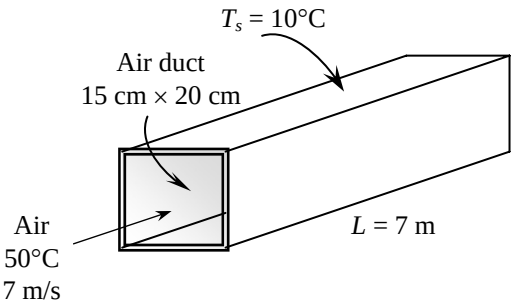
**13-55** Air enters a rectangular duct. The exit temperature of the air, the rate of heat transfer, and the fan power are to be determined.

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

***Properties*** We assume the bulk mean temperature for air to be 40°C since the mean temperature of air at the inlet will drop somewhat as a result of heat loss through the duct whose surface is at a lower temperature. The properties of air at this temperature and 1 atm are (Table A-22)

$\rho = 1.127\ \text{kg/m}^3$
$k = 0.02662\ \text{W/m.°C}$
$\nu = 1.702\times10^{-5}\ \text{m}^2/\text{s}$
$c_p = 1007\ \text{J/kg.°C}$
$\text{Pr} = 0.7255$




***Analysis*** (*a*) The hydraulic diameter, the mean velocity of air, and the Reynolds number are

$$D_h = \frac{4A_c}{p} = \frac{4(0.15\ \text{m})(0.20\ \text{m})}{2[(0.15\ \text{m}) + (0.20\ \text{m})]} = 0.1714\ \text{m}$$

$$\text{Re} = \frac{V_{\text{avg}} D_h}{\nu} = \frac{(7\ \text{m/s})(0.1714\ \text{m})}{1.702\times10^{-5}\ \text{m}^2/\text{s}} = 70{,}500$$

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

$$L_h \approx L_t \approx 10 D_h = 10(0.1714\ \text{m}) = 1.714\ \text{m}$$

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

$$Nu = \frac{hD_h}{k} = 0.023\,\text{Re}^{0.8}\,\text{Pr}^{0.3} = 0.023(70{,}500)^{0.8}(0.7255)^{0.3} = 157.9$$

Heat transfer coefficient is

$$h = \frac{k}{D_h} Nu = \frac{0.02662\ \text{W/m.°C}}{0.1714\ \text{m}}(157.9) = 24.52\ \text{W/m}^2\text{.°C}$$

Next we determine the exit temperature of air

$$A_s = 2\times7[(0.15\ \text{m}) + (0.20\ \text{m})] = 4.9\ \text{m}^2$$

$$A_c = (0.15\ \text{m})(0.20\ \text{m}) = 0.03\ \text{m}^2$$

$$\dot{m} = \rho V A_c = (1.127\ \text{kg/m}^3)(7\ \text{m/s})(0.03\ \text{m}^2) = 0.2367\ \text{kg/s}$$

$$T_e = T_s - (T_s - T_i)e^{-hA_s/(\dot{m}c_p)} = 10 - (10-50)e^{-\frac{(24.52)(4.9)}{(0.2367)(1007)}} = \mathbf{34.16°C}$$

(*b*) The logarithmic mean temperature difference and the rate of heat loss from the air are

$$\Delta T_{\ln} = \frac{T_e - T_i}{\ln\left(\frac{T_s - T_e}{T_s - T_i}\right)} = \frac{34.16 - 50}{\ln\left(\frac{10 - 34.16}{10 - 50}\right)} = 31.42°\text{C}$$

$$\dot{Q} = hA_s \Delta T_{\ln} = (24.52\ \text{W/m}^2\text{.°C})(4.9\ \text{m}^2)(31.42°\text{C}) = \mathbf{3775\ W}$$

(*c*) The friction factor, the pressure drop, and then the fan power can be determined for the case of fully developed turbulent flow to be

$$f = 0.184\,\text{Re}^{-0.2} = 0.184(70{,}500)^{-0.2} = 0.01973$$

$$\Delta P = f\frac{L}{D}\frac{\rho V_{\text{avg}}^2}{2} = 0.01973\frac{(7\ \text{m})}{(0.1714\ \text{m})}\frac{(1.127\ \text{kg/m}^3)(7\ \text{m/s})^2}{2} = 22.25\ \text{N/m}^2$$

$$\dot{W}_{pump} = \frac{\dot{m}\Delta P}{\rho} = \frac{(0.2367\ \text{kg/s})(22.25\ \text{N/m}^2)}{1.127\ \text{kg/m}^3} = \mathbf{4.67\ W}$$

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