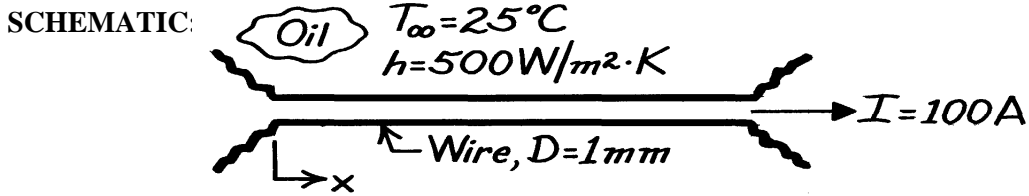


### PROBLEM 03

**KNOWN:** Diameter, resistance and current flow for a wire. Convection coefficient and temperature of surrounding oil.

**FIND:** Steady-state temperature of the wire. Time for the wire temperature to come within 1°C of its steady-state value.



**ASSUMPTIONS:** (1) Constant properties, (2) Wire temperature is independent of  $x$ .

**PROPERTIES:** Wire (given):  $\rho = 8000 \text{ kg/m}^3$ ,  $c_p = 500 \text{ J/kg} \cdot \text{K}$ ,  $k = 20 \text{ W/m} \cdot \text{K}$ ,  $R'_e = 0.01 \Omega/\text{m}$ .

**ANALYSIS:** Since

$$Bi = \frac{h(r_o/2)}{k} = \frac{500 \text{ W/m}^2 \cdot \text{K} (2.5 \times 10^{-4} \text{ m})}{20 \text{ W/m} \cdot \text{K}} = 0.006 < 0.1$$

the lumped capacitance method can be used. The problem has been analyzed in Example 1.4, and without radiation the steady-state temperature is given by

$$\pi Dh(T - T_\infty) = I^2 R'_e.$$

Hence

$$T = T_\infty + \frac{I^2 R'_e}{\pi Dh} = 25^\circ \text{C} + \frac{(100 \text{ A})^2 0.01 \Omega/\text{m}}{\pi (0.001 \text{ m}) 500 \text{ W/m}^2 \cdot \text{K}} = 88.7^\circ \text{C}. \quad <$$

With no radiation, the transient thermal response of the wire is governed by the expression (Example 1.4)

$$\frac{dT}{dt} = \frac{I^2 R'_e}{\rho c_p (\pi D^2 / 4)} - \frac{4h}{\rho c_p D} (T - T_\infty).$$

With  $T = T_i = 25^\circ \text{C}$  at  $t = 0$ , the solution is

$$\frac{T - T_\infty - (I^2 R'_e / \pi Dh)}{T_i - T_\infty - (I^2 R'_e / \pi Dh)} = \exp\left(-\frac{4h}{\rho c_p D} t\right).$$

Substituting numerical values, find

$$\frac{87.7 - 25 - 63.7}{25 - 25 - 63.7} = \exp\left(-\frac{4 \times 500 \text{ W/m}^2 \cdot \text{K}}{8000 \text{ kg/m}^3 \times 500 \text{ J/kg} \cdot \text{K} \times 0.001 \text{ m}} t\right)$$

$$t = 8.31 \text{ s}. \quad <$$

**COMMENTS:** The time to reach steady state increases with increasing  $\rho$ ,  $c_p$  and  $D$  and with decreasing  $h$ .