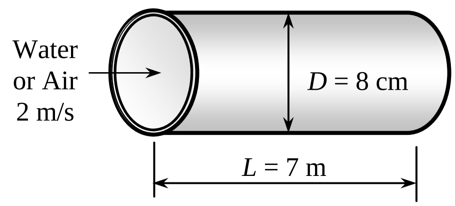
13-39 The convection heat transfer coefficients for the flow of air and water are to be determined under similar conditions.

Assumptions **1** Steady flow conditions exist. **2** The surface heat flux is uniform. **3** The inner surfaces of the tube are smooth.

Properties The properties of air at 25°C are (Table A-22)

$$k = 0.02551 \text{ W/m.°C}$$
$$\nu = 1.562\times10^{-5} \text{ m}^2\text{/s}$$
$$\text{Pr} = 0.7296$$



The properties of water at 25°C are (Table A-15)

$$\rho = 997 \text{ kg/m}^3$$
$$k = 0.607 \text{ W/m.°C}$$
$$\nu = \mu/\rho = 0.891\times10^{-3}/997 = 8.937\times10^{-7} \text{ m}^2\text{/s}$$
$$\text{Pr} = 6.14$$

Analysis The Reynolds number is

$$\text{Re} = \frac{VD}{\nu} = \frac{(2 \text{ m/s})(0.08 \text{ m})}{1.562\times10^{-5} \text{ m}^2\text{/s}} = 10{,}243$$

which is greater than 10,000. Therefore, the flow is turbulent and the entry lengths in this case are roughly

$$L_h \approx L_t \approx 10D = 10(0.08 \text{ m}) = 0.8 \text{ m}$$

which is much shorter than the total length of the tube. Therefore, we can assume fully developed turbulent flow in the entire duct, and determine the Nusselt number from

$$Nu = \frac{hD}{k} = 0.023\,\text{Re}^{0.8}\,\text{Pr}^{0.4} = 0.023(10{,}243)^{0.8}(0.7296)^{0.4} = 32.76$$

Heat transfer coefficient is

$$h = \frac{k}{D}Nu = \frac{0.02551 \text{ W/m.°C}}{0.08 \text{ m}}(32.76) = \mathbf{10.45\ W/m^2.°C}$$

Repeating calculations for water:

$$\text{Re} = \frac{VD}{\nu} = \frac{(2 \text{ m/s})(0.08 \text{ m})}{8.937\times10^{-7} \text{ m}^2\text{/s}} = 179{,}035$$

$$Nu = \frac{hD}{k} = 0.023\,\text{Re}^{0.8}\,\text{Pr}^{0.4} = 0.023(179{,}035)^{0.8}(6.14)^{0.4} = 757.4$$

$$h = \frac{k}{D}Nu = \frac{0.607 \text{ W/m.°C}}{0.08 \text{ m}}(757.4) = \mathbf{5747\ W/m^2.°C}$$

Discussion The heat transfer coefficient for water is 550 times that of air.

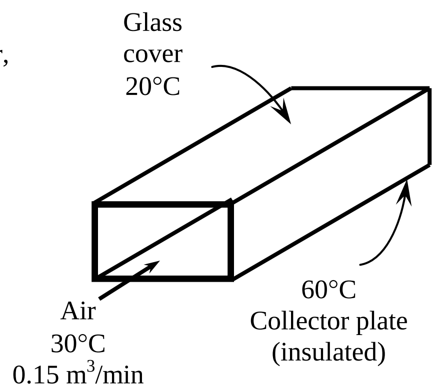
13-47 Air enters the constant spacing between the glass cover and the plate of a solar collector. The net rate of heat transfer and the temperature rise of air are to be determined.

Assumptions **1** Steady operating conditions exist. **2** The inner surfaces of the spacing are smooth. **3** Air is an ideal gas with constant properties. **4** The local atmospheric pressure is 1 atm.

