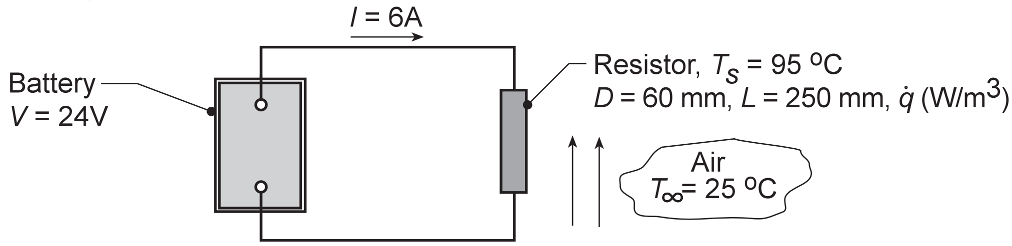
PROBLEM 1.35

KNOWN: Resistor connected to a battery operating at a prescribed temperature in air.

FIND: (a) Considering the resistor as the system, determine corresponding values for $\dot{E}_{in}(W)$, $\dot{E}_g(W)$, $\dot{E}_{out}(W)$ and $\dot{E}_{st}(W)$. If a control surface is placed about the entire system, determine the values for $\dot{E}_{in}$, $\dot{E}_g$, $\dot{E}_{out}$, and $\dot{E}_{st}$. (b) Determine the volumetric heat generation rate within the resistor, $\dot{q}$ (W/m^3), (c) Neglecting radiation from the resistor, determine the convection coefficient.

SCHEMATIC:



ASSUMPTIONS: (1) Electrical power is dissipated uniformly within the resistor, (2) Temperature of the resistor is uniform, (3) Negligible electrical power dissipated in the lead wires, (4) Negligible radiation exchange between the resistor and the surroundings, (5) No heat transfer occurs from the battery, (5) Steady-state conditions in the resistor.

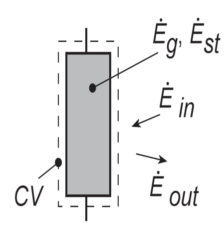
ANALYSIS: (a) Referring to Section 1.3.1, the conservation of energy requirement for a control volume at an instant of time, Equation 1.12c, is

$$\dot{E}_{in} + \dot{E}_g - \dot{E}_{out} = \dot{E}_{st}$$

where $\dot{E}_{in}$, $\dot{E}_{out}$ correspond to *surface* inflow and outflow processes, respectively. The energy generation term $\dot{E}_g$ is associated with conversion of some other energy form (chemical, electrical, electromagnetic or nuclear) to thermal energy. The energy storage term $\dot{E}_{st}$ is associated with changes in the internal, kinetic and/or potential energies of the matter in the control volume. $\dot{E}_g$, $\dot{E}_{st}$ are *volumetric* phenomena. The electrical power delivered by the battery is P = VI = 24V×6A = 144 W.

Control volume: Resistor.

$$\dot{E}_{in} = 0 \qquad \dot{E}_{out} = 144\,W \qquad <$$
$$\dot{E}_g = 144\,W \qquad \dot{E}_{st} = 0$$



The $\dot{E}_g$ term is due to conversion of electrical energy to thermal energy. The term $\dot{E}_{out}$ is due to convection from the resistor surface to the air.

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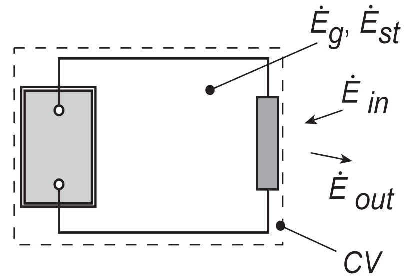
PROBLEM 1.35 (Cont.)

Control volume: Battery-Resistor System.



$$\dot{E}_{in} = 0 \qquad \dot{E}_{out} = 144\,\text{W} \qquad <$$
$$\dot{E}_g = 144\text{W} \qquad \dot{E}_{st} = 0$$

Since we are considering conservation of thermal and mechanical energy, the conversion of chemical energy to electrical energy in the battery is irrelevant, and including the battery in the control volume doesn't change the thermal and mechanical energy terms

(b) From the energy balance on the resistor with volume, $\forall = (\pi D^2/4)L$,

$$\dot{E}_g = \dot{q}\forall \qquad 144\,\text{W} = \dot{q}\left(\pi(0.06\,\text{m})^2/4\right)\times 0.25\,\text{m} \qquad \dot{q} = 2.04\times10^5\,\text{W/m}^3 \qquad <$$

(c) From the energy balance on the resistor and Newton's law of cooling with $A_s = \pi DL + 2(\pi D^2/4)$,

$$\dot{E}_{out} = q_{cv} = hA_s(T_s - T_\infty)$$

$$144\,\text{W} = h\left[\pi\times0.06\,\text{m}\times0.25\,\text{m} + 2\left(\pi\times0.06^2\,\text{m}^2/4\right)\right](95-25)^\circ\text{C}$$

$$144\,\text{W} = h[0.0471 + 0.0057]\text{m}^2(95-25)^\circ\text{C}$$

$$h = 39.0\,\text{W/m}^2{\cdot}\text{K} \qquad <$$

COMMENTS: (1) In using the conservation of energy requirement, Equation 1.12c, it is important to recognize that $\dot{E}_{in}$ and $\dot{E}_{out}$ will always represent *surface* processes and $\dot{E}_g$ and $\dot{E}_{st}$, *volumetric* processes. The generation term $\dot{E}_g$ is associated with a *conversion* process from some form of energy to *thermal energy*. The storage term $\dot{E}_{st}$ represents the rate of change of *internal kinetic, and potential energy*.

(2) From Table 1.1 and the magnitude of the convection coefficient determined from part (c), we conclude that the resistor is experiencing forced, rather than free, convection.