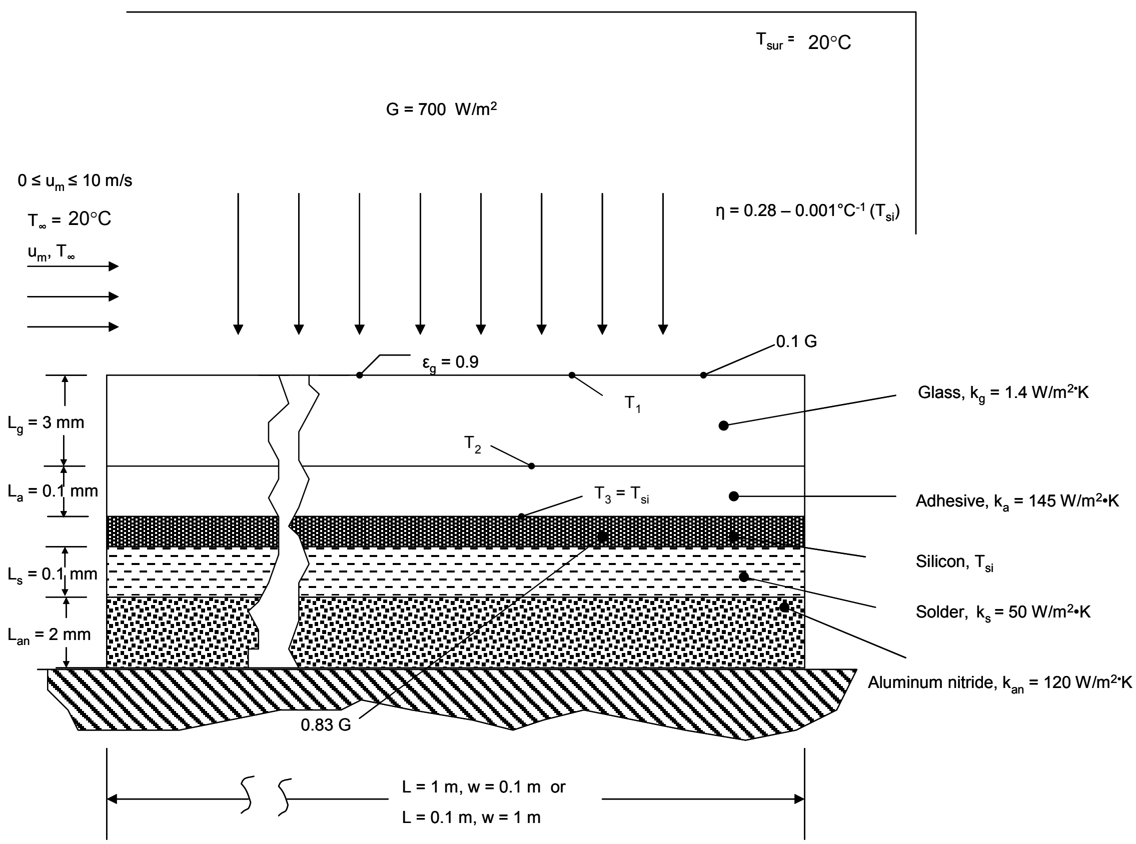
PROBLEM 7.18

KNOWN: Solar cell material dimensions and properties, solar-to-electrical conversion efficiency dependence on silicon temperature, solar irradiation and location where the irradiation is absorbed, air velocity and temperature.

FIND: (a) Electrical power produced and silicon temperature for a L = 1 m long, w = 0.1 m wide solar cell with G = 700 W/m^2 with tripped boundary layer, (b) Same as Part (a) but with L = 0.1 m, w = 1 m, (c) Plot of the electrical power produced and the silicon temperature for air velocities in the range $0 \le u_m \le 10$ m/s for the L = 0.1 m configuration.

SCHEMATIC:



ASSUMPTIONS: (1) Steady-state conditions, (2) Constant properties, (3) One-dimensional heat transfer, (4) Tripped and turbulent boundary layer, (5) Large surroundings, (6) Negligible contact resistances.

PROPERTIES: Table A.4, air (assume T_f = 308 K, p = 1 atm): k = 0.0269 W/m·K, $\nu = 1.669 \times 10^{-5}$ m^2/s, Pr = 0.706.

ANALYSIS:

(a) We begin by drawing the thermal circuit for the problem, recognizing that there is no heat transfer downward from the thin silicon layer.

