PROBLEM 5.7

KNOWN: The temperature-time history of a pure copper sphere in an air stream.FIND: The heat transfer coefficient between the sphere and the air stream.SCHEMATIC:



ASSUMPTIONS: (1) Temperature of sphere is spatially uniform, (2) Negligible radiation exchange, (3) Constant properties.

PROPERTIES: Table A-1, Pure copper (333K): $\rho = 8933 \text{ kg/m}^3$, $c_p = 389 \text{ J/kg} \cdot \text{K}$, $k = 398 \text{ W/m} \cdot \text{K}$.

ANALYSIS: The time-temperature history is given by Eq. 5.6 with Eq. 5.7.

$$\frac{\theta(t)}{\theta_{i}} = \exp\left(-\frac{t}{R_{t}C_{t}}\right) \quad \text{where} \quad R_{t} = \frac{1}{hA_{s}} \quad A_{s} = \pi D^{2}$$
$$C_{t} = \rho V c_{p} \quad V = \frac{\pi D^{3}}{6}$$
$$\theta = T - T_{\infty}.$$

Recognize that when t = 69s,

$$\frac{\theta(t)}{\theta_{i}} = \frac{(55-27)^{\circ} C}{(66-27)^{\circ} C} = 0.718 = \exp\left(-\frac{t}{\tau_{t}}\right) = \exp\left(-\frac{69s}{\tau_{t}}\right)$$

and solving for τ_t find

$$\tau_{\rm t} = 208 {\rm s.}$$

Hence,

h =
$$\frac{\rho V c_p}{A_s \tau_t}$$
 = $\frac{8933 \text{ kg/m}^3 (\pi 0.0127^3 \text{ m}^3/6) 389 \text{J/kg} \cdot \text{K}}{\pi 0.0127^2 \text{m}^2 \times 208 \text{s}}$
h = 35.3 W/m² · K.

COMMENTS: Note that with $L_c = D_0/6$,

Bi =
$$\frac{hL_c}{k}$$
 = 35.3 W/m² · K × $\frac{0.0127}{6}$ m/398 W/m · K = 1.88×10⁻⁴.

Hence, Bi < 0.1 and the spatially isothermal assumption is reasonable.

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