11-14 The temperature of a gas stream is to be measured by a thermocouple. The time it takes to register 99 percent of the initial ΔT is to be determined.

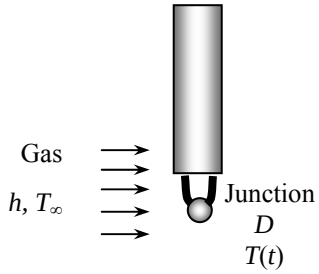
Assumptions **1** The junction is spherical in shape with a diameter of $D = 0.0012$ m. **2** The thermal properties of the junction are constant. **3** The heat transfer coefficient is constant and uniform over the entire surface. **4** Radiation effects are negligible. **5** The Biot number is Bi < 0.1 so that the lumped system analysis is applicable (this assumption will be verified).

Properties The properties of the junction are given to be $k = 35$ W/m.°C, $\rho = 8500$ kg/m^3, and $c_p = 320$ J/kg.°C.

Analysis The characteristic length of the junction and the Biot number are

$$L_c = \frac{V}{A_{\text{surface}}} = \frac{\pi D^3/6}{\pi D^2} = \frac{D}{6} = \frac{0.0012\text{ m}}{6} = 0.0002\text{ m}$$

$$Bi = \frac{hL_c}{k} = \frac{(90\text{ W/m}^2.^\circ\text{C})(0.0002\text{ m})}{(35\text{ W/m.°C})} = 0.00051 < 0.1$$



Since $Bi < 0.1$, the lumped system analysis is applicable. Then the time period for the thermocouple to read 99% of the initial temperature difference is determined from

$$\frac{T(t) - T_\infty}{T_i - T_\infty} = 0.01$$

$$b = \frac{hA}{\rho c_p V} = \frac{h}{\rho c_p L_c} = \frac{90\text{ W/m}^2.^\circ\text{C}}{(8500\text{ kg/m}^3)(320\text{ J/kg.°C})(0.0002\text{ m})} = 0.1654\text{ s}^{-1}$$

$$\frac{T(t) - T_\infty}{T_i - T_\infty} = e^{-bt} \longrightarrow 0.01 = e^{-(0.1654\text{ s}^{-1})t} \longrightarrow t = \mathbf{27.8\text{ s}}$$