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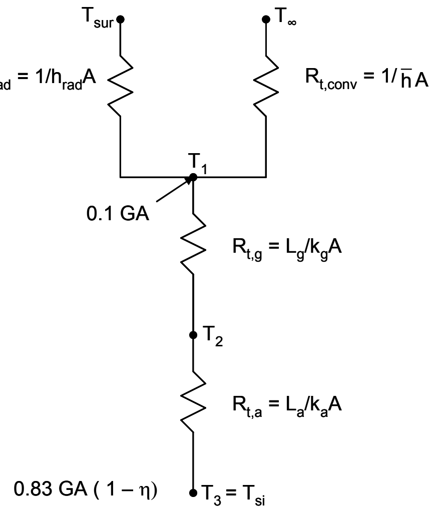

The thermal resistances are

$$R_{t,g} = L_g/k_gA = 3 \times 10^{-3}\ \text{m}\big/(1.4\ \text{W/m}\cdot\text{K} \times 1\ \text{m} \times 0.1\ \text{m}) = 21.43 \times 10^{-3}\ \text{K/W}$$

$$R_{t,a} = L_a/k_aA = 0.1 \times 10^{-3}\ \text{m}\big/(145\ \text{W/m}\cdot\text{K} \times 1\ \text{m} \times 0.1\ \text{m}) = 6.897 \times 10^{-6}\ \text{K/W}$$

$$h_{rad} = \varepsilon_g\sigma\,(T_1 + T_{sur})(T_1^2 + T_{sur}^2)$$

$$R_{t,rad} = \frac{1}{0.9 \times 5.67 \times 10^{-8}\ \text{W/m}^2\cdot\text{K}^4 \times (T_1 + 295\ \text{K}) \times (T_1^2 + (295\text{K})^2) \times 1\ \text{m} \times 0.1\ \text{m}} \quad (1)$$

For the tripped boundary layer,

$$Re_L = \frac{u_m L}{\nu} = \frac{4\text{m/s} \times 1\text{m}}{1.669 \times 10^{-5}\ \text{m}^2/\text{s}} = 239.7 \times 10^3$$

From Equation 7.38

$$\overline{Nu}_L = 0.037 Re_L^{4/5} Pr^{1/3} = 0.037 \times \left[239.7 \times 10^3\right]^{0.8} \times 0.706^{1/3} = 662.8$$

$$\bar{h} = \overline{Nu}_L k/L = 662.8 \times 0.0269\ \text{W/m}\cdot\text{K/1m} = 17.82\ \text{W/m}^2\cdot\text{K}$$

$$R_{t,conv} = 1/\bar{h}A = \frac{1}{17.82\ \text{W/m}^2\cdot\text{K} \times 1\ \text{m} \times 0.1\ \text{m}} = 561.2 \times 10^{-3}\ \text{K/W}$$

From the thermal circuit,

$$0.83GA\,(1 - \eta) = (T_3 - T_1)/(R_{t,g} + R_{t,a}) \ \text{ or }\ T_3 - T_1 = (R_{t,g} + R_{t,a})\,0.83GA\,(1 - \eta)$$

$$T_3 - T_1 = (21.43 \times 10^{-3}\ \text{K/W} + 6.897 \times 10^{-6}\ \text{K/W}) \times 0.83 \times 700\ \text{W/m}^2 \times 1\text{m} \times 0.1\text{m} \times (1-\eta)$$

$$T_3 - T_1 = 1.245(1 - \eta) \quad (2)$$

We also note from the thermal circuit,

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$$0.83GA\,(1-\eta) + 0.1G = (T_1 - T_{sur})/R_{t,rad} + (T_1 - T_\infty)/R_{t,conv}$$

Since $T_\infty = T_{sur}$

$$0.83GA\,(1-\eta) + 0.1G = (T_1 - T_{sur})\left[\frac{1}{R_{t,rad}} + \frac{1}{R_{t,conv}}\right]$$

$$T_1 - T_{sur} = \frac{0.83GA\,(1-\eta) + 0.1GA}{\left[1/R_{t,rad} + 1/R_{t,conv}\right]}$$

$$T_1 - T_{sur} = \frac{0.83 \times 700\ \text{W/m}^2 \times 1\ \text{m} \times 0.1\ \text{m} \times (1-\eta) + 0.1 \times 700\ \text{W/m}^2 \times 1\ \text{m} \times 0.1\ \text{m}}{\left[1/R_{t,rad} + 1.7819\ \text{W/K}\right]}$$

$$T_1 - T_{sur} = \frac{58.1\ \text{W}\,(1-\eta) + 7\ \text{W}}{\left[1/R_{t,rad} + 1.7819\ \text{W/K}\right]} \qquad (3)$$

where $\eta = 0.28 - 0.001°\text{C}^{-1} \times (T_3 - 273)°\text{C}$ (4)

Equations (1) – (4) may be solved simultaneously to yield

$$\eta = 0.2353,\ T_3 = T_{si} = 44.7°\text{C},\ T_1 = 43.7°\text{C},\ R_{t,rad} = 1.71\ \text{K/W}$$ <

