Problem Identification / Formulation

1–77 A transistor with a height of 0.4 cm and a diameter of 0.6 cm is mounted on a circuit board. The transistor is cooled by air flowing over it with an average heat transfer coefficient of 30 W/m²·K. If the air temperature is 55°C and the transistor case temperature is not to exceed 70°C, determine the amount of power this transistor can dissipate safely. Disregard any heat transfer from the transistor base.

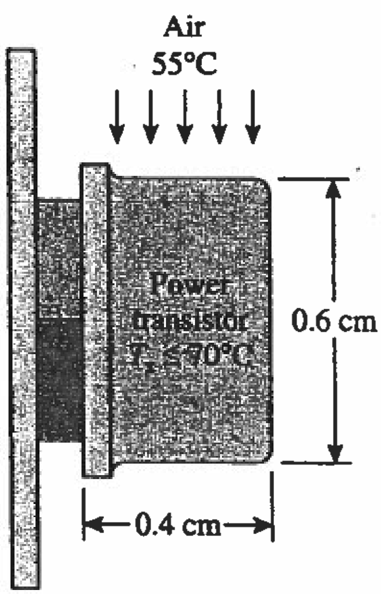


FIGURE P1–77

1–80 The boiling temperature of nitrogen at atmospheric pressure at sea level (1 atm) 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 remains constant at −196°C until the liquid nitrogen in the tank is depleted. Any heat transfer to the tank results in the evaporation of some liquid nitrogen, which has a heat of vaporization of 198 kJ/kg and a density of 810 kg/m³ at 1 atm.

Consider a 4-m-diameter spherical tank initially filled with liquid nitrogen at 1 atm and −196°C. The tank is exposed to 20°C ambient air with a heat transfer coefficient of 25 W/m²·K. The temperature of the thin-shelled spherical tank is observed to be almost the same as the temperature of the nitrogen inside. Disregarding any radiation heat exchange, determine the rate of evaporation of the liquid nitrogen in the tank as a result of the heat transfer from the ambient air.

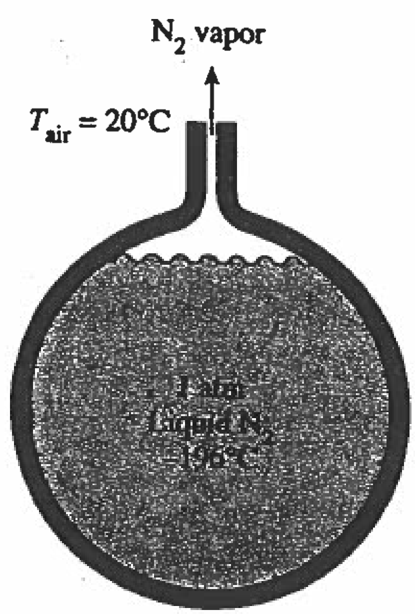


FIGURE P1–80

1–97 The inner and outer surfaces of a 25-cm-thick wall in summer are at 27°C and 44°C, respectively. The outer surface of the wall exchanges heat by radiation with surrounding surfaces at 40°C, and convection with ambient air also at 40°C with a convection heat transfer coefficient of 8 W/m²·K. Solar radiation is incident on the surface at a rate of 150 W/m². If both the emissivity and the solar absorptivity of the outer surface are 0.8, determine the effective thermal conductivity of the wall.

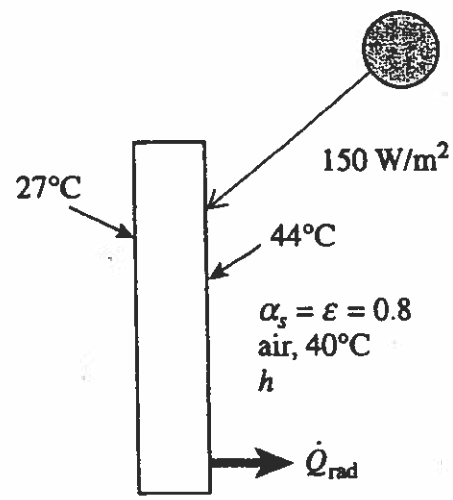


FIGURE P1–97

1–104 Heat treatment is common in processing of semiconductor material. A 200-mm-diameter silicon wafer with thickness of 725 μm is being heat treated in a vacuum chamber by infrared heater. The surrounding walls of the chamber have a uniform temperature of 310 K. The infrared heater provides an incident radiation flux of 200 kW/m^2 on the upper surface of the wafer, and the emissivity and absorptivity of the wafer surface are 0.70. Using a pyrometer, the lower surface temperature of the wafer is measured to be 1000 K. Assuming there is no radiation exchange between the lower surface of the wafer and the surroundings, determine the upper surface temperature of the wafer. (*Note:* A *pyrometer* is a noncontacting device that intercepts and measures thermal radiation. This device can be used to determine the temperature of an object's surface.)

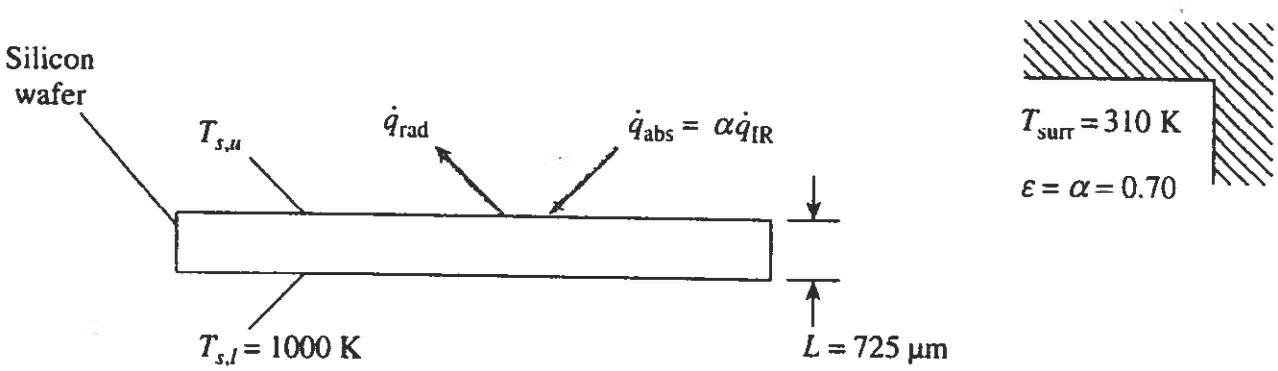


FIGURE P1–104

1–27 A 5-m × 6-m × 8-m room is to be heated by an electrical resistance heater placed in a short duct in the room. Initially, the room is at 15°C, and the local atmospheric pressure is 98 kPa. The room is losing heat steadily to the outside at a rate of 200 kJ/min. A 300-W fan circulates the air steadily through the duct and the electric heater at an average mass flow rate of 50 kg/min. The duct can be assumed to be adiabatic, and there is no air leaking in or out of the room. If it takes 18 minutes for the room air to reach an average temperature of 25°C, find (*a*) the power rating of the electric heater and (*b*) the temperature rise that the air experiences each time it passes through the heater.

