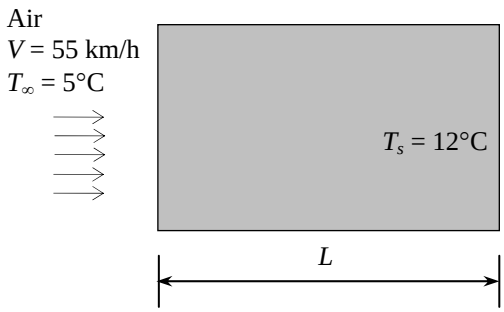
12-41 Wind is blowing parallel to the wall of a house. The rate of heat loss from that wall is to be determined for two cases.

Assumptions **1** Steady operating conditions exist. **2** The critical Reynolds number is $\text{Re}_{cr} = 5\times10^5$. **3** Radiation effects are negligible. **4** Air is an ideal gas with constant properties.

Properties The properties of air at 1 atm and the film temperature of $(T_s + T_\infty)/2 = (12+5)/2 = 8.5°\text{C}$ are (Table A-22)

$$k = 0.02428\ \text{W/m}\cdot°\text{C}$$
$$\nu = 1.413\times10^{-5}\ \text{m}^2/\text{s}$$
$$\text{Pr} = 0.7340$$



Analysis *Air flows parallel to the 10 m side*:

The Reynolds number in this case is

$$\text{Re}_L = \frac{VL}{\nu} = \frac{[(55\times1000/3600)\text{m/s}](10\ \text{m})}{1.413\times10^{-5}\ \text{m}^2/\text{s}} = 1.081\times10^7$$

which is greater than the critical Reynolds number. Thus we have combined laminar and turbulent flow. Using the proper relation for Nusselt number, heat transfer coefficient and then heat transfer rate are determined to be

$$Nu = \frac{hL}{k} = (0.037\,\text{Re}_L^{\,0.8} - 871)\,\text{Pr}^{1/3} = [0.037(1.081\times10^7)^{0.8} - 871](0.7340)^{1/3} = 1.336\times10^4$$

$$h = \frac{k}{L}Nu = \frac{0.02428\ \text{W/m.°C}}{10\ \text{m}}(1.336\times10^4) = 32.43\ \text{W/m}^2.°\text{C}$$

$$A_s = wL = (4\ \text{m})(10\ \text{m}) = 40\ \text{m}^2$$

$$\dot{Q} = hA_s(T_\infty - T_s) = (32.43\ \text{W/m}^2.°\text{C})(40\ \text{m}^2)(12-5)°\text{C} = 9080\ \text{W} = \mathbf{9.08\ kW}$$

If the wind velocity is doubled:

$$\text{Re}_L = \frac{VL}{\nu} = \frac{[(110\times1000/3600)\text{m/s}](10\ \text{m})}{1.413\times10^{-5}\ \text{m}^2/\text{s}} = 2.162\times10^7$$

which is greater than the critical Reynolds number. Thus we have combined laminar and turbulent flow. Using the proper relation for Nusselt number, the average heat transfer coefficient and the heat transfer rate are determined to be

$$Nu = \frac{hL}{k} = (0.037\,\text{Re}_L^{\,0.8} - 871)\,\text{Pr}^{1/3} = [0.037(2.162\times10^7)^{0.8} - 871](0.7340)^{1/3} = 2.384\times10^4$$

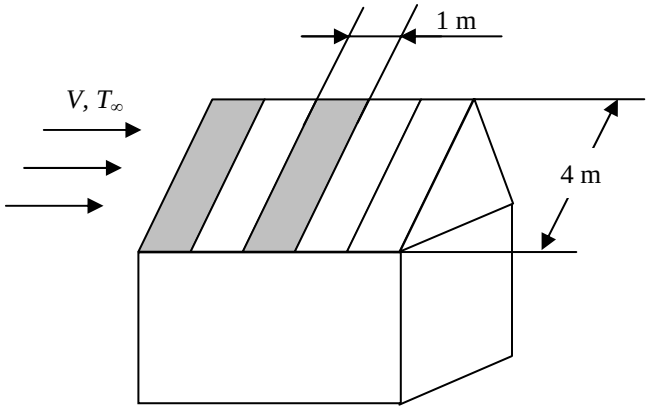
$$h = \frac{k}{L}Nu = \frac{0.02428\ \text{W/m.°C}}{10\ \text{m}}(2.384\times10^4) = 57.88\ \text{W/m}^2.°\text{C}$$

$$\dot{Q} = hA_s(T_\infty - T_s) = (57.88\ \text{W/m}^2.°\text{C})(40\ \text{m}^2)(12-5)°\text{C} = 16{,}210\ \text{W} = \mathbf{16.21\ kW}$$