The electric power is $P = 0.83GA\eta = 0.83 \times 700\ \text{W/m}^2 \times 1\ \text{m} \times 0.1\ \text{m} \times 0.2353 = 13.67\ \text{W}$ <

(b) For the tripped boundary layer

$$Re_L = \frac{u_m L}{\nu} = \frac{4/\text{ms} \times 0.1\text{m}}{1.669 \times 10^{-5}\ \text{m}^2/\text{s}} = 239.7 \times 10^2$$

From Equation 7.38

$$\overline{Nu}_L = 0.037 Re^{4/5} Pr^{1/3} = 0.037 \times \left[239.7 \times 10^2\right]^{0.8} \times 0.706^{1/3} = 105$$

$$\bar{h} = \overline{Nu}_L k/L = 105 \times 0.0269\ \text{W/m}\cdot\text{K}/1\text{m} = 28.25\ \text{W/m}^2\cdot\text{K}$$

$$R_{t,conv} = 1/\bar{h}A = \frac{1}{28.25\ \text{W/m}^2\cdot\text{K} \times 1\ \text{m} \times 0.1\ \text{m}} = 354.0 \times 10^{-3}\ \text{K/W}$$

Proceeding as in Part (a) we find

$$\eta = 0.242,\ T_3 = T_{si} = 38.0°\text{C},\ T_1 = 37.1°\text{C},\ R_{t,rad} = 1.768\ \text{K/W},\ P = 14.06\ \text{W}$$ <

(c) Solving Equations 1 through 4 over the velocity range $0 \le u_m \le 10$ m/s yields the following behavior

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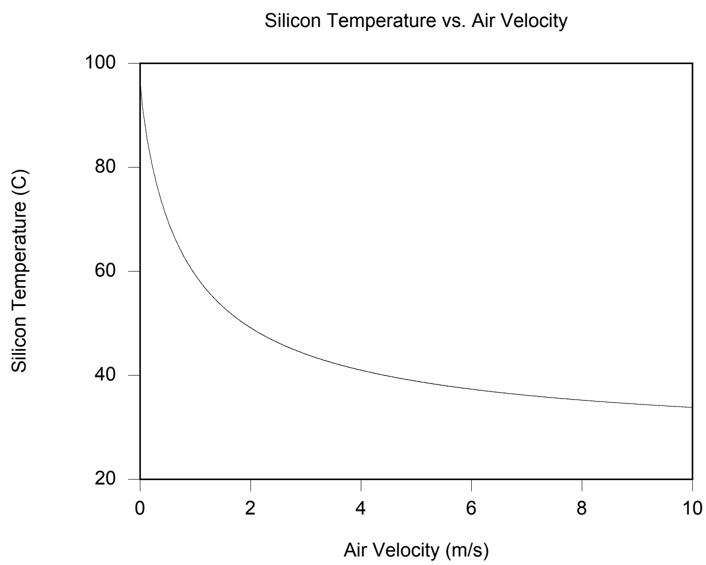
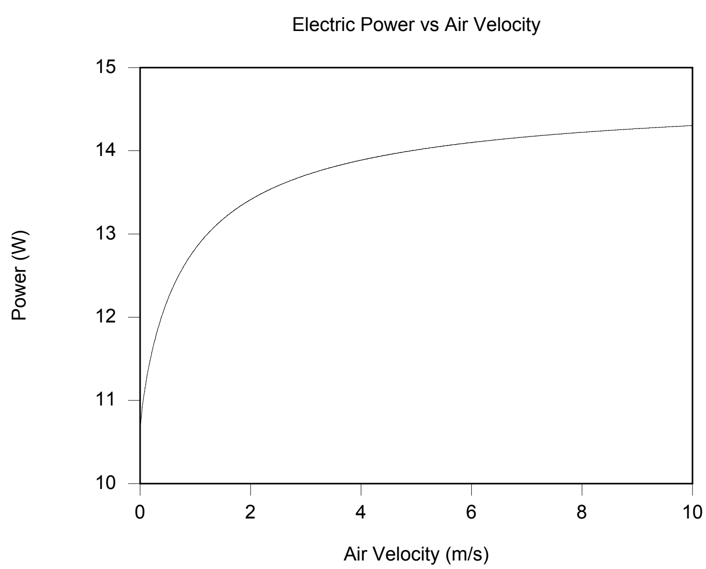
PROBLEM 7.18 (Cont.)





COMMENTS: (1) Changing the orientation of the solar panel to the L = 0.1 m configuration reduces the temperature of the silicon semiconductor significantly. The influence of the orientation on the electric power would be more pronounced for warmer air temperatures. (2) Decreasing the air velocity results in significantly diminished power output. At very low cross flow velocities, natural convection would become significant and would lead to slightly improved power output relative to that predicted here. (3) Film temperatures for Parts (a) and (b) are 31.9 °C and 28.6 °C, respectively. The assumed value of the film temperature is good.