Cartesian Problems / Cylindrical Problems

2–59 Consider a large plane wall of thickness $L = 0.3$ m, thermal conductivity $k = 2.5$ W/m·K, and surface area $A = 12$ m^2. The left side of the wall at $x = 0$ is subjected to a net heat flux of $\dot{q}_0 = 700$ W/m^2 while the temperature at that surface is measured to be $T_1 = 80°C$. Assuming constant thermal conductivity and no heat generation in the wall, (*a*) express the differential equation and the boundary conditions for steady one-dimensional heat conduction through the wall, (*b*) obtain a relation for the variation of temperature in the wall by solving the differential equation, and (*c*) evaluate the temperature of the right surface of the wall at $x = L$.

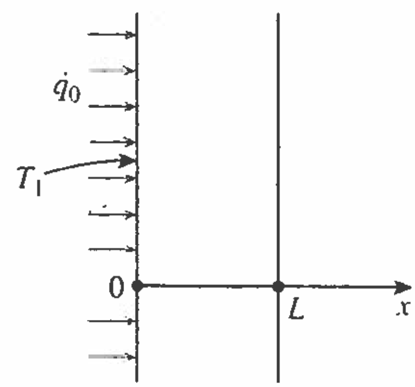


FIGURE P2–59

2–72E A large steel plate having a thickness of $L = 4$ in, thermal conductivity of $k = 7.2$ Btu/h·ft·°F, and an emissivity of $\varepsilon = 0.7$ is lying on the ground. The exposed surface of the plate at $x = L$ is known to exchange heat by convection with the ambient air at $T_\infty = 90$°F with an average heat transfer coefficient of $h = 12$ Btu/h·ft^2·°F as well as by radiation with the open sky with an equivalent sky temperature of $T_{sky} = 480$ R. Also, the temperature of the upper surface of the plate is measured to be 80°F. Assuming steady one-dimensional heat transfer, (*a*) express the differential equation and the boundary conditions for heat conduction through the plate, (*b*) obtain a relation for the variation of temperature in the plate by solving the differential equation, and (*c*) determine the value of the lower surface temperature of the plate at $x = 0$.

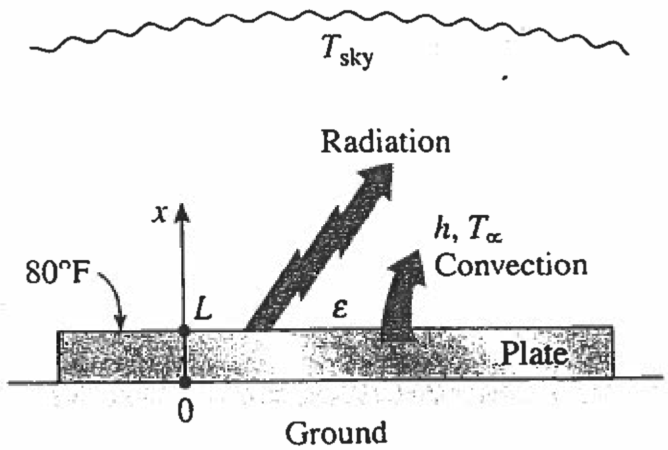


FIGURE P2–72E

2–67 Consider a chilled-water pipe of length L, inner radius r_1, outer radius r_2, and thermal conductivity k. Water flows in the pipe at a temperature T_f and the heat transfer coefficient at the inner surface is h. If the pipe is well-insulated on the outer surface, (a) express the differential equation and the boundary conditions for steady one-dimensional heat conduction through the pipe and (b) obtain a relation for the variation of temperature in the pipe by solving the differential equation.

2–68 A pipe in a manufacturing plant is transporting superheated vapor at a mass flow rate of 0.3 kg/s. The pipe is 10 m long, has an inner diameter of 5 cm and pipe wall thickness of 6 mm. The pipe has a thermal conductivity of 17 W/m·K, and the inner pipe surface is at a uniform temperature of 120 °C.

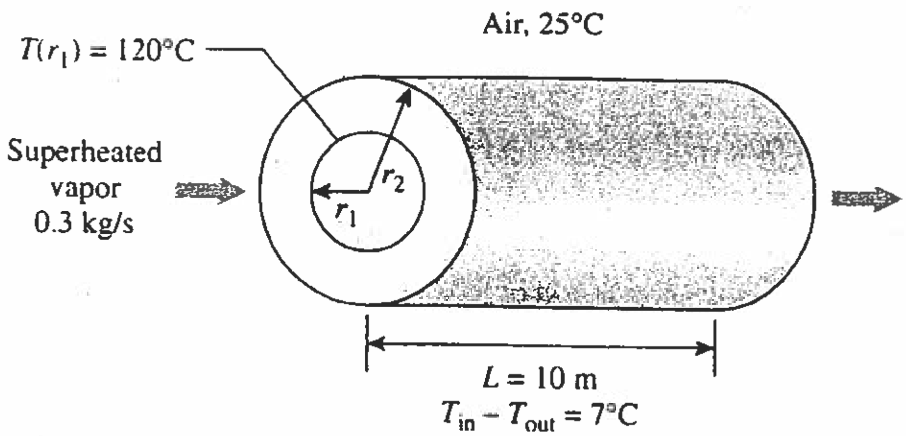


FIGURE P2–68

The temperature drop between the inlet and exit of the pipe is 7 °C, and the constant pressure specific heat of vapor is 2190 J/kg·°C. If the air temperature in the manufacturing plant is 25 °C, determine the heat transfer coefficient as a result of convection between the outer pipe surface and the surrounding air.

Resistance Concept / Critical Insulation Thickness

3–95E A 0.083-in-diameter electrical wire at 90°F is covered by 0.02-in-thick plastic insulation ($k = 0.075$ Btu/h·ft·°F). The wire is exposed to a medium at 50°F, with a combined convection and radiation heat transfer coefficient of 2.5 Btu/h·ft^2·°F. Determine if the plastic insulation on the wire will increase or decrease heat transfer from the wire.

3–96E Repeat Prob. 3–95E, assuming a thermal contact resistance of 0.001 h·ft^2·°F/Btu at the interface of the wire and the insulation.

3–33 A 2-m × 1.5-m section of 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 110°C. The temperature of the furnace room is 32°C, and the combined convection and radiation heat transfer coefficient at the surface of the outer furnace is 10 $W/m^2 \cdot K$. It is proposed to insulate this section of the furnace wall with glass wool insulation (k = 0.038 $W/m \cdot K$) in order to reduce the heat loss by 90 percent. Assuming the outer surface temperature of the metal section still remains at about 110°C, determine the thickness of the insulation that needs to be used.

The furnace operates continuously and has an efficiency of 78 percent. The price of the natural gas is $1.10/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.

3–86 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/m³ 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 W/m²·K. 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 W/m·K), and (*c*) insulated with 2-cm-thick superinsulation which has an effective thermal conductivity of 0.00005 W/m·K.

