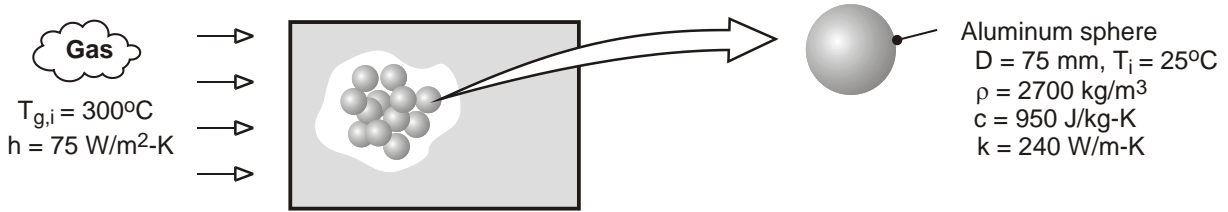


PROBLEM 5.13

KNOWN: Diameter, density, specific heat and thermal conductivity of aluminum spheres used in packed bed thermal energy storage system. Convection coefficient and inlet gas temperature.

FIND: Time required for sphere to acquire 90% of maximum possible thermal energy and the corresponding center temperature. Potential advantage of using copper in lieu of aluminum.

SCHEMATIC:



ASSUMPTIONS: (1) Negligible heat transfer to or from a sphere by radiation or conduction due to contact with other spheres, (2) Constant properties.

ANALYSIS: To determine whether a lumped capacitance analysis can be used, first compute $Bi = h(r_o/3)/k = 75 \text{ W/m}^2 \cdot \text{K} (0.0125 \text{ m})/240 \text{ W/m} \cdot \text{K} = 0.0039 < 0.1$. Hence, the lumped capacitance approximation may be made, and a uniform temperature may be assumed to exist in the sphere at any time. From Eq. 5.8a, achievement of 90% of the maximum possible thermal energy storage corresponds to

$$\frac{Q}{\rho c V \theta_i} = 0.90 = 1 - \exp(-t / \tau_t)$$

where $\tau_t = \rho V c / h A_s = \rho D c / 6h = 2700 \text{ kg/m}^3 \times 0.075 \text{ m} \times 950 \text{ J/kg} \cdot \text{K} / 6 \times 75 \text{ W/m}^2 \cdot \text{K} = 427 \text{ s}$. Hence,

$$t = -\tau_t \ln(0.1) = 427 \text{ s} \times 2.30 = 984 \text{ s} \quad <$$

From Eq. (5.6), the corresponding temperature at any location in the sphere is

$$T(984 \text{ s}) = T_{g,i} + (T_i - T_{g,i}) \exp(-6ht / \rho D c)$$

$$T(984 \text{ s}) = 300^\circ\text{C} - 275^\circ\text{C} \exp\left(-6 \times 75 \text{ W/m}^2 \cdot \text{K} \times 984 \text{ s} / 2700 \text{ kg/m}^3 \times 0.075 \text{ m} \times 950 \text{ J/kg} \cdot \text{K}\right)$$

$$T(984 \text{ s}) = 272.5^\circ\text{C} \quad <$$

Obtaining the density and specific heat of copper from Table A-1, we see that $(\rho c)_{\text{Cu}} \approx 8900 \text{ kg/m}^3 \times 400 \text{ J/kg} \cdot \text{K} = 3.56 \times 10^6 \text{ J/m}^3 \cdot \text{K} > (\rho c)_{\text{Al}} = 2.57 \times 10^6 \text{ J/m}^3 \cdot \text{K}$. Hence, for an equivalent sphere diameter, the copper can store approximately 38% more thermal energy than the aluminum.

COMMENTS: Before the packed bed becomes fully charged, the temperature of the gas decreases as it passes through the bed. Hence, the time required for a sphere to reach a prescribed state of thermal energy storage increases with increasing distance from the bed inlet.