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12-48 Ambient air flows over parallel plates of a solar collector that is maintained at a specified temperature. The rates of convection heat transfer from the first and third plate are to be determined.

Assumptions **1** Steady operating conditions exist. **2** The critical Reynolds number is $\text{Re}_{cr} = 5\times10^5$. **3** Radiation effects are negligible. **4** Atmospheric pressure is taken 1 atm.



Properties The properties of air at the film temperature of (15+10)/2=12.5°C are (Table A-22)

$$k = 0.02458\ \text{W/m.°C}$$
$$\nu = 1.448\times10^{-5}\ \text{m}^2/\text{s}$$
$$\text{Pr} = 0.7330$$

Analysis (*a*) The critical length of the plate is first determined to be

$$x_{cr} = \frac{\text{Re}_{cr}\,\nu}{V} = \frac{(5\times10^5)(1.448\times10^{-5}\ \text{m}^2/\text{s})}{2\ \text{m/s}} = 3.62\ \text{m}$$

Therefore, both plates are under laminar flow. The Reynolds number for the first plate is

$$\text{Re}_1 = \frac{VL_1}{\nu} = \frac{(2\ \text{m/s})(1\,\text{m})}{1.448\times10^{-5}\ \text{m}^2/\text{s}} = 1.381\times10^5$$

Using the relation for Nusselt number, the average heat transfer coefficient and the heat transfer rate are determined to be

$$\text{Nu}_1 = 0.664\,\text{Re}_1^{\,1/2}\,\text{Pr}^{1/3} = 0.664(1.381\times10^5)^{1/2}(0.7330)^{1/3} = 222.5$$
$$h_1 = \frac{k}{L_1}Nu = \frac{0.02458\ \text{W/m.°C}}{1\,\text{m}}(222.5) = 5.47\ \text{W/m}^2.\text{°C}$$
$$A = wL = (4\,\text{m})(1\,\text{m}) = 4\,\text{m}^2$$
$$\dot{Q} = hA(T_s - T_\infty) = (5.47\ \text{W/m}^2.\text{°C})(4\,\text{m}^2)(15-10)\text{°C} = \mathbf{109\ W}$$

(*b*) Repeating the calculations for the second and third plates,

$$\text{Re}_2 = \frac{VL_2}{\nu} = \frac{(2\ \text{m/s})(2\,\text{m})}{1.448\times10^{-5}\ \text{m}^2/\text{s}} = 2.762\times10^5$$
$$\text{Nu}_2 = 0.664\,\text{Re}_2^{\,1/2}\,\text{Pr}^{1/3} = 0.664(2.762\times10^5)^{1/2}(0.7330)^{1/3} = 314.7$$
$$h_2 = \frac{k}{L_2}Nu = \frac{0.02458\ \text{W/m.°C}}{2\,\text{m}}(314.7) = 3.87\ \text{W/m}^2.\text{°C}$$
$$\text{Re}_3 = \frac{VL_3}{\nu} = \frac{(2\ \text{m/s})(3\,\text{m})}{1.448\times10^{-5}\ \text{m}^2/\text{s}} = 4.144\times10^5$$
$$\text{Nu}_3 = 0.664\,\text{Re}_3^{\,1/2}\,\text{Pr}^{1/3} = 0.664(4.144\times10^5)^{1/2}(0.7330)^{1/3} = 385.4$$
$$h_3 = \frac{k}{L_3}Nu = \frac{0.02458\ \text{W/m.°C}}{3\,\text{m}}(385.4) = 3.16\ \text{W/m}^2.\text{°C}$$