Properties The properties of air at 1 atm and estimated average temperature of 35°C are (Table A-22)

$$\rho = 1.145 \text{ kg/m}^3, \quad k = 0.02625 \text{ W/m.°C}$$

$$\nu = 1.655 \times 10^{-5} \text{ m}^2\text{/s}, \quad c_p = 1007 \text{ J/kg.°C}, \quad \text{Pr} = 0.7268$$



Analysis Mass flow rate, cross sectional area, hydraulic diameter, mean velocity of air and the Reynolds number are

$$\dot{m} = \rho \dot{V} = (1.145 \text{ kg/m}^3)(0.15 \text{ m}^3\text{/s}) = 0.1718 \text{ kg/s}$$

$$A_c = (1 \text{ m})(0.03 \text{ m}) = 0.03 \text{ m}^2$$

$$D_h = \frac{4A_c}{P} = \frac{4(0.03 \text{ m}^2)}{2(1 \text{ m} + 0.03 \text{ m})} = 0.05825 \text{ m}$$

$$V_{\text{avg}} = \frac{\dot{V}}{A_c} = \frac{0.15 \text{ m}^3\text{/s}}{0.03 \text{ m}^2} = 5 \text{ m/s}$$

$$\text{Re} = \frac{V_{\text{avg}} D_h}{\nu} = \frac{(5 \text{ m/s})(0.05825 \text{ m})}{1.655 \times 10^{-5} \text{ m}^2\text{/s}} = 17{,}600$$

which is greater than 10,000. Therefore, the flow is turbulent and the entry lengths in this case are roughly

$$L_h \approx L_t \approx 10 D_h = 10(0.05825 \text{ m}) = 0.5825 \text{ m}$$

which are much shorter than the total length of the collector. Therefore, we can assume fully developed turbulent flow in the entire collector, and determine the Nusselt number from

$$Nu = \frac{hD_h}{k} = 0.023 \text{Re}^{0.8} \text{Pr}^{0.4} = 0.023(17{,}600)^{0.8}(0.7268)^{0.4} = 50.43$$

and $$h = \frac{k}{D_h} Nu = \frac{0.02625 \text{ W/m.°C}}{0.05825 \text{ m}}(50.43) = 22.73 \text{ W/m}^2\text{.°C}$$

The exit temperature of air can be calculated using the "average" surface temperature as

$$A_s = 2(5 \text{ m})(1 \text{ m}) = 10 \text{ m}^2, \qquad T_{s,avg} = \frac{60 + 20}{2} = 40°\text{C}$$

$$T_e = T_{s,avg} - (T_{s,avg} - T_i)\exp\left(-\frac{hA_s}{\dot{m}c_p}\right) = 40 - (40 - 30)\exp\left(-\frac{22.73 \times 10}{0.1718 \times 1007}\right) = 37.31°\text{C}$$

The temperature rise of air is

$$\Delta T = 37.3°\text{C} - 30°\text{C} = \mathbf{7.3°C}$$

The logarithmic mean temperature difference and the heat loss from the glass are

$$\Delta T_{\ln,glass} = \frac{T_e - T_i}{\ln \frac{T_s - T_e}{T_s - T_i}} = \frac{37.31 - 30}{\ln \frac{20 - 37.31}{20 - 30}} = 13.32°\text{C}$$

$$\dot{Q}_{glass} = hA_s \Delta T_{\ln} = (22.73 \text{ W/m}^2\text{.°C})(5 \text{ m}^2)(13.32°\text{C}) = 1514 \text{ W}$$

The logarithmic mean temperature difference and the heat gain of the absorber are

$$\Delta T_{\ln,absorber} = \frac{T_e - T_i}{\ln \frac{T_s - T_e}{T_s - T_i}} = \frac{37.31 - 30}{\ln \frac{60 - 37.31}{60 - 30}} = 26.17°\text{C}$$

$$\dot{Q}_{absorber} = hA\Delta T_{\ln} = (22.73 \text{ W/m}^2\text{.°C})(5 \text{ m}^2)(26.17°\text{C}) = 2975 \text{ W}$$

