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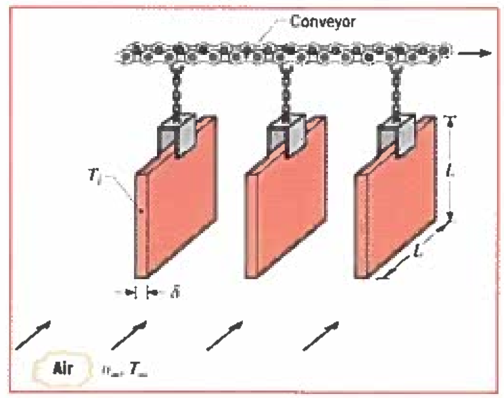
CHG 2314 **March 25, 2019**

Quiz 9

Solution

Steel (AISI 1010) plates of thickness $\delta = 6$ mm and length $L = 1$ m on a side are conveyed from a heat treatment process and are concurrently cooled by atmospheric air of velocity $u_\infty = 10$ m/s and $T_\infty = 20$°C in a parallel flow over the plates. The initial temperature of the plates is $T_i = 300$°C and they are to be cooled to the final safe to touch temperature $T_f = 50$°C. Assuming that the velocity of the air is much larger than that of the plate, determine:



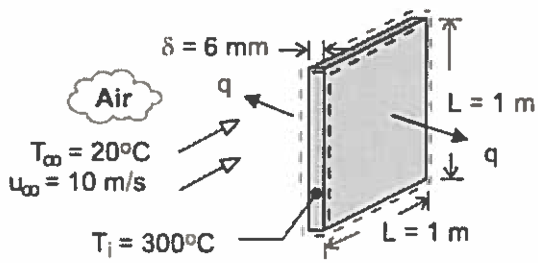
1. The average initial heat transfer coefficient between the plate surface and the air **(5 points)**.
2. The initial rate of temperature change of the plate **(5 points)**.

You may use the following properties:

AISI 1010 steel: $k_p = 49.2$ W/m·K, $c = 549$ J/kg·K, $\rho = 7832$ kg/m^3.

Air: $\nu = 30.4 \times 10\text{-}6$ m^2/s, $k = 0.0361$ W/m·K, Pr = 0.688.

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.

Analysis

a) Determination of $\bar{h}$: Forced external flow over a flat plate. characteristic length $L_c = L = 1$ m

$$\cdot\ Re_L = \frac{u_\infty L}{\nu} = \frac{10\left[\frac{m}{s}\right]\cdot 1[m]}{30.4\cdot10^{-6}\left[\frac{m^2}{s}\right]} = 3.29\cdot10^5 < 5\cdot10^5 \Rightarrow \text{laminar BL over entire plate}$$

$$\cdot\ \overline{Nu}_L = \frac{\bar{h}L}{k} = 0.664\,Re_L^{1/2}\cdot Pr^{1/3} = 0.664\cdot(3.29\cdot10^5)^{1/2}\cdot(0.688)^{1/3} = 336 \Rightarrow \bar{h} = \frac{0.0361\left[\frac{W}{m\cdot K}\right]\cdot 336}{1[m]}$$

$$\therefore \bar{h} = 12.1\ \frac{W}{m^2K}$$

b) $\left(\frac{dT}{dt}\right)_{t=0}$ Energy balance over the plate: $\dot{E}_{st} = \cancel{\dot{E}_{in}}^{\,0} - \dot{E}_{out} + \cancel{\dot{E}_g}^{\,0} \Leftrightarrow \rho\delta L^2 c \left.\frac{dT}{dt}\right|_{t=0} = -\bar{h}2L^2(T_i - T_\infty)$

Rearranging and sub-in numerical values $\left.\frac{dT}{dt}\right|_{t=0} = -\frac{2\bar{h}(T_i - T_\infty)}{\rho\delta} = -\frac{2\cdot12.1\left[\frac{W}{m^2K}\right](300-20)\,K}{7832\left[\frac{kg}{m^3}\right]\cdot0.006[m]\cdot549\left[\frac{J}{kg\,K}\right]}$

$$\therefore \left.\frac{dT}{dt}\right|_{t=0} = -0.26\left[\frac{K}{s}\right]$$