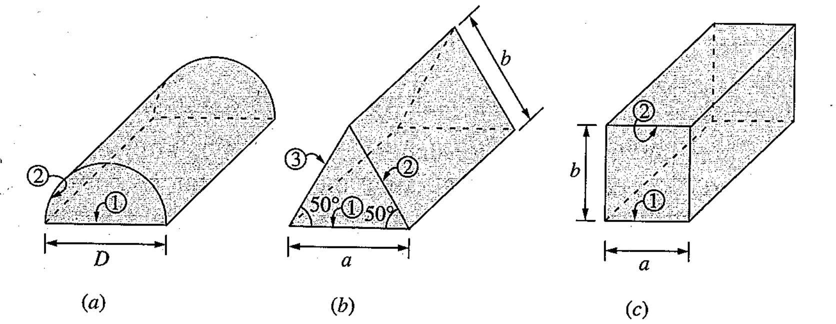


FIGURE P12-61
(*a*) Semicylindrical duct.
(*b*) Triangular duct.
(*c*) Rectangular duct.

12-62 Determine the view factors from the very long grooves shown in Fig. P12-62 to the surroundings without using any view factor tables or charts. Neglect end effects.

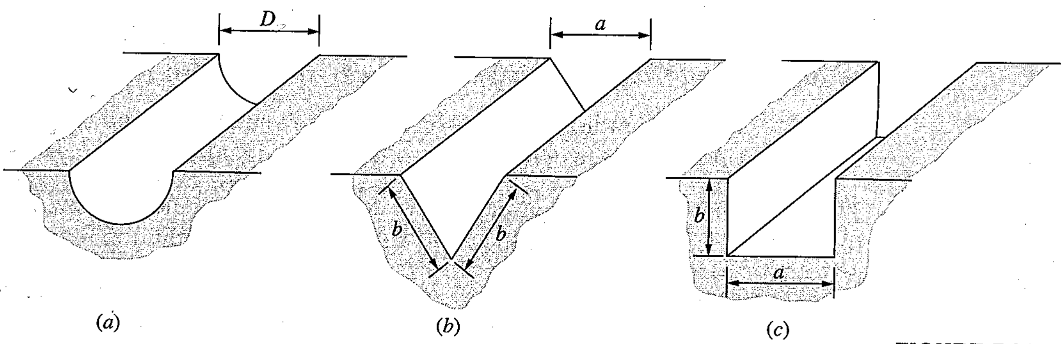
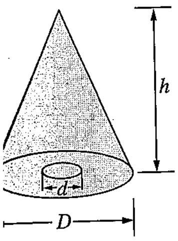


FIGURE P12-62
(*a*) Semicylindrical groove.
(*b*) Triangular groove.
(*c*) Rectangular groove.



IGURE P12-64

12-63 Determine the view factors from the base of a cube to each of the other five surfaces. *Answer:* 0.2

12-64 Consider a conical enclosure of height h and base diameter D. Determine the view factor from the conical side surface to a hole of diameter d located at the center of the base.

12-65 Determine the four view factors associated with an enclosure formed by two very long concentric cylinders of radii r_1 and r_2. Neglect the end effects.

12-66 Determine the view factor F_{12} between the rectangular surfaces shown in Fig. P12-66.

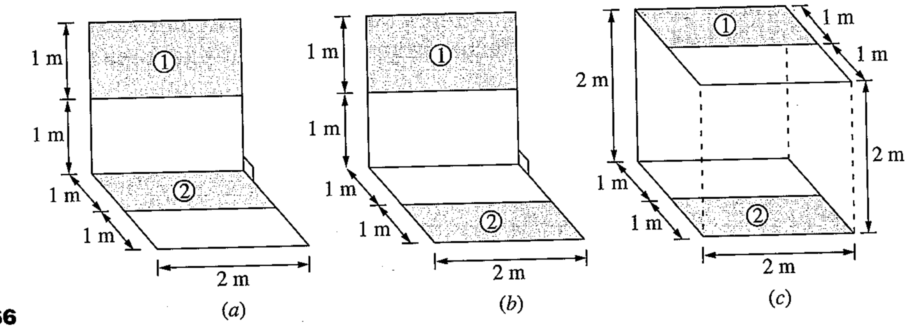


FIGURE P12-66

12-67 Two infinitely long parallel cylinders of diameter D are located a distance s apart from each other. Determine the view factor F_{12} between these two cylinders.