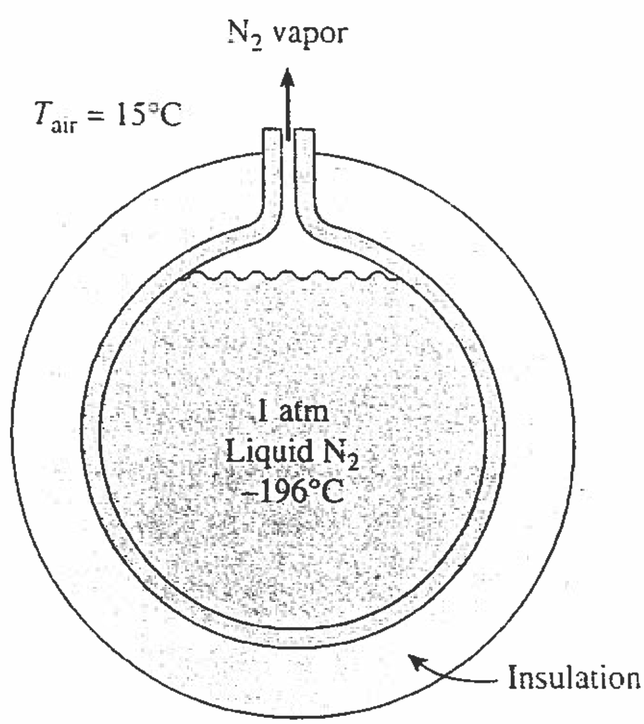


FIGURE P3–86

3–25 To defog the rear window of an automobile, a very thin transparent heating element is attached to the inner surface of the window. A Uniform heat flux of 1300 W/m² is provided to the heating element for defogging a rear window with thickness of 5 mm. The interior temperature of the automobile is 22°C and the convection heat transfer coefficient is 15 W/m²·K. The outside ambient temperature is −5°C and the convection heat transfer coefficient is 100 W/m²·K. If the thermal conductivity of the window is 1.2 W/m·K, determine the inner surface temperature of the window.

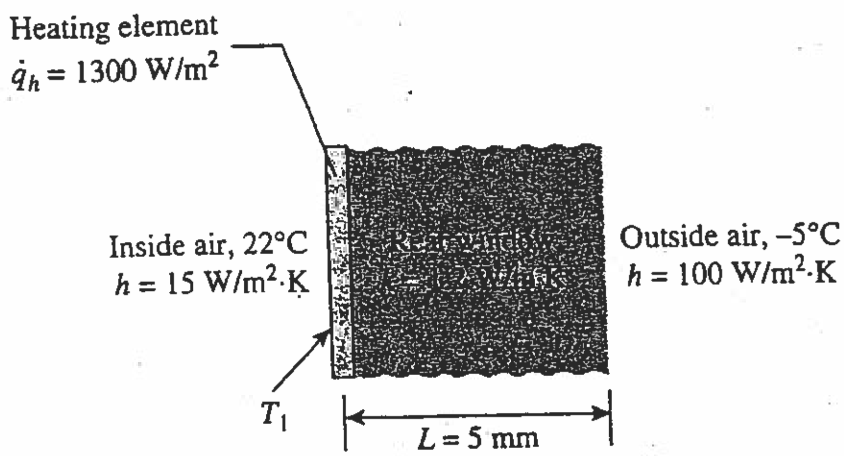


FIGURE P3–25

3–36 Consider a house that has a 10-m × 20-m base and a 4-m-high wall. All four walls of the house have an R-value of 2.31 $m^2\cdot°C/W$. 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·K), 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·K) enclosed between two 0.5-cm-thick glass layers. The thermostat in the house is set at 24°C and the average temperature outside at that location is 8°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 18 $W/m^2\cdot K$, respectively, determine the average rate of heat transfer through each wall.

If the house is electrically heated and the price of electricity is $0.08/kWh, determine the amount of money this household will save per heating season by converting the single-pane windows to double-pane windows.

Energy Generation / Extended Surfaces

2–88 Consider a large plate of thickness L and thermal conductivity k in which heat is generated uniformly at a rate of $\dot{e}_{gen}$. One side of the plate is insulated while the other side is exposed to an environment at T_∞ with a heat transfer coefficient of h. (*a*) Express the differential equation and the boundary conditions for steady one-dimensional heat conduction through the plate, (*b*) determine the variation of temperature in the plate, and (*c*) obtain relations for the temperatures on both surfaces and the maximum temperature rise in the plate in terms of given parameters.

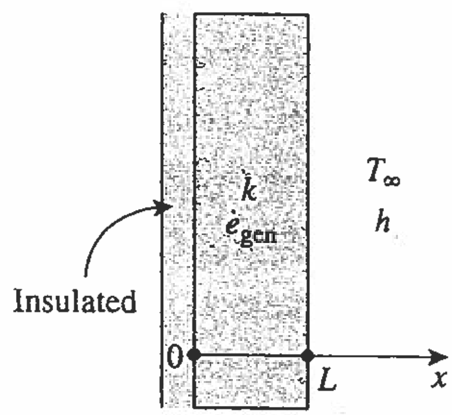


FIGURE P2–88

2–96 Consider a homogeneous spherical piece of radioactive material of radius $r_o = 0.04$ m that is generating heat at a constant rate of $\dot{e}_{gen} = 5 \times 10^7$ W/m³. The heat generated is dissipated to the environment steadily. The outer surface of the sphere is maintained at a uniform temperature of 110°C and the thermal conductivity of the sphere is $k = 15$ W/m·K. Assuming steady one-dimensional heat transfer, (*a*) express the differential equation and the boundary conditions for heat conduction through the sphere, (*b*) obtain a relation for the variation of temperature in the sphere by solving the differential equation, and (*c*) determine the temperature at the center of the sphere.

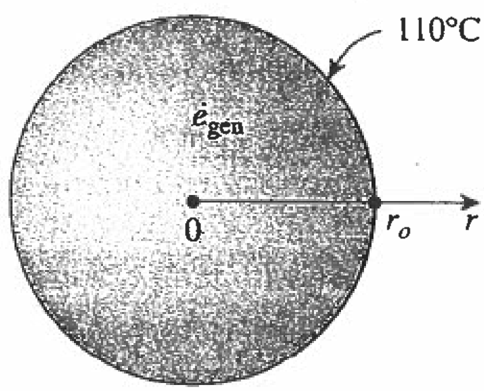


FIGURE P2–96

3–115 Consider a very long rectangular fin attached to a flat surface such that the temperature at the end of the fin is essentially that of the surrounding air, i.e. 20°C. Its width is 5.0 cm; thickness is 1.0 mm; thermal conductivity is 200 W/m·K; and base temperature is 40°C. The heat transfer coefficient is 20 W/m^2·K. Estimate the fin temperature at a distance of 5.0 cm from the base and the rate of heat loss from the entire fin.

3–120 A turbine blade made of a metal alloy (k = 17 W/m·K) has a length of 5.3 cm, a perimeter of 11 cm, and a cross-sectional area of 5.13 cm^2. The turbine blade is exposed to hot gas from the combustion chamber at 973°C with a convection heat transfer coefficient of 538 W/m^2·K. The base of the turbine blade maintains a constant temperature of 450°C and the tip is adiabatic. Determine the heat transfer rate to the turbine blade and temperature at the tip.

