19-5C What is the physical significance of the Nusselt number? How is it defined?

19-6C When is heat transfer through a fluid conduction and when is it convection? For what case is the rate of heat transfer higher? How does the convection heat transfer coefficient differ from the thermal conductivity of a fluid?

19-7 During air cooling of potatoes, the heat transfer coefficient for combined convection, radiation, and evaporation is determined experimentally to be as shown:

| Air Velocity, m/s | Heat Transfer Coefficient, W/m²·K |
|---|---|
| 0.66 | 14.0 |
| 1.00 | 19.1 |
| 1.36 | 20.2 |
| 1.73 | 24.4 |

Consider an 8-cm-diameter potato initially at 20°C with a thermal conductivity of 0.49 W/m·K. Potatoes are cooled by refrigerated air at 5°C at a velocity of 1 m/s. Determine the initial rate of heat transfer from a potato, and the initial value of the temperature gradient in the potato at the surface. *Answers:* 5.8 W, −585°C/m

19-8 An average man has a body surface area of 1.8 m² and a skin temperature of 33°C. The convection heat transfer coefficient for a clothed person walking in still air is expressed as $h = 8.6V^{0.53}$ for $0.5 < V < 2$ m/s, where $V$ is the walking velocity in m/s. Assuming the average surface temperature of the clothed person to be 30°C, determine the rate of heat loss from an average man walking in still air at 7°C by convection at a walking velocity of (*a*) 0.5 m/s, (*b*) 1.0 m/s, (*c*) 1.5 m/s, and (*d*) 2.0 m/s.

19-9 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 are 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.

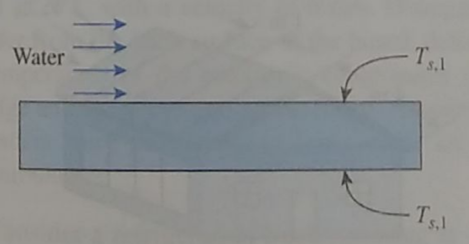


FIGURE P19–9

19–10 Consider air flow over a plate surface maintained at a temperature of 220°C. The temperature profile of the air flow is given as

$$T(y) = T_\infty - (T_\infty - T_s)\exp\left(-\frac{V}{\alpha_{\text{fluid}}}y\right)$$

The air flow at 1 atm has a free-stream velocity and temperature of 0.08 m/s and 20°C, respectively. Determine the heat flux on the plate surface and the convection heat transfer coefficient of the air flow. *Answers:* $1.45 \times 10^4$ W/m², 72.6 W/m²·K

19–11 The convection heat transfer coefficient for a clothed person standing in moving air is expressed as $h = 14.8V^{0.69}$ for $0.15 < V < 1.5$ m/s, where $V$ is the air velocity. For a person with a body surface area of 1.7 m² and an average surface temperature of 29°C, determine the rate of heat loss from the person in windy air at 10°C by convection for air velocities of (*a*) 0.5 m/s, (*b*) 1.0 m/s, and (*c*) 1.5 m/s.

19–12 During air cooling of oranges, grapefruit, and tangelos, the heat transfer coefficient for combined convection, radiation, and evaporation for air velocities of $0.11 < V < 0.33$ m/s is determined experimentally and is expressed as $h = 5.05\,k_{\text{air}}\text{Re}^{1/3}/D$, where the diameter $D$ is the characteristic length. Oranges are cooled by refrigerated air at 3°C and 1 atm at a velocity of 0.3 m/s. Determine (*a*) the initial rate of heat transfer from a 7-cm-diameter orange initially at 15°C with a thermal conductivity of 0.70 W/m·K, (*b*) the value of the initial temperature gradient inside the orange at the surface, and (*c*) the value of the Nusselt number.

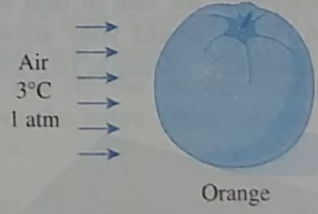


FIGURE P19–12

## Flow over Flat Plates

19–13C What does the friction coefficient represent in flow over a flat plate? How is it related to the drag force acting on the plate?