Then

$$h_{2-3} = \frac{h_3L_3 - h_2L_2}{L_3 - L_2} = \frac{3.16\times3 - 3.87\times2}{3-2} = 1.74\ \text{W/m}^2.\text{°C}$$

The rate of heat loss from the third plate is

$$\dot{Q} = hA(T_s - T_\infty) = (1.74\ \text{W/m}^2.\text{°C})(4\ \text{m}^2)(15-10)\text{°C} = \mathbf{34.8\ W}$$

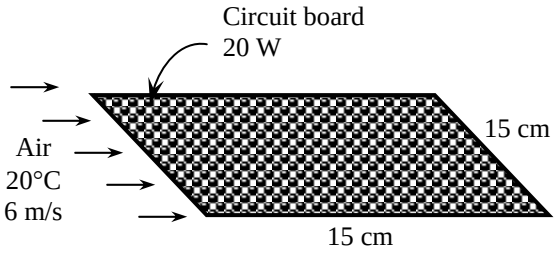
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12-53 A circuit board is cooled by air. The surface temperatures of the electronic components at the leading edge and the end of the board are to be determined.

Assumptions **1** Steady operating conditions exist. **2** The critical Reynolds number is $\mathrm{Re}_{cr} = 5\times10^5$. **3** Radiation effects are negligible. **4** Any heat transfer from the back surface of the board is disregarded. **5** Air is an ideal gas with constant properties.

Properties Assuming the film temperature to be approximately 35°C, the properties of air are evaluated at this temperature to be (Table A-22)

$$k = 0.0265\ \mathrm{W/m.°C}$$
$$\nu = 1.655\times10^{-5}\ \mathrm{m^2/s}$$
$$\mathrm{Pr} = 0.7268$$



Analysis (*a*) The convection heat transfer coefficient at the leading edge approaches infinity, and thus the surface temperature there must approach the air temperature, which is 20°C.

(*b*) The Reynolds number is

$$\mathrm{Re}_x = \frac{Vx}{\nu} = \frac{(6\ \mathrm{m/s})(0.15\ \mathrm{m})}{1.655\times10^{-5}\ \mathrm{m^2/s}} = 5.438\times10^4$$

which is less than the critical Reynolds number but we assume the flow to be turbulent since the electronic components are expected to act as turbulators. Using the Nusselt number uniform heat flux, the local heat transfer coefficient at the end of the board is determined to be

$$Nu_x = \frac{h_x x}{k} = 0.0308\,\mathrm{Re}_x^{\,0.8}\,\mathrm{Pr}^{1/3} = 0.0308(5.438\times10^4)^{0.8}(0.7268)^{1/3} = 170.1$$
$$h_x = \frac{k_x}{x}Nu_x = \frac{0.02625\ \mathrm{W/m.°C}}{0.15\ \mathrm{m}}(170.1) = 29.77\ \mathrm{W/m^2.°C}$$

Then the surface temperature at the end of the board becomes

$$\dot{q} = h_x(T_s - T_\infty) \longrightarrow T_s = T_\infty + \frac{\dot{q}}{h_x} = 20°\mathrm{C} + \frac{(20\ \mathrm{W})/(0.15\ \mathrm{m})^2}{29.77\ \mathrm{W/m^2.°C}} = \mathbf{49.9°C}$$

Discussion The heat flux can also be determined approximately using the relation for isothermal surfaces,

$$Nu_x = \frac{h_x x}{k} = 0.0296\,\mathrm{Re}_x^{\,0.8}\,\mathrm{Pr}^{1/3} = 0.0296(5.438\times10^4)^{0.8}(0.7268)^{1/3} = 163.5$$
$$h_x = \frac{k_x}{x}Nu_x = \frac{0.02625\ \mathrm{W/m.°C}}{0.15\ \mathrm{m}}(163.5) = 28.61\ \mathrm{W/m^2.°C}$$

Then the surface temperature at the end of the board becomes

$$\dot{q} = h_x(T_s - T_\infty) \longrightarrow T_s = T_\infty + \frac{\dot{q}}{h_x} = 20°\mathrm{C} + \frac{(20\ \mathrm{W})/(0.15\ \mathrm{m})^2}{28.61\ \mathrm{W/m^2.°C}} = \mathbf{51.1°C}$$

Note that the two results are close to each other.