12-68 Three infinitely long parallel cylinders of diameter D are located a distance s apart from each other. Determine the view factor between the cylinder in the middle and the surroundings.

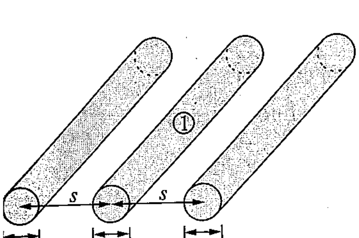


FIGURE P12-68

Radiation Heat Transfer Between Surfaces

12-69C Why is the radiation analysis of enclosures that consist of black surfaces relatively easy? How is the rate of radiation heat transfer between two surfaces expressed in this case?

12-70C How does radiosity differ for a surface from the emitted energy? For what kind of surfaces are these two quantities identical?

12-71C What are the radiation surface and space resistances? How are they expressed? For what kind of surfaces is the radiation surface resistance zero?

12-72C What are the two methods used in radiation analysis? How do these two methods differ?

12-73C What is a reradiating surface? What simplifications does a reradiating surface offer in the radiation analysis?

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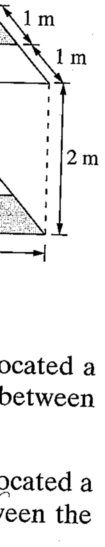

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12-74 Consider a 3 m × 3 m × 3 m cubical furnace whose top and side surfaces closely approximate black surfaces, and whose base surface has an emissivity $\varepsilon = 0.7$. The base, top, and side surfaces of the furnace are maintained at uniform temperatures of 400 K, 800 K, and 1200 K, respectively. Determine the net rate of radiation heat transfer between (*a*) the base and side surfaces and (*b*) the base and top surfaces. Also determine the net rate of radiation heat transfer to the base surface.

12-74E Consider a 10 ft × 10 ft × 10 ft cubical furnace whose top and side surfaces closely approximate black surfaces, and whose base surface has an emissivity $\varepsilon = 0.7$. The base, top, and side surfaces of the furnace are maintained at uniform temperatures of 800 R, 1600 R, and 2400 R, respectively. Determine the net rate of radiation heat transfer between (*a*) the base and side surfaces and (*b*) the base and top surfaces. Also determine the net rate of radiation heat transfer to the base surface.

12-75 Two very large parallel plates are maintained at uniform temperatures of $T_1 = 600$ K and $T_2 = 400$ K, and have emissivities $\varepsilon_1 = 0.5$ and $\varepsilon_2 = 0.9$, respectively. Determine the net rate of radiation heat transfer between the two surfaces per unit area of the plates.

12-76 A furnace is of cylindrical shape with $r = h = 2$ m. The base, top, and side surfaces of the furnace are all black, and are maintained at uniform temperatures of 500, 700, and 800 K, respectively. Determine the net rate of radiation heat transfer from the top surface during steady operation.

12-76E A furnace is of cylindrical shape with $r = h = 6$ ft. The base, top, and side surfaces of the furnace are all black, and are maintained at uniform temperatures of 900, 1200, and 1400 R, respectively. Determine the net rate of radiation heat transfer from the top surface during steady operation.

