PROBLEM 5.6
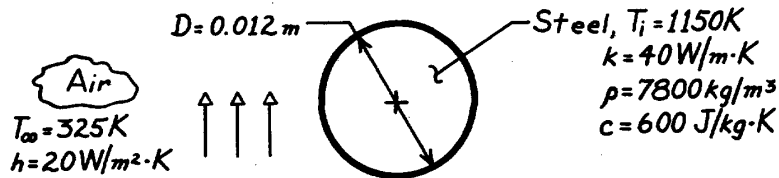
KNOWN: Diameter and initial temperature of steel balls cooling in air.

FIND: Time required to cool to a prescribed temperature.

SCHEMATIC:

ASSUMPTIONS: (1) Negligible radiation effects, (2) Constant properties.

ANALYSIS: Applying Eq. 5.10 to a sphere ($L_c = r_o/3$),

$$Bi = \frac{hL_c}{k} = \frac{h(r_o/3)}{k} = \frac{20 \text{ W/m}^2 \cdot K \ (0.002m)}{40 \text{ W/m} \cdot K} = 0.001.$$

Hence, the temperature of the steel remains approximately uniform during the cooling process, and the lumped capacitance method may be used. From Eqs. 5.4 and 5.5,

$$t = \frac{\rho V c_p}{hA_s} \ln \frac{T_i - T_\infty}{T - T_\infty} = \frac{\rho\left(\pi D^3/6\right)c_p}{h\pi \ D^2} \ln \frac{T_i - T_\infty}{T - T_\infty}$$

$$t = \frac{7800 \text{kg/m}^3 (0.012m) \, 600 \text{J/kg} \cdot K}{6 \times 20 \text{ W/m}^2 \cdot K} \ln \frac{1150 - 325}{400 - 325}$$

$$t = 1122 \text{ s } = 0.312h \qquad\qquad <$$

COMMENTS: Due to the large value of T_i, radiation effects are likely to be significant during the early portion of the transient. The effect is to shorten the cooling time.