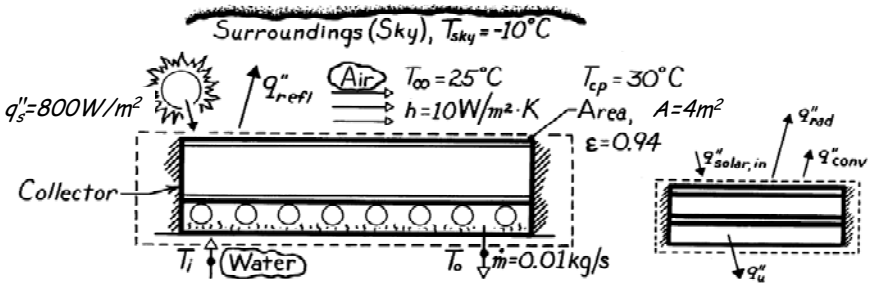
PROBLEM 1.85

KNOWN: Solar collector designed to heat water operating under prescribed solar irradiation and loss conditions.

FIND: (a) Useful heat collected per unit area of the collector, q''_u, (b) Temperature rise of the water flow, $T_o - T_i$, and (c) Collector efficiency.

SCHEMATIC:



ASSUMPTIONS: (1) Steady-state conditions, (2) No heat losses out sides or back of collector, (3) Collector area is small compared to sky surroundings.

PROPERTIES: *Table A.6*, Water (300K): c_p = 4179 J/kg·K.

ANALYSIS: (a) Defining the collector as the control volume and writing the conservation of energy requirement on a per unit area basis, find that

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

Identifying processes as per above right sketch,

$$q''_{solar} - q''_{rad} - q''_{conv} - q''_u = 0$$

where $q''_{solar} = 0.9\ q''_s$; that is, 90% of the solar flux is absorbed in the collector (Eq. 1.6). Using the appropriate rate equations, the useful heat rate per unit area is

$$q''_u = 0.9\ q''_s - \varepsilon\sigma\left(T_{cp}^4 - T_{sky}^4\right) - h\left(T_s - T_\infty\right)$$

$$q''_u = 0.9\times 800\frac{W}{m^2} - 0.94\times 5.67\times 10^{-8}\frac{W}{m^2\cdot K^4}\left(303^4 - 263^4\right)K^4 - 10\frac{W}{m^2\cdot K}(30-25)^\circ C$$

$$q''_u = 720 W/m^2 - 194 W/m^2 - 50 W/m^2 = 476 W/m^2 \quad <$$

(b) The total useful heat collected is $q''_u \cdot A$. Defining a control volume about the water tubing, the useful heat causes an enthalpy change of the flowing water. That is,

$$q''_u \cdot A = \dot{m} c_p \left(T_i - T_o\right) \quad \text{or}$$

$$\left(T_i - T_o\right) = 476\ W/m^2 \times 4m^2 / 0.01 kg/s \times 4179 J/kg\cdot K = 45.6^\circ C. \quad <$$

(c) The efficiency is $\eta = q''_u / q''_S = \left(476\ W/m^2\right)/\left(800\ W/m^2\right) = 0.60$ or 60%. <

COMMENTS: Note how the sky has been treated as large surroundings at a uniform temperature T_{sky}.