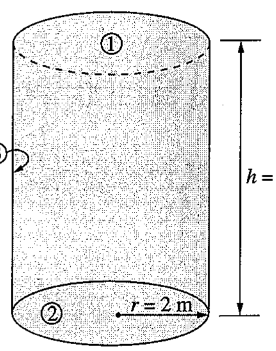

FIGURE P12-

12-77 Consider a hemispherical furnace of diameter $D = 5$ m with a flat base. The dome of the furnace is black, and the base has an emissivity of 0.7. The base and the dome of the furnace are mainteaned at uniform temperatures of 400 and 1000 K, respectively. Determine the net rate of radiation heat transfer from the dome to the base surface during steady operation. *Answer:* 759 kW

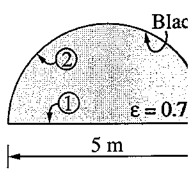

FIGURE P12-

12-77E Consider a hemispherical furnace of diameter D = 15 ft with a flat base. The dome of the furnace is black, and the base has an emissivity of 0.7. The base and the dome of the furnace are maintained at uniform temperatures of 800 and 1800 R, respectively. Determine the net rate of radiation heat transfer from the dome to the base surface during steady operation. *Answer:* 2,139,000 Btu/h

12-78 Two very long concentric cylinders of diameters $D_1 = 0.2$ m and $D_2 = 0.5$ m are maintained at uniform temperatures of $T_1 = 800$ K and $T_2 = 500$ K, and have emissivities $\varepsilon_1 = 1$ and $\varepsilon_2 = 0.7$, respectively.

Determine the net rate of radiation heat transfer between the two cylinders per unit length of the cylinders.

12-79 The following experiment is conducted to determine the emissivity of a certain material. A long cylindrical rod of diameter $D_1 = 0.01$ m is coated with this new material, and is placed in an evacuated long cylindrical enclosure of diameter $D_2 = 0.1$ m and emissivity $\varepsilon_2 = 0.95$, which is cooled externally and is maintained at a temperature of 200 K at all times. The rod is heated by passing electric current through it. When steady operating conditions are reached, it is observed that the rod is dissipating electric power at a rate of 8 W per unit of its length, and its surface temperature is 500 K. Based on these measurements, determine the emissivity of the coating on the rod.

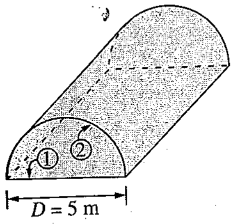

FIGURE P12-80

12-80 A furnace is shaped like a long semicylindrical duct of diameter $D = 5$ m. The base and the dome of the furnace have emissivities of 0.5 and 0.9, and are maintained at uniform temperatures of 400 and 1000 K, respectively. Determine the net rate of radiation heat transfer from the dome to the base surface per unit length during steady operation.

12-80E A furnace is shaped like a long semicylindrical duct of diameter $D = 15$ ft. The base and the dome of the furnace have emissivities of 0.5 and 0.9, and are maintained at uniform temperatures of 700 and 1800 R, respectively. Determine the net rate of radiation heat transfer from the dome to the base surface per unit length during steady operation.

12-81 Two parallel disks of diameter $D = 0.6$ m separated by $L = 0.4$ m are located directly on top of each other. Both disks are black, and are maintained at a temperature of 700 K. The back sides of the disks are insulated, and the environment that the disks are in can be considered to be a blackbody at $T_\infty = 300$ K. Determine the net rate of radiation heat transfer from the disks to the environment. *Answer:* 5505 W

12-82 A furnace is shaped like a long equilateral-triangular duct where the width of each side is 2 m. Heat is supplied from the base surface, whose emissivity is $\varepsilon_1 = 0.8$, at a rate of 800 W/m^2 while the side surfaces, whose emissivities are 0.5, are maintained at 500 K. Neglecting the end effects, determine the temperature of the base surface. Can you treat this geometry as a two-surface enclosure?

12-83 Consider a 4 m × 4 m × 4 m cubical furnace whose floor and ceiling are black and whose side surfaces are reradiating. The floor and the ceiling of the furnace are maintained at temperatures of 550 K and 1100 K, respectively. Determine the net rate of radiation heat transfer between the floor and the ceiling of the furnace.

12-84 Two concentric spheres of diameters $D_1 = 0.3$ m and $D_2 = 0.8$ m are maintained at uniform temperatures $T_1 = 700$ K and $T_2 = 400$ K, and have emissivities $\varepsilon_1 = 0.5$ and $\varepsilon_2 = 0.7$, respectively. Determine the net rate of radiation heat transfer between the two spheres. Also determine the convection heat transfer coefficient at the outer surface if both the

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