PROBLEM 5.23

KNOWN: Droplet properties, diameter, velocity and initial and final temperatures.

FIND: Travel distance and rejected thermal energy.

SCHEMATIC:



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

PROPERTIES: Droplet (given): $\rho = 885 \text{ kg/m}^3$, $c = 1900 \text{ J/kg} \cdot \text{K}$, $k = 0.145 \text{ W/m} \cdot \text{K}$, $\epsilon = 0.95$.

ANALYSIS: To assess the suitability of applying the lumped capacitance method, use Equation 1.9 to obtain the maximum radiation coefficient, which corresponds to $T = T_i$.

$$h_r = \varepsilon \sigma T_i^3 = 0.95 \times 5.67 \times 10^{-8} \text{ W/m}^2 \cdot \text{K}^4 (500 \text{ K})^3 = 6.73 \text{ W/m}^2 \cdot \text{K}.$$

Hence

$$\operatorname{Bi}_{r} = \frac{\operatorname{h}_{r}(r_{o}/3)}{k} = \frac{\left(6.73 \text{ W/m}^{2} \cdot \text{K}\right)\left(0.25 \times 10^{-3} \text{ m/3}\right)}{0.145 \text{ W/m} \cdot \text{K}} = 0.0039$$

and the lumped capacitance method can be used. From Equation 5.19,

$$t = \frac{L}{V} = \frac{\rho c \left(\pi D^{3} / 6\right)}{3 \varepsilon \left(\pi D^{2}\right) \sigma} \left(\frac{1}{T_{f}^{3}} - \frac{1}{T_{i}^{3}}\right)$$

$$L = \frac{(0.1 \text{ m/s})885 \text{ kg/m}^{3} (1900 \text{ J/kg} \cdot \text{K}) 0.5 \times 10^{-3} \text{ m}}{18 \times 0.95 \times 5.67 \times 10^{-8} \text{ W/m}^{2} \cdot \text{K}^{4}} \left(\frac{1}{300^{3}} - \frac{1}{500^{3}}\right) \frac{1}{\text{K}^{3}}$$

$$L = 2.52 \text{ m}.$$

The amount of energy rejected by each droplet is equal to the change in its internal energy.

$$E_{i} - E_{f} = \rho Vc(T_{i} - T_{f}) = 885 \text{ kg/m}^{3} \pi \frac{\left(5 \times 10^{-4} \text{ m}\right)^{3}}{6} 1900 \text{ J/kg} \cdot \text{K}(200 \text{ K})$$
$$E_{i} - E_{f} = 0.022 \text{ J}.$$

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COMMENTS: Because some of the radiation emitted by a droplet will be intercepted by other droplets in the stream, the foregoing analysis overestimates the amount of heat dissipated by radiation to space.

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