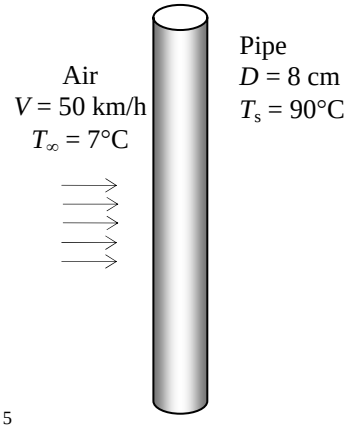
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12-68 A steam pipe is exposed to windy air. The rate of heat loss from the steam is to be determined.√

Assumptions **1** Steady operating conditions exist. **2** Radiation effects are negligible. **3** Air is an ideal gas with constant properties.

Properties The properties of air at 1 atm and the film temperature of $(T_s + T_\infty)/2 = (90+7)/2 = 48.5°C$ are (Table A-22)

$$k = 0.02724 \text{ W/m.°C}$$
$$\nu = 1.784\times10^{-5} \text{ m}^2/\text{s}$$
$$\text{Pr} = 0.7232$$



Analysis The Reynolds number is

$$\text{Re} = \frac{VD}{\nu} = \frac{[(50 \text{ km/h})(1000 \text{ m/km})/(3600 \text{ s/h})](0.08 \text{ m})}{1.784\times10^{-5} \text{ m}^2/\text{s}} = 6.228\times10^4$$

The Nusselt number corresponding to this Reynolds number is

$$Nu = \frac{hD}{k} = 0.3 + \frac{0.62 \text{ Re}^{0.5} \text{ Pr}^{1/3}}{\left[1+(0.4/\text{Pr})^{2/3}\right]^{1/4}}\left[1+\left(\frac{\text{Re}}{282{,}000}\right)^{5/8}\right]^{4/5}$$

$$= 0.3 + \frac{0.62(6.228\times10^4)^{0.5}(0.7232)^{1/3}}{\left[1+(0.4/0.7232)^{2/3}\right]^{1/4}}\left[1+\left(\frac{6.228\times10^4}{282{,}000}\right)^{5/8}\right]^{4/5} = 159.1$$

The heat transfer coefficient and the heat transfer rate become

$$h = \frac{k}{D}Nu = \frac{0.02724 \text{ W/m.°C}}{0.08 \text{ m}}(159.1) = 54.17 \text{ W/m}^2\text{.°C}$$

$$A_s = \pi DL = \pi(0.08 \text{ m})(1 \text{ m}) = 0.2513 \text{ m}^2$$

$$\dot{Q}_{conv} = hA_s(T_s - T_\infty) = (54.17 \text{ W/m}^2\text{.°C})(0.2513 \text{ m}^2)(90-7)°C = \mathbf{1130\ W} \text{ (per m length)}$$

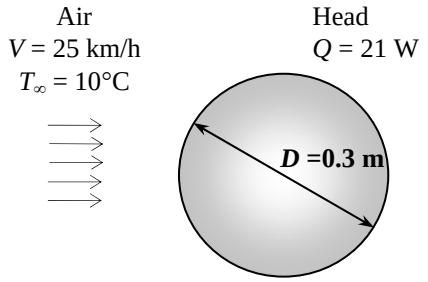
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12-74 The average surface temperature of the head of a person when it is not covered and is subjected to winds is to be determined.

Assumptions **1** Steady operating conditions exist. **2** Radiation effects are negligible. **3** Air is an ideal gas with constant properties. **4** One-quarter of the heat the person generates is lost from the head. **5** The head can be approximated as a 30-cm-diameter sphere. **6** The local atmospheric pressure is 1 atm.