Then the net rate of heat transfer becomes

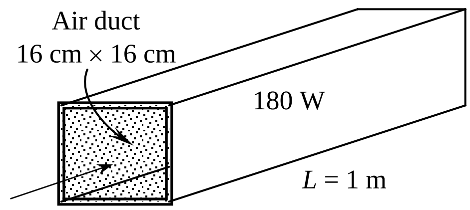
$$\dot{Q}_{net} = 2975 - 1514 = \mathbf{1461 \ W}$$

13-59 The components of an electronic system located in a rectangular horizontal duct are cooled by forced air. The exit temperature of the air and the highest component surface temperature are to be determined.

Assumptions **1** Steady flow conditions exist. **2** The inner surfaces of the duct are smooth. **3** The thermal resistance of the duct is negligible. **4** Air is an ideal gas with constant properties. **5** The pressure of air is 1 atm.

Properties We assume the bulk mean temperature for air to be 35°C since the mean temperature of air at the inlet will rise somewhat as a result of heat gain through the duct whose surface is exposed to a constant heat flux. The properties of air at 1 atm and this temperature are (Table A-22)

$$\rho = 1.145\ \text{kg/m}^3$$
$$k = 0.02625\ \text{W/m.°C}$$
$$\nu = 1.655\times10^{-5}\ \text{m}^2/\text{s}$$
$$c_p = 1007\ \text{J/kg.°C}$$
$$\Pr = 0.7268$$



Analysis (*a*) The mass flow rate of air and the exit temperature are determined from

$$\dot{m} = \rho\dot{V} = (1.145\ \text{kg/m}^3)(0.65\ \text{m}^3/\text{min}) = 0.7443\ \text{kg/min} = 0.0124\ \text{kg/s}$$

$$\dot{Q} = \dot{m}c_p(T_e - T_i) \rightarrow T_e = T_i + \frac{\dot{Q}}{\dot{m}c_p} = 27°\text{C} + \frac{(0.85)(180\ \text{W})}{(0.0124\ \text{kg/s})(1007\ \text{J/kg.°C})} = \mathbf{39.3°C}$$

(*b*) The mean fluid velocity and hydraulic diameter are

$$V_m = \frac{\dot{V}}{A_c} = \frac{0.65\ \text{m/min}}{(0.16\ \text{m})(0.16\ \text{m})} = 25.4\ \text{m/min} = 0.4232\ \text{m/s}$$

$$D_h = \frac{4A_c}{p} = \frac{4(0.16\ \text{m})(0.16\ \text{m})}{4(0.16\ \text{m})} = 0.16\ \text{m}$$

Then

$$\text{Re} = \frac{V_{\text{avg}}D_h}{\nu} = \frac{(0.4232\ \text{m/s})(0.16\ \text{m})}{1.655\times10^{-5}\ \text{m}^2/\text{s}} = 4091$$

which is not greater than 10,000 but the components will cause turbulence and thus we can assume fully developed turbulent flow in the entire duct, and determine the Nusselt number from

$$Nu = \frac{hD_h}{k} = 0.023\,\text{Re}^{0.8}\,\Pr^{0.4} = 0.023(4091)^{0.8}(0.7268)^{0.4} = 15.69$$

and

$$h = \frac{k}{D_h}Nu = \frac{0.02625\ \text{W/m.°C}}{0.16\ \text{m}}(15.69) = 2.574\ \text{W/m}^2.°\text{C}$$

The highest component surface temperature will occur at the exit of the duct. Assuming uniform surface heat flux, its value is determined from

$$\dot{Q}/A_s = h(T_{s,highest} - T_e)$$

$$T_{s,highest} = T_e + \frac{\dot{Q}/A_s}{h} = 39.2°\text{C} + \frac{(0.85)(180\ \text{W})/[4(0.16\ \text{m})(1\ \text{m})]}{2.574\ \text{W/m}^2.°\text{C}} = \mathbf{132°C}$$