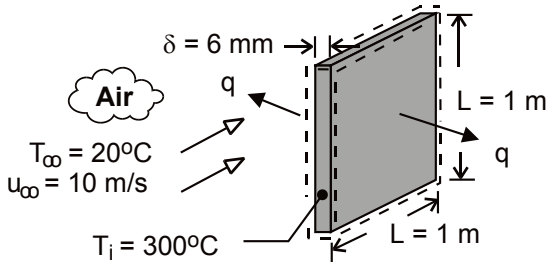
PROBLEM 01

KNOWN: Plate dimensions and initial temperature. Velocity and temperature of air in parallel flow over plates.

FIND: Initial rate of heat transfer from plate. Rate of change of plate temperature.

SCHEMATIC:



ASSUMPTIONS: (1) Negligible radiation, (2) Negligible effect of conveyor velocity on boundary layer development, (3) Plates are isothermal, (4) Negligible heat transfer from sides of plate, (5) $Re_{x,c} = 5\times10^5$, (6) Constant properties.

PROPERTIES: *Table A-1*, AISI 1010 steel (573K): k_p = 49.2 W/m·K, c = 549 J/kg·K, ρ = 7832 kg/m^3. *Table A-4*, Air (p = 1 atm, T_f = 433K): ν = 30.4 × 10^{-6} m^2/s, k = 0.0361 W/m·K, Pr = 0.688.

ANALYSIS: The initial rate of heat transfer from a plate is

$$q = 2\bar{h}\,A_S\left(T_i - T_\infty\right) = 2\bar{h}\,L^2\left(T_i - T_\infty\right)$$

With $Re_L = u_\infty L/\nu = 10\,m/s\times 1m/30.4\times10^{-6}\,m^2/s = 3.29\times10^5$, flow is laminar over the entire surface and

$$\overline{Nu}_L = 0.664\,Re_L^{1/2}\,Pr^{1/3} = 0.664\left(3.29\times10^5\right)^{1/2}\left(0.688\right)^{1/3} = 336$$

$$\bar{h} = \left(k/L\right)\overline{Nu}_L = \left(0.0361\,W/m\cdot K/1m\right)336 = 12.1\,W/m^2\cdot K$$

Hence,

$$q = 2\times12.1\,W/m^2\cdot K\left(1m\right)^2\left(300-20\right)°C = 6780\,W \qquad <$$

Performing an energy balance at an instant of time for a control surface about the plate, $-\dot{E}_{out} = \dot{E}_{st}$, we obtain,

$$\rho\,\delta L^2 c\left.\frac{dT}{dt}\right|_i = -\bar{h}\,2L^2\left(T_i - T_\infty\right)$$

$$\left.\frac{dT}{dt}\right|_i = -\frac{2\left(12.1\,W/m^2\cdot K\right)\left(300-20\right)°C}{7832\ kg/m^3\times0.006m\times549\,J/kg\cdot K} = -0.26°C/s \qquad <$$

COMMENTS: (1) With $Bi = \bar{h}\left(\delta/2\right)/k_p = 7.4\times10^{-4}$, use of the lumped capacitance method is appropriate. (2) Despite the large plate temperature and the small convection coefficient, if adjoining plates are in close proximity, radiation exchange with the surroundings will be small and the assumption of negligible radiation is justifiable.