Properties We assume the surface temperature to be 15°C for viscosity. The properties of air at 1 atm pressure and the free stream temperature of 10°C are (Table A-22)

$$k = 0.02439 \text{ W/m.°C}$$
$$\nu = 1.426\times10^{-5} \text{ m}^2/\text{s}$$
$$\mu_\infty = 1.778\times10^{-5} \text{ kg/m.s}$$
$$\mu_{s,@15°C} = 1.802\times10^{-5} \text{ kg/m.s}$$
$$\text{Pr} = 0.7336$$



Analysis The Reynolds number is

$$\text{Re} = \frac{VD}{\nu} = \frac{[(25\times1000/3600) \text{ m/s}](0.3 \text{ m})}{1.426\times10^{-5} \text{ m}^2/\text{s}} = 1.461\times10^5$$

The proper relation for Nusselt number corresponding to this Reynolds number is

$$Nu = \frac{hD}{k} = 2 + \left[0.4\,\text{Re}^{0.5} + 0.06\,\text{Re}^{2/3}\right]\text{Pr}^{0.4}\left(\frac{\mu_\infty}{\mu_s}\right)^{1/4}$$

$$= 2 + \left[0.4(1.461\times10^5)^{0.5} + 0.06(1.461\times10^5)^{2/3}\right](0.7336)^{0.4}\left(\frac{1.778\times10^{-5}}{1.802\times10^{-5}}\right)^{1/4} = 283.2$$

The heat transfer coefficient is

$$h = \frac{k}{D}Nu = \frac{0.02439 \text{ W/m.°C}}{0.3 \text{ m}}(283.2) = 23.02 \text{ W/m}^2\text{.°C}$$

Then the surface temperature of the head is determined to be

$$A_s = \pi D^2 = \pi(0.3 \text{ m})^2 = 0.2827 \text{ m}^2$$

$$\dot{Q} = hA_s(T_s - T_\infty) \longrightarrow T_s = T_\infty + \frac{\dot{Q}}{hA_s} = 10 \text{ °C} + \frac{(84/4) \text{ W}}{(23.02 \text{ W/m}^2\text{.°C})(0.2827 \text{ m}^2)} = \mathbf{13.2\ °C}$$

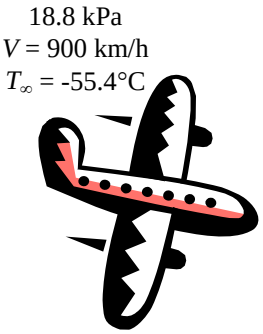
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12-78 An aircraft is cruising at 900 km/h. A heating system keeps the wings above freezing temperatures. The average convection heat transfer coefficient on the wing surface and the average rate of heat transfer per unit surface area are to be determined.

Assumptions **1** Steady operating conditions exist. **2** Radiation effects are negligible. **3** Air is an ideal gas with constant properties. **4** The wing is approximated as a cylinder of elliptical cross section whose minor axis is 50 cm.

Properties The properties of air at 1 atm and the film temperature of $(T_s + T_\infty)/2 = (0\text{-}55.4)/2 = -27.7°C$ are (Table A-22)

$$k = 0.02152 \text{ W/m.°C}$$
$$\nu = 1.106\times10^{-5} \text{ m}^2/\text{s}$$
$$\text{Pr} = 0.7421$$



Note that the atmospheric pressure will only affect the kinematic viscosity. The atmospheric pressure in atm unit is

$$P = (18.8 \text{ kPa})\frac{1 \text{ atm}}{101.325 \text{ kPa}} = 0.1855 \text{ atm}$$

The kinematic viscosity at this atmospheric pressure is

$$\nu = (1.106\times10^{-5} \text{ m}^2/\text{s})/0.1855 = 5.961\times10^{-5} \text{ m}^2/\text{s}$$

Analysis The Reynolds number is

$$\text{Re} = \frac{VD}{\nu} = \frac{[(900\times1000/3600) \text{ m/s}](0.5 \text{ m})}{5.961\times10^{-5} \text{ m}^2/\text{s}} = 2.097\times10^6$$

The Nusselt number relation for a cylinder of elliptical cross-section is limited to Re < 15,000, and the relation below is not really applicable in this case. However, this relation is all we have for elliptical shapes, and we will use it with the understanding that the results may not be accurate.

$$Nu = \frac{hD}{k} = 0.248\,\text{Re}^{0.612}\,\text{Pr}^{1/3} = 0.248(2.097\times10^6)^{0.612}(0.7241)^{1/3} = 1660$$

