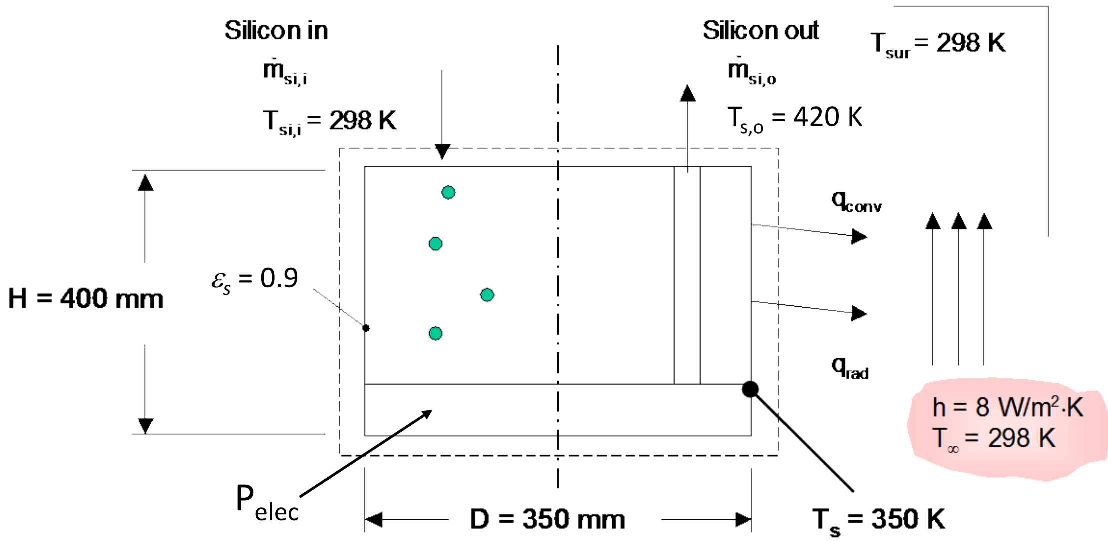
PROBLEM 1.37

KNOWN: Process for growing thin, photovoltaic grade silicon sheets. Sheet dimensions and velocity. Dimensions, surface temperature and surface emissivity of growth chamber. Surroundings and ambient temperatures, and convective heat transfer coefficient. Amount of time-averaged absorbed solar irradiation and photovoltaic conversion efficiency.

FIND: (a) Electric power needed to operate at steady state, (b) Time needed to operate the photovoltaic panel to produce enough energy to offset energy consumed during its manufacture.

SCHEMATIC:



ASSUMPTIONS: (1) Steady-state conditions, (2) Large surroundings, (3) Constant properties, (4) Neglect the presence of the strings.

PROPERTIES: *Table A-1*, Silicon (T = 300 K): c = 712 J/kg·K, ρ = 2330 kg/m^3, (T = 420 K): c = 798 J/kg·K.

ANALYSIS: (a) At steady state, the mass of silicon produced per unit time is equal to the mass of silicon added to the system per unit time. The amount of silicon produced is

$$\dot{m} = W_{\rm si} \times t_{\rm si} \times V_{\rm si} \times \rho = 0.075\text{m} \times 140 \times 10^{-6}\text{m} \times 0.018\text{m/min} \times (1/60)\text{min/s} \times 2330\text{kg/m}^3 = 7.34 \times 10^{-6}\text{kg/s}$$

At steady state, $\dot{E}_{in} = \dot{E}_{out}$ where

$$\dot{E}_{\rm in} = P_{\rm elec} + \dot{m}cT_{{\rm si},i} = P_{\rm elec} + 7.34 \times 10^{-6}\frac{\text{kg}}{\text{s}} \times 712\frac{\text{J}}{\text{kg}\cdot\text{K}} \times 298\text{K} = P_{\rm elec} + 2.10 \text{ J/s} = P_{\rm elec} + 1.56 \text{ W}$$

and

$$\dot{E}_{\rm out} = \dot{m}cT_{{\rm si},o} + \left[2\pi D^2/4 + H\pi D\right]\left[h(T_s - T_\infty) + \varepsilon\sigma(T_s^4 - T_{\rm sur}^4)\right]$$

$$= 7.34 \times 10^{-6}\frac{\text{kg}}{\text{s}} \times 798\frac{\text{J}}{\text{kg}\cdot\text{K}} \times 420\text{K} + \left[2\pi \times (0.35\text{m})^2/4 + 0.4\text{m} \times \pi \times 0.35\text{m}\right]$$

$$\times\left[8\frac{\text{W}}{\text{m}^2\cdot\text{K}} \times (350-298)\text{K} + 5.67 \times 10^{-8}\frac{\text{W}}{\text{m}^2\cdot\text{K}^4} \times 0.9 \times \left((350\text{K})^4 - (298\text{K})^4\right)\right] = 493 \text{ W}$$

Therefore,

Continued…

PROBLEM 1.37 (Cont.)

$$P_{\text{elec}} = 493\text{ W} - 1.56\text{ W} = 491\text{ W}$$ <

(b) The electric energy needed to manufacture the photovoltaic material is

$$E_m = P_{\text{elec}}/(W_s V_s) = 491\text{ W}/(0.075\text{ m} \times 0.018\text{ m/min} \times (1/60)\text{ min/s}) = 21.9 \times 10^6\text{ J/m}^2 = 21.9 \times 10^3\text{kJ/m}^2$$

The time needed to generate E_m by the photovoltaic panel is

$$t = E_m / q''_{\text{sol}}\eta = 21.9 \times 10^6\text{ J/m}^2/(180\text{W/m}^2 \times 0.20) = 609 \times 10^3\text{s} = 169\text{ h}$$ <

COMMENTS: (1) The radiation and convection losses are primarily responsible for the electric power needed to manufacture the photovoltaic material. Of these, radiation is responsible for 47% of the losses. The radiation losses could be reduced by coating the exposed surface of the chamber with a low emissivity material. (2) Assuming an electricity price of \$0.15/kWh, the cost of electricity to manufacture the material is 21.9×10^3 kJ/m^2 × (\$0.15/kWh) × (1h/3600s) = \$0.92/m^2. (3) This problem represents a type of *life cycle analysis* in which the energy consumed to manufacture a product is of interest. The analysis presented here does not account for the energy that is consumed to produce the silicon powder, the energy used to fabricate the growth chamber, or the energy that is used to fabricate and install the photovoltaic panel. The actual time needed to offset the energy to manufacture and install the photovoltaic panel will be much greater than 169 h. See Keoleian and Leis, “Application of Life-cycle Energy Analysis to Photovoltaic Module Design, *Progress in Photovoltaics: Research and Applications*, Vol. 5, pp. 287-300, 1997.