14-100 A flat-plate solar collector tilted 40°C from the horizontal is exposed to the calm ambient air. The total rate of heat loss from the collector, the collector efficiency, and the temperature rise of water in the collector are to be determined.

Assumptions **1** Steady operating conditions exist. **2** Air is an ideal gas with constant properties. **3** The local atmospheric pressure is 1 atm. **4** There is no heat loss from the back surface of the absorber plate.

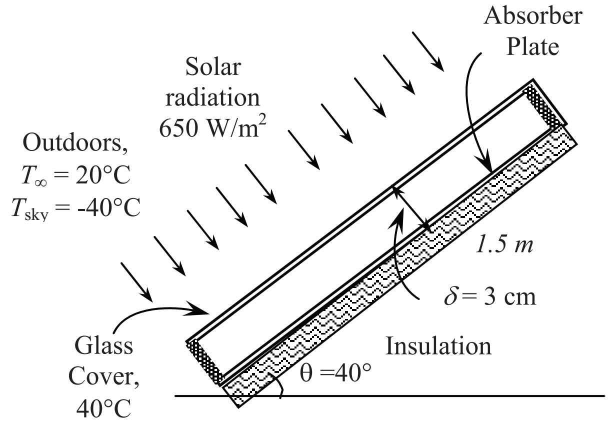
Properties The properties of air at 1 atm and the film temperature of $(T_s+T_\infty)/2 = (40+20)/2 = 30°C$ are (Table A-22)

$$k = 0.02588 \text{ W/m.°C}$$

$$\nu = 1.608 \times 10^{-5} \text{ m}^2/\text{s}$$

$$\Pr = 0.7282$$

$$\beta = \frac{1}{T_f} = \frac{1}{(30+273)\text{K}} = 0.0033 \text{ K}^{-1}$$



Analysis (*a*) The characteristic length in this case is determined from

$$L_c = \frac{A_s}{p} = \frac{(1.5\text{ m})(2\text{ m})}{2(1.5\text{ m}+2\text{ m})} = 0.429\text{ m}^2$$

Then,

$$Ra = \frac{g\beta(T_\infty - T_s)L_c^3}{\nu^2}\Pr$$

$$= \frac{(9.81\text{ m/s}^2)(\cos 40°)(0.0033\text{ K}^{-1})(40-20\text{ K})(0.429\text{ m})^3}{(1.608\times10^{-5}\text{ m}^2/\text{s})^2}(0.7282) = 1.103\times10^8$$

$$Nu = 0.15Ra^{1/3} = 0.15(1.103\times10^8)^{1/3} = 71.94$$

$$h = \frac{k}{L_s}Nu = \frac{0.02588\text{ W/m.°C}}{0.429\text{ m}}(71.94) = 4.340\text{ W/m}^2.°\text{C}$$

$$A_s = (1.5\text{ m})(2\text{ m}) = 3\text{ m}^2$$

and $\dot{Q}_{conv} = hA_s(T_s - T_\infty) = (4.340\text{ W/m}^2.°\text{C})(3\text{ m}^2)(40-20)°\text{C} = 260.4\text{ W}$

Heat transfer rate by radiation is

$$\dot{Q}_{rad} = \varepsilon A_s \sigma(T_{surr}^4 - T_s^4)$$

$$= (0.9)(3\text{ m}^2)(5.67\times10^{-8}\text{ W/m}^2.\text{K}^4)[(40+273\text{ K})^4 - (-40+273\text{ K})^4] = 1018\text{ W}$$

and $\dot{Q}_{total} = 260.4 + 1018 = \mathbf{1278\ W}$

(*b*) The solar energy incident on the collector is

$$\dot{Q}_{incident} = \alpha\dot{q}A_s = (0.88)(650\text{ W/m}^2)(3\text{ m}^2) = 1716\text{ W}$$

Then the collector efficiency becomes

$$efficiency = \frac{\dot{Q}_{incident} - \dot{Q}_{lost}}{\dot{Q}_{incident}} = \frac{1716-1278}{1716} = 0.255 = \mathbf{25.5\%}$$

(*c*) The temperature rise of the water as it passes through the collector is

$$\dot{Q} = \dot{m}c_p\Delta T \rightarrow \Delta T = \frac{\dot{Q}}{\dot{m}c_p} = \frac{(1716-1278)\text{W}}{(1/60\text{ kg/s})(4180\text{ J/kg.°C})} = \mathbf{6.3°C}$$

14-101 ….. 14-103 Design and Essay Problems