The average heat transfer coefficient on the wing surface is

$$h = \frac{k}{D}Nu = \frac{0.02152 \text{ W/m.°C}}{0.5 \text{ m}}(1660) = \mathbf{71.45 \text{ W/m}^2\text{.°C}}$$

Then the average rate of heat transfer per unit surface area becomes

$$\dot{q} = h(T_s - T_\infty) = (71.45 \text{ W/m}^2\text{.°C})[0-(-55.4)]°C = \mathbf{3958 \text{ W/m}^2}$$

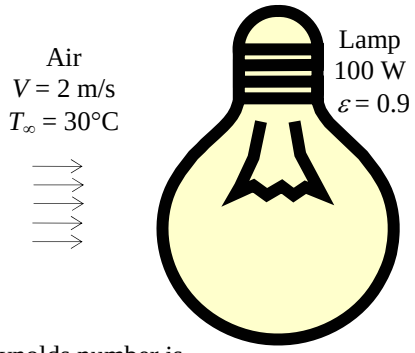
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12-81 A light bulb is cooled by a fan. The equilibrium temperature of the glass bulb is to be determined.

Assumptions **1** Steady operating conditions exist. **2** Air is an ideal gas with constant properties. **3** The light bulb is in spherical shape. **4** The local atmospheric pressure is 1 atm.

Properties We assume the surface temperature to be 100°C for viscosity. The properties of air at 1 atm pressure and the free stream temperature of 30°C are (Table A-22)

$$k = 0.02588 \text{ W/m.°C}$$
$$\nu = 1.608\times10^{-5} \text{ m}^2\text{/s}$$
$$\mu_\infty = 1.872\times10^{-5} \text{ kg/m.s}$$
$$\mu_{s,@100°C} = 2.181\times10^{-5} \text{ kg/m.s}$$
$$\text{Pr} = 0.7282$$



Analysis The Reynolds number is

$$\text{Re} = \frac{VD}{\nu} = \frac{(2 \text{ m/s})(0.1 \text{ m})}{1.608\times10^{-5} \text{ m}^2\text{/s}} = 1.244\times10^4$$

The proper relation for Nusselt number corresponding to this Reynolds number is

$$Nu = \frac{hD}{k} = 2 + \left[0.4\,\text{Re}^{0.5} + 0.06\,\text{Re}^{2/3}\right]\text{Pr}^{0.4}\left(\frac{\mu_\infty}{\mu_s}\right)^{1/4}$$

$$= 2 + \left[0.4(1.244\times10^4)^{0.5} + 0.06(1.244\times10^4)^{2/3}\right](0.7282)^{0.4}\left(\frac{1.872\times10^{-5}}{2.181\times10^{-5}}\right)^{1/4} = 67.14$$

The heat transfer coefficient is

$$h = \frac{k}{D}Nu = \frac{0.02588 \text{ W/m.°C}}{0.1 \text{ m}}(67.14) = 17.37 \text{ W/m}^2\text{.°C}$$

Noting that 90 % of electrical energy is converted to heat,

$$\dot{Q} = (0.90)(100 \text{ W}) = 90 \text{ W}$$

The bulb loses heat by both convection and radiation. The equilibrium temperature of the glass bulb can be determined by iteration or by an equation solver:

$$A_s = \pi D^2 = \pi(0.1 \text{ m})^2 = 0.0314 \text{ m}^2$$

$$\dot{Q}_{\text{total}} = \dot{Q}_{conv} + \dot{Q}_{rad} = hA_s(T_s - T_\infty) + \varepsilon A_s\sigma(T_s^4 - T_{surr}^4)$$

$$90 \text{ W} = (17.37 \text{ W/m}^2\text{.°C})(0.0314 \text{ m}^2)\left[T_s - (30+273)\text{K}\right]$$
$$+ (0.9)(0.0314 \text{ m}^2)(5.67\times10^{-8} \text{ W/m}^2\text{.K}^4)\left[T_s^4 - (30+273 \text{ K})^4\right]$$

$$T_s = 409.9 \text{ K} = \mathbf{136.9°C}$$

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