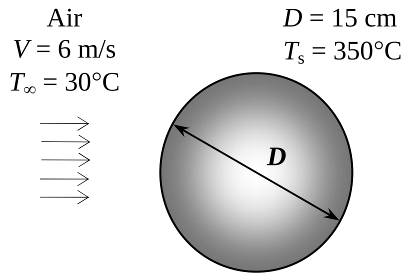
12-70 A hot stainless steel ball is cooled by forced air. The average convection heat transfer coefficient and the cooling time are to be determined.

Assumptions **1** Steady operating conditions exist. **2** Radiation effects are negligible. **3** Air is an ideal gas with constant properties. **4** The outer surface temperature of the ball is uniform at all times.

Properties The average surface temperature is (350+250)/2 = 300°C, and the properties of air at 1 atm pressure and the free stream temperature of 30°C are (Table A-22)

$$k = 0.02588 \text{ W/m.°C}$$
$$\nu = 1.608\times10^{-5} \text{ m}^2\text{/s}$$
$$\mu_\infty = 1.872\times10^{-5} \text{ kg/m.s}$$
$$\mu_{s,@\,300\,°\text{C}} = 2.934\times10^{-5} \text{ kg/m.s}$$
$$\Pr = 0.7282$$



Analysis The Reynolds number is

$$\text{Re} = \frac{VD}{\nu} = \frac{(6 \text{ m/s})(0.15 \text{ m})}{1.608\times10^{-5} \text{ m}^2\text{/s}} = 5.597\times10^4$$

The Nusselt number corresponding to this Reynolds number is determined to be

$$Nu = \frac{hD}{k} = 2 + \left[0.4\,\text{Re}^{0.5} + 0.06\,\text{Re}^{2/3}\right]\Pr^{0.4}\left(\frac{\mu_\infty}{\mu_s}\right)^{1/4}$$
$$= 2 + \left[0.4(5.597\times10^4)^{0.5} + 0.06(5.597\times10^4)^{2/3}\right](0.7282)^{0.4}\left(\frac{1.872\times10^{-5}}{2.934\times10^{-5}}\right)^{1/4} = 145.6$$

Heat transfer coefficient is

$$h = \frac{k}{D}Nu = \frac{0.02588 \text{ W/m.°C}}{0.15 \text{ m}}(145.6) = \mathbf{25.12\ W/m^2.°C}$$

The average rate of heat transfer can be determined from Newton's law of cooling by using average surface temperature of the ball

$$A_s = \pi D^2 = \pi(0.15 \text{ m})^2 = 0.07069 \text{ m}^2$$
$$\dot{Q}_{avg} = hA_s(T_s - T_\infty) = (25.12 \text{ W/m}^2.°\text{C})(0.07069 \text{ m}^2)(300-30)°\text{C} = 479.5 \text{ W}$$

Assuming the ball temperature to be nearly uniform, the total heat transferred from the ball during the cooling from 350°C to 250°C can be determined from

$$Q_{\text{total}} = mc_p(T_1 - T_2)$$

where $m = \rho \boldsymbol{V} = \rho\frac{\pi D^3}{6} = (8055 \text{ kg/m}^3)\frac{\pi(0.15 \text{ m})^3}{6} = 14.23 \text{ kg}$

Therefore, $Q_{\text{total}} = mc_p(T_1 - T_2) = (14.23 \text{ kg})(480 \text{ J/kg.°C})(350-250)°\text{C} = 683{,}250 \text{ J}$

Then the time of cooling becomes

$$\Delta t = \frac{Q}{\dot{Q}_{avg}} = \frac{683{,}250 \text{ J}}{479.5 \text{ J/s}} = 1425 \text{ s} = \mathbf{23.7\ min}$$