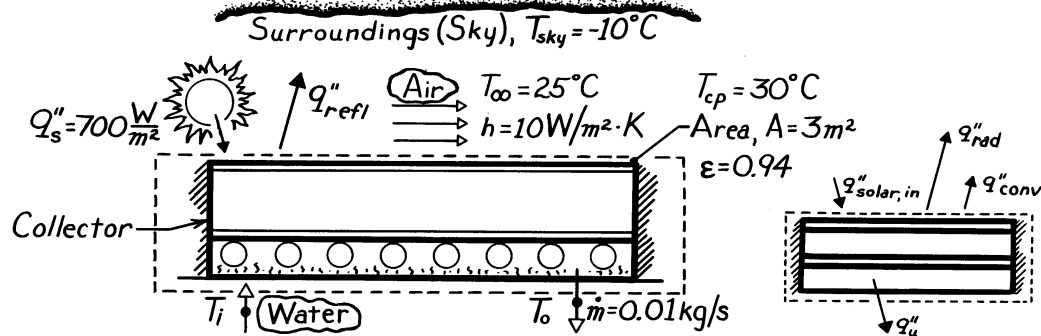


PROBLEM 1.61

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): $c_p = 4179 \text{ J/kg}\cdot\text{K}$.

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

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

Identifying processes as per above right sketch,

$$q_{\text{solar}}'' - q_{\text{rad}}'' - q_{\text{conv}}'' - q_u'' = 0$$

where $q_{\text{solar}}'' = 0.9 q_s''$; 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

$$\begin{aligned} q_u'' &= 0.9 q_s'' - \epsilon \sigma (T_{\text{cp}}^4 - T_{\text{sky}}^4) - h (T_s - T_{\infty}) \\ q_u'' &= 0.9 \times 700 \frac{\text{W}}{\text{m}^2} - 0.94 \times 5.67 \times 10^{-8} \frac{\text{W}}{\text{m}^2 \cdot \text{K}^4} (303^4 - 263^4) \text{K}^4 - 10 \frac{\text{W}}{\text{m}^2 \cdot \text{K}} (30 - 25)^\circ \text{C} \\ q_u'' &= 630 \text{ W/m}^2 - 194 \text{ W/m}^2 - 50 \text{ W/m}^2 = 386 \text{ W/m}^2. \end{aligned} \quad <$$

(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,

$$q_u'' \cdot A = \dot{m} c_p (T_i - T_o) \quad \text{or}$$

$$(T_i - T_o) = 386 \text{ W/m}^2 \times 3 \text{ m}^2 / 0.01 \text{ kg/s} \times 4179 \text{ J/kg} \cdot \text{K} = 27.7^\circ \text{C}. \quad <$$

(c) The efficiency is $\eta = q_u'' / q_s'' = (386 \text{ W/m}^2) / (700 \text{ W/m}^2) = 0.55$ or 55%. <

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