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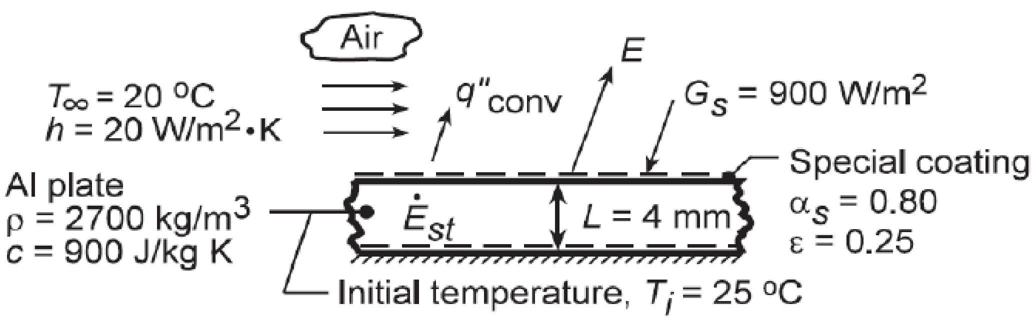
Quiz 1 - Solution

An aluminum plate 4 mm thick is mounted in a horizontal position, and its bottom surface is well insulated. A special, thin coating is applied to the top surface such that it absorbs 80% of any incident solar radiation, while having an emissivity of 0.25. The density ρ and specific heat c of aluminum are known to be 2700 kg/m^3 and 900 J/kg · K, respectively.

Consider conditions for which the plate is at a temperature of 25°C and its top surface is suddenly exposed to ambient air at T_∞= 20°C and to solar radiation that provides an incident flux of 900 W/m^2. The convection heat transfer coefficient between the surface and the air is h = 20 W/m^2 · K. What is the initial rate of change of the plate temperature?

Hint 1: In your analysis, use a unit surface area of the plate of 1 m^2.
Hint 2: Since T_{sur} is not given, assume T_{sur} = 0 K.

SCHEMATIC:



ASSUMPTIONS: (1) Negligible end effects, (2) Uniform plate temperature at any instant, (3) Constant properties, (4) Adiabatic bottom surface, (5) Negligible radiation from surroundings, (6) No internal heat generation.

ANALYSIS: (a) Applying an energy balance, Eq. 1.12c, at an instant of time to a control volume about the plate, $\dot{E}_{in} - \dot{E}_{out} = \dot{E}_{st}$, it follows for a unit surface area.

$$\alpha_S G_S \left(1\,m^2\right) - E\left(1\,m^2\right) - q''_{conv}\left(1\,m^2\right) = (d/dt)(McT) = \rho\left(1\,m^2 \times L\right)c\,(dT/dt).$$

Rearranging and substituting from Eqs. 1.3 and 1.7, we obtain

$$dT/dt = (1/\rho Lc)\left[\alpha_S G_S - \varepsilon\sigma T_i^4 - h\left(T_i - T_\infty\right)\right].$$

$$dT/dt = \left(2700\,kg/m^3 \times 0.004\,m \times 900\,J/kg\cdot K\right)^{-1} \times$$

$$\left[0.8 \times 900\,W/m^2 - 0.25 \times 5.67 \times 10^{-8}\,W/m^2\cdot K^4\,(298\,K)^4 - 20\,W/m^2\cdot K\,(25-20)^\circ C\right]$$

$$dT/dt = 0.052^\circ C/s.$$ <