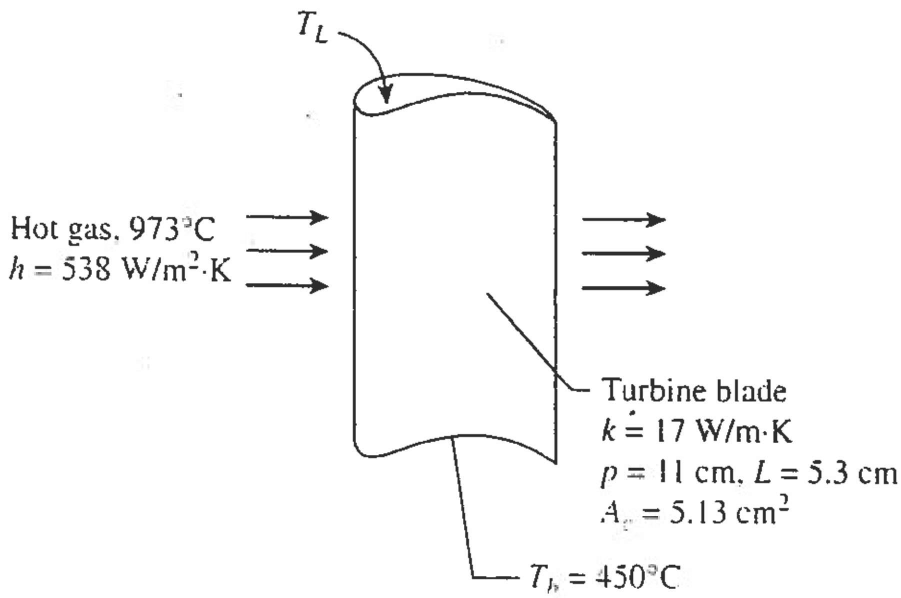


FIGURE P3–120

3–123 Steam in a heating system flows through tubes whose outer diameter is 5 cm and whose walls are maintained at a temperature of 130°C. Circular aluminum alloy 2024-T6 fins (k = 186 W/m·K) of outer diameter 6 cm and constant thickness 1 mm are attached to the tube. The space between the fins is 3 mm, and thus there are 250 fins per meter length of the tube. Heat is transferred to the surrounding air at T_∞ = 25°C, with a heat transfer coefficient of 40 W/m²·K. Determine the increase in heat transfer from the tube per meter of its length as a result of adding fins. *Answer:* 1788 W

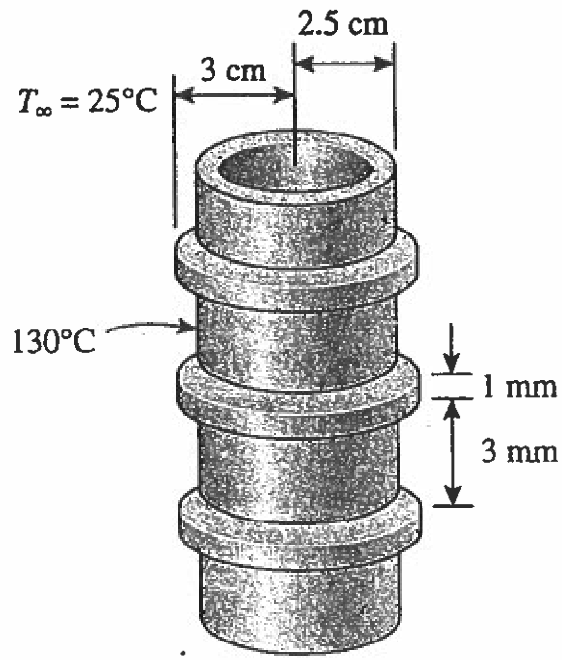


FIGURE P3–123

Lumped System Analysis Problems

4–19 A long copper rod of diameter 2.0 cm is initially at a uniform temperature of 100°C. It is now exposed to an air stream at 20°C with a heat transfer coefficient of 200 W/m^2·K. How long would it take for the copper road to cool to an average temperature of 25°C?

4–16E In a manufacturing facility, 2-in-diameter brass balls (k = 64.1 Btu/h·ft·°F, ρ = 532 lbm/ft^3, and c_p = 0.092 Btu/lbm·°F) initially at 250°F are quenched in a water bath at 120°F for a period of 2 min at a rate of 120 balls per minute. If the convection heat transfer coefficient is 42 Btu/h·ft^2·°F, determine (*a*) the temperature of the balls after quenching and (*b*) the rate at which heat needs to be removed from the water in order to keep its temperature constant at 120°F.

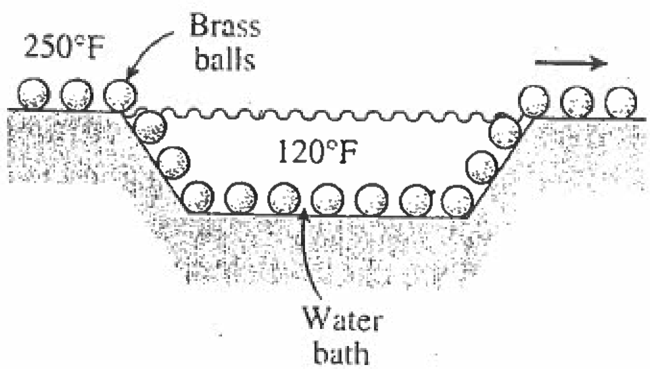


FIGURE P4–16E

4–27 Consider a spherical shell satellite with outer diameter of 4 m and shell thickness of 10 mm is reentering the atmosphere. The shell satellite is made of stainless steel with properties of $\rho = 8238$ kg/m^3, $c_p = 468$ J/kg·K, and $k = 13.4$ W/m·K. During the reentry, the effective atmosphere temperature surrounding the satellite is 1250°C with convection heat transfer coefficient of 130 W/m^2·K. If the initial temperature of the shell is 10°C, determine the shell temperature after 5 minutes of reentry. Assume heat transfer occurs only on the satellite shell.

4–21 Consider a 800-W iron whose base plate is made of 0.5-cm-thick aluminum alloy 2024–T6 (ρ = 2770 kg/m^3, c_p = 875 J/kg·K, α = 7.3 × 10^{-5} m^2/s). The base plate has a surface area of 0.03 m^2. Initially, the iron is in thermal equilibrium with the ambient air at 22°C. Taking the heat transfer coefficient at the surface of the base plate to be 12 W/m^2·K and assuming 85 percent of the heat generated in the resistance wires is transferred to the plate, determine how long it will take for the plate temperature to reach 140°C. Is it realistic to assume the plate temperature to be uniform at all times?

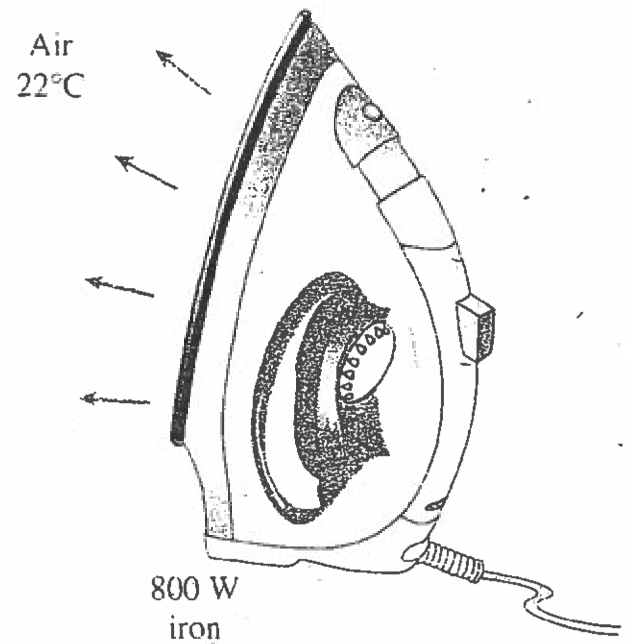
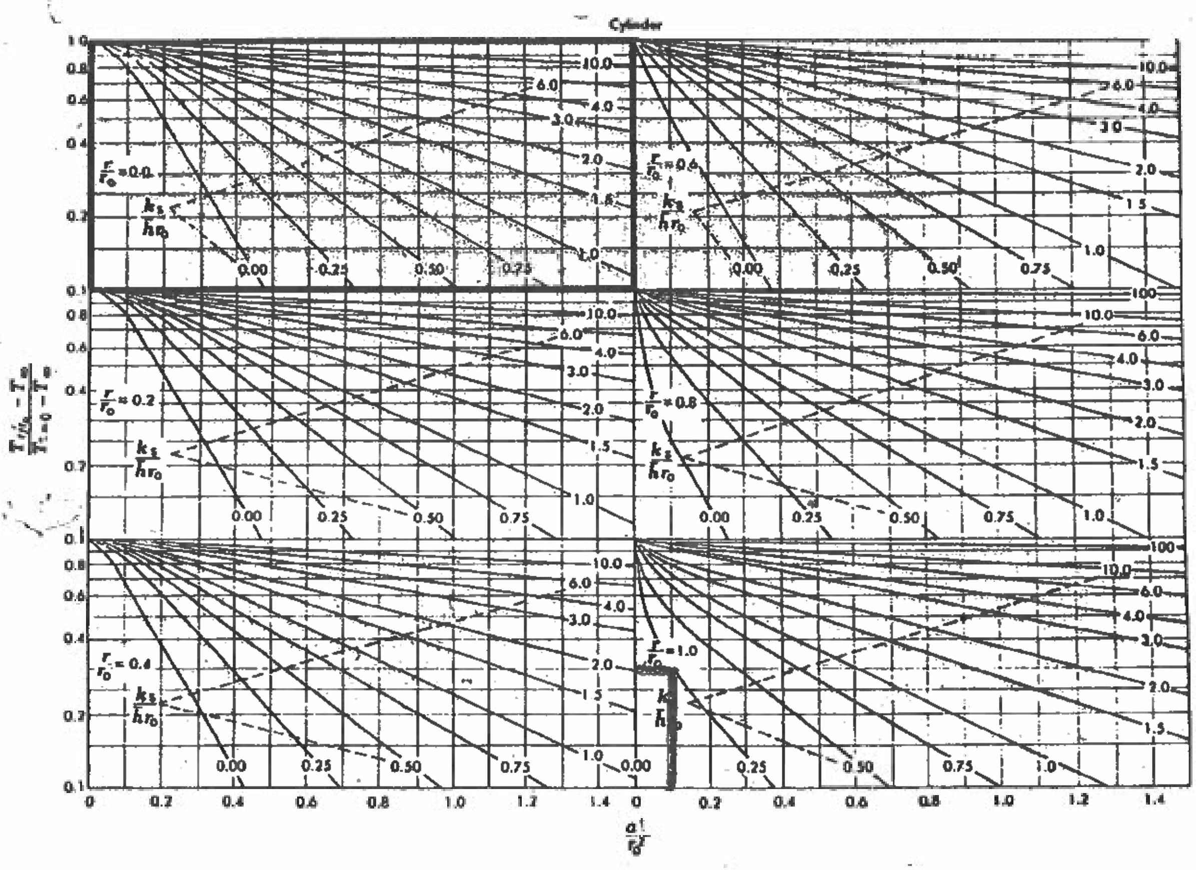


FIGURE P4–21

4–30 An electronic device dissipating 18 W has a mass of 20 g, a specific heat of 850 J/kg·K, and a surface area of 4 cm^2. The device is lightly used, and it is on for 5 min and then off for several hours, during which it cools to the ambient temperature of 25°C. Taking the heat transfer coefficient to be 12 $W/m^2 \cdot K$, determine the temperature of the device at the end of the 5-min operating period. What would your answer be if the device were attached to an aluminum heat sink having a mass of 200 g and a surface area of 80 cm^2? Assume the device and the heat sink to be nearly isothermal.

Distributed System Analysis Problems

4–39 A long cylindrical wood log ($k = 0.17$ W/m·K and $\alpha = 1.28 \times 10^{-7}$ m²/s) is 10 cm in diameter and is initially at a uniform temperature of 25°C. It is exposed to hot gases at 600°C in a fireplace with a heat transfer coefficient of 13.6 W/m²·K on the surface. If the ignition temperature of the wood is 420°C, determine how long it will be before the log ignites.



4–43 An ordinary egg can be approximated as a 5.5-cm-diameter sphere whose properties are roughly $k = 0.6$ W/m·K and $\alpha = 0.14 \times 10^{-6}$ m²/s. The egg is initially at a uniform temperature of 4°C and is dropped into boiling water at 97°C. Taking the convection heat transfer coefficient to be $h = 1400$ W/m²·K, determine how long it will take for the center of the egg to reach 70°C.

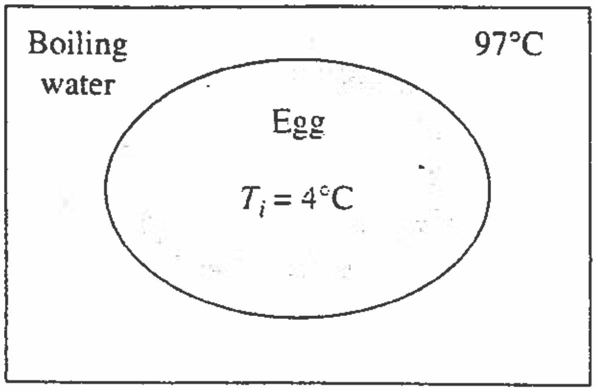
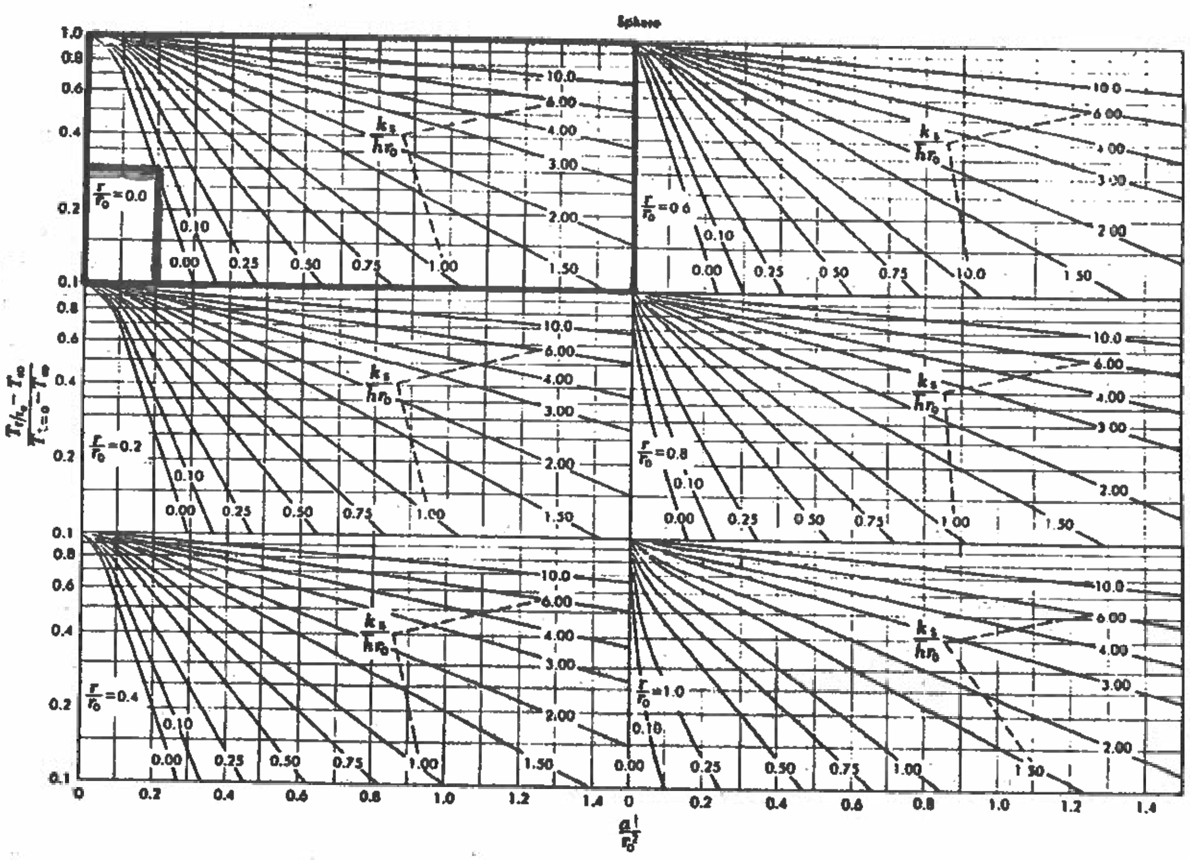
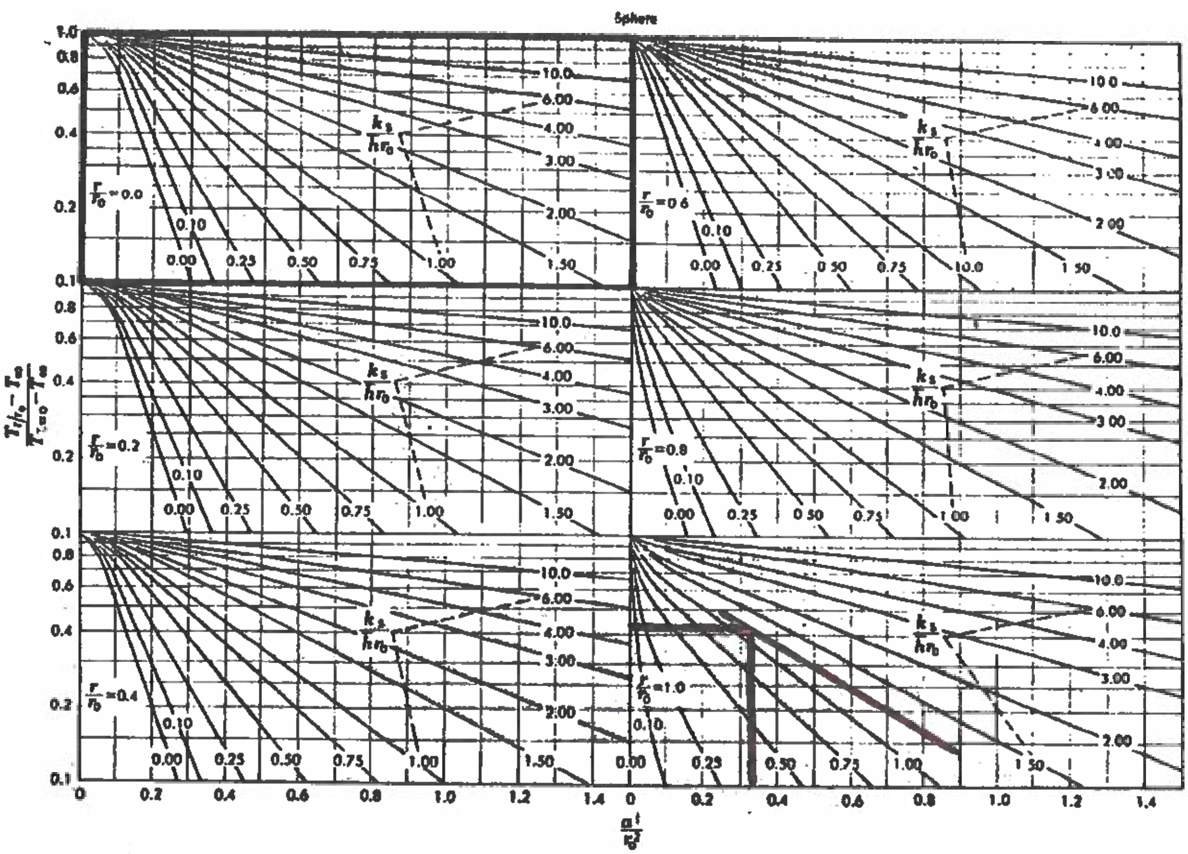


FIGURE P4–43

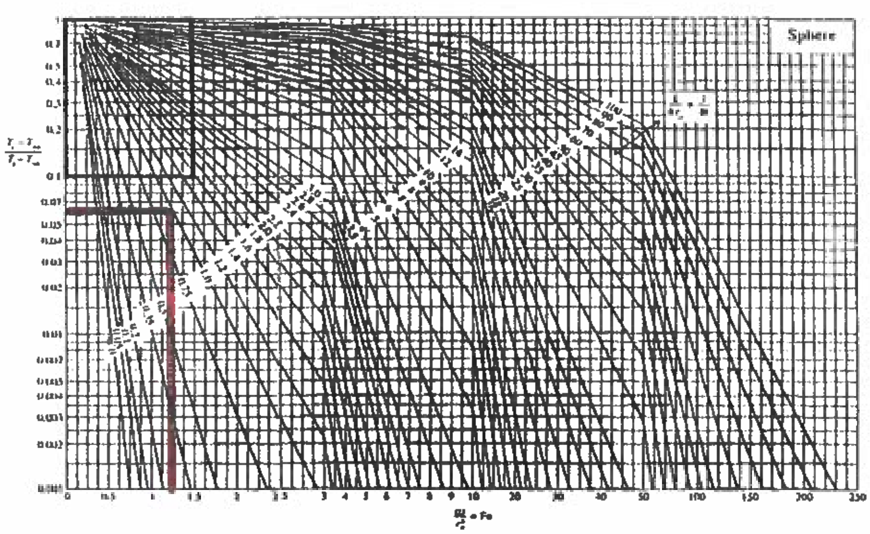


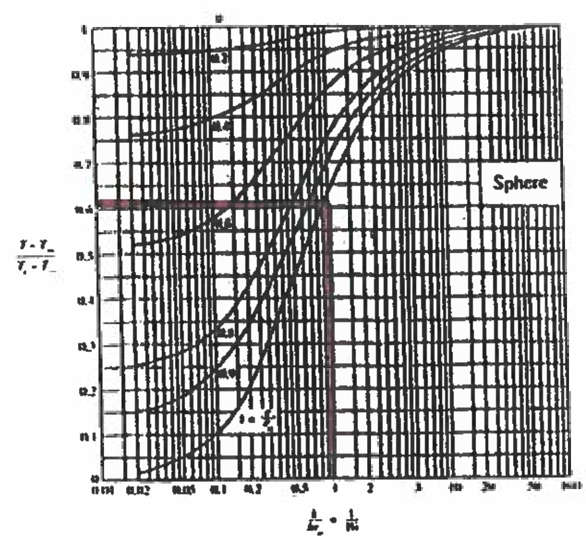
4–51 A student calculates that the total heat transfer from a spherical copper ball of diameter 18 cm initially at 200°C and its environment at a constant temperature of 25°C during the first 20 min of cooling is 3150 kJ. Is this result reasonable? Why?

4–73 Hailstones are formed in high altitude clouds at 253 K. Consider a hailstone with diameter of 20 mm and is falling through air at 15°C with convection heat transfer coefficient of 163 W/m²·K. Assuming the hailstone can be modeled as a sphere and has properties of ice at 253 K, determine the duration it takes to reach melting point at the surface of the falling hailstone.



4–56 Citrus fruits are very susceptible to cold weather, and extended exposure to subfreezing temperatures can destroy them. Consider an 8-cm-diameter orange that is initially at 15°C. A cold front moves in one night, and the ambient temperature suddenly drops to −6°C, with a heat transfer coefficient of 15 W/m²·K. Using the properties of water for the orange and assuming the ambient conditions to remain constant for 4 h before the cold front moves out, determine if any part of the orange will freeze that night.





$$\frac{T(r_0,t)-T_\infty}{T_i-T_\infty} = \frac{T_0-T_\infty}{T_i-T_\infty} \times \frac{T-T_\infty}{T_0-T_\infty} = 0.059 \times 0.62 = 0.0366$$

Convective Heat Transfer with Flow over Surfaces

6–10 The upper surface of a 50-cm-thick solid plate (k = 237 W/m·K) is being cooled by water with temperature of 20°C. The upper and lower surfaces of the solid plate maintained at constant temperatures of 60°C and 120°C, respectively. Determine the water convection heat transfer coefficient and the water temperature gradient at the upper plate surface.

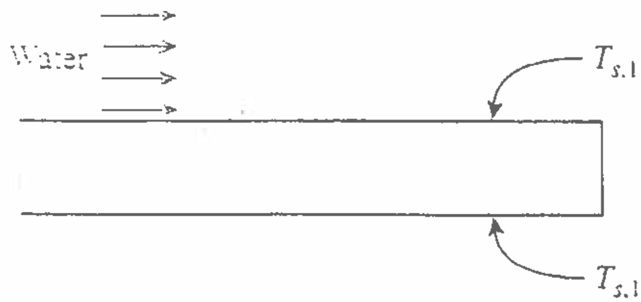


FIGURE P6–10

7–26 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 12 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. Assume the flow is laminar over the entire finned surface of the transformer.

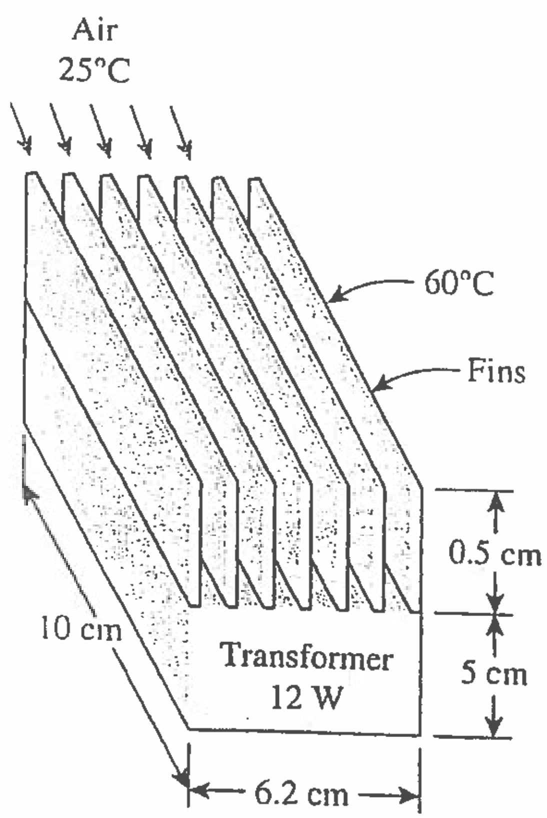
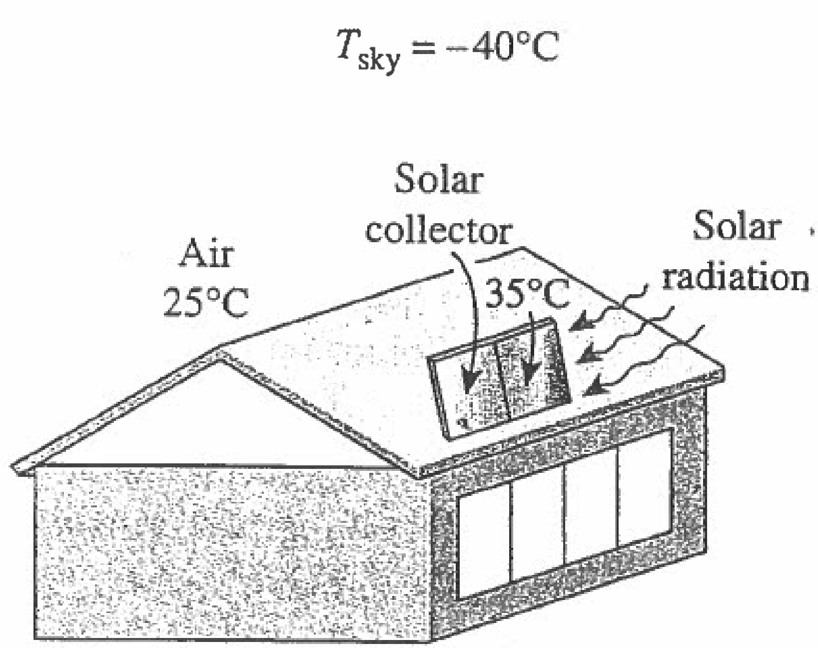


FIGURE P7–26

7–66 A heated long cylindrical rod is placed in a cross flow of air at 20°C (1 atm) with velocity of 10 m/s. The rod has a diameter of 5 mm and its surface has an emissivity of 0.95. If the surrounding temperature is 20°C and the heat flux dissipated from the rod is 16000 W/m^2, determine the surface temperature of the rod. Evaluate the air properties at 70°C.

7–47 Solar radiation is incident on the glass cover of a solar collector at a rate of 700 W/m^2. 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 25°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 back surface of the absorber plate to be heavily insulated and the only heat loss to occur 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.



Convective Heat Transfer with Flow in Tubes

8–2[illegible] Cooling water available at 10°C is used to condense steam at 30°C in the condenser of a power plant at a rate of 0.15 kg/s by circulating the cooling water through a bank of 5-m-long 1.2-cm-internal-diameter thin copper tubes. Water enters the tubes at a mean velocity of 4 m/s and leaves at a temperature of 24°C. The tubes are nearly isothermal at 30°C. Determine the average heat transfer coefficient between the water, the tubes, and the number of tubes needed to achieve the indicated heat transfer rate in the condenser.

8–40 An 8-m long, uninsulated square duct of cross section 0.2 m × 0.2 m and relative roughness 10^{-3} passes through the attic space of a house. Hot air enters the duct at 1 atm and 80°C at a volume flow rate of 0.15 m^3/s. The duct surface is nearly isothermal at 60°C. Determine the rate of heat loss from the duct to the attic space and the pressure difference between the inlet and outlet sections of the duct.

8–51 A concentric annulus tube has inner and outer diameters of 25 mm and 100 mm, respectively. Liquid water flows at a mass flow rate of 0.05 kg/s through the annulus with the inlet and outlet mean temperatures of 20°C and 80°C, respectively. The inner tube wall is maintained with a constant surface temperature of 120°C, while the outer tube surface is insulated. Determine the length of the concentric annulus tube.

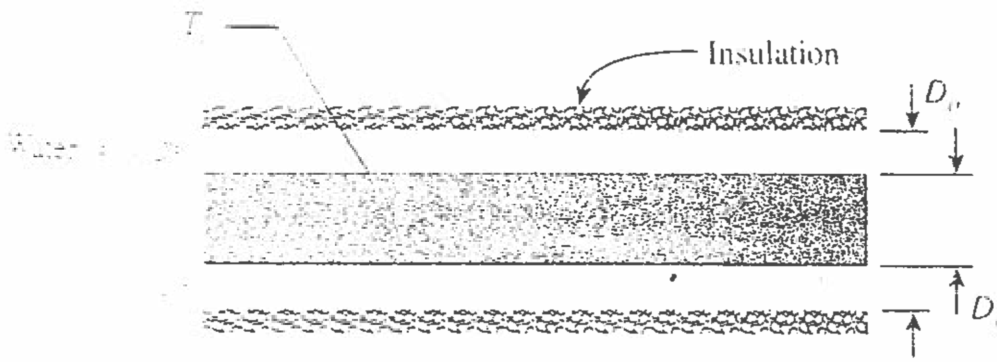


FIGURE P8–51

8–58 A 15-cm × 20-cm printed circuit board whose components are not allowed to come into direct contact with air for reliability reasons is to be cooled by passing cool air through a 20-cm-long channel of rectangular cross section 0.2 cm × 14 cm drilled into the board. The heat generated by the electronic components is conducted across the thin layer of the board to the channel, where it is removed by air that enters the channel at 15°C. The heat flux at the top surface of the channel can be considered to be uniform, and heat transfer through other surfaces is negligible. If the velocity of the air at the inlet of the channel is not to exceed 4 m/s and the surface temperature of the channel is to remain under 50°C, determine the maximum total power of the electronic components that can safely be mounted on this circuit board. As a first approximation, assume flow is fully developed in the channel. Evaluate properties of air at a bulk mean temperature of 25°C. Is this a good assumption?

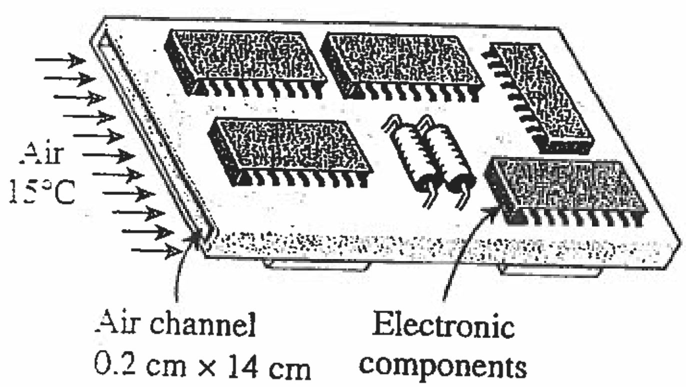


FIGURE P8–58

Natural Convection Problems

-19 A can of engine oil with a length of 150 mm and a diameter of 100 mm is placed vertically in the trunk of a car. In a hot summer day, the temperature in the trunk is 43°C. If the surface temperature of the can is 17°C, determine heat transfer rate from the can surface. Neglect the heat transfer from the ends of the can.

9-25 An incandescent lightbulb is an inexpensive but highly inefficient device that converts electrical energy into light. It converts about 5 percent of the electrical energy it consumes into light while converting the remaining 95 percent into heat. 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 an 8-cm-diameter 60-W lightbulb in a room at 25°C. The emissivity of the glass is 0.9. Assuming that 5 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 by natural convection and radiation, determine the equilibrium temperature of the glass bulb. Assume the interior surfaces of the room to be at room temperature.

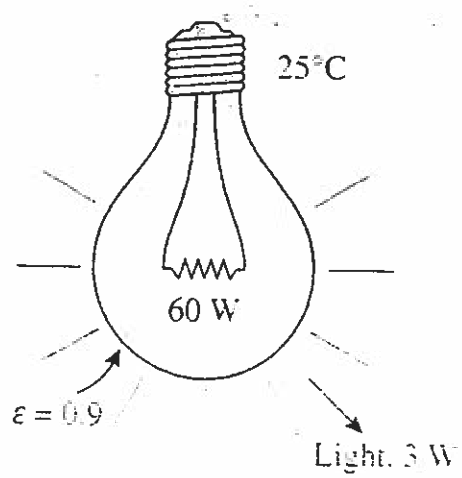


FIGURE P9-25

9–48 A 1.5-m-diameter, 4-m-long cylindrical propane tank is initially filled with liquid propane, whose density is 581 kg/m^3. The tank is exposed to the ambient air at 25°C in calm weather. The outer surface of the tank is polished so that the radiation heat transfer is negligible. Now a crack develops at the top of the tank, and the pressure inside drops to 1 atm while the temperature drops to −42°C, which is the boiling temperature of propane at 1 atm. The heat of vaporization of propane at 1 atm is 425 kJ/kg. The propane is slowly vaporized as a result of the heat transfer from the ambient air into the tank, and the propane vapor escapes the tank at −42°C through the crack. Assuming the propane tank to be at about the same temperature as the propane inside at all times, determine how long it will take for the tank to empty if it is not insulated.

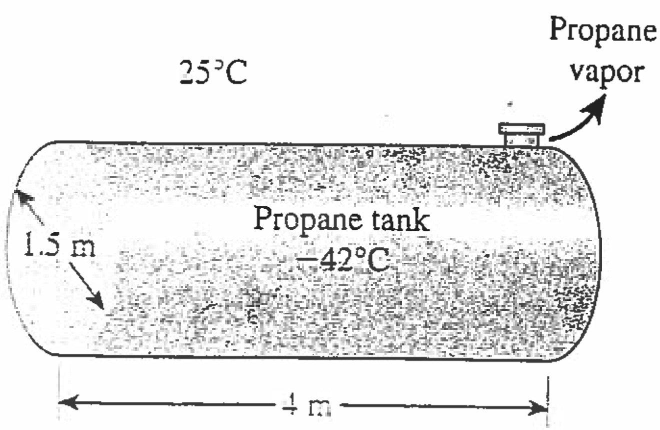


FIGURE P9–48

9–29 In a plant that manufactures canned aerosol paints, the cans are temperature-tested in water baths at 60°C before they are shipped to ensure that they withstand temperatures up to 55°C during transportation and shelving. The cans, moving on a conveyor, enter the open hot water bath, which is 0.5 m deep, 1 m wide, and 3.5 m long, and move slowly in the hot water toward the other end. Some of the cans fail the test and explode in the water bath. The water container is made of sheet metal, and the entire container is at about the same temperature as the hot water. The emissivity of the outer surface of the container is 0.7. If the temperature of the surrounding air and surfaces is 20°C, determine the rate of heat loss from the four side surfaces of the container (disregard the top surface, which is open).

The water is heated electrically by resistance heaters, and the cost of electricity is $0.085/kWh. If the plant operates 24 h a day 365 days a year and thus 8760 h a year, determine the annual cost of the heat losses from the container for this facility.

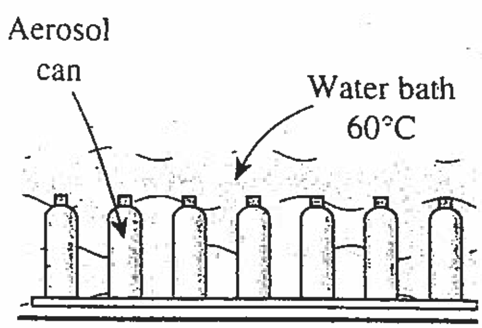


FIGURE P9–29