19–14 In an experiment, the local heat transfer over a flat plate was correlated in the form of local Nusselt number as expressed by the following correlation

$$\text{Nu}_x = 0.035\text{Re}_x^{0.8}\text{Pr}^{1/3}$$

Determine the ratio of the average convection heat transfer coefficient ($h$) over the entire plate length to the local convection heat transfer coefficient ($h_x$) at $x = L$. *Answer:* 1.25

**19–15** A 5-m-long strip of sheet metal is being transported on a conveyor at a velocity of 5 m/s, while the coating on the upper surface is being cured by infrared lamps. The coating on the upper surface of the metal strip has an absorptivity of 0.6 and an emissivity of 0.7, while the surrounding ambient air temperature is 25°C. Radiation heat transfer occurs only on the upper surface, while convection heat transfer occurs on both upper and lower surfaces of the sheet metal. If the infrared lamps supply a constant heat flux of 5000 W/m², determine the surface temperature of the sheet metal. Evaluate the properties of air at 80°C. *Answer:* 138°C

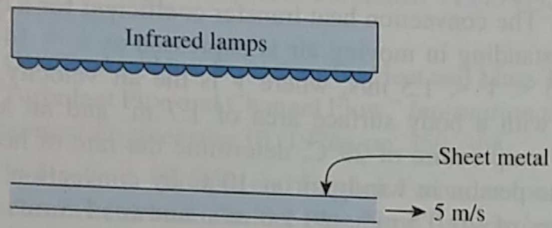


**FIGURE P19–15**

**19–16** The local atmospheric pressure in Denver, Colorado (elevation 1610 m), is 83.4 kPa. Air at this pressure and at 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.

**19–17** During a cold winter day, wind at 42 km/h is blowing parallel to a 6-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 was doubled? *Answers:* 10.8 kW, 19.4 kW

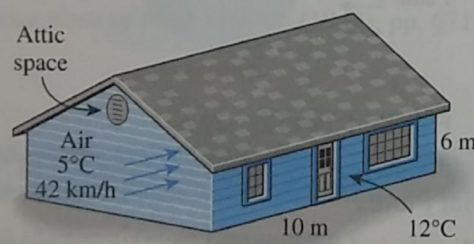


**FIGURE P19–17**

**19–18** Reconsider Prob. 19–17. Using EES (or other) software, investigate the effects of wind velocity and outside air temperature on the rate of heat loss from the wall by convection. Let the wind velocity vary from 10 km/h to 80 km/h and the outside air temperature from 0°C to 10°C. Plot the rate of heat loss as a function of the wind velocity and of the outside temperature, and discuss the results.

**19–19** Water at 43.3°C flows over a large plate at a velocity of 30.0 cm/s. The plate is 1.0 m long (in the flow direction), and its surface is maintained at a uniform temperature of 10.0°C. Calculate the steady rate of heat transfer per unit width of the plate.

**19–20** Hot carbon dioxide exhaust gas at 1 atm is being cooled by flat plates. The gas at 220°C flows in parallel over the upper and lower surfaces of a 1.5-m-long flat plate at a velocity of 3 m/s. If the flat plate surface temperature is maintained at 80°C, determine (*a*) the local convection heat transfer coefficient at 1 m from the leading edge, (*b*) the average convection heat transfer coefficient over the entire plate, and (*c*) the total heat flux transfer to the plate.

**19–21** Hot engine oil at 150°C is flowing in parallel over a flat plate at a velocity of 2 m/s. Surface temperature of the 0.5-m-long flat plate is constant at 50°C. Determine (*a*) the local convection heat transfer coefficient at 0.2 m from the leading edge and the average convection heat transfer coefficient and (*b*) repeat part (*a*) using the Churchill and Ozoe (1973) relation.

**19–22** Mercury at 25°C flows over a 3-m-long and 2-m-wide flat plate maintained at 75°C with a velocity of 0.8 m/s. Determine the rate of heat transfer from the entire plate.

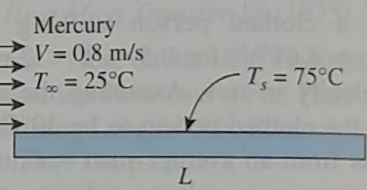


**FIGURE P19–22**

**19–23** Parallel plates form a solar collector that covers a roof, as shown in the figure. The plates are maintained at 15°C, while ambient air at 10°C flows over the roof with $V$ = 4 m/s. Determine the rate of convective heat loss from (*a*) the first plate and (*b*) the third plate.

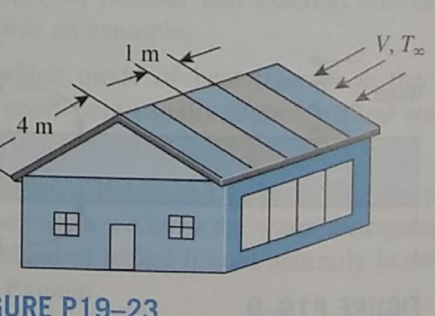


**FIGURE P19–23**

19-24 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 100°C and has an emissivity of 0.95. The ambient air is at 20°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.

19-25 The top surface of the passenger car of a train moving at a velocity of 95 km/h is 2.8 m wide and 8 m long. The top surface is absorbing solar radiation at a rate of 380 W/m², 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:* 37.5°C

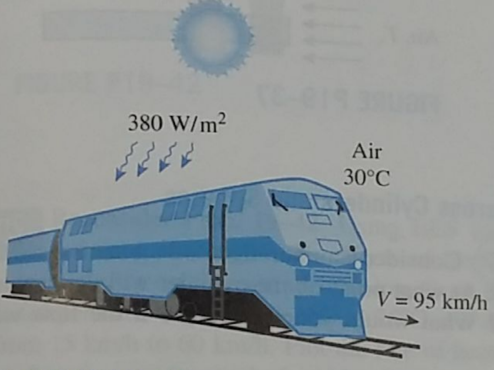


**FIGURE P19–25**

19-26 Reconsider Prob. 19–25. Using EES (or other) software, investigate the effects of the train velocity and the rate of absorption of solar radiation on the equilibrium temperature of the top surface of the car. Let the train velocity vary from 10 km/h to 120 km/h and the rate of solar absorption from 100 W/m² to 500 W/m². Plot the equilibrium temperature as functions of train velocity and solar radiation absorption rate, and discuss the results.

19-27 A 15-cm × 15-cm circuit board dissipating 20 W of power uniformly is cooled by air, which approaches the circuit board at 20°C with a velocity of 6 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.

19-28 Consider a refrigeration truck traveling at 110 km/h at a location where the air temperature is 25°C. The refrigerated compartment of the truck can be considered to be a 2.8-m-wide, 2.1-m-high, and 6-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 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.

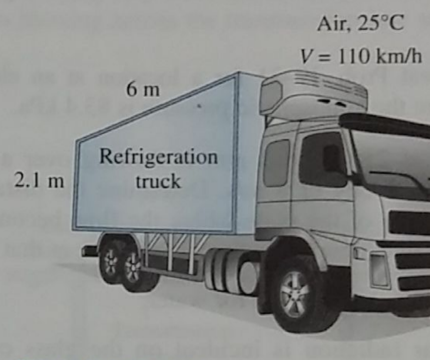


**FIGURE P19–28**

19–29 Liquid mercury at 250°C is flowing in parallel over a flat plate at a velocity of 0.3 m/s. Surface temperature of the 0.1-m-long flat plate is constant at 50°C. Determine (*a*) the local convection heat transfer coefficient at 5 cm from the leading edge and (*b*) the average convection heat transfer coefficient over the entire plate. *Answers:* (*a*) 5343 W/m²·K, (*b*) 7555 W/m²·K

19–30 Liquid mercury at 250°C is flowing with a velocity of 0.3 m/s in parallel over a 0.1-m-long flat plate where there is an unheated starting length of 5 cm. The heated section of the flat plate is maintained at a constant temperature of 50°C. Determine (*a*) the local convection heat transfer coefficient at the trailing edge, (*b*) the average convection heat transfer coefficient for the heated section, and (*c*) the rate of heat transfer per unit width for the heated section.

19–31 An array of power transistors, dissipating 5 W of power each, are to be cooled by mounting them on a 25-cm × 25-cm square aluminum plate and blowing air at 35°C over the plate with a fan at a velocity of 4 m/s. The average temperature of the plate is not to exceed 65°C. Assuming the heat transfer from the back side of the plate to be negligible and disregarding radiation, determine the number of transistors that can be placed on this plate.

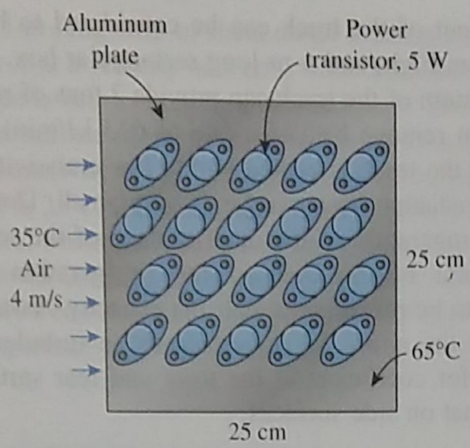


FIGURE P19–31

19–32 Repeat Prob. 19–31 for a location at an elevation of 1610 m where the atmospheric pressure is 83.4 kPa. *Answer:* 5

19–33 Air at 25°C and 1 atm is flowing over a long flat plate with a velocity of 8 m/s. Determine the distance from the leading edge of the plate where the flow becomes turbulent, and the thickness of the boundary layer at that location.

19–34 Repeat Prob. 19–33 for water.

19–35 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 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.

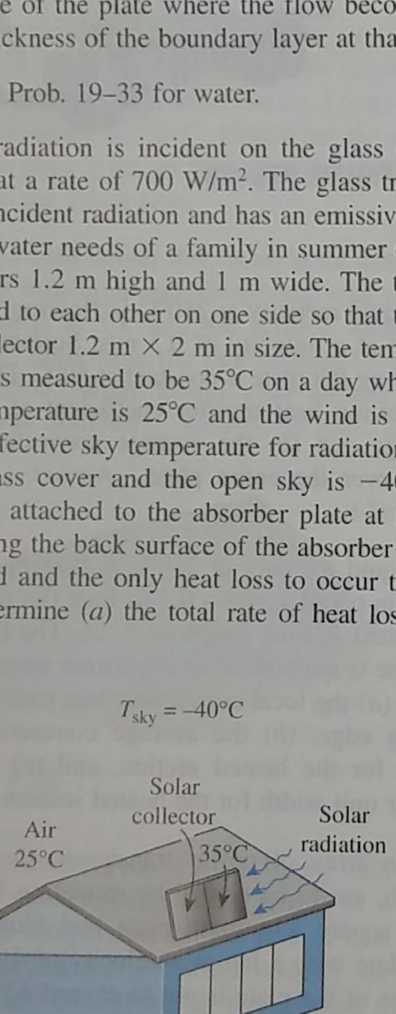


FIGURE P19–35

19–36 A 15-mm × 15-mm silicon chip is mounted such that the edges are flush in a substrate. The chip dissipates 1.4 W of power uniformly, while air at 20°C (1 atm) with a velocity of 25 m/s is used to cool the upper surface of the chip. If the substrate provides an unheated starting length of 15 mm, determine the surface temperature at the trailing edge of the chip. Evaluate the air properties at 50°C.

19–37 Air at 1 atm and 20°C is flowing over the top surface of a 0.5-m-long thin flat plate. The air stream velocity is 50 m/s and the plate is maintained at a constant surface temperature of 180°C. Determine (*a*) the average convection heat transfer coefficient and (*b*) repeat part (*a*) using the modified Reynolds analogy. *Answers:* (*a*) 89.5 W/m²·K, (*b*) 89.5 W/m²·K

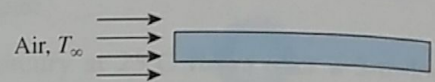


FIGURE P19–37

## Flow across Cylinders and Spheres

19–38C 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?

19–39 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 16,000 W/m², determine the surface temperature of the rod. Evaluate the air properties at 70°C.

19–40 A stainless steel ball ($\rho$ = 8055 kg/m³, $c_p$ = 480 J/kg·K) 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.

19–41 EES Reconsider Prob. 19–40. Using EES (or other) software, investigate the effect of air velocity on the average convection heat transfer coefficient and the cooling time. Let the air velocity vary from 1 m/s to 10 m/s. Plot the heat transfer coefficient and the cooling time as a function of air velocity, and discuss the results.

19–42 A person extends his uncovered arms into the windy air outside at 10°C and 50 km/h in order to feel nature closely. Initially, the skin temperature of the arm is 30°C. Treating the arm as a 0.6-m-long and 7.5-cm-diameter cylinder, determine the rate of heat loss from the arm.

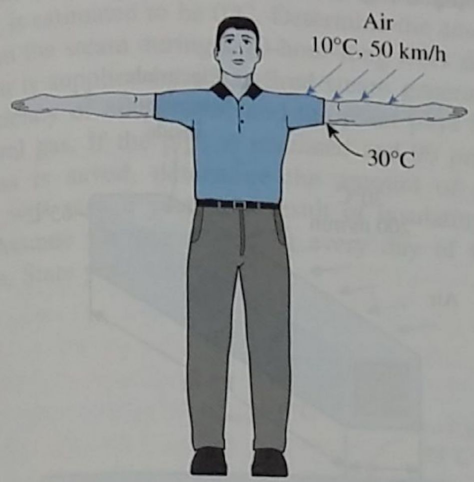


FIGURE P19–42

19–43 Reconsider Prob. 19–42. Using EES (or other) software, investigate the effects of air temperature and wind velocity on the rate of heat loss from the arm. Let the air temperature vary from −5°C to 25°C and the wind velocity from 15 km/h to 60 km/h. Plot the rate of heat loss as a function of air temperature and of wind velocity, and discuss the results.

19–44 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 25 km/h. The head can be approximated as a 30-cm-diameter sphere. *Answer:* 13.2°C

19–45 A long 12-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 65 km/h.

19–46 In a geothermal power plant, the used geothermal water at 80°C enters a 15-cm-diameter and 400-m-long uninsulated pipe at a rate of 8.5 kg/s and leaves at 70°C before being reinjected back to the ground. Windy air at 15°C flows normal to the pipe. Disregarding radiation, determine the average wind velocity in km/h.

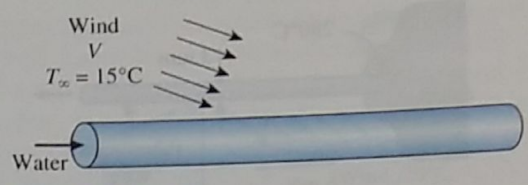


FIGURE P19–46

19–47 A 5-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 50 km/h.

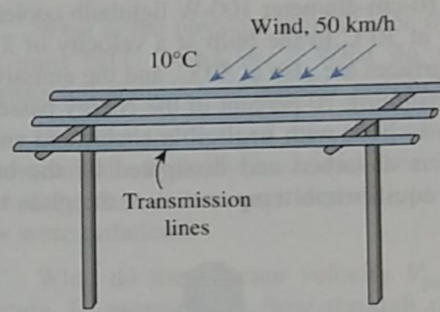


FIGURE P19–47

19–48 Reconsider Prob. 19–47. Using EES (or other) software, investigate the effect of the wind velocity on the surface temperature of the wire. Let the wind velocity vary from 10 km/h to 80 km/h. Plot the surface temperature as a function of wind velocity, and discuss the results.

19–49 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 50 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.

19–50 A long aluminum wire of diameter 3 mm is extruded at a temperature of 280°C. The wire is subjected to cross air flow at 20°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.

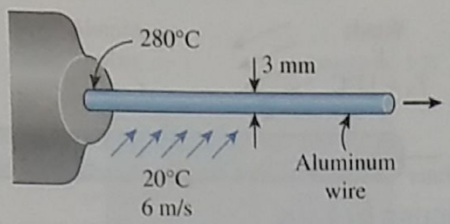


FIGURE P19–50

19–51 An incandescent lightbulb is an inexpensive but highly inefficient device that 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 lightbulb 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 lightbulb.) 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 lightbulb cooled by a fan that blows air at 30°C to the bulb at a velocity of 2 m/s. The surrounding surfaces are also at 30°C, and the emissivity of the glass is 0.9. Assuming 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.

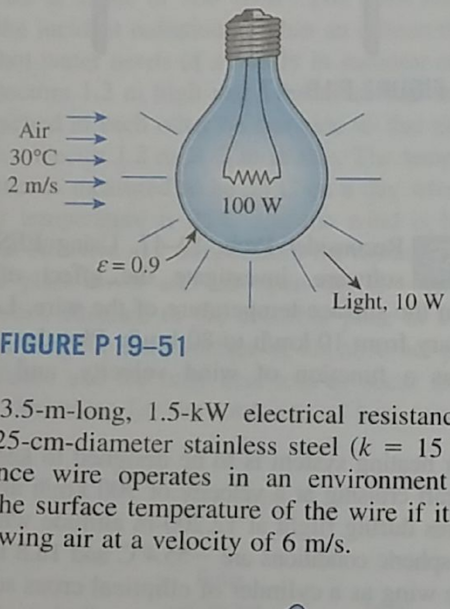


FIGURE P19–51

19–52 A 3.5-m-long, 1.5-kW electrical resistance wire is made of 0.25-cm-diameter stainless steel ($k$ = 15 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 6 m/s.

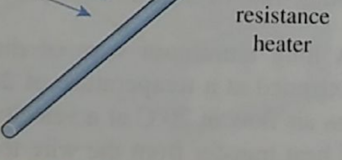


FIGURE P19–52

19–53 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:* 640 W

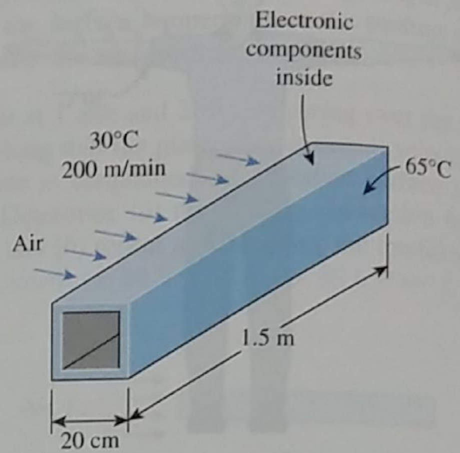


FIGURE P19–53

19–54 Repeat Prob. 19–53 for a location at 3000-m altitude where the atmospheric pressure is 70.12 kPa.

19–55 A 0.4-W cylindrical electronic component with diameter 0.3 cm and length 1.8 cm and mounted on a circuit board is cooled by air flowing across it at a velocity of 240 m/min. If the air temperature is 35°C, determine the surface temperature of the component.

19–56 Consider a 50-cm-diameter and 95-cm-long hot water tank. The tank is placed on the roof of a house. The water inside the tank is heated to 80°C by a flat-plate solar collector during the day. The tank is then exposed to windy air at 18°C with an average velocity of 40 km/h during the night. Estimate the temperature of the tank after a 45-min period. Assume the tank surface to be at the same temperature as the water inside, and the heat transfer coefficient on the top and bottom surfaces to be the same as that on the side surface.

19–57 EES Reconsider Prob. 19–56. Using EES (or other) software, plot the temperature of the tank as a function of the cooling time as the time varies from 30 min to 5 hours, and discuss the results.

19–58 A 2.2-m-diameter spherical tank of negligible thickness contains iced water at 0°C. Air at 25°C flows over the tank with a velocity of 6 m/s. Determine the rate of heat transfer to the tank and the rate at which ice melts. The heat of fusion of water at 0°C is 333.7 kJ/kg.

19–59 During a plant visit, it was noticed that a 12-m-long section of a 12-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 75°C when the ambient temperature is 5°C. There are also light winds in the area at 25 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-hour-long work day.

Steam is supplied by a gas-fired steam generator that has an efficiency of 80 percent, and the plant pays $1.05/therm of natural gas. 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 hours. State your assumptions.

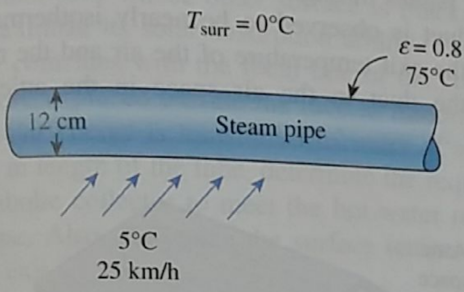


FIGURE P19–59

19–60 Reconsider Prob. 19–59. 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 for average surrounding and surface temperatures of −20°C and 25°C, respectively, and determine the change in the values obtained.

19–61 A 10-cm-diameter, 30-cm-high cylindrical bottle contains cold water at 3°C. The bottle is placed in windy air at 27°C. The water temperature is measured to be 11°C after 45 min of cooling. Disregarding radiation effects and heat transfer from the top and bottom surfaces, estimate the average wind velocity.

19–62 A 0.2-m × 0.2-m street sign surface has an absorptivity of 0.6 and an emissivity of 0.7, while the street sign is subjected to a cross flow wind at 20°C with a velocity of 1 m/s. Solar radiation is incident on the street sign at a rate of 1100 W/m², and the surrounding temperature is 20°C. Determine the surface temperature of the street sign. Evaluate the air properties at 30°C.

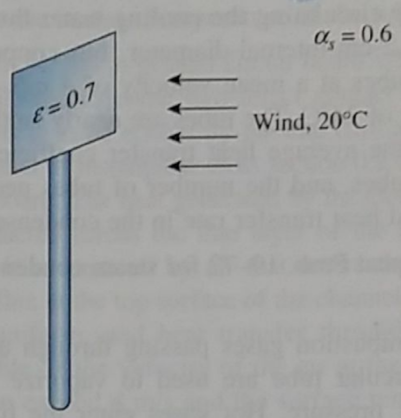


FIGURE P19–62

## Flow in Tubes

19–63C What is the physical significance of the number of transfer units NTU $= hA_s/\dot{m}c_p$? What do small and large NTU values tell about a heat transfer system?

19–64C Consider the flow of mercury (a liquid metal) in a tube. How will the hydrodynamic and thermal entry lengths compare if the flow is laminar? How would they compare if the flow were turbulent?

19–65C What do the average velocity $V_{avg}$ and the mean temperature $T_m$ represent in flow through circular tubes of constant diameter?

19–66C 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?

19–67C How is the thermal entry length defined for flow in a tube? In what region is the flow in a tube fully developed?

19–68C 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?

19–69C 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?

19–70C Consider fluid flow in a tube whose surface temperature remains constant. What is the appropriate temperature difference for use in Newton's law of cooling with an average heat transfer coefficient?

19–71 Air enters an 18-cm-diameter 12-m-long underwater duct at 50°C and 1 atm at a mean velocity of 7 m/s, and is cooled by the water outside. If the average heat transfer coefficient is 65 W/m²·K and the tube temperature is nearly equal to the water temperature of 10°C, determine the exit temperature of air and the rate of heat transfer.

(*a*) The required surface heat flux $\dot{q}_s$, produced by the heater
(*b*) The surface temperature at the exit, $T_s$

**19–79** Determine the hydrodynamic and thermal entry lengths for water, engine oil, and liquid mercury flowing through a 2.5-cm-diameter smooth tube with mass flow rate of 0.01 kg/s and temperature of 100°C.

**19–80** Water is to be heated from 10°C to 80°C as it flows through a 2-cm-internal-diameter, 13-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 5 L/min, determine the power rating of the resistance heater. Also, estimate the inner surface temperature of the pipe at the exit.

**19–81** Hot air at atmospheric pressure and 75°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 0.2 $m^3$/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:* 72.2°C, 582 W

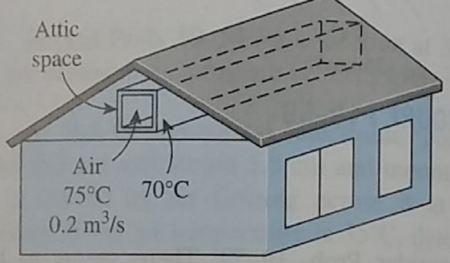


**FIGURE P19–81**

**19–82** Reconsider Prob. 19–81. Using EES (or other) software, investigate the effect of the volume flow rate of air on the exit temperature of air and the rate of heat loss. Let the flow rate vary from 0.05 $m^3$/s to 0.15 $m^3$/s. Plot the exit temperature and the rate of heat loss as a function of flow rate, and discuss the results.

**19–83** Consider a fluid with a Prandtl number of 7 flowing through a smooth circular tube. Using the Colburn, Petukhov, and Gnielinski equations, determine the Nusselt numbers for Reynolds numbers at 3500, $10^4$, and $5 \times 10^5$. Compare and discuss the results.

**19–84** 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. *Answer:* 38.5 m

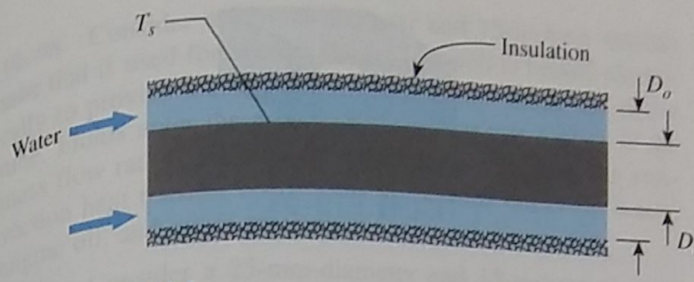


**FIGURE P19–84**

**19–85** The hot-water needs of a household are to be met by heating water at 15°C to 85°C by a parabolic solar collector at a rate of 2.2 kg/s. Water flows through a 3-cm-diameter thin aluminum tube whose outer surface is blackanodized in order to maximize its solar absorption ability. The centerline of the tube coincides with the focal line of the collector, and a glass sleeve is placed outside the tube to minimize the heat losses. If solar energy is transferred to water at a net rate of 350 W per m length of the tube, determine the required length of the parabolic collector to meet the hot-water requirements of this house. Also, determine the surface temperature of the tube at the exit.

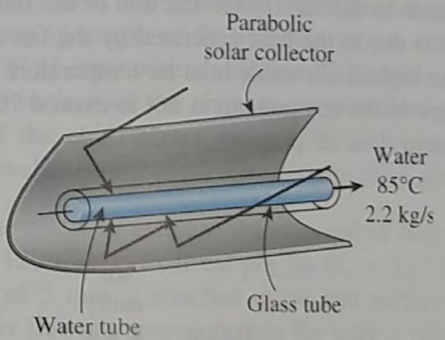


**FIGURE P19–85**

**19–86** In a manufacturing plant that produces cosmetic products, glycerin is being heated by flowing through a 25-mm-diameter and 10-m-long tube. With a mass flow rate of 0.5 kg/s, the flow of glycerin enters the tube at 25°C. The tube surface is maintained at a constant surface temperature of 140°C. Determine the outlet mean temperature and the total rate of heat transfer for the tube. Evaluate the properties for glycerin at 30°C. *Answers:* 35.7°C, 13.1 kW

**19–87** Liquid glycerin is flowing through a 25-mm-diameter and 10-m-long tube. The liquid glycerin enters the tube at

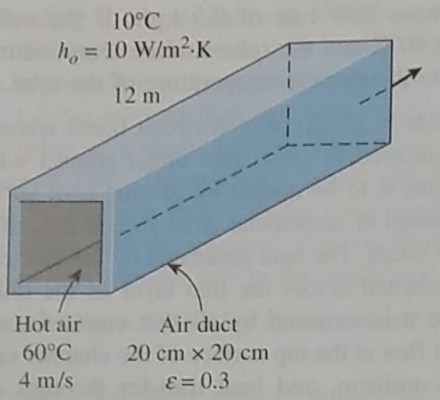


FIGURE P19–91

**19–92** Reconsider Prob. 19–91. Using EES (or other) software, investigate the effect of air velocity and the surface emissivity on the exit temperature of air and the rate of heat loss. Let the air velocity vary from 1 m/s to 10 m/s and the emissivity from 0.1 to 1.0. Plot the exit temperature and the rate of heat loss functions of the air velocity and emissivity, and discuss the results.

**19–93** Liquid water flows at a mass flow rate of 0.7 kg/s through a concentric annulus tube with the inlet and outlet mean temperatures of 20°C and 80°C, respectively. The concentric annulus tube has inner and outer diameters of 10 mm and 100 mm, 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.

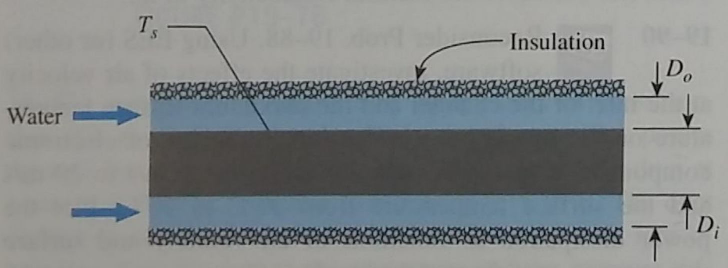


FIGURE P19–93

**19–94** Consider a 10-m-long smooth rectangular tube, with $a$ = 50 mm and $b$ = 25 mm, that is maintained at a constant surface temperature. Liquid water enters the tube at 20°C with a mass flow rate of 0.01 kg/s. Determine the tube surface temperature necessary to heat the water to the desired outlet temperature of 80°C.

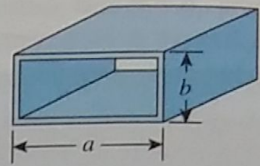


FIGURE P19–94

**19–95** The components of an electronic system dissipating 220 W are located in a 1-m-long horizontal duct whose cross section is 16 cm × 16 cm. The components in the duct are cooled by forced air, which enters at 27°C at a rate of 0.65 m³/min. Assuming 85 percent of the heat generated inside is transferred to air flowing through the duct and the remaining 15 percent is lost through the outer surfaces of the duct, determine (*a*) the exit temperature of air and (*b*) the highest component surface temperature in the duct.

**19–96** Repeat Prob. 19–95 for a circular horizontal duct of 15 cm diameter.

**19–97** A computer cooled by a fan contains eight printed circuit boards (PCBs), each dissipating 12 W of power. The height of the PCBs is 12 cm and the length is 15 cm. The clearance between the tips of the components on the PCB and the back surface of the adjacent PCB is 0.3 cm. The cooling air is supplied by a 10-W fan mounted at the inlet. If the temperature rise of air as it flows through the case of the computer is not to exceed 10°C, determine (*a*) the flow rate of the air that the fan needs to deliver, (*b*) the fraction of the temperature rise of air that is due to the heat generated by the fan and its motor, and (*c*) the highest allowable inlet air temperature if the surface temperature of the components is not to exceed 70°C anywhere in the system. Use air properties at 25°C.

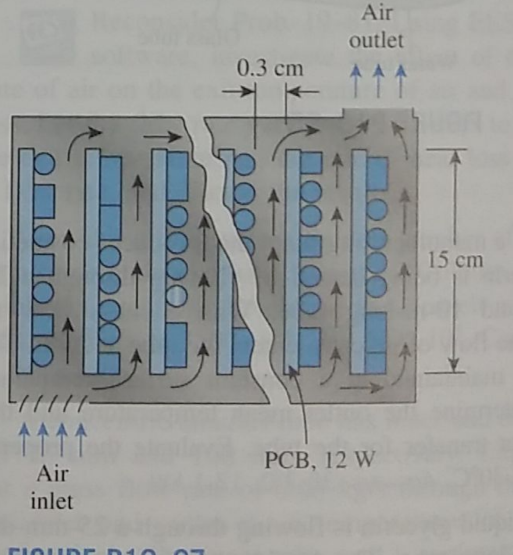


